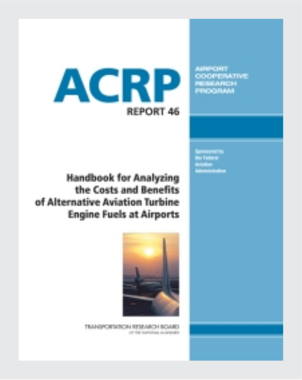

Handbook for Analyzing the Costs and Benefits of Alternative Aviation Turbine Engine Fuels at Airports

DETAILS

67 pages | | PAPERBACK
ISBN 978-0-309-15540-3 | DOI 10.17226/14531

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 46

Handbook for Analyzing the Costs and Benefits of Alternative Aviation Turbine Engine Fuels at Airports

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Subscriber Categories
Energy • Environment • Aviation

Research sponsored by the Federal Aviation Administration

TRANSPORTATION RESEARCH BOARD
WASHINGTON, D.C.
2011
www.TRB.org

AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

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The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

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ACRP REPORT 46

Project 02-07
ISSN 1935-9802
ISBN 978-0-309-15540-3
Library of Congress Control Number 2011921470

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AIRPORT COOPERATIVE RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

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Printed in the United States of America

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AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under ACRP Project 02-07 by CSSI, Inc., Massachusetts Institute of Technology, and the Environmental Consulting Group, Inc. CSSI served as the prime contractor.

Mr. Frederick Morser of CSSI was the Principal Investigator. The other authors of this report were Phillip Soucacos, CSSI, Dr. James Hileman, Principal Research Engineer, MIT, and Associate Director, Partnership for AiR Transportation Noise and Emissions Reduction, Pearl Donohoo, S.M. Candidate at MIT, and Sandy Webb, Managing Director, Environmental Consulting Group.

Many researchers and experts in alternative fuel production, fuel combustion, aircraft and vehicle engines, fuel distribution, airport operations, and emissions modeling provided essential assistance with the work presented in this report. The authors would especially like to thank Dr. Saravanan Arunachalam, Center for Environmental Modeling for Policy Development, University of North Carolina–Chapel Hill, for his contribution on the analysis of ambient particulate matter concentrations around Atlanta Hartsfield International Airport.

FOREWORD

By Lawrence D. Goldstein
Staff Officer
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ACRP Report 46 provides a handbook and analytical model that airport operators and fuel suppliers can use to evaluate the costs associated with introducing "drop-in" alternative turbine engine fuel at airports and the benefits as measured by reduced emissions. The analytical model also includes evaluation tools that take into account options for using alternative fuel for other airside equipment, including diesel-powered ground support equipment. Alternative fuels considered are an ultralow sulfur (ULS) jet fuel and synthetic paraffinic kerosenes (SPKs). SPKs include Fischer-Tropsch fuels and hydroprocessed renewable jet fuel created from feedstocks such as algae and palm oils. The analytical model, which is contained on an accompanying CD-ROM, is the Alternative Fuel Investigation Tool (AFIT). An accompanying research report covers background analysis used in the formulation of the AFIT model, addresses characteristics of current fuel usage and distribution, and describes what is required to switch to alternatives. Also addressed in the report and incorporated in AFIT are critical environmental factors to be considered when calculating costs and environmental benefits. Environmental benefits are measured based on the degree to which use of alternative fuels can improve air quality within the airport boundaries. The handbook also includes a discussion of data requirements and sources of data required for use in the model.

Jet A kerosene is a petroleum-based fuel that is presently used to power turbine engines on aircraft. Certification of two or more substitutes for Jet A fuel is anticipated in the near future, and this research was designed to provide guidance to airport operators on the steps necessary to evaluate costs and environmental benefits for implementing a fuel substitution program. The objective of the research was to prepare a handbook for use by airport operators to measure the associated costs and environmental benefits. This handbook was also to provide guidance on possible uses of alternative fuels as substitutes for diesel-powered ground support equipment to maximize the return on the required investment.

To accomplish this objective, the research team headed by CSSI, Inc., in association with the Massachusetts Institute of Technology and the Environmental Consulting Group, Inc., evaluated current airport fuel supply systems; reviewed current research on development and suitability of alternative fuels; evaluated certification and implementation requirements; interviewed airports on current fuel acquisition, supply, and delivery procedures; and assessed potential environmental benefits associated with use of alternative fuels. Based on this review and analysis, the research team formulated an evaluation model to facilitate the decision-making process with sufficient flexibility to incorporate individual airport characteristics.

The report that accompanies the handbook includes an assessment of steps involved in bringing alternative fuels to airports, what airports need to know to accommodate these fuels, how the cost of using alternative fuels compares to that of current fuel, what the environmental benefits are, and how to measure those benefits. It also describes the underlying analysis that is incorporated in the computational tool. The decision to switch in part or in whole to an alternative fuel is the responsibility of and peculiar to an individual airport. Specific conditions will guide airport management decisions, and any model or decision-making tool must be flexible enough to recognize unique characteristics of a specific airport community. This report is the result of extensive research into the key issues affecting the aviation industry's efforts to pursue cleaner fuels, and the decision-making factors that emerge are built into the model. As a result, members of the airport community can use the report, handbook, and AFIT to make their own determination of the costs and environmental benefits of various alternative fuels and implementation strategies.

The handbook guides the AFIT user in evaluating the cost of acquiring, transporting, distributing, and using an alternative jet fuel as well as evaluating environmental benefits. Although designed with airports in mind, it is also useful to others interested in using alternative fuel at airports. For example, an alternative jet fuel producer can use AFIT to develop a marketing approach for working with an airport. A fuel service company could use it to better understand the process and costs involved in acquiring and transporting an alternative jet fuel from a production site to an airport. An environmental analyst could use it to evaluate the degree to which emissions could be mitigated though the use of alternative jet fuel.

The science and engineering of alternative fuels development is dynamic. Assumptions and results can become obsolete as a result of political, technological, and economic change. Therefore, alternative fuels research in general and a measure of its applicability to airport planning and aviation in particular are in constant need of updating. For example, with respect to the modeling side, the environmental input to the benefit analysis, which relies on the FAA's preferred air quality model, the Emissions and Dispersion Modeling System (EDMS) will soon be replaced or augmented by other more sophisticated environmental models as tools and techniques improve. The structure of the decision-making process for use of alternative fuels must remain flexible, and that is the approach incorporated into the AFIT and its application.

CONTENTS

Handbook for Using AFIT, the Alternative Fuels Investigation Tool

SUMMARY

Handbook for Analyzing the Costs and Benefits of Alternative Aviation Turbine Engine Fuels at Airports

Aviation has a long and successful record of improving fuel efficiency over time; however, it is still facing significant pressure to reduce its greenhouse gas (GHG) emissions and offset emissions that may result from growing demand for air travel. Industry stakeholders have committed to a wide range of measures for reducing GHG emissions, such as further fuel efficiency improvements, advanced air traffic management techniques to shorten routes, more efficient operations, and market-based and regulatory measures to further reduce emissions. Perhaps the most promising approach for reducing aviation GHG emissions is the use of alternative fuels. These fuels can also reduce surface emissions, which could also be a barrier to the growth of aviation.

Environmentally beneficial alternatives to current Jet A fuel are in the early stages of commercialization, although rapid progress is being made in their development. It is important for stakeholders to understand how these new fuels will fit into the current system, how they will move from fuel production sites to airports, and what is involved on the part of the airports to accommodate the fuels and deliver them to aircraft.

This project has assessed what is involved in getting alternative fuels to airports, what airports need to know to accommodate them, how the costs of using these fuels compares to current fuel, what the environmental benefits are, and what practical considerations are involved at the airport. In addition to this technical report, which provides the detailed information and analysis needed to understand alternative fuel use at airports, there are two other products from this project: a computational tool for evaluating the costs and benefits of airport alternative fuel use and an accompanying handbook that guides the user through the application of the tool.

This report describes how alternative fuels may be used to supplement and eventually replace conventional fuels and what is important for airports to consider. It also describes the underlying analysis that is incorporated in the computational tool. The following key accomplishments of the project are described in the report:

- An extensive search of the scientific literature on alternative fuel production and use was conducted to assess viable alternative fuels, environmental impacts of using alternative fuels in aircraft and ground support equipment, and how these fuels might be deployed at airports.
- Detailed interviews and surveys of fueling equipment were conducted at seven airports to assess airports' readiness for using alternative fuels and to better understand what fueling equipment may be involved in the transition to these new fuels.
- Key environmental factors for aircraft and GSE emissions affecting surface air quality were assessed in detail to evaluate potential environmental benefits of alternative fuel use. The life-cycle GHG emissions from alternative fuel production and use were also evaluated and compared among different fuel sources.

- A full atmospheric chemistry assessment was conducted of changes in particulate matter concentrations from aircraft in the vicinity of Atlanta Hartsfield International Airport to evaluate the impacts of alternative fuel use on ambient pollution concentrations, which is a better proxy for human health effects than a simple emissions inventory.
- The Alternative Fuel Investigation Tool (AFIT) was produced to provide a computational tool for airports and others interested in alternative jet fuels to evaluate the costs and benefits of employing these fuels.
- A handbook was prepared to guide AFIT users and provide background information on the tool, suggest data inputs, and provide information on evaluating outputs.

While alternative fuels are not yet in use at airports, this project has identified some of the essential considerations that airports and other stakeholders will need to evaluate as opportunities arise. It has also provided a user-friendly tool for quantifying the costs and benefits of alternative fuel use at airports.

ACRP Report 46 contains the contractor's research report followed by instructions for using AFIT: the Alternative Fuels Investigation Tool. The AFIT model is provided on the CD-ROM attached to this report.

CHAPTER 1

Introduction

1.1 Summary

There is a growing disparity between the growth rate of demand for petroleum-based fuels, such as Jet A fuel and diesel, and available petroleum-based fuel production, as well as an increasing awareness of airport source contribution to local air quality and global climate change. In response, the introduction of more environmentally beneficial substitutes for Jet A is anticipated within the next decade. Currently, Jet A is used to power turbine engines on aircraft, while ground support equipment (GSE) is fuelled by diesel, unleaded gasoline, compressed natural gas, or electricity. However, given the similarities between diesel fuel and Jet A, it is possible, though not currently permissible, to operate diesel-powered GSE using Jet A. Fueling GSE with the substitute jet fuels may offer additional benefits to airports.

Within the next decade, it is anticipated that fuels created from Fischer-Tropsch (F-T) synthesis and hydroprocessing of renewable oils [both are classified as synthetic paraffinic kerosene (SPK) fuels for the purposes of this report] could be commercially available, and/or an ultralow sulfur (ULS) standard for Jet A could be introduced. ASTM has already certified a 50-50 SPK blend (with fuels created by the F-T process), and the Commercial Aviation Alternative Fuels Initiative (CAAFI) has a goal of certifying a hydroprocessed renewable jet (HRJ) fuel as a blending feedstock by the end of 2010. It is also conceivable that the existing fuel specification may be modified to reduce maximum fuel sulfur content.

This report describes the research conducted on ACRP Project 02-07, Handbook for Analyzing the Costs and Benefits of Alternative Turbine Engine Fuels at Airports. It provides information on development of the Alternative Fuels Investigation Tool (AFIT), a computational tool to assess the costs associated with using alternative fuels at airports and emissions benefits that may result from using those fuels. AFIT is a key product of this project. Much of the research conducted for the project underlies the computations made in AFIT.

Subsequent sections of this report describe the literature search, airport surveys, analysis of environmental factors, and practical considerations for using alternative fuels at airports, both in aircraft and as diesel replacement fuel for GSE. The AFIT tool and handbook are described, as are some limitations that result from the quality of the underlying data and the fact that alternative jet fuels are not yet commercial.

1.2 Handbook Purpose

The primary purpose of this project was to develop a handbook that will allow airport operators and/or fuel suppliers or other interested parties to perform a cost–benefit analysis in a consistent manner for using a drop-in alternative to Jet A as well as evaluating the benefits of expanding the use of a drop-in alternative to Jet A to previously diesel-powered GSE. The important elements of this assessment procedure have been incorporated into AFIT. The tool incorporates a methodology for estimating the costs and benefits of providing the fuel for existing airports, airport expansions projects, and new airports. This methodology provides a list of considerations for the fuel delivery infrastructure, including obtaining, storing, and distributing the fuels at the airport as well as any required infrastructure or maintenance changes. Environmental changes associated with the use of the fuels in diesel-powered GSE and in turbine-powered aircraft main engines are also assessed.

The handbook considers the relative costs and benefits of using an alternative fuel compared to a fuel that is already in production and available at the airport. However, the process by which the fuel is derived is important to understand the life-cycle costs and benefits from using the fuel. Alternative fuel life-cycle data is included for several production routes so that life-cycle emission benefits can be determined comparing the alternative fuel to conventional Jet A. Also, the handbook provides the decision maker with a consistent basis for assessing the relative difference in benefits or costs from fueling GSE and aircraft with the same fuel versus continuing to fuel GSE using conventional fuel.

In order to develop the handbook, a comprehensive literature search, airport surveys, and an analysis of the driving environmental factors were conducted. An assessment of on-airport infrastructure considerations when transitioning to an alternate fuel was evaluated, and estimates of emission factors for the new fuels were developed. These assessments are incorporated into the cost–benefit computational module, AFIT. The accompanying handbook describes the use of the tool.

1.3 Economic Considerations

It is anticipated that SPK fuels will deliver benefits for airport operators. They offer the potential to ensure supply stability and possibly reduce price volatility. In addition, the possibility of a single fuel that could be used in both aircraft and ground support equipment may allow airports to reduce the amount of fuel distribution equipment, including tanks, pumps, and other peripheral equipment. Assuming the alternative jet fuel received by an airport is a drop-in fuel, then currently used seals (including O-rings) required in fuel distribution systems will function satisfactorily. This is discussed more fully in Chapter 2.

1.4 Environmental Considerations

Particulate matter (PM) is one of the six criteria air pollutants that the U.S. Environmental Protection Agency (U.S. EPA) regulates through the Clean Air Act Amendments of 1990 (Public Law 101-549), and it is of particular concern for airports. PM specifically refers to a complex mixture of solid particles and liquid droplets that are suspended in the atmosphere. Sources include fuel combustion emissions from transportation, industry, and electricity generation; forest fires; and wind-blown dust. Because PM with smaller diameters has greater health impacts than larger diameters (Greco et al., 2007), PM is referred to by its size in micrometers (μm), and the NAAQS has two listings for particulate pollution, PM_{10} and $PM_{2.5}$, to reflect PM with diameters less than 10μm and 2.5μm, respectively. Aircraft gas turbines and ground support equipment contribute directly to ambient concentrations of $PM_{2.5}$ through engine emissions (these emissions are referred to as primary PM); these vehicles also contribute indirectly to the formation of $PM_{2.5}$ through gaseous emissions of nitrogen oxide (NO_x) and sulfur oxide (SO_x), known as precursor gases, which undergo chemical and physical processes in the jet plume and atmosphere to form $PM_{2.5}$. Although the health impacts of primary PM are greater than those of secondary PM on a per-mass basis, the larger total mass of emitted secondary PM leads to both primary and secondary PM having significant effects on the health and welfare of the general public.

In addition to concerns regarding surface air quality, there is growing pressure on aviation to reduce its greenhouse gas (GHG) emissions. Aviation contributes roughly 2% of the world's CO_2 emissions (Intergovernmental Panel on Climate Change, 1999), and recently it has received considerable attention regarding these emissions. The attention is most acute in Europe, where rules are already in place to put all EU and some international aviation under the EU's carbon cap-and-trade framework. Multiple expansion projects in the London area have been blocked based on concerns regarding aviation's contribution to climate change, and several of the protests have caught the attention of the international news media. Within the United States, recent domestic legislation, specifically Section 526 of the Energy Independence and Security Act of 2007 (Public Law 110-140), has placed restrictions on the alternative fuels that can be used by federal agencies; these restrictions are based on life-cycle greenhouse gas emissions.

Carbon dioxide is not the only aircraft emission that has an impact on global climate change. The full effects include those from CO_2, water (H_2O) emissions, the indirect forcing from changes in the distributions and concentrations of ozone and methane as a consequence of nitrogen oxide (NO_x) emissions, the direct effects (and indirect effects on clouds) from aerosols and aerosol precursors, and the effects associated with condensation trails (contrails) and high-altitude (cirrus) clouds. Each of these emissions and effects has a varied residence time within the atmosphere; CO_2 has a residence time of 50 to 200 years, methane of 8 to 10 years, ozone on the order of months, water vapor and NO_x on the order of weeks, and contrails and cirrus clouds on the order of hours. Taken together, these individual effects act to further increase the warming effect of aviation relative to that associated with CO_2 alone, although the relative amount of this additional warming is still the subject of scientific study (Intergovernmental Panel on Climate Change, 1999 and Wuebbles et al., 2007). In addition, the emissions from fuel production also lead to global climate change; these well-to-tank emissions include CO_2, methane, and nitrous oxide. Because of the scientific uncertainty regarding the impact of the non-CO_2 combustion emissions on global climate change, however, this report focuses on emissions from fuel production and carbon dioxide emissions from combustion only. Environmental considerations are discussed in Chapters 3 and 4.

1.5 System Boundary

For the purposes of this study, aircraft main engines and the GSE that operates solely on the "airside" of the airport are considered. This includes GSE such as baggage tugs and tow tractors but explicitly does not include airport shuttles to parking lots and other "landside" operations. Aircraft auxiliary power units (APU) are not included in the analysis because there is insufficient information on emission factors for these engines to conduct an environmental analysis. Their fuel use and emissions are very small relative to the aircraft main engines. Additionally, jet fuel is not a drop-in fuel for gasoline engines; therefore, only turbine-powered aircraft main engines and diesel-powered GSE are considered.

All off-airport and on-airport fuel-handling infrastructure is included in the scope of the study. This includes fuel transport from production facilities along traditional transportation corridors to airport receiving stations; the fuel tanks and associated pumps, filters, and piping on the airport; and the fuel delivery equipment, including hydrant systems, fuel trucks, and fuel dispensers.

CHAPTER 2

Key Project Findings

Over the course of the work, the project team reviewed the available information on alternative jet fuels, their effects on different engine types, airport fuel delivery processes, and the needs of the airport community. The information gained from the literature search allowed for targeted questions to be presented to the airport operators during their interviews. This chapter describes the key outcomes from the literature search and airport surveys.

A thorough literature review was performed as the foundation of this project. The team was able to leverage the extensive work conducted by MIT researchers in support of PARTNER Projects 17 and 28. The reports from these activities provided the basis of the literature review since they provided a comprehensive analysis of near-term feasibility of many potential fuels as well as an examination of the life-cycle GHG emissions that result from alternative aviation fuel production and combustion within gas turbine engines (Hileman et al., 2009; Stratton et al., 2010; and Hileman et al., forthcoming). The results presented in the following pages include an identification of the fuels that are potentially viable in the next 10 years, a summary of the lessons learned by the Department of Defense regarding using jet-like fuels in diesel equipment, a summary of engine-related issues to be considered, a summary of specific considerations when using jet fuel in GSE, and finally a summary of the anticipated changes to emissions resulting from using alternate fuels in aircraft and GSE.

2.1 Potentially Viable Alternative Turbine Engine Fuels

2.1.1 Composition of Current Jet Fuel

Although turbine engines can in theory operate with a broad range of fuels, the requirements of high altitude flight and the existing infrastructure place considerable limitations on which fuels could be deemed viable for use in aviation turbine engines. Safety is of paramount importance in terms of both handling the fuel and of aircraft operation. Fuels with high vapor pressure could lead to operability problems at cruise altitude, while those with a low flash point pose a safety hazard during fueling and operation. Some fuels decompose at temperatures typically experienced by conventional jet fuel; prolonged use of these fuels could lead to fuel system failure. Because of the low temperatures of the atmosphere where aircraft fly, an alternative jet fuel must also have a low freeze point.

Fuel energy content, in terms of energy per volume and energy per mass, is another key factor that must be considered when examining alternative jet fuels. This is because an aircraft expends significant energy carrying fuel. If a lower-energy fuel is used, then additional fuel weight, as compared to Jet A, is required to deliver sufficient energy to fly a given distance. In order for the aircraft to carry this additional fuel weight, additional fuel must be carried. The increasing fuel requirement leads to an overall increase in the amount of energy that is expended to deliver passengers and cargo between the origin and destination. Conversely, if one uses an alternative jet fuel with an increased energy per unit mass, then less energy is required to fly a given payload between two places. Therefore, in order to be viable, the fuel must have, at a minimum, an energy density comparable to conventional Jet A.

2.1.2 Source of Current Jet Fuel

The American Society of Testing and Materials (ASTM) determines the requirements that jet fuel must meet for physical properties, chemical content, contaminant limits, and overall performance requirements. ASTM D1655 is the current fuel specification and enumerates all of the requirements for Jet A. Most of the conventional Jet A purchased in the United States is produced from conventional petroleum (i.e., crude oil). Some of it also comes from unconventional petroleum sources such as Canadian oil sands and Venezuelan very heavy oils. In the future, it is conceivable that

Jet A could also be created from oil shale such as that found in Colorado. All of these sources can be refined to a hydrocarbon fuel that meets all of the requirements for ASTM D1655. For most of this handbook, the source of Jet A will be assumed to be conventional petroleum. This will be discussed further in Section 3.4 on life-cycle GHG emissions.

2.1.3 Sulfur Content of Current Jet Fuel

The specification that defines Jet A currently allows sulfur content up to 3,000 parts per million (ppm). However, the fuel sulfur content of jet fuel used throughout the United States is closer to 700 ppm (Taylor, 2009 and DESC, 2008). To reduce aviation's impact on air quality, Jet A could be desulfurized to a level of 15 ppm; this would result in roughly a 1% increase in volumetric fuel consumption and a cost of 4 cents to 7 cents per gallon (Hileman et al., 2009, and references therein). Part of this cost is to pay for additional fuel additives to ensure that the fuel meets lubricity requirements. To account for a potentially reduced fuel sulfur specification, the use of ULS Jet A is examined in this handbook.

2.2 Potentially Viable Fuels and Their Benefits

Two broad types of near-term alternative fuels have been identified that could both meet ASTM D1655 (i.e., be suitable for use in aircraft) and are suitable for use in diesel-powered GSE: **ULS jet fuel and SPK fuels.** SPK fuels are hydrocarbon fuels with nearly zero aromatics content; this differs from Jet A or ULS Jet A, which are composed of roughly 20% aromatics by volume (Shafer et al., 2006). The lack of aromatics in SPK fuels affects their density and energy content; it can also lead to issues of seal compatibility, but as will be discussed shortly, there is an air quality benefit. The density of SPK fuels is below that required by ASTM D1655, but it results in a fuel that has increased energy per unit weight. If used on a typical flight, this increased energy content results in a 0.3% decrease in the energy requirement (Hileman et al., forthcoming). SPK fuels could be created from a variety of feedstock and processes. One pathway is via F-T synthesis of coal, natural gas, biomass, or a mix of biomass and coal; another pathway is through hydroprocessing of renewable oils such as plant oils or waste greases. These fuels are termed HRJ fuels in this report. Recently, ASTM passed D7566, which approves the use of up to a 50% blend use of F-T fuels with conventional jet fuel. Efforts are ongoing to obtain similar certification of a 50% blend of HRJ fuels, with a goal of certification by the end of 2010 (Rumizen, 2009).

Alternative jet fuels with either reduced fuel sulfur content or reduced fuel aromatics content offer the potential to reduce PM emissions. If both are reduced, as is the case for SPK fuels, then the reduction in PM emissions can be substantial. This is because fuels that have lower aromatics content have been shown to have reduced primary PM emissions (e.g., Corporan et al., 2007; Timko et al. 2008; Whitefield and Miake-Lye, 2008), and fuels that have lower fuel sulfur content have reduced primary PM emissions and fewer emissions of SO_x that would later react in the atmosphere to form PM.

2.2.1 Fuels Not Viable for Use in Gas Turbine-Powered Aircraft

Blends of Jet A with either biodiesel or bio-kerosene have been discussed for aviation. Both of these fuels are created via addition of an alcohol, typically methanol, to a renewable oil source in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide. This process is known as transesterification and the resulting fuel is often referred to as fatty acid methyl ester (FAME). The oil feedstock used to create bio-kerosene results in a fuel with a freeze point that is lower than that of biodiesel (roughly 0°C), but both are much higher than would be required for operations at cruise altitudes. Both of these fuels have less energy than Jet A (roughly 12% less energy by mass), and neither is suitable for transportation in the existing pipeline system. Furthermore, these fuels have thermal stability issues when used in gas turbine engines. Because of these concerns, these fuels were not deemed to be viable alternatives to Jet A, and they are not considered further.

Alcohols (ethanol and butanol) are not viable for use in gas turbine engines for a number of reasons, including volatility, lower energy content, lower flash point, and material compatibility problems. Because of the many problems involving their use in aviation and the energy penalty associated with their use (see Hileman et al., 2009), alcohol fuels are not examined further within the handbook.

Finally, cryogenic fuels such as hydrogen and liquefied natural gas (LNG) are incompatible with current infrastructure and aircraft; therefore, they are not considered in this handbook. A summary of the fuels reviewed and their viability is presented in Table 1.

2.2.2 GSE Use of Alternative Turbine Engine Fuels

In contrast to Jet A, diesel fuel, which is traditionally used to power GSE, is not required to meet D1655; instead it meets ASTM D975. One of the major factors that must be taken into consideration to ensure that a replacement for Jet A is suitable for use in a diesel GSE engine is the readiness of a fuel (petroleum distillates specifically) to auto-ignite. Cetane number (CN) indicates how fast the fuel self-ignites from the time the fuel is injected into the cylinder. Cetane index (CI) is estimated mathematically from CN based on

Table 1. Summary of fuels evaluated.

Fuel	Thermal Stability	Freeze Point	Vapor Pressure or Flash Point	Energy Content	Aircraft and Airport Compatible
ULS jet fuel	✓	✓	✓	✓	✓
SPK	✓	✓	✓	✓	✓
FAME	×	×	✓	×	×
Ethanol	✓	✓	×	×	×
Butanol	✓	✓	×	×	×
Liquid hydrogen	✓	✓	×	✓	×
LNG	✓	✓	×	✓	×

distillation temperatures and density. Many studies have shown that the faster the engine starts at low air temperature, the lower the emissions are shortly after engine start, and the lower overall the fuel consumption is. Therefore, CI is seen as an integral environmental and operability factor in diesel engines.

2.2.3 Single Battlefield Fuel (Jet Fuel Use in Diesel Engines)

Most experience using jet fuel in diesel engines derives from the Single Battlefield Fuel initiative. Single Battlefield Fuel refers to the U.S. military's strategic decision to simplify logistics with one fuel for all equipment when possible. Through the initiative, there is more than 20 years of experience with jet fuel use in diesel engines. The Single Battlefield Fuel concept began in the late 1970s in response to differing fuel requirements by the U.S. Air Force and Army. As a result, the U.S. Air Force transitioned from JP-4 to JP-8. The ratification of this change occurred in 1986. JP-8, the military specification for jet fuel, is principally the same standard as Jet A, but contains additives not present in Jet A. When there is a large navy presence, JP-5 may be used as the single fuel.

The transition to land vehicles operating on JP-8 was first prompted by unusually cold winters in Europe in the 1980s. The cold weather produced cold flow problems—waxing and high viscosity—in the diesel fuel. As a result, the military began mixing jet fuel, with its significantly improved cold flow properties, and diesel in a 1:1 ratio. This mix was adopted by NATO as fuel F-65, and standardizing on JP-8 became a NATO initiative. At this time, the U.S. Army already had experience with the use of jet fuel in ground equipment. Due to its cold weather properties, the army has been operating on jet fuel in Alaska since the early 1970s. This includes all diesel equipment and vehicles.

Large-scale testing of jet fuel in military vehicles was initiated in 1988 at Fort Bliss, Texas. During the testing, over 2,800 vehicles were transitioned from diesel to JP-8. Changes in performance and maintenance were monitored for both tactical and non-tactical vehicles. In addition to monitoring equipment at Fort Bliss, the military conducted 10,000-mile performance tests using jet fuel in diesel engines. At the end of the testing period, no major problems were encountered and Ft. Bliss petitioned to continue using JP-8 as a diesel replacement. More than 19 bases have now converted to JP-8. In 1990, Operation Desert Shield used the Single Battlefield Fuel strategy with jet fuel. The U.S. military was granted permission by the U.S. EPA to use JP-8 for domestic on- and off-road applications in 1995. The *JP-8 Single Fuel Forward, Information Compendium* is periodically updated to include relevant testing and experience. Additionally, France, Norway, the United Kingdom, and the Netherlands accept standard NATO jet fuel as a diesel substitute.

Due to their low sulfur and low aromatic content, F-T diesel fuels have been tested extensively for their air quality benefits. These tests tend to be dynamometer-based, short-term, and focus almost exclusively on emissions. Thus, the published literature on long-term engine effects is not as well developed (Alleman and McCormick, 2003). There have, however, been Fischer-Tropsch pilot programs in California and Sweden, as well as many years of experience in South Africa. F-T blends are currently marketed in Europe and Thailand as premium diesel blends (U.S. DOE, 2007).

The majority of this F-T testing has been done using F-T diesel fuels, not the F-T jet fuel considered in this study. The main differences between these two fuels are the distillation range and the resulting cetane number.

2.2.4 Limits of Jet Fuel Use in Diesel Engines

As noted in Section 2.1.3 on the sulfur content of jet fuel, the ASTM jet fuel specification (D1655) allows up to 3,000 ppm sulfur; however, jet fuel in the market has a lower sulfur content. Worldwide surveys conducted during 2007 found that annual weighted average jet fuel sulfur content ranged from 321 to 800 ppm (Taylor, 2009). As a result of the 3,000-ppm specification, the EPA does not permit the use of jet fuel in diesel engines. EPA's new clean diesel regulations for non-road vehicles limit sulfur content to 15 ppm. Even the new jet fuel—F-T blend specification (ASTM D7566)—would not result in sulfur that low. Only neat F-T fuel or F-T fuel blended with an ultralow sulfur jet fuel would be able to meet the EPA's diesel sulfur limits for use in GSE.

2.2.5 Engine Modifications and Maintenance Changes

The major issues identified with switching to the identified viable alternatives to Jet A are the low aromatic and low sulfur contents. Low aromatic content is linked to decreased seal swelling, and the processing typically used to create low sulfur content fuel can result in low fuel lubricity. Military experience with JP-8 has also raised specific concerns related to low viscosity fuels and fuel pumps. In the diesel industry, a transition to 15-ppm ultralow sulfur and lower aromatics fuel has largely already occurred. California ULS diesel fuels, for example, must have less than 10% aromatics (Chevron, 2007), and aromatic contents have been observed to be as low as 1.2% (Alleman and McCormick, 2003). Issues arising from low fuel sulfur and aromatic content in the diesel industry are directly applicable to these same issues in the aviation industry for SPK and ULS Jet A.

The first concern is that fuel leakage is possible due to reduced elastomeric swelling caused by a low aromatic content. If seals do not swell properly, fuel leakage may occur at joints in the fuel system. The standard material for these seals has been Buna-N rubber. This concern is applicable anywhere in the airport that fuel is being used. The seals in on-road diesel engines would likely not need to be replaced because manufacturers switched materials when lower sulfur diesel standards came out in the 1990s.

Leakage due to seal swell is unlikely to be an issue with the currently envisioned use of SPK fuel. Although the processed fuels themselves are low aromatic, jet fuel producers are cognizant of possible elastomeric complications, and an 8% minimum aromatic content is currently being used as a rule-of-thumb for minimum safe aromatic content in jet fuel. For example, a 50% F-T blend has been approved by the United Kingdom Ministry of Defense Turbine Fuel Standard (DEF STAN 91-91) because the mixture is likely to provide a minimum 8% aromatic content (Moses et al., 2003). Moses et al. (2003) found that elastomers tested using synthetic jet fuel with 7.2% to 16.9% aromatics had the same response as with traditional Jet A-1. These concerns led to the choice of a 50% maximum blending percentage with ASTM D7566. If, however, a fuel with significantly lower aromatic content is used, the Buna-N rubber seals will need to be identified and replaced with fluoroelastomers to prevent fuel leakage.

The second concern is the low lubricity associated with the processing used to create low sulfur content. F-T fuels, for example, have shown lubricity well below accepted standards for diesel fuel (Alleman and McCormick, 2003). In the diesel industry, the low lubricity concerns have been addressed with fuel additives (British Petroleum, 2007; Chevron, 2007; Exxon, 2002). The additives contain esters (10 to 50 ppm) or fatty acids (20 to 250 ppm) (Chevron, 2007). For example, all of Exxon's diesel fuels have incorporated lubricity additives since 2005 (Exxon Diesel FAQ, undated). Lubricity additives are estimated to cost approximately 0.2 cents/gallon (U.S. EPA, 2000). These fuels then meet the diesel fuel standard ASTM D975. It is important to note that the aforementioned additives may cause thermal stability problems and have not been approved for use in jet fuel; if present in jet fuel, the fuel would be considered contaminated and not allowed for flight use. Also, fuels with these additives are not presently being transported within the pipeline system due to their potential for trailing back into jet fuel.

Unlike for the diesel industry, however, there is no requirement for additives to meet lubricity standards for Jet A. Lubricity additives may be added to Jet A by agreement; however, most Jet A does not contain any additives (Chevron, 2006). There are, however, U.S. military standards for JP-4, JP-5, and JP-8 that require a corrosion inhibitor and lubricity improver, and lubricity and corrosion inhibitors may also be added to Jet A-1 (Chevron, 2000). Without a lubricity enhancer, however, the military found increased wear on fuel pumps (U.S. Army ACOM-TARDEC, 2001). In 2006, the California Energy Commission noted that based on its experience, there was no reported increased engine maintenance for diesel-engine vehicles using F-T fuels (Boyd, 2006); however, Alleman and McCormick (2003) note that long-term testing is still required. Therefore, unless a lubricity additive is included in ULS Jet A or SPK, there could be increased engine wear when using these fuels in diesel engines.

Finally, during the military's experience, specific issues were discovered with fuel pumps in very hot conditions. During Desert Shield/Storm, the ground vehicles were fueled with a low sulfur Jet A-1, and restarting high-mobility multipurpose wheeled vehicles after reaching operating temperature became difficult or impossible with ambient temperatures over 104°F (U.S. Army ACOM-TARDEC, 2001). This difficulty occurred in a specific Stanadyne fuel pump (model 2DB) and was traced to the low sulfur/low viscosity and dirt contamination combined with the lack of lubricity additive that is mandated for JP-8. Model 2DB fuel pumps are found, though not exclusively, in GM 6.2 and 6.5 liter engines. In response to the low viscosity fuel and restarting issues, Stanadyne issued four service bulletins (see Appendix B). Bulletin 484R specifically addresses the hot restart issues with a new hydraulic head and rotary assembly; the other service bulletins provide for fuel pump changes intended to specifically adapt to low viscosity fuels, including changing certain seal components. With the exception of the Stanadyne fuel pump, however, the military has found no required modifications or adjustments to engines (U.S. Army ACOM-TARDEC, 2001), although Fernandes et al. (2007) showed that performance could be improved by specifically tuning engines for jet fuel.

The military did not find any increased maintenance requirements in using jet fuel in diesel engines; however, it did find several advantages. These include reduced nozzle fouling, increased fuel filter replacement intervals, extended oil change intervals, reduced potential for microbiological growth in fuel tanks, and reduced water emulsification problems in fuel tanks. With sufficient additives, the military also found reduced wear on components and reduced potential for fuel system corrosion (U.S. Army ACOM-TARDEC, 2001).

2.3 Outcomes from Airport Surveys

To understand how airports receive, test, handle, and dispense jet and diesel fuels, the project team visited several airports to interview their fuel management staff and survey their fuel storage and distribution infrastructure. (A copy of the interview form used during the visits is presented in Appendix C.) This information gave the project team a real-world context for applying the information gained from the literature.

2.3.1 Airport Fuel Management Practices

Airports are complex operations, often compared to small cities. Fueling practices at airports are no different. While Jet A is by far the dominant fuel dispensed at commercial airports, many other fuels are found there as well:

- Diesel fuel – GSE, maintenance vehicles, and on- and off-airport shuttles and buses;
- Unleaded gasoline – GSE, fleet vehicles, and on- and off-airport shuttle vehicles;
- Aviation gasoline – piston-engine aircraft;
- Compressed natural gas – GSE, fleet vehicles, and on- and off-airport shuttles; and
- Propane – some GSE and, most commonly, forklifts.

There are many separate companies and organizations that purchase, store, and dispense fuels at airports as well, including

- Fueling consortia – At many large airports, the tenant airlines form a fueling consortium that is responsible for the lease, design, and management of the aircraft fueling system. Some consortia purchase jet fuel for all participating airlines, while others require each airline to purchase its own fuel, which is commingled in the storage tanks. Most consortia hire third-party service companies to operate the fueling system.
- Airlines – At many airports, individual airlines are responsible for purchasing and dispensing fuel for their aircraft and GSE. In practice, several airlines may hire the same third-party service provider to operate the fueling system.
- Airports – Some airports manage the fueling system operations for their tenant airlines. This is particularly true for fuels other than jet fuel, although some airports also fuel aircraft.
- FBOs – Fixed based operators, or FBOs, are usually private companies located on airports that offer a variety of services such as fuel, oil, parking, hangar space, and aircraft and instrument maintenance and repair. FBOs may also offer restrooms, lounges, telephones, flight training, and baggage handling. They often manage a fuel farm to support their services.
- Third-party service companies – Many airport tenants, especially airlines, hire private companies to provide supporting functions like operating fuel storage and distribution facilities, ground support functions including GSE operations, and baggage and cargo handling.

Individual airports have unique combinations of these providing fuel services to aircraft and GSE around the airport.

2.3.2 Airport Fuel Infrastructure

Airports all have a similar fuel infrastructure, uniquely adapted to the specific needs and organizational structure of the individual airport. The basic infrastructure described here is typical for a large hub airport with a consortium responsible for aircraft fueling. Common infrastructure variations are described for the other airport types.

Jet fuel is received from a fuel storage terminal managed by a major petroleum pipeline operator. The pipeline operator periodically draws volumes of different petroleum products [e.g., unleaded regular gasoline, unleaded premium gasoline, jet fuel, ultralow sulfur diesel (ULSD), off-road diesel] from the pipeline for regional storage along the pipeline route. The fuels are then redistributed to large customers, such as airports, or to secondary fuel supply companies. Marine transportation companies and petroleum refiners also operate regional fuel storage terminals, shipping and receiving fuels via pipeline, barge, oceangoing tankers, rail, and truck.

Jet fuel is supplied to airports from these terminals via dedicated pipelines or large fuel trucks. Custody transfer typically takes place at the airport fence line at a metering station or truck connection. The fuel then goes into fuel storage tanks at the airport fuel farm.

On-site fuel storage infrastructure includes filters and conditioners that ensure the jet fuel is free from water, dirt, pipe scale, rust, and similar contaminants. Tanks have gauges to track fuel storage volumes, and meters are used to track fuel quantities dispensed. Storage tanks are typically interconnected with pipes to provide flexibility for receiving and dispensing fuel simultaneously as well as supplying multiple pumps that circulate the fuel through a hydrant system or supply a truck loading rack.

Fuel is dispensed to aircraft in one of two ways: through a hydrant system or via trucks. A hydrant system is an underground pipeline that goes from the tank farm to the terminal gate area. At the gate, a hydrant cart connects the hydrant system to an aircraft, passing the fuel through a filter and meter. Hydrant carts do not pump the fuel but use the pressure of the hydrant system to fuel the aircraft. For airports without hydrant systems, trucks deliver jet fuel from loading racks near the tank farm to the aircraft. As with the hydrant carts, the fuel trucks have filters and meters to manage the fuel loading process, although the fuel trucks do require fuel pumps.

Diesel fuel is most commonly dispensed to GSE using fuel trucks. These trucks are smaller than those used for fueling aircraft since the fuel volumes transferred in each fueling operation are considerably smaller. Some airports have stationary pump stands, which require the GSE to go to the stand rather than be refueled at the gate. Many airports have a mix of these systems.

A third-party service provider typically manages aircraft fueling under contract to the airport's fueling consortium or the individual airlines. The service provider owns and manages the fuel trucks and equipment, while the consortium or airport owns the tanks, pumps, and associated fixed equipment. Diesel fuel delivery is often more of a mixed bag, with multiple service providers supplying fuel for different operating entities. For example, one company may be fueling GSE for some airlines and another company supporting other airlines, while a third company may be providing fueling services for airport-owned vehicles. Each service may maintain its own diesel storage tank(s) either on or off the airport.

In addition to diesel fuel sulfur content as noted in Section 2.2.4, an important consideration for airports considering using the same fuel for GSE as for aircraft is that the fuels are taxed separately. Jet fuel is often untaxed at the state level while diesel fuel is subject to state fuel taxes. Fuel taxation is very complex, reflecting international treaties and national and state legislation. Redirecting jet fuel or supplying an alternative fuel to GSE does not change the taxation requirements since they are dependent on the vehicle serviced rather than fuel quality or other fuel property.

For both aircraft and GSE, there is essentially always a fuel ticket produced at each fueling event. This ticket records fuel volumes transferred along with supporting data that may include date, time, fuel type, or temperature. The data from the fuel tickets is used for fuel use accounting, charges for fuel volume, flowage fees, fuel tax reporting, and other related reports.

2.3.3 Airports Selected for Analysis

Facilities at airports ranging from large, medium, and small hub airports to small non-hub airports were inspected to assess the fueling requirements, infrastructure, and fuel management practices. Airports were selected to represent a range of geographic regions and operational settings, including a large hub airport with no dominant airline, a large hub airport with a dominant airline, medium and small hub airports, a cargo-only airport, and an airport that serves primarily business jets and private aircraft.

To develop information on airport fuel management practices, seven airports were interviewed and are listed in Table 2.

These airports represent a sample of the range of airports that may consider the use of drop-in alternative fuels in the foreseeable future. The form used for conducting the airport inspection interviews is included in Appendix C.

2.3.4 Airport Readiness to Switch to an Alternative Fuel

The airport interviews indicate that airports could readily convert to a drop-in alternative fuel for aircraft as long as the drop-in fuel is supplied to the airport.

- On-airport blending has been determined to be infeasible due to cost, support needs (e.g., laboratory support and added holding tanks), and system inflexibility.
- Fueling system materials at the airports studied, including connectors, pipes, tanks, filters and conditioners, hydrant systems, gauges, meters, hydrant vehicles, and

Table 2. Study airports.

Large Hub	Medium Hub	Small Hub	Non Hub
Boston (BOS)	Columbus (CMH)	Richmond (RIC)	Rickenbacker (LCK)
Detroit (DTW)	Ontario (ONT)		Van Nuys (VNY)

fuel trucks, would not require modification to switch to drop-in alternative fuel. As discussed in Section 2.2.5, seal changes are not required until total aromatics fall below 8%, which will not occur within the timeframe of this study, which considers only fuel blends of up to 50% alternative fuels.

- There will be no change in the number of fueling events and, for most airports, no change in the number of fueling vehicles. This will limit the opportunity for reducing manpower even where an airport would choose to use a single fuel for aircraft and GSE.
- On-airport infrastructure and operating cost savings from converting to a single airport fuel for aircraft and GSE are modest and unlikely to be a deciding factor in using an alternative jet fuel.
- In view of excise tax considerations (airlines may have to pay a higher tax rate and receive a subsequent rebate for the portion of fuel used in aircraft to ensure all fuels are properly taxed), many airports may opt for separate fuel systems for aircraft and vehicles even when using the same fuel. The system for vehicles would have smaller capacity and be equipped with vehicle nozzles rather than aircraft nozzles. Some airports converting to a single fueling system for aircraft and GSE may choose to decommission the current diesel system but leave the equipment in place as a backup, while others may choose to remove the equipment.

CHAPTER 3

Key Environmental Factors

In order to present a complete cost–benefit analysis for the transition to an alternative fuel, it is necessary to examine changes in fuel consumption as well as emissions that affect air quality and global climate change. For some airports, the motivating factor for transitioning to an alternative fuel may be the emissions benefits. This section summarizes how changes in emissions, both those affecting air quality and life-cycle greenhouse gas emissions, and fuel consumption for the alternative fuels can be estimated. This information was used to develop the emissions components of the AFIT computational tool.

3.1 Fuel Consumption

The different fuel properties of SPK or ULS Jet (ULSJ) could produce a change in fuel use in both diesel engines within GSE and the gas turbine engines that power aircraft. As discussed below, the change in fuel burn for diesel engines that use alternative jet fuels varies based on the specific engine and testing cycle, whereas the fuel burn changes in aircraft depend on the fuel-specific energy.

3.1.1 Changes in Jet Fuel Use in Jet Engines

Aircraft engine combustion of either SPK or ULSJ should also result in a change in fuel use because energy content is the driver of fuel consumption. For this study, the change in fuel use is estimated based on the ratio of fuel energy content. As discussed previously, the energy content of a fuel can be determined on a gravimetric or volumetric basis. If the energy density (volume) is not sufficient, there may not be enough room in the aircraft's fuel tanks. If the specific energy (gravimetric) is not sufficient, the aircraft will have to carry more fuel, making the aircraft heavier and again requiring extra fuel. Because most commercial aircraft do not fly with full tanks, specific energy is more salient for calculating a change in fuel use.

The specific energy densities of Jet A, ULSJ, and SPK have been summarized by Hileman et al. (forthcoming), and are shown in Table 3. The baseline value of Jet A is based on the average value from the Petroleum Quality Information System (PQIS) database of military JP-8 jet fuel. The specific energy for ULSJ is based on the decrease in energy density and related increase in hydrogen content due to the hydrodesulfurization process. SPK specific energy values are based on a literature review of actual fuel testing. A 50-50 blend would have the average specific energies of the fuels comprising the mixture. Because of their increased specific energy, using a 50-50 SPK fuel blend in aircraft would to lead to a 1% decrease in fuel consumption, as measured on a mass basis.

3.1.2 Changes in Fuel Use in Diesel Engines

Studies comparing the use of a synthetic paraffinic diesel fuel to conventional diesel fuel in diesel engines show conflicting results. Schaberg et al. (1997) found a 1% to 2.9% decrease in fuel use using a transient engine test with a heavy-duty DDC 60 series engine. However, in full-vehicle dynamometer testing completed with a diesel bus and semi-truck tractor, Clark et al. (1999) found a 4.4% average fuel use increase. Using up to an 85% blend of hydroprocessed renewable diesel (HRD), Rantanen et al. (2005) found no change in fuel use.

Military studies examining jet fuel use in diesel engines also show conflicting results. Initial predictions ranged from a 1% to 5% increase in fuel usage based on the change in energy density (BTU/gallon) of the fuels, while engine testing indicated a 2% increase in fuel use (U.S. Army ACOM-TARDEC, 2001). Additional testing by Fernandes et al. (2007) initially found an increased fuel consumption of 1% with JP-8 when testing engines at low load but then found a decreased fuel consumption of approximately 1% with modified injection timing (Fernandes et al., 2007). Yost et al. (1996) found varying levels of fuel consumption based on loading, which ranged from –5.4% to 3.9%. Overall, military field testing of diesel vehicles burning jet fuel indicates that "there has been no

Table 3. Fuel scaling factors and energy content for aircraft fuels.

Fuel	Specific Energy (MJ/kg)	Fuel Scaling Factor
Jet A	43.2	1
ULSJ	43.4	0.995
100% SPK	44.1	0.979

indication of a significant increase in fuel consumption being evidenced" (U.S. Army ACOM-TARDEC, 2001). Due to the variation in fuel use change across studies, both positive and negative, it is assumed herein that there is no change in either SPK or ULSJ fuel use within diesel engines.

3.2 Aircraft Emissions Affecting Air Quality

The focus of the air quality aspect of this work was on ambient concentrations of $PM_{2.5}$. Aircraft emissions of nitrogen oxides, sulfur oxides, and primary particulate matter all contribute to ambient concentrations of $PM_{2.5}$; as such, these are the focus of this section. Emission factors, also called emissions indices, are the key ingredient for an emissions inventory. This section provides scaling factors for aircraft and GSE emissions. Further details on their derivation can be found in Donohoo (2010).

A review of the existing literature was used to estimate the changes to NO_x, SO_x, and primary PM emissions from the use of both SPK and ULS Jet A in aircraft. It must be noted that the Alternative Aviation Fuels Experiment (AAFEX) team acquired considerable data after the analysis presented here was completed. These data were presented in a public forum in January 2010. As such, the scaling relationships presented herein do not reflect all of the latest scientific knowledge.

3.2.1 Nitrogen Oxides

Aircraft NO_x emissions are created by oxidation of atmospheric nitrogen, and their rate of production is determined by combustion temperature. For a ULS jet fuel, there should be negligible change in the combustion temperature; therefore, the amount of NO_x produced per mass of fuel consumed should be unchanged. There is preliminary data indicating SPK use could reduce NO_x emissions by roughly 5% to 10%; however, these results were within experimental uncertainty (Miake-Lye and Timko, 2008). Since this is preliminary data based on one study, a conservative assumption was made that NO_x emissions are unchanged with SPK fuel use. As more data, such as the AAFEX results, are published, these scaling relationships should be updated.

3.2.2 Sulfur Dioxide

SO_x emissions from an aircraft engine scale directly with the sulfur content of the fuel. The Emissions and Dispersion Modeling System (EDMS), used for emissions analysis on this project, assumes a fuel sulfur content of 680 ppm. Thus, the SO_x emissions from a fuel with a different fuel sulfur content would simply be the ratio of the alternative fuel's sulfur content to 680 ppm.

ULS jet fuel is intentionally processed to an ultralow sulfur level. A typical ULS diesel leaves the refinery gate at 7 ppm such that it contains less than 15 ppm when it reaches the fuel tank. For this study, a sulfur level of 15 ppm was assumed for jet fuel when it reaches the aircraft fuel tank, although this may not be the most cost-beneficial level; instead, it matches the level in use by diesel fuel. Due to the nature of the fuel processing techniques used, SPK fuels have essentially zero sulfur level. However, their transport in pipelines could result in some trail-back of sulfur from other flows such as from conventional jet fuel. As such, a value of 15 ppm sulfur was also chosen for SPK fuels.

3.2.3 Primary Particulate Matter

Primary particulate matter emissions were calculated according to the first order approximation (FOA) methodology. FOA was developed by the FAA's Office of the Environment in response to a need for a scientifically based methodology to estimate primary PM; prior to FOA, emissions were based on a small number of aircraft tests or diesel particulate matter emissions estimates. EDMS uses a conservatively modified form of the third version of FOA (FOA3a). A complete discussion of the evolution and methodology behind the FOA methodology can be found in Ratliff (2007) Ratliff et al. (2009).

The FOA methodology speciates PM into volatile and nonvolatile components. The nonvolatile component (PMNV) refers to the solid particulate component. PMNV is a result of incomplete combustion and is also referred to as soot, hard particles, black carbon, or elemental carbon. The volatile component of aircraft PM comes from the condensation of volatile compounds in the exhaust plume. Volatile PM is broken down into three categories: PM from sulfur (PMS), PM from unburned fuel organics (PMFO), and PM from lube oil (PMLO). The sum of each of these components yields the full primary PM emissions.

In this report, it is assumed that the PMLO emissions index (EI) and PMFO EI values do not change with fuel composition. Recent testing from the AAFEX team indicates that there could be a reduction in PMFO with the use of SPK fuels. As such, this assumption is overly conservative and should be corrected in future work. The PMS component was assumed to

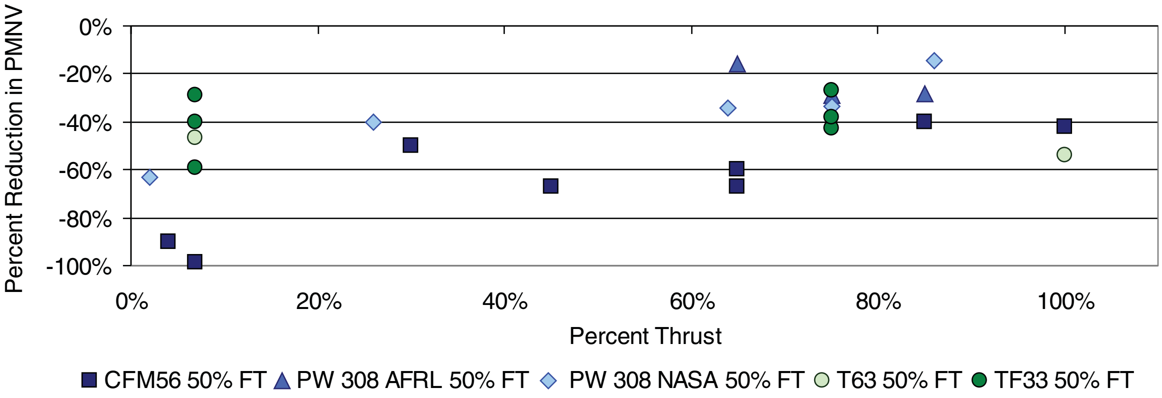


Figure 1. Reduction in PMNV mass for gas turbine combustion of a 50-50 blend of SPK with conventional jet fuel as a function of thrust setting [from Donohoo (2010) with permission].

scale in a similar manner as the SO_x emissions. The conversion rate of fuel sulfur to sulfuric acid, the precursor to PMS emissions, was assumed to be unchanged with fuel composition.

Recent measurements in a wide range of gas turbine engines have shown that the use of F-T fuels reduces PMNV emissions. This trend has been observed in four different types of gas turbine engines with varied combustor technologies: a turboshaft helicopter gas turbine (T63), a low bypass ratio engine with older combustor technologies from the B52 (TF33), the Pratt and Whitney 308 engine (PW308), and a higher bypass ratio engine with a modern combustor design used in the Boeing 737 (CFM56). Given the wide range of engine vintages and technologies that have this reduction in emissions, it is most likely that the reduction is due to the lack of aromatic compounds in the fuel.

For ULSJ, it is conceivable that there could be reductions of PMNV as a result of reduced aromatic content due to the hydrodesulfurization process; however, data used by the EPA for the ULSD rulemaking indicate that aromatic content is not significantly affected (<10% reductions) by the hydrodesulfurization process. For this study, it is assumed that ULSJ has the same aromatic content as conventional jet fuel and that it will have the same emissions of PMNV per unit of fuel consumed.

For SPK fuels, F-T emission measurements have been used to provide an approximation to the PMNV reductions that may be experienced with the use of an SPK fuel blend with conventional jet fuel. As shown in Figures 1 and 2, PMNV emission reductions are generally greater at reduced thrust settings as compared to higher thrust settings.

An approximation of the PMNV reduction was created with a least-squares fit of data from the CFM56 and PW308. This curve fit was used to calculate PMNV reductions at each of the thrust settings in the landing takeoff (LTO) cycle. The final scaling factor was calculated using these reductions

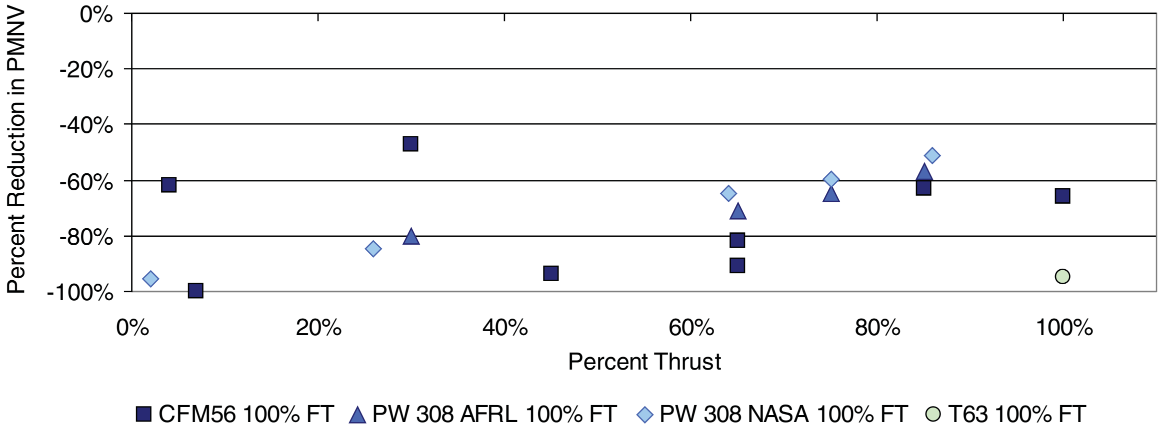


Figure 2. Reduction in PMNV mass for gas turbine combustion of 100% SPK as a function of thrust setting [from Donohoo (2010) with permission].

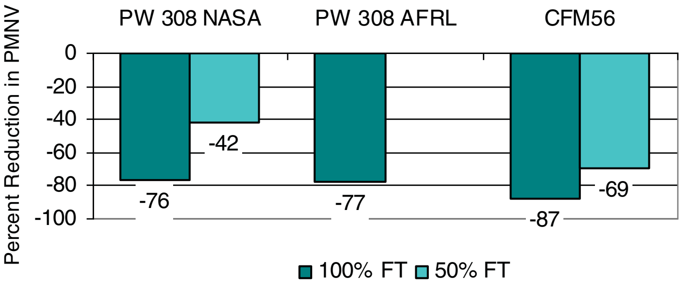


Figure 3. Engine-specific PMNV reductions for LTO cycle [from Donohoo (2010) with permission].

weighted by the total fuel burn in each stage (taxi/idle, climb-out, takeoff, approach). The fuel burn was calculated using the average time in mode and thrust from ICAO Annex 17 and the fuel burn at each corresponding thrust point from the ICAO engine databank (International Civil Aviation Organization, 1993). The engine specific reductions in PMNV for the LTO cycle are shown in Figure 3. The 100% F-T PMNV reductions range from 76% to 86%, while the 50-50 blend shows a broader range of reductions, from 42% to 69%. An average value for the Air Force Research Laboratory (AFRL) PW308 50-50 blend is not included because the highest reductions occur at the low power settings and AFRL data does not include measurements at thrusts lower than 65%. The relatively tight range of values for 100% SPK within Figure 3 should not be interpreted as meaning the fleet-wide reduction in PMNV is well known because different engine types may produce varied reductions in PMNV and the measurements still contain uncertainty.

The scaling used in this study is based on the PW308 data provided by NASA as recommended by experts in the field, Dr. Miake-Lye and Dr. Timko from Aerodyne Research, Inc., because the PW308 NASA data has smaller uncertainty bands and it used an improved testing methodology (Miake-Lye and Timko, 2008). The PMNV reduction for blends having SPK concentration between 0% and 50% was assumed to be linear between zero and the reduction value for the 50-50 blend. This is likely an erroneous assumption since the measured PMNV reduction for a 100% SPK fuel is not twice that observed for a 50-50 blend; future work should therefore refine this estimate. Once they are published, PMNV measurements from more recent tests, such as the AAFEX campaign, should be used to augment these data.

3.2.4 Carbon Monoxide

For both ULSJ and SPK fuels, it is assumed that the emissions of carbon monoxide (CO) are unchanged on a per-kilogram-of-fuel basis. For ULSJ, this was based on the similarity of fuel composition to conventional Jet A. For SPK, this was based on a lack of experimental data, although preliminary results may indicate changes and are discussed below. Therefore, the emissions of CO were scaled only with fuel use for both ULSJ and SPK fuels, as was done for NO_x emissions.

3.3 Diesel GSE Emissions Affecting Air Quality

The emissions from diesel GSE were scaled based on experimental measurements with surrogate fuels that have similar fuel properties to those being considered. This is an imperfect solution to deal with a lack of emissions data from the combustion of ULSJ and SPK fuels in diesel engines. The change in emissions depends on a variety of factors, including age of engine, type of testing cycle, installed pollution control, and fuel properties such as cetane number, fuel density, and aromatic content (Lee, Pedley, and Hobbs, 1998). These are discussed with each pollutant alongside a scaling factor that could be used with the NONROAD model formulae as described in more detail in Donohoo (2010).

3.3.1 Unburned Hydrocarbons, Nitrogen Oxide, and Carbon Monoxide

Scaling factors for hydrocarbons (HC), NO_x, and CO were derived from the literature for ULSJ and SPK fuels using JP-8 and synthetic diesel fuels as surrogates. The JP-8 tests were conducted in support of military needs relating to the Single Battlefield Fuel initiative, and as a result, the testing focused exclusively on heavy-duty engines (Fernandes et al., 2007; Yost, 1993; Yost, Montalvo, and Frame, 1996). F-T diesel fuels are not substitutes for SPK fuel; however, there is only one published diesel engine test of an SPK fuel that the project team identified, but there have been many tests of synthetic paraffinic diesel fuels (e.g., F-T diesel and HRD). One possible difference in the fuel properties between F-T fuels for jet engines and F-T fuels for diesel engines is the cetane number, which reflects the ignition properties of the fuel. Using synthetic paraffinic diesel as a substitute for SPK fuel use, scaling values were derived from F-T diesel fuel tests that compared a certification diesel with an F-T diesel in the same engine using identical test schemes (Alleman and McCormick, 2003; E. A. Frame, 2004; Fanick, Schubert, Russell, and Freerks, 2001; Nord and Haupt, 2002; Rantanen et al., 2005; Schaberg et al., 2000; Schaberg et al., 1997). A variety of testing cycles with varied engine cycles were examined. Also included was testing of a synthetic jet fuel (S5) that was formulated to meet requirements for the U.S. Navy. The results from this literature survey are summarized in Table 4.

SPK, ULSJ, and S5 fuels all produced NO_x reductions within 2% of each other. The reduction was expected due to changes in cetane number, aromatic content, and density, which all indicate a decrease in NO_x emissions (Lee, Pedley, and Hobbs,

Table 4. GSE SPK (F-T diesel proxy) HC, NO_x, and CO scaling factors [from Donohoo (2010) with permission].

Fuel	Term	HC	NO_x	CO
ULSJ (Jet A or JP-8 proxy)	Number of tests	6	9	6
	Scaling factor	0.90	0.84	0.66
	Standard deviation	0.18	0.17	0.11
SPK (F-T diesel proxy)	Number of tests	14	14	13
	Scaling factor	0.55	0.87	0.61
	Standard deviation	0.17	0.11	0.15
	S5 (from 2 tests)	0.33	0.86	0.47

1998). The reductions for SPK (F-T diesel proxy) and S5 were within 1%, indicating that F-T diesel is an appropriate substitute for F-T jet fuel for NO_x scaling.

The trends for HC emissions matched expectations, although the gross reductions did not. Due to the decreased density of jet fuel compared to diesel and the similar cetane number of jet fuel to diesel fuel, it was expected that unburned hydrocarbon emissions would increase. The testing, however, reflects a 10% decrease in emissions. The expected change for the SPK (F-T diesel proxy) HC emissions was neutral since the decrease in emissions due to cetane number was expected to be offset by an increase in emissions due to a decrease in density. The experimental results, however, reflected a 45% to 67% decrease. This may be because cetane has the dominant influence on emissions; it could be due to the fact that Lee, Pedley, and Hobbs only explored increasing rather than decreasing density values; it may also be due to other uncaptured variables, such as a reduction due to polyaromatic compounds or changes resulting from engine geometry. Some percentage of emissions may also be due to decreased fuel use. Additionally, for HC emissions, F-T diesel may be a conservative proxy for SPK jet fuel since the S5 results were 22% lower than the F-T diesel results.

CO emissions were also reduced more than expected. Again, based on Lee, Pedley, and Hobbs (1998), it was expected that CO emissions would increase with the use of a jet fuel and decrease or remain stable for a synthetic fuel; however, all three fuels showed significant (34% to 53%) reductions in emissions. As with HC emission changes, this indicates that some element of fuel composition or effect of engine geometry is not being captured. The emission changes also indicate that F-T diesel may be a conservative surrogate for SPK CO emissions since S5 emissions were 14% lower than F-T diesel.

3.3.2 Sulfur Dioxide

For calculations in the NONROAD model, which EDMS uses to estimate diesel engine GSE emissions, the sulfur dioxide emission factor is a function of the sulfur content of the fuel, the unburned hydrocarbon emissions, and the quantity of fuel burned. As such, this model was used for both ULSJ and SPK fuels to estimate sulfur dioxide emissions with assumed fuel sulfur content of 15 ppm (0.15 weight percent). As such, the specific blend of SPK, ULSJ, or ULSD is irrelevant because of the 15-ppm sulfur assumption. The ULSJ fuel sulfur content of 15 ppm was chosen to mirror the maximum allowed in the U.S. ULSD standard, and SPK was also assumed to have a sulfur content of 15 ppm due to contamination in pipelines. The actual sulfur content of these fuels will be less than 15 ppm. For example, the EPA published estimates of sulfur content for NONROAD diesel fuels, as seen in Figure 4.

3.3.3 Particulate Matter

The NONROAD model calculates two sizes of particulate matter, $PM_{2.5}$ and PM_{10}, where the subscript indicates the

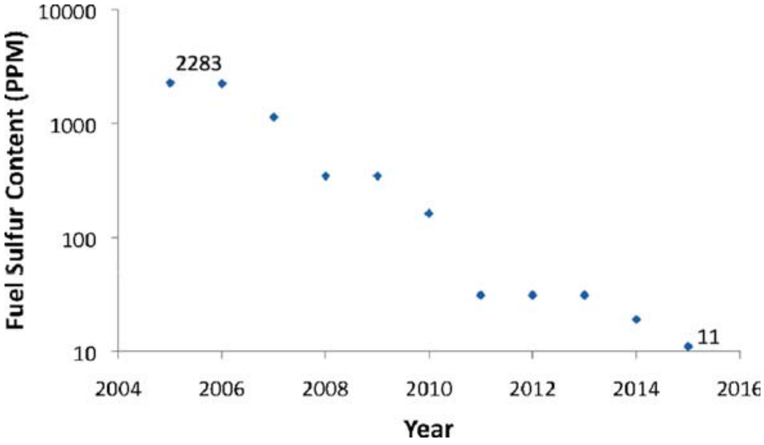


Figure 4. EPA Estimated sulfur content of NONROAD diesel fuel in continental United States (U.S. EPA, 2004).

maximum diameter in micrometers of the particulate matter. The NONROAD model calculates PM_{10} and assumes that 90% of PM_{10} by unit mass is $PM_{2.5}$. For this document, PM refers only to $PM_{2.5}$, and the 90% scaling is implicitly assumed in the calculations.

Table 5 presents a comparison of the primary PM emissions from diesel engine combustion of various fuels. The JP-8 data were based on the studies of Yost, Montalvo, and Frame (1996) and Fernandes et al. (2007), who examined a ~300-ppm sulfur diesel fuel and compared that to 1100-ppm and 40-ppm sulfur JP-8 fuel, respectively. The study of Yost, Montalvo, and Frame (1996) was also examined, but the sulfur content of the diesel fuel that was used as a baseline (9500 ppm fuel sulfur content) was deemed excessively high to yield a useful comparison. Reducing sulfur also has the effect of reducing PM emissions, but this is only the case when sulfur levels drop significantly, from 3,000 ppm to 500 ppm. At sulfur levels below 500 ppm, the driving factor behind PM emission becomes PM filters and emission traps (Lee, Pedley, and Hobbs, 1998). Sixteen different engine tests were compiled for the F-T diesel data point in Table 5 (Alleman and McCormick, 2003; Cheng and Dibble, 1999; Clark et al., 1999; Frame et al, 2004; Fanick et al., 2001; Nord and Haupt, 2002; Rantanen et al., 2005; Schaberg et al., 2000; Schaberg et al., 1997; Sirman et al., 2000; Tao Wu et al., 2007). These studies included six light-duty engine tests and 10 heavy-duty engine tests and included transient test cycles, both hot and cold, and steady-state test studies. These studies also used a 300-ppm sulfur diesel fuel baseline.

The average scaling factors for JP-8 and S5 (scaling factors of ~0.48) are both about 0.19 lower than the scaling factor for synthetic diesel (0.67). Further, the scaling factors for JP-8 and S5 do not fall within two standard deviations of the F-T diesel scaling factor. This reduction in particulate matter is in agreement with observations from Lee, Pedley, and Hobbs (1998), which indicate that PM should decrease because of the reduced density of jet fuel relative to that of diesel. Lee et al. indicated that reducing aromatic content and increasing cetane have relatively little impact in comparison to the change in density. Because of this, the JP-8 value was used as a proxy for the reduction that could be anticipated with the use of either ULSJ or SPK in diesel GSE engines.

Table 5. PM scaling results for JP-8, F-T diesel, and S5 relative to diesel [from Donohoo (2010) with permission].

Fuel	JP- 8	F-T Diesel	S5
PM scaling factor	0.48	0.67	0.47
	n=7	*n=16*	*n=2*
	σ=0.15	*σ=0.067*	

As with both CO and HC, PM emission reductions matched the expected trend from Lee et al., but with greater reductions than expected. Reduction for both ULSJ and SPK were expected due to decreases in fuel density; however, F-T diesel showed lesser reductions than either S5 or JP8. This again indicates that Lee et al. do not capture some necessary element of fuel composition or engine geometry.

3.4 Life-Cycle Greenhouse Gas Emissions

To accurately assess the impact of fuel combustion on global climate change, it is essential to consider the full fuel life cycle, from feedstock extraction through fuel combustion. If one only considers combustion, then for the fuels considered here (conventional jet fuel, SPK, and ULSJ fuel) the emissions of an alternative fuel will vary by less than 4%, and this is true regardless of the feedstock used to create the fuel (petroleum, natural gas, coal, or biomass) or how the fuel is processed. It is only from a life-cycle standpoint that one can see that biofuels offer the potential to reduce aviation's impact on global climate change. Biofuels can lessen aviation's production of greenhouse gases because the biofuel feedstock was created by photosynthetic reaction of water with carbon dioxide; thus, if atmospheric carbon dioxide was used to grow the biomass, then the combustion of the biofuel results in the carbon dioxide being returned to the atmosphere from which it came and there is zero net emission of carbon dioxide into the atmosphere from fuel combustion. This is not true for fossil fuel combustion, where the fuel feedstock contains carbon that has been sequestered from the atmosphere for millions of years. Further background information and guidance on creating a life-cycle GHG inventory can be found within the *Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels* (AFLCAWG, 2009).

The life-cycle GHG emissions from a variety of potential alternative jet fuels are plotted in Figure 5; these data are from the analysis of Stratton et al. (2010). The results of Figure 5 include an assessment of the anticipated impact of variations in feedstock properties and process efficiencies on life-cycle GHG emissions as well as an analysis of the impacts of land-use changes. Five life-cycle steps were considered: feedstock recovery (e.g., mining, farming, pumping), feedstock transportation, feedstock processing (e.g., gasification, F-T synthesis, refining), transportation (of finished fuel), and fuel combustion. Because of the increased energy intensity of feedstock extraction, unconventional petroleum fuels (oil sands and oil shale) have increased life-cycle carbon dioxide emissions relative to fuels created from crude oil. A ULS fuel has a slight increase in life-cycle carbon dioxide emissions because of the additional processing (i.e., refining) that is necessary to

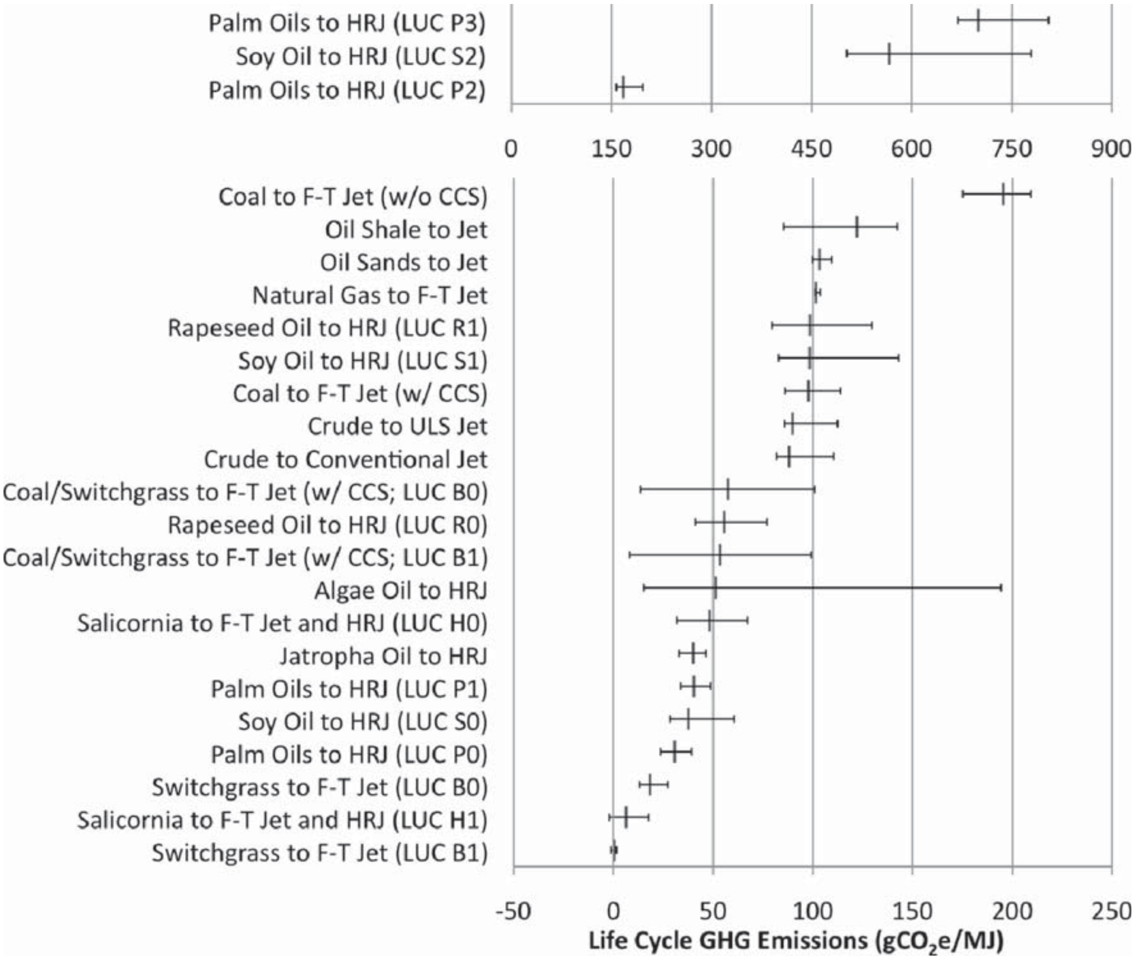


Figure 5. Life-cycle GHG emissions from a variety of potential alternative fuel pathways that could result in SPK, ULS, or conventional fuels [from Stratton et al. (2010) with permission].

Table 6. Land-use change scenarios explored [from Stratton et al. (2010) with permission].

Land-Use Change	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Switchgrass	None	Carbon depleted soils converted to switchgrass cultivation	n/a	n/a
Soy oil	None	Grassland conversion to soybean field	Tropical rainforest conversion to soybean field	n/a
Palm oil	None	Logged over forest conversion to palm plantation field	Tropical rainforest conversion to palm plantation field	Peatland rainforest conversion to palm plantation field
Rapeseed oil	None	Set-aside land converted to rapeseed cultivation	n/a	n/a
Salicornia	None	Desert land converted to *Salicornia* cultivation field	n/a	n/a

desulfurize the fuel. To achieve emissions comparable to conventional fuels, F-T fuels must either use carbon capture and sequestration (CCS) or incorporate biomass. Without CCS, F-T fuels from coal will have roughly twice the life-cycle carbon dioxide emissions. HRJ fuels have emissions that are highly dependent on the feedstock that is being used, with emissions from either direct or indirect land-use change dominating. The biomass to F-T fuel analysis assumes that the fuel was created from waste products or products from marginal land; thus there would be negligible net CO_2 emissions from land-use changes.

The production of biofuels from food crops can lead to emissions that are either an indirect or a direct result of land-use changes. Direct land-use change emissions result from the conversion of non-cropland (e.g., grasslands, rainforests, peatland) to cropland, while indirect land-use change emissions occur because food crops are diverted to biofuel production and this results in non-cropland elsewhere being diverted to create food crops—the latter is subject to much debate within the scientific community because of the complexity of the problem. The magnitude of the emissions depends on the type of land being converted to cropland, and in certain cases (e.g., conversion of rainforest or peatland), the emissions from land-use change can lead to a dramatic increase in life-cycle GHG emissions. The land-use change emission estimates within Figure 5, which are described in Table 6, are meant to provide a range of GHG emissions that may result from converting food crops to biofuel use.

CHAPTER 4

Air Quality Assessment for a Selected Airport

Although emissions inventory scaling as described in Chapter 3 illuminates the changes in primary PM and precursors for secondary PM such as nitrogen oxides and sulfur dioxide, it does not capture the end changes in particulate matter concentration. Capturing these changes in concentration, which ultimately affect human health, requires a full atmospheric chemistry model.

To demonstrate the changes in concentration and changes in emission inventories, the Hartsfield-Jackson Atlanta International Airport (ATL), located in Atlanta, Georgia, was modeled. ATL was chosen for its size, its location in a nonattainment area, and importantly, to leverage previous research efforts on ATL. In addition to being the busiest airport in the world, ATL is also located in both $PM_{2.5}$ and ozone nonattainment areas (Environmental Protection Agency, 2008).

4.1 Methodology

In order to model the changes in pollutant concentrations, a series of three programs was used. First, the EDMS was used to create an emissions inventory for aircraft and GSE. For the air quality modeling, the months of June and July were used. Second, the emission inventories were reformatted in SMOKE (Sparse Matrix Operator Kernel Emissions). The reformatted emissions inventories were then combined with a dispersion model, an atmospheric chemistry model, background inventories, and meteorological conditions in CMAQ (Community Multiscale Air Quality modeling system). Finally, the CMAQ output was processed using the EPA program MATS (Modeled Attainment Test Software). MATS adds the particle-bound water to the ionic concentrations computed by CMAQ.

EDMS is the required tool for airport emissions inventory compilation. EDMS calculates GSE emissions by using emission factors provided by EPA's NONROAD model and considers the regulations in effect for the year being modeled, engine age, and horsepower. EDMS computes aircraft emissions by using a combination of the ICAO Engine Exhaust Emissions Databank, thrust calculations obtained through SAE-AIR-1845, fuel flow rates from Eurocontrol's Base of Aircraft Data (BADA), and Boeing Fuel Flow Method 2. The model year within EDMS was set to 2011 to force a low sulfur content fuel for the GSE. This choice was made because using an earlier year with high sulfur content fuel would overstate the benefits of an alternative jet fuel, and an alternative jet fuel will not realistically be available in large quantities while the high sulfur content diesel fuel is in use; therefore, the reductions in SO_x would be overstated. For the inventory scaling, the full annual inventory for both GSE and aircraft was used.

CMAQ is an EPA-developed, three-dimensional Eulerian chemical-transport model. The model has three main components: a meteorological model system, an emissions model, and a chemistry-transport modeling system. For each time step and grid cell, CMAQ calculates the change in chemical concentration based on advection, diffusion, chemical formation, removal of each species, and the given emissions.

Previous modeling of ATL provided aircraft emission inventories for scaling and the necessary information for simulating the change in air quality (Arunachalam et al., 2008). This included the EDMS emissions inventories processed by SMOKE. The work by Arunachalam et al. used a four-kilometer grid size to examine the relative impact of aircraft at ATL on the region. Details regarding the analysis are provided in Arunachalam et al. (2008) and Donohoo (2010).

4.2 GSE Vehicle Inventory

The GSE emissions inventory was created with EDMS using the ATL aircraft schedule. To assess model accuracy, a comparison was made to a partial GSE inventory from Delta Airlines. For ATL, EDMS models 684 individual GSE, 445 of which are diesel. Because EDMS does not record emissions for individual GSE, the emissions cannot be scaled on a unit-by-unit basis. Instead, it is assumed that the proportion of GSE emissions from diesel GSE is directly related to the number of GSE. Although diesel GSE comprise approximately 66% of the total GSE inventory by fuel type, electric GSE are not responsible for any emissions at the airport. Therefore, the emissions were divided between the gasoline- and diesel-powered GSE. Of this portion, diesel GSE makes up 78%.

Unlike the aircraft flight schedule, which provided actual flights and aircraft used, the GSE vehicle inventory was produced by an internal EDMS algorithm. Although the actual GSE vehicle inventory for all of ATL is unknown, the GSE inventory for Delta was provided for analysis. The Delta GSE vehicle inventory differs from the EDMS inventory both in composition and number. The Delta vehicle inventory contains 2,251 individual pieces of equipment compared to the EMDS vehicle inventory, which has 684. The Delta vehicle categories were mapped into the EDMS categories, but 372 vehicles in the Delta GSE fleet did not have a corresponding EDMS category.

As can be seen in Figure 6, there are also several categories for which vehicles exist in one vehicle inventory but not another. For example, the EDMS inventory includes 51 hydrant trucks while the Delta inventory has none. One of the greatest disparities is that the Delta inventory contains 918 baggage tractors while the EDMS inventory contains 61. Within the baggage tractor category, the Delta inventory indicates that 58% of baggage tractors are diesel powered while the EDMS inventory assumes that all are gasoline. For some vehicle categories missing from the Delta inventory, such as catering trucks, it is likely that Delta outsources the task to an outside company and thus does not own or track the vehicles.

Although the gross number of vehicles varies dramatically, it is difficult to compare the two inventories because the manner in which the vehicles operate is unknown. For example, the vehicles in the EDMS inventory could be modeled as operating continuously throughout the day while the Delta inventory could contain units that are no longer operated or are only operated sporadically. Nonetheless, the differences in types of units indicate that the EDMS default modeling may not accurately capture the GSE population at ATL.

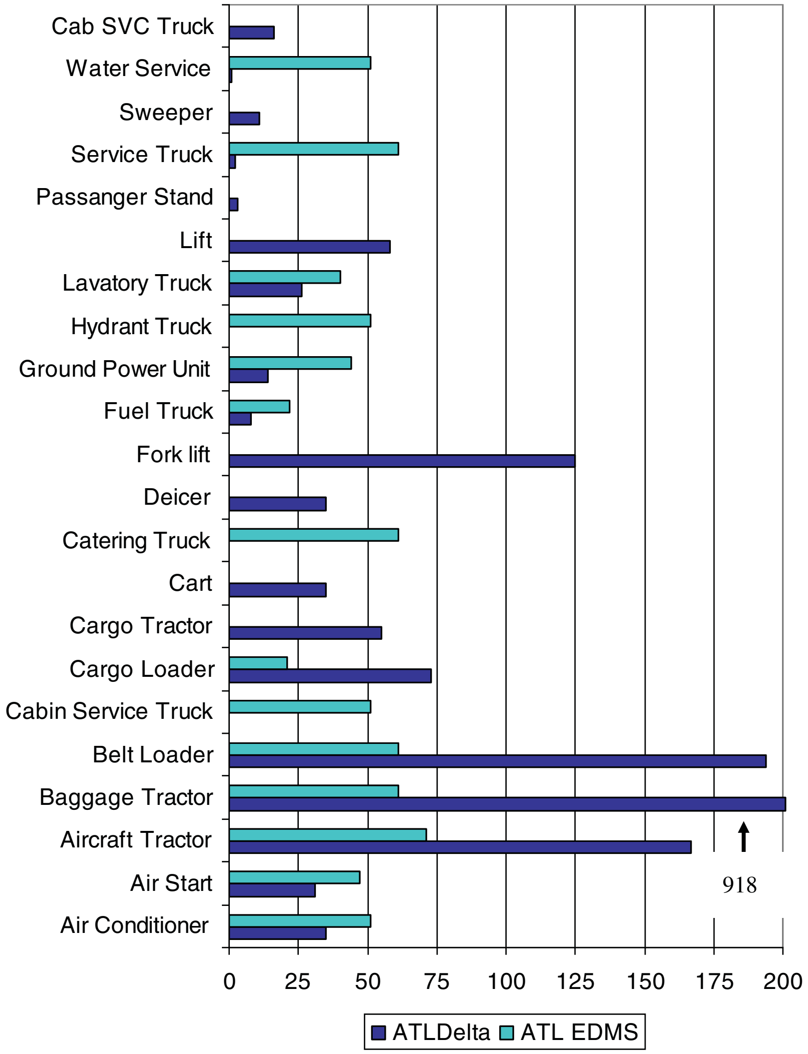


Figure 6. Delta and EDMS GSE vehicle inventories. The number of baggage tractors in the Delta inventory (918) exceeds the range covered in the chart [from Donohoo (2010) with permission].

Due to the discrepancies in vehicle inventories, a rudimentary check was conducted on the total GSE fuel consumption. Although EDMS does not calculate fuel burn, there is a linear relationship between SO_x emissions and fuel burn, which can be used to estimate fuel consumption. According to EDMS, the total mass of SO_x produced by the GSE at ATL based on the 2002 aircraft schedule is 7,500 grams, which equates to a fuel consumption of approximately 61 million gallons.

An alternative estimate of GSE fuel use is 0.25 to 0.30 gallons of diesel per enplaned passenger. This would result in 9.6 to 11.6 million gallons fuel based on 36,639,600 enplaned passengers at ATL in 2002 (Hartsfield-Jackson Atlanta International, 2008). This represents a potential uncertainty factor of 6 in fuel use and emissions between the EDMS methodology and an independent estimate of GSE fuel use. Due to this uncertainty as well as the uncertainty associated with both the NONROAD model and the scaling factors, GSE were not included in the full air-quality model.

4.3 Emissions Inventory

The aircraft and GSE emissions from EDMS were scaled according to the relationships outlined in Chapter 3 (summarized in Appendix D) to examine various GSE and aircraft fueling scenarios as outlined in Table 7. The first scenario models the aircraft emissions with Jet A and GSE emissions from ULSD as it will be operating in 2011 when the ULSD standard comes into full effect. The second scenario is a low-sulfur scenario with aircraft using USLJ and GSE using USLD. The third scenario considers a potential single-fuel airport with both GSE and aircraft using a 50-50 blend of SPK and ULSJ. The last scenario considers the lowest emission case possible, with GSE producing no emissions (for example being converted to all electric or fuel cell) and aircraft burning 100% SPK fuel. These scenarios are summarized in Table 7.

As shown in Figure 7, EDMS predicts that aircraft are responsible for more of the emissions affecting air quality at ATL than GSE. Across all of the scenarios, GSE produced 6% or less of the NO_x emissions. Because scenarios 1 to 3 assume the GSE use a ULS fuel instead of conventional diesel, the GSE SO_x emissions are negligible in comparison to aircraft SO_x emissions. The contribution of GSE to primary PM emissions varies with the scenario; GSE contribute 11% of the PM in the baseline scenario (Scenario 2 with ULSJ/ULSD), and the contribution would increase with the use of 50-50 SPK and ULSD to 16% (Scenario 3). If both GSE and aircraft were operating on a 50-50 blend of SPK and ULSJ, then GSE would comprise 14% of the emissions (SPK/ULSJ). GSE are responsible for a larger percentage of CO than PM, SO_x, or NO_x. With the use of ULSD, GSE are responsible for 37% of all CO emissions, but this is reduced to 30% with the use of the SPK-ULSJ blend.

Table 7. Fuel scenarios modeled for ATL emissions inventory analysis [from Donohoo (2010) with permission].

Fuel	Aircraft	GSE
Scenario 1	Jet A	ULSD
Scenario 2	ULSJ	ULSD
Scenario 3	50-50 blend SPK-ULSJ	50-50 blend SPK-ULSJ
Scenario 4	100% SPK	–

The changes in aircraft NO_x and CO emissions were assumed to be only due to changes in fuel burn. The aircraft NO_x emissions for ULSJ are reduced by the change in fuel burn 0.5%, while the NO_x emissions for 100% SPK would be reduced by 2.1% and the 50-50 blend would be reduced by 1.3%. This result is likely conservative since preliminary studies show that NO_x is reduced with SPK fuels. The SO_x emissions from aircraft were reduced as a result of the change in fuel sulfur content. The 98% reductions shown in Figure 7 are a result of the change from 680 ppm to 15 ppm fuel sulfur content.

The aircraft primary PM emissions from Figure 7 have been broken out by type within Figure 8 to explain the variation in reduction with the various fuels. ULSJ and SPK fuels have ultralow sulfur levels and therefore the emissions of PMS are also nearly zero. The PMFO and PMLO were both assumed to be unchanged with fuel composition; the PMFO reduction is likely erroneous since recent preliminary AAFEX results indicate a reduction in volatile gaseous emissions. As discussed in Section 3.2.3, each of these fuels will have varied emissions of non-volatile PM (PMNV). ULSJ is expected to have similar PMNV emissions to conventional fuel, while a neat (i.e., 100%) SPK fuel should have a large PMNV reduction. The 50-50 blend fell in between these. The result is that the primary PM emissions for ULSJ were 37% lower than Jet A, SPK were 72% lower, and the 50-50 blend were 56% lower than conventional jet fuel.

4.4 Ambient Particulate Matter Concentration

Due to the uncertainty in the GSE inventories, only the emissions from the aircraft were modeled for air quality. These cases included aircraft emissions for a baseline scenario with Jet A, as well as three additional scenarios using ULSJ, a 50-50 blend of ULSJ and SPK, and a 100% SPK fuel. Thus, the aircraft inventories from the previous section were input to CMAQ with the output being a cell-by-cell concentration of ionic compounds that comprise particulate matter. These compounds consisted of ammonia, sulfates, nitrates, elemental carbon, organic carbon, and crustal material.

In addition to showing the region that was modeled within CMAQ, Figure 9 presents the ambient concentrations of $PM_{2.5}$ without aviation activity. This background level should

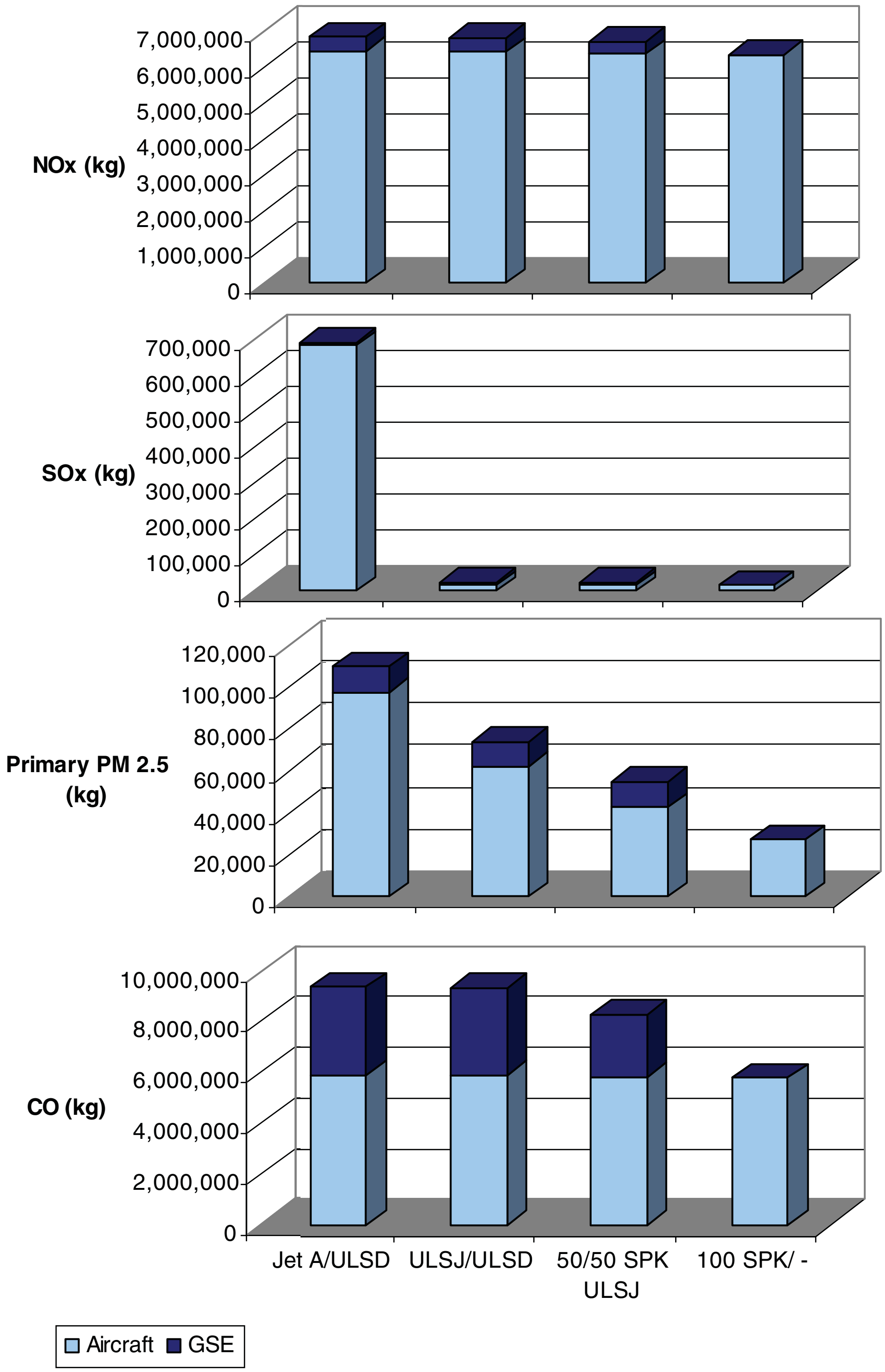


Figure 7. Scaled emissions inventories for GSE and aircraft based on EDMS analysis of ATL [from Donohoo (2010) with permission].

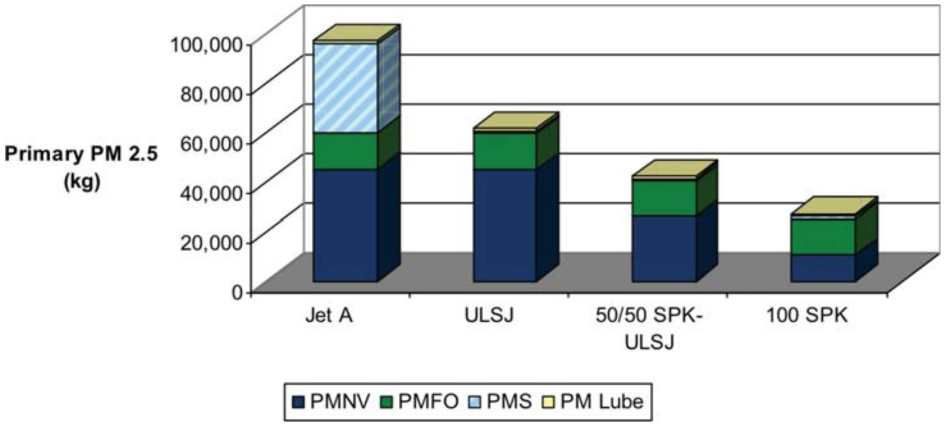


Figure 8. Scaled aircraft primary PM emissions by species using EDMS [from Donohoo (2010) with permission].

be kept in mind when reviewing aviation's contribution since the background level is several orders of magnitude larger.

The incremental contributions of aircraft emissions in each of the fuel scenarios are shown using an approximate radial distance, which is shown schematically in Figure 10. In this manner, all of the emissions in the grid cell that correspond to each radius number were averaged. This provides an approximate distance from ATL that should suffice for comparing the impact of alternative fuel use on ambient PM emissions from aviation. Distances within the circle shown in Figure 9 have been plotted in this manner.

As expected, the composition of the ambient $PM_{2.5}$ from aircraft emissions, shown in Figure 11, changes with fuel composition. The peak $PM_{2.5}$ level of ~0.6 ug/m^3 that is due to aviation is two orders of magnitude smaller than the background concentration. Each of these charts provides the contribution of each $PM_{2.5}$ component to the total ambient $PM_{2.5}$. With Jet A, the largest contribution to $PM_{2.5}$ is due to sulfates. With each of the alternative fuels considered, the ultralow sulfur content of the fuels makes the sulfate contribution negligible. The largest contributor of $PM_{2.5}$ for all three alternative fuel scenarios is organics, followed by elemental carbon. The elemental carbon fraction changes as expected with the reduced inventories for the 50-50 blend and straight SPK. Across all scenarios, the nitrate contribution to $PM_{2.5}$ is negligible, which is consistent with prior work (Arunachalam et al., 2008) for ATL; however, this is not uniformly observed. A nationwide analysis of the air quality impacts from aviation suggests nitrates may be the largest source of aircraft-related PM; see, for example, Brunelle-Yeung (2009).

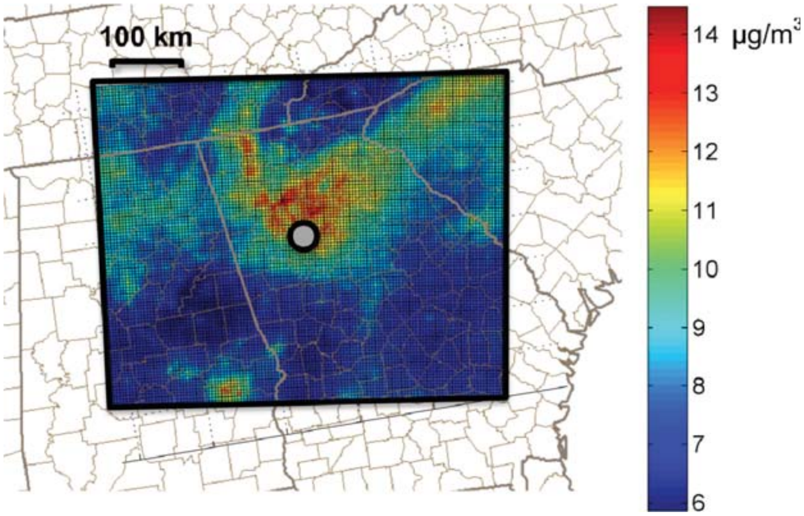
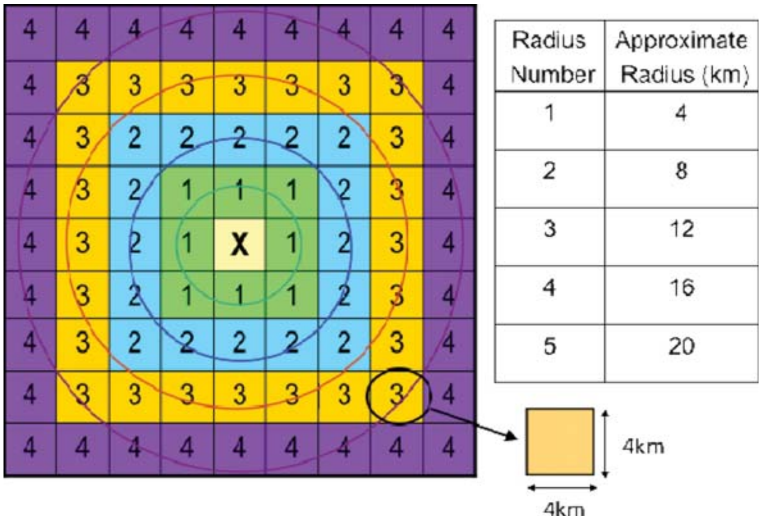


Figure 9. Ambient concentrations of $PM_{2.5}$ in the study area. The circle roughly denotes the location of ATL with the size of the circle corresponding to the radii covered in subsequent charts [from Donohoo (2010) with permission].



4	4	4	4	4	4	4	4	4
4	3	3	3	3	3	3	3	4
4	3	2	2	2	2	2	3	4
4	3	2	1	1	1	2	3	4
4	3	2	1	X	1	2	3	4
4	3	2	1	1	1	2	3	4
4	3	2	2	2	2	2	3	4
4	3	3	3	3	3	3	3	4
4	4	4	4	4	4	4	4	4

Radius Number	Approximate Radius (km)
1	4
2	8
3	12
4	16
5	20

Figure 10. Grid definition for radial plots of ambient $PM_{2.5}$ concentration [from Donohoo (2010) with permission].

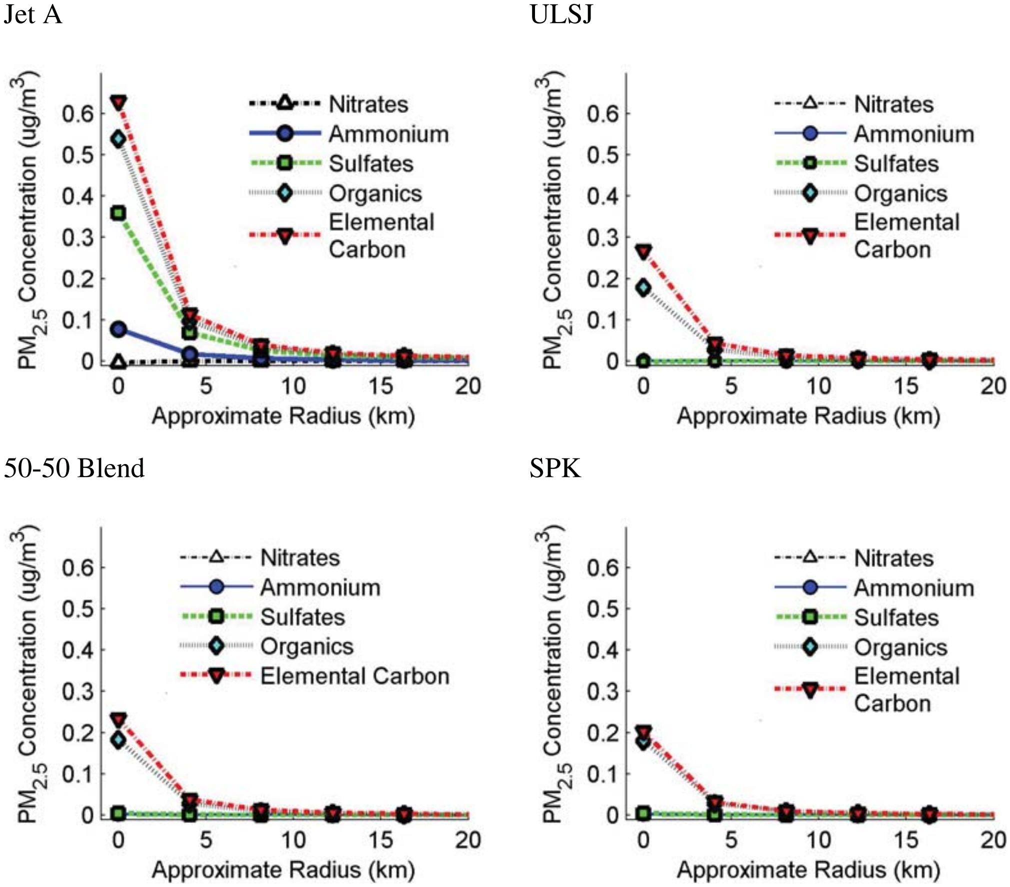


Figure 11. Ambient $PM_{2.5}$ concentration from aircraft for each of the four fuel compositions considered in this work, with the breakout of individual species [from Donohoo (2010) with permission].

CHAPTER 5

About the Handbook

The main goals of this project were the development of a computational tool and a handbook to analyze the costs and benefits of using alternative fuels at airports. The handbook is organized according to the structure of AFIT. It describes inputs, outputs, and use and interpretation of the results.

The AFIT tool is available on the CD-ROM that accompanies this report. The handbook can be loaded onto the user's computer by clicking the help button on any screen of AFIT. The handbook describes the intent, purpose, limits, and general use of AFIT and offers sources of information potentially useful to the user.

The handbook is designed to help airports, fuel suppliers, and other interested parties evaluate the costs and benefits of using an alternative jet fuel at an airport. The alternative fuels addressed in the handbook and tool are ULSJ and SPK. SPK includes Fischer-Tropsch fuels and hydroprocessed renewable jet fuel created from feedstocks such as algae and palm oils.

5.1 AFIT Use

AFIT has been developed to estimate costs associated with the introduction of an alternative fuel and associated emissions reductions. AFIT does not provide a cost–benefit metric. Deciding whether to introduce an alternative fuel to a specific airport is a complex decision and is beyond the scope of this research and the AFIT software tool. It must also be noted that AFIT, in its present configuration, is only for analyzing alternative jet and ground support equipment fuels and not for analyzing all fuels in use at airports, which may include compressed natural gas, biodiesel, propane, or electric power.

The primary costs related to introduction of an alternative fuel are transportation and delivery to the airport. Typically, costs are captured in two stages of delivery. Off airport, which are the costs associated with delivering the fuel to the airport perimeter, and on airport, which are the costs of delivery to the airport fueling facilities as well as the GSE and aircraft wing.

Costs unrelated to delivery are decommissioning—diesel handling and distribution equipment that is taken out of service where alternatives are used with GSE—and the avoided costs associated with a single fuel source and unnecessary diesel equipment. These costs are included to capture any costs an airport is likely to incur.

Chapter 1 of the handbook lays the foundation for understanding the intended cost–benefit analysis. It describes the key functions and parameters to be investigated, the limitations in data availability, eventual barriers, sources, and challenges of information gathering. The handbook also discusses interrelations between parameters: fuel, airport landscape, weather conditions, and so on. It also introduces concepts that are inherent to a cost–benefit analysis but may be unfamiliar in aviation settings.

The more accurate the analyst can be with input values, the more useful the outcome will be. For the convenience of users, AFIT has typical cost numbers included in a range that can be selected by the user. These costs are based on research during development of the tool and are intended to capture the typical costs and range of costs associated with transportation and storage of fuels. The AFIT user should, however, understand that commodity prices vary by time, region, supplier, volume, and other factors, and the ranges provided may not reflect an individual airport's circumstances.

AFIT uses relatively simple, readily available data to quantify alternative fuel transportation and equipment modification costs. AFIT is a stand-alone application that runs on computers using the Windows operating system. Total fuel costs are determined using inputs related to fuel use quantity, transportation sequence, and handling requirements. To determine environmental benefits, AFIT requires a baseline emissions inventory for the subject airport, created by FAA's EDMS, as an input.

AFIT produces a report enumerating the costs and potential savings that can come from using alternative jet fuel and summarizes changes to an airport's emissions inventory. Additional details on using AFIT are presented in the handbook.

The user needs to be familiar with the airport's current fuel usage, either annual or monthly, for both diesel and Jet A. The user also needs to be familiar with the price per gallon paid for each fuel. AFIT has default fuel price settings based on typical prices paid throughout the Unites States and averaged. Appendix B in the handbook also lists several sources for fuel information, which are described below. The user also has to determine whether the study is for alternative fuels to be run through existing equipment or whether the alternative fuel use is associated with a significant expansion to the airport where new construction will be required. The user also must select the type of alternative fuel to be considered in the study and should be familiar with types of fuel available and cost at the production facility.

Familiarity with the current costs of fuel delivery will also be helpful. Storage, flowage, throughput, and other fuel handling per-gallon costs of existing fuels and those expected for the alternative fuel are also helpful. AFIT supplies default costs, but they are averaged from airports across the United States. Knowledge of the current GSE fleet and suppliers of parts and service will be needed to estimate change-out costs in those cases where modifications are necessary. Access to past construction estimates and project documents or current contact with construction companies and fuel supply vendors will improve the accuracy of estimates. Where the alternative fuel replaces diesel fuel, removal and decommission costs of the diesel system also need to be estimated.

The final chapter of the handbook shows the user how to interpret the results of the analysis and presents additional considerations for the airport prior to deciding whether to implement the alternative.

Whether an airport would choose to adopt an alternative fuel depends on a multitude of factors. Cost and emission reduction numbers, as computed by AFIT, can give a sense of expected change in only two aspects of fuel use at airports. Cost and emission reduction numbers can give a sense of expected change in only two aspects of fuel use at airports. Other factors, such as supply availability, regulations, long-term sustainability, and broader regional environmental considerations must be weighed accordingly.

AFIT is not intended to provide the user with a clear result to use or not use an alternative fuel. However, it will give some valuable information to estimate costs of adopting alternative fuels, in total or in cents per gallon, and will also provide estimates of the potential reduction in emissions one can expect given the equipment at an airport. As with any investment decision, costs and benefits are crucial components, but they should be considered in light of airport traffic forecasts, economic outlook, local and regional considerations, and options concerning financing and raising capital to undertake such a significant change.

5.2 Data References

Some data needed for the fuel comparisons can be easily sourced. Other information, such as transportation costs (e.g., pipeline, truck, barge, and rail, and storage and blending fees) depends on the facility and businesses involved. References for fuel information are illustrated below. The AFIT tool provides the typical cost range for the various handling fees.

5.2.1 Fuel

5.2.1.1 Gasoline and Diesel

EIA gasoline and diesel prices:
http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm
U.S. Gulf Coast No. 2 Diesel Low Sulfur Spot Price FOB (cents per gallon):
http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=rdlusg&f=d
IATA Jet Fuel Price Monitor:
http://www.iata.org/whatwedo/economics/fuel_monitor/index.htm
ATA jet fuel price statistics:
http://www.airlines.org/Energy/FuelCost/Pages/MonthlyJetFuelCostandConsumptionReport.aspx

5.2.1.2 Alternative Fuel Price Estimates at the Producer

Many reports (e.g., Hileman et al., 2009) provide estimates of the economic costs of producing fuel, but these values are from the viewpoint of the fuel producer. This should not be confused with the price that would be paid by a fuel consumer. The price paid by a consumer will be set by the prevailing market price for conventional jet fuel. Assuming that the fuel producer can create its alternative jet fuel at a cost that is less than the prevailing price of conventional jet fuel, it will sell it at the market price of conventional jet fuel to maximize profits. However, if the fuel producer and fuel buyer go into a long-term contract, then the fuel producer may sell its product at a discount to conventional jet fuel. Because of these issues, AFIT has a default assumption that the price of the alternative fuel is assumed to be the same as conventional jet fuel.

5.2.1.3 Transportation and Storage Costs

These costs are not collected and posted conveniently on any single website. The cost ranges provided in AFIT were collected by reviewing financial filings, regulatory requirements, and other legal and non-legal documents and sources. Pipeline, barge, truck, and rail costs vary widely depending on a multitude of factors. The Energy Information Administration (EIA) is a large repository of useful information and can be found at http://www.eia.doe.gov/.

5.2.1.4 New Diesel Fueling Station Costs

Construction costs vary depending on region, project type, preexisting arrangements, and so on, but the RSMeans *Building Construction Cost Data* manual is an excellent source for the latest industry standards. The 2008 edition was used for this handbook. A 2010 version of the manual is now available.

5.2.1.5 Equipment Costs

GSE equipment replacement costs vary widely depending on the equipment on site, its age and condition, onsite inventory, mechanical skill level of employees, and other factors. Fleet and equipment managers currently maintaining the equipment are likely the best source for cost data with the airport's current suppliers.

CHAPTER 6

Issues and Challenges

6.1 Available Data for Estimating Emissions

As noted throughout the report, the research team has encountered some data limitations. The emissions data used for the development of the handbook come from ongoing research projects; it is not certification data. As such, the results of this project are also of a research nature, and the resulting estimated emission factors will have an associated level of uncertainty. Once the fuels are available, then certification measurements will be made and the resultant emission factors should have increased certainty.

The emissions scaling relationships that form the foundation of the emissions portion of this work will need to be reconsidered as additional data become available. Given the current lack of data, determining an appropriate methodology for scaling emissions is difficult, but not impossible, for both diesel engine and jet engine combustion. This stems from the relative lack of scientific understanding of how these emissions are formed during the combustion process (from any fuel, conventional or alternative); this is especially true for the formation of primary PM. For jet engine combustion, this lack of scientific knowledge is being addressed through detailed measurement campaigns of both conventional jet fuel and alternative jet fuels. As an example, considerable aircraft engine emissions data was acquired by the AAFEX research team, which became public at the January 2010 AIAA Aerospace Sciences Meeting. This includes data for all of the species considered here. Based on unpublished results from this study, it appears that consistent trends are starting to emerge. As noted in Section 3.2, these data should be used to augment or replace the preliminary scaling factors in this report. However, primary PM production from diesel engine combustion is less well understood than jet engine combustion due to the additional factors that affect diesel combustion, such as cetane number. Because of these factors, there will be a limit to the accuracy of these estimates. The key to all of this is to use the best data available at the time of conducting an airport analysis to modify the relationships herein.

As noted in Chapter 5, changes in infrastructure costs due to alternative fuel use are marginal and could bring considerable variation to the results. Fuel prices are influenced by market values and are prone to speculation that may not have any reasonable foundation.

6.2 Maturity of Alternative Fuels for Aviation

There will be delays before alternative jet fuels will be available for widespread use. This delay is the result of the fundamental steps that are required to bring an alternative fuel to market. These include:

- The feedstock to create the fuel needs to be created in large quantities. (A large airport consumes ~25,000 barrels per day of fuel, and the nation consumes 1.6 million barrels of jet fuel per day.)
- Processing facilities must be built to convert the feedstock into the final certified fuel.

Multiple feedstocks are available for the production of SPK fuels. On a worldwide basis, natural gas that is stranded far from populations is available for F-T synthesis into an SPK fuel; in the United States, available natural gas resources are used for heating and electricity generation since these are more profitable. For SPK fuels created by the liquefaction of coal via F-T synthesis, a limitation exists in the lack of a system for carbon capture and sequestration that would support a widespread coal-to-liquids industry. Biomass could also be used to create an SPK fuel either by F-T synthesis or via hydrotreatment; however, the existing agricultural infrastructure is designed for the harvest of food crops, and the ability to harvest large quantities of high-energy biomass that does not offset food production is currently limited. Some testing is now underway for growing fuel crops in rotation with food crops, such as growing *Camelina* between wheat crops when the fields would otherwise lie fallow. Also, there is considerable promise since multiple crops (e.g., *Jatropha*, halophytes, and algae) could yield large quantities of renewable oil on marginal land that is not otherwise suitable for agriculture.

The construction of facilities to process these fuels will require considerable investment and time. Some examples merit consideration. The first example is the Oryx plant in Qatar that will convert natural gas to SPK fuels via the F-T process. The construction of the facility required two and a half years (not including the time for planning, permitting, etc.) at a capital cost of $950 million; it will produce roughly 34,000 barrels per day (24,000 of which will be diesel fuel). Such a facility could also be designed to produce a comparable amount of jet fuel since diesel and jet fuels have similar refining requirements. The second facility to consider is the Neste plant that is being built in Singapore to hydrotreat vegetable oils to create an SPK diesel fuel. Scheduled for completion in 2010 and at a cost of $850 million, it will produce roughly 15,000 barrels per day of fuel. These plants both cost nearly a billion dollars and could produce fuel sufficient for a medium- to large-sized airport.

Several companies are in the process of planning F-T facilities for the conversion of coal to liquids (e.g., Rentech, BAARD Energy, and American Clean Coals Fuels), and the Solena Group has announced plans to develop an F-T facility to create SPK fuels from municipal waste. All of these facilities could come online early this decade. When completed, these facilities would have a combined capacity slightly over 100,000 barrels per day, of which some fraction could be available to jet fuel use.

As an indication of the movement toward commercialization of alternative jet fuels, in December 2009, 12 airlines (Air Canada, American Airlines, Atlas Air, Delta Air Lines, FedEx Express, JetBlue Airways, Lufthansa Airlines, Mexicana Airlines, Polar Air Cargo, United Airlines, and US Airways) signed memoranda of understanding (MOU) with AltAir Fuels, LLC, and Rentech, Inc., to begin purchase negotiations for alternative aviation fuels. Two additional airlines (Alaska Airlines and Hawaiian Airlines) signed an MOU with AltAir fuels, and AirTran signed an MOU with Rentech. Based on these events, it is likely that over the coming decade, alternative jet fuels will be available in quantities sufficient to meet the needs of a few large airports.

6.3 Implementation Realities

The airports surveyed for this project were generally open to the idea of using alternative fuels as long as they met the current or new jet fuel specifications and were drop-in fuels. However, the airports generally take their cues from their tenant airlines since jet fuel use for aircraft exceeds the volume of fuel use for GSE by two or three orders of magnitude. While some airports were enthusiastic about the environmental benefits that could be gained by using alternative fuels, practical considerations were also significant. The concerns expressed included:

- At airports that do not have fueling consortia, individual airlines purchase and own their jet fuel, where it is usually commingled with other airlines' fuel in the fuel storage tanks.
- Aircraft fueling and GSE fueling are entirely separate, with different service companies responsible for each.
- Unless there were a guarantee that the alternative fuel would always be cheaper than diesel fuel for off-road equipment (considering all costs and subsidies), airports would want to maintain separate fuel storage and handling systems for GSE.

None of the concerns expressed by airports are insurmountable. However, each airport presents a unique set of hurdles that will have to be overcome to gain the benefits of using a single alternative fuel for both aircraft and GSE.

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APPENDIX A

Glossary, Acronyms, and Abbreviations

Aircraft gas turbine engine[1] – Any gas turbine engine used for aircraft propulsion or for power generation on an aircraft, including those commonly called turbojet-, turbofan-, turboprop-, or turboshaft-type engines.

Alternative fuel – An advanced fuel other than conventional fuels; for this report, alternative fuels are those that do not come from petroleum and could potentially replace jet fuel.

Black carbon – Nonvolatile diesel particulate matter, often used interchangeably with soot or elemental carbon, although it is most often used when discussing optical properties.

Cetane[2] – Hexadecane, an organic molecule consisting of a chain of 16 carbon atoms; also short for cetane number.

Cetane index[2] – Used as a substitute for the cetane number of diesel fuel; cetane index is calculated based on the fuel's density and distillation range.

Cetane number[2] – A measure of the detonation of diesel fuel.

Combustion CO_2e – Carbon-dioxide–equivalent emissions resulting from fuel combustion.

Drop-in alternative fuel – An alternative jet fuel that can be accommodated at an airport with little or no modification.

Elemental carbon[1] – Often referred to as EC and frequently used interchangeably with black carbon and soot, although it is most often used when referring to chemical properties; the refractory carbon found in combustion-generated particulate matter; the portion of a sample of combustion-generated particulate matter that remains after volatile components have been removed; also known as graphitic carbon.

Fine particle[3] – Particle with a classical aerodynamic diameter less than 2.5 μm.

Life-cycle CO_2e – Carbon-dioxide–equivalent emissions from all aspects of fuel production (e.g., refining and transporting) and combustion.

Organic carbon[3] – Often referred to as OC; is a major component of particulate carbon and is composed of many compounds, most of which partition between the gas and aerosol phases at ambient conditions and are referred to as semivolatile organic compounds (SVOC).

PM – Particulate matter.

$PM_{2.5}$ – Particulate matter less than 2.5 μm in diameter; similar to the term fine particle.

Primary particle – A particle emitted directly from the source.

Secondary particle – A particle that forms as the result of a chemical reaction or other means by combining with other elements after leaving the source.

Soot – Nonvolatile diesel particulate matter; also referred to as black carbon or elemental carbon.

Synthetic paraffinic kerosene – Fuels created from Fischer-Tropsch synthesis of coal, natural gas, biomass, or a mix of biomass and coal and hydroprocessed renewable jet fuel created from feedstocks such as algae and palm oils.

Total carbon[1] – The sum of elemental carbon and organic carbon.

Ultrafine particles – Particles with a classical aerodynamic diameter of less than 0.1 μm.

Volatile particles[1] – Particles formed from condensable gases after the exhaust has been cooled to below engine-exit conditions.

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[1] Definition from Society of Automotive Engineers, *Aerospace Information Report 5892*, 2007.

[2] Definition from Wikipedia, http://en.wikipedia.org/.

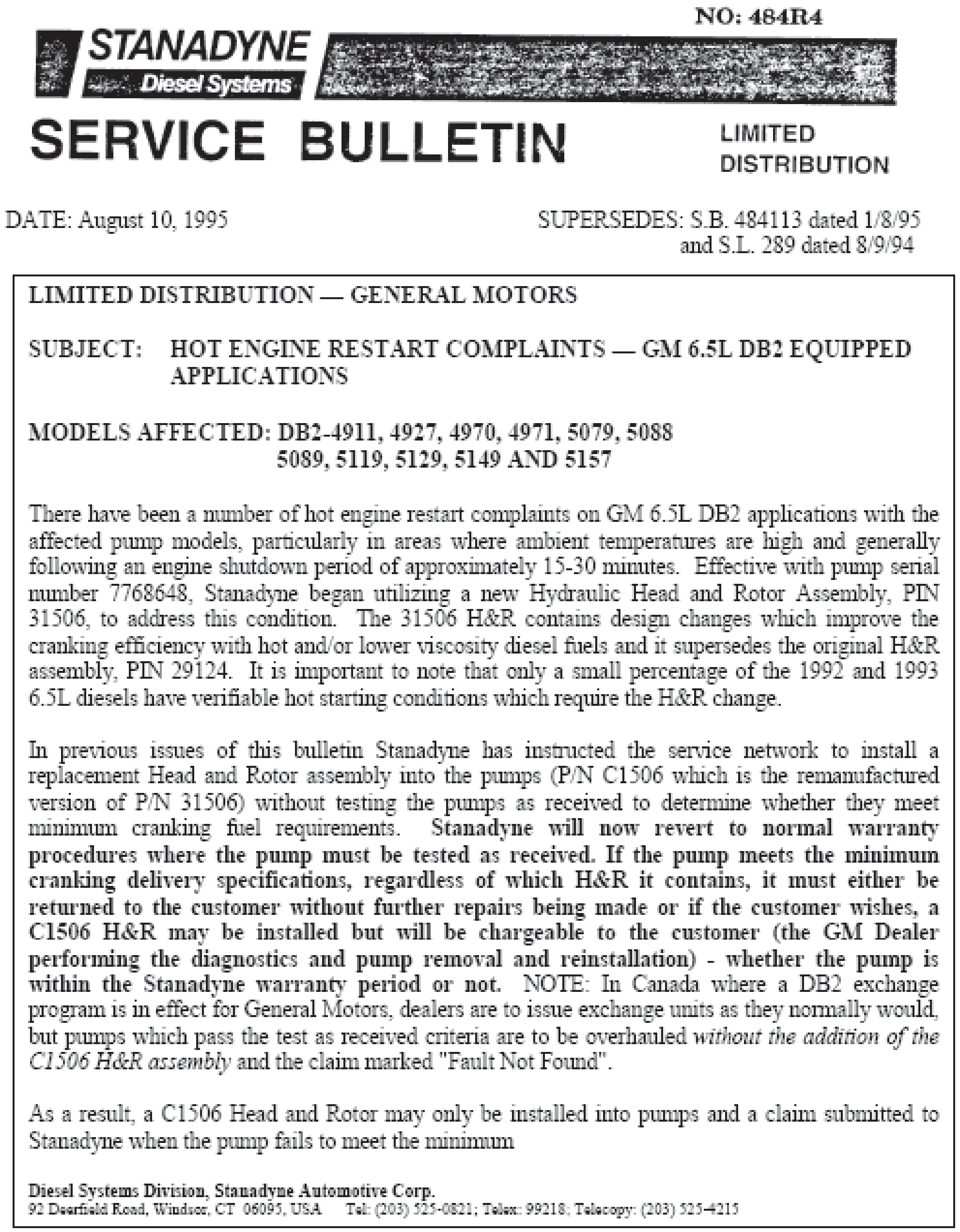
[3] Definition from http://www.epa.gov/pmdesignations/faq.htm.

Acronyms and Abbreviations

AAFEX – Alternative Aviation Fuels Experiment
ACRP – Airport Cooperative Research Program
AEDT – Aviation Environmental Design Tool
AERMOD – Atmospheric Dispersion Modeling System
AFIT – Alternative Fuels Investigation Tool
AFRL – Air Force Research Laboratory
APU – auxiliary power unit
ASTM – American Society of Testing and Materials
BADA – Base of Aircraft Data
BSFC – brake-specific fuel consumption
BTS – Bureau of Transportation Statistics
CAAFI – Commercial Aviation Alternative Fuel Initiative
CBA – cost–benefit analysis
CCS – carbon capture and sequestration
CI – cetane index
CMAQ – Community Multiscale Air Quality
CN – cetane number
CTL – coal to liquids
DESC – Defense Energy Support Center
EDMS – Emissions and Dispersion Modeling System
EF – emission factor
EPA – Environmental Protection Agency
ETMS – Enhanced Traffic Management System
EU – European Union
FAA – Federal Aviation Administration
FAME – fatty acid methyl ester
F-T – Fischer-Tropsch
GHG – greenhouse gas
GSE – ground support equipment
IPCC – Intergovernmental Panel on Climate Change
LNG – liquefied natural gas
LTO – landing takeoff cycle
MATS – Modeled Attainment Test Software
NAAQS – National Ambient Air Quality Standards
PM – particulate matter
PMFO – particulate matter composed of fuel organics
PMNV – nonvolatile particulate matter
PMSO – particulate matter composed of sulfur organics
SMOKE – Sparse Matrix Operator Kernel Emissions
SPK – synthetic paraffinic kerosene
ULS – ultralow sulfur

APPENDIX B

Stanadyne Fuel Pump Repair Bulletins



NO: 484R4

STANADYNE
Diesel Systems

SERVICE BULLETIN

LIMITED DISTRIBUTION

DATE: August 10, 1995

SUPERSEDES: S.B. 484113 dated 1/8/95
and S.L. 289 dated 8/9/94

LIMITED DISTRIBUTION — GENERAL MOTORS

SUBJECT: HOT ENGINE RESTART COMPLAINTS — GM 6.5L DB2 EQUIPPED APPLICATIONS

MODELS AFFECTED: DB2-4911, 4927, 4970, 4971, 5079, 5088
5089, 5119, 5129, 5149 AND 5157

There have been a number of hot engine restart complaints on GM 6.5L DB2 applications with the affected pump models, particularly in areas where ambient temperatures are high and generally following an engine shutdown period of approximately 15-30 minutes. Effective with pump serial number 7768648, Stanadyne began utilizing a new Hydraulic Head and Rotor Assembly, P/N 31506, to address this condition. The 31506 H&R contains design changes which improve the cranking efficiency with hot and/or lower viscosity diesel fuels and it supersedes the original H&R assembly, P/N 29124. It is important to note that only a small percentage of the 1992 and 1993 6.5L diesels have verifiable hot starting conditions which require the H&R change.

In previous issues of this bulletin Stanadyne has instructed the service network to install a replacement Head and Rotor assembly into the pumps (P/N C1506 which is the remanufactured version of P/N 31506) without testing the pumps as received to determine whether they meet minimum cranking fuel requirements. **Stanadyne will now revert to normal warranty procedures where the pump must be tested as received. If the pump meets the minimum cranking delivery specifications, regardless of which H&R it contains, it must either be returned to the customer without further repairs being made or if the customer wishes, a C1506 H&R may be installed but will be chargeable to the customer (the GM Dealer performing the diagnostics and pump removal and reinstallation) - whether the pump is within the Stanadyne warranty period or not.** NOTE: In Canada where a DB2 exchange program is in effect for General Motors, dealers are to issue exchange units as they normally would, but pumps which pass the test as received criteria are to be overhauled *without the addition of the C1506 H&R assembly* and the claim marked "Fault Not Found".

As a result, a C1506 Head and Rotor may only be installed into pumps and a claim submitted to Stanadyne when the pump fails to meet the minimum

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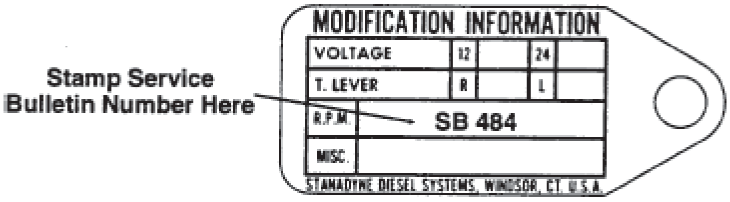
cranking delivery test and is within the 3 year/50,000 mile (80,000 km) Stanadyne warranty period.

When one of the affected pump models is upgraded with a C1506 H&R to address a hot, hard starting complaint, it must be identified by stamping "SB484" in the miscellaneous section of a 30607 Stanadyne Modification Nameplate as shown below and then affixing the plate to the pump under the rear governor cover screw as outlined in Service Bulletin 486.



Modification Nameplate 30607

Warranty

If one of the affected DB2 model injection pumps is received for a complaint of hard starting hot, and fails to meet the minimum cranking delivery specification when tested as received, and is within Stanadyne's warranty period of 3 years or 50,000 miles (whichever comes first), Service Dealers may submit a warranty claim for up to 3.7 hours labor broken down as follows:

Labor Operation No.	Description	Allowance (Hours)
00	Administration Time	0.5
01	Test as Received	1.0
50	Disassembly, Reassembly	1.2
51	Calibration	1.0
		TOTAL: 3.7

Please circle Class Code 3 and reference S.B. 484 on your warranty claim form. Canadian Service Dealers may submit a claim for overhauling the pump for their exchange unit shelf stock as outlined in Service Letter 273C.

NOTE: Only remanufactured H&R assemblies (P/N C1506) are to be used for this repair when performed within the Stanadyne warranty period.

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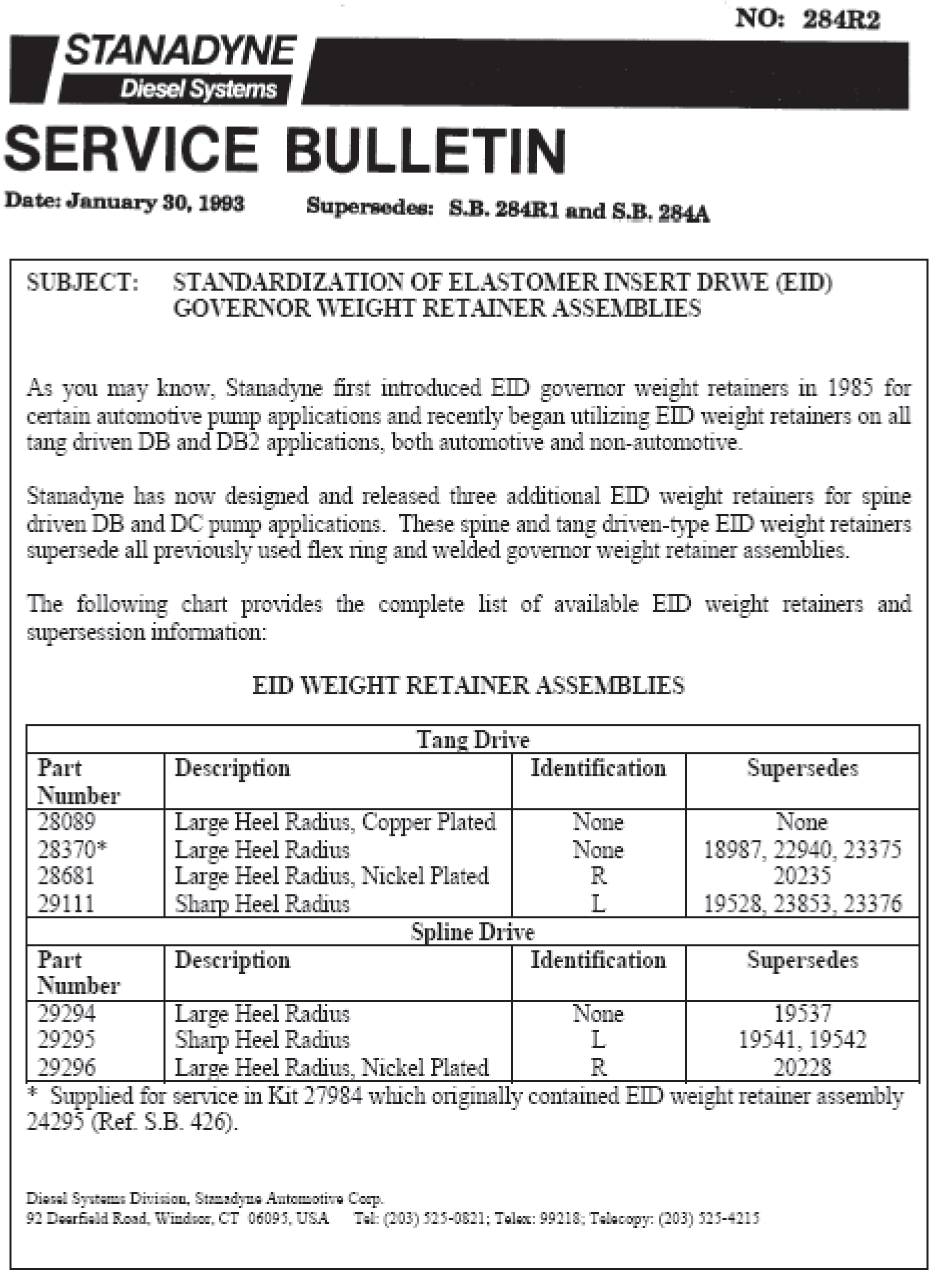

NO: 284R2

STANADYNE
Diesel Systems

SERVICE BULLETIN

Date: January 30, 1993 **Supersedes: S.B. 284R1 and S.B. 284A**

SUBJECT: STANDARDIZATION OF ELASTOMER INSERT DRWE (EID) GOVERNOR WEIGHT RETAINER ASSEMBLIES

As you may know, Stanadyne first introduced EID governor weight retainers in 1985 for certain automotive pump applications and recently began utilizing EID weight retainers on all tang driven DB and DB2 applications, both automotive and non-automotive.

Stanadyne has now designed and released three additional EID weight retainers for spine driven DB and DC pump applications. These spine and tang driven-type EID weight retainers supersede all previously used flex ring and welded governor weight retainer assemblies.

The following chart provides the complete list of available EID weight retainers and supersession information:

EID WEIGHT RETAINER ASSEMBLIES

Tang Drive			
Part Number	**Description**	**Identification**	**Supersedes**
28089	Large Heel Radius, Copper Plated	None	None
28370*	Large Heel Radius	None	18987, 22940, 23375
28681	Large Heel Radius, Nickel Plated	R	20235
29111	Sharp Heel Radius	L	19528, 23853, 23376
Spline Drive			
Part Number	**Description**	**Identification**	**Supersedes**
29294	Large Heel Radius	None	19537
29295	Sharp Heel Radius	L	19541, 19542
29296	Large Heel Radius, Nickel Plated	R	20228

* Supplied for service in Kit 27984 which originally contained EID weight retainer assembly 24295 (Ref. S.B. 426).

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Identification

EID weight retainer assemblies are identified in the following manner:

Large heel radius:	No identification mark (previously marked "CL" on weight retainers prior to the EID version).
Sharp heel radius:	Stamped "L" on the flat surface area of the retainer between the weight sockets.
Nickel plated:	Stamped "R" on the flat surface area of the retainer between the weight sockets.

Flexible Retaining Rings

Although the flex ring governor weight retainer assemblies have been superseded by the EID version, the 22935 flexible retaining ring is still available for servicing these governor weight assemblies. Flex ring replacement instructions are as follows:

Disassembly

To disassemble a retaining ring from a weight retainer, insert the tips of snap ring pliers 13337 under the flexible ring between any two rivets. Expand the pliers while applying pressure in an upward direction. A slight twisting motion will snap the ring off the rivet. The ring may then be pulled by hand from the remaining rivets.

Assembly

To assemble a new flex ring to a weight retainer:

1. Place the weight retainer cage with the three rivets face up on a work bench.

2. Assemble the hub (rivets facing up) to the weight cage.

3. Insert the tips of snap ring pliers 13337 into one of the holes in the new flexible retaining ring, and expand the hole by squeezing the pliers. *Caution: over expansion may damage the ring.*

4. While holding the hub and retainer with one hand, catch the back edge of the hole in the ring under the head of a rivet on the retainer (Figure 1).

5. Pivot the pliers around the rivet until the ring snaps into its groove beneath the head of the rivet.

6. Repeat this process to assemble the ring to the remaining five rivets.

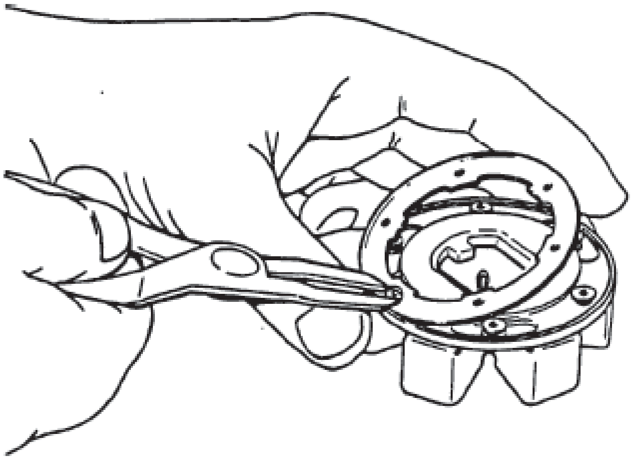

Figure 1

Governor Weight Retainers & Thrust Washers

Weight retainers utilized prior to the EID standardization, were identified by a stamped "L" (sharp corner) or "CL" (radiused corner) in the location as shown in Figure 2. In 1981 the inside diameter of the weight retainer was increased (Ref. Figure 3) to allow for the use of a thrust washer without a chamfered edge and were identified by a stamped line under the "L" or "CL".

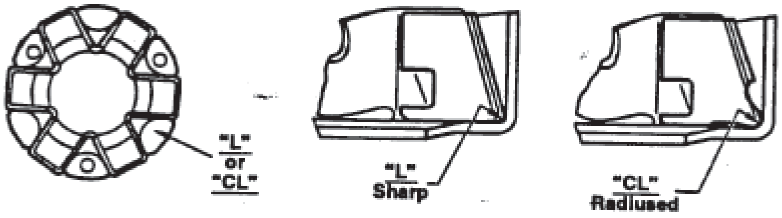

Figure 2

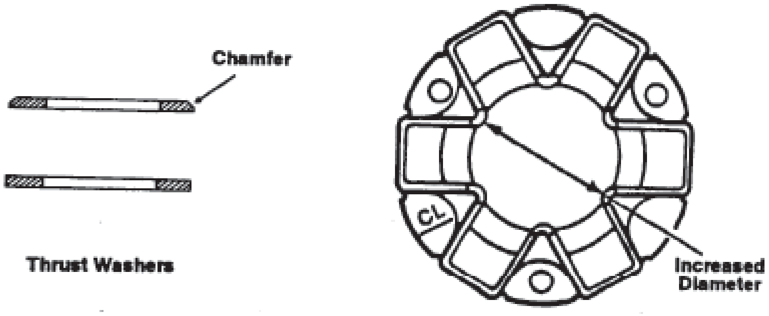

Figure 3

A chamfered thrust washer must be used in conjunction with weight retainers with the smaller inside diameter. This chamfer eliminates the possibility of interference between the thrust washer and the weight sockets when the weights are in their outermost position. *NOTE: A new plated, chamfered thrust washer, part number 29709, is now available for pumps which are equipped with a small inside diameter weight retainer that operate on lower viscosity fuels (Ref. S.B. 125).*

Un-chamfered thrust washers should be utilized on pumps with increased inside diameter (which includes all EID types) weight retainer assemblies. However, the chamfered thrust washers may be used with all weight retainer assemblies. Thrust washer part numbers and usage is provided in the following chart:

Part No.	Description	Where Used
11620	Chamfered	Smaller inside diameter Weight Retainers (prior to 1981)
29709	Chamfered (Plated)	
20222	Un-chamfered (Plated)	Increased inside diameter Weight Retainers (1981 - present, all EID's)
23272	Un-chamfered	

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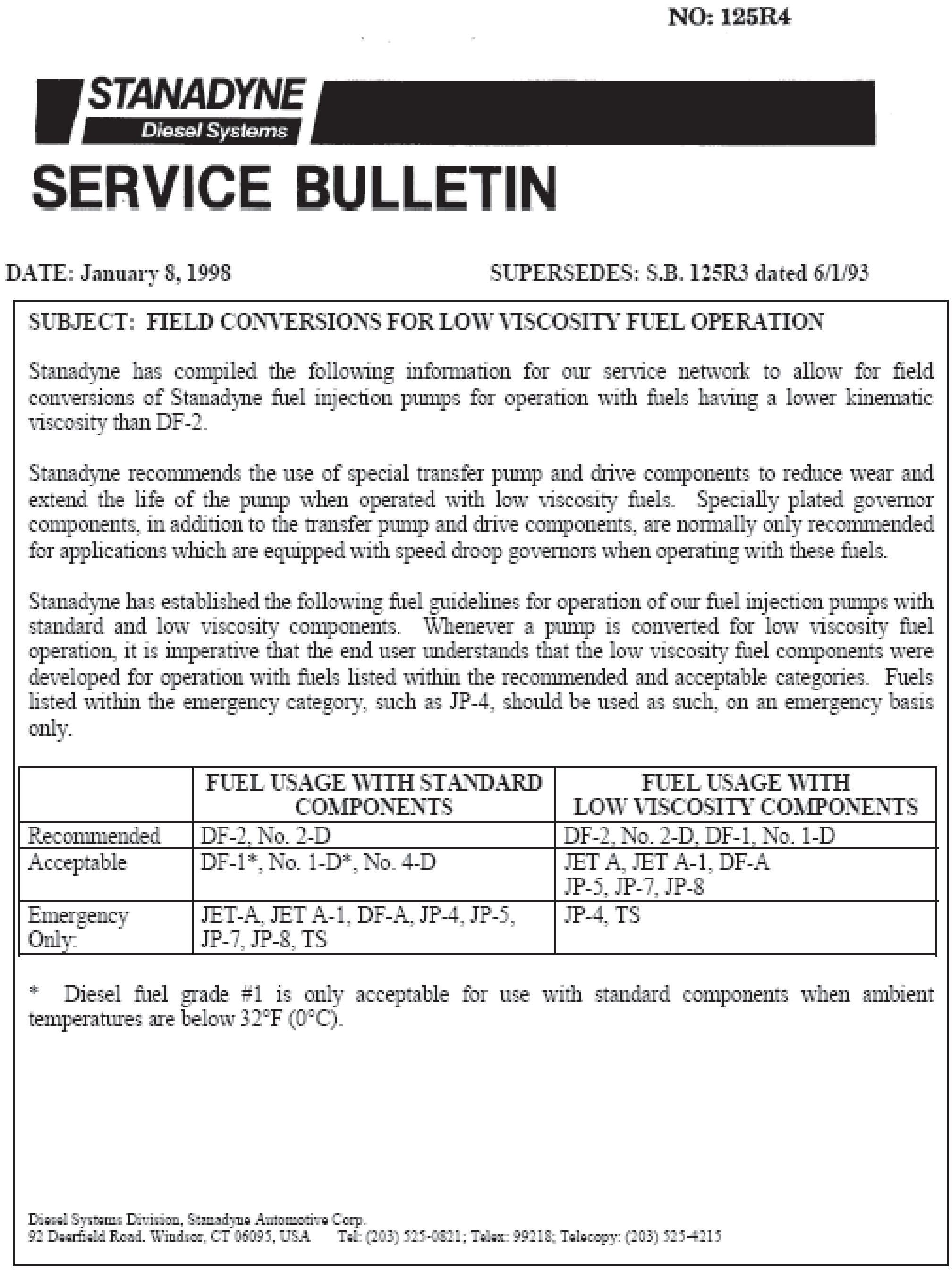

NO: 125R4

STANADYNE
Diesel Systems

SERVICE BULLETIN

DATE: January 8, 1998 SUPERSEDES: S.B. 125R3 dated 6/1/93

SUBJECT: FIELD CONVERSIONS FOR LOW VISCOSITY FUEL OPERATION

Stanadyne has compiled the following information for our service network to allow for field conversions of Stanadyne fuel injection pumps for operation with fuels having a lower kinematic viscosity than DF-2.

Stanadyne recommends the use of special transfer pump and drive components to reduce wear and extend the life of the pump when operated with low viscosity fuels. Specially plated governor components, in addition to the transfer pump and drive components, are normally only recommended for applications which are equipped with speed droop governors when operating with these fuels.

Stanadyne has established the following fuel guidelines for operation of our fuel injection pumps with standard and low viscosity components. Whenever a pump is converted for low viscosity fuel operation, it is imperative that the end user understands that the low viscosity fuel components were developed for operation with fuels listed within the recommended and acceptable categories. Fuels listed within the emergency category, such as JP-4, should be used as such, on an emergency basis only.

	FUEL USAGE WITH STANDARD COMPONENTS	FUEL USAGE WITH LOW VISCOSITY COMPONENTS
Recommended	DF-2, No. 2-D	DF-2, No. 2-D, DF-1, No. 1-D
Acceptable	DF-1*, No. 1-D*, No. 4-D	JET A, JET A-1, DF-A JP-5, JP-7, JP-8
Emergency Only:	JET-A, JET A-1, DF-A, JP-4, JP-5, JP-7, JP-8, TS	JP-4, TS

* Diesel fuel grade #1 is only acceptable for use with standard components when ambient temperatures are below 32°F (0°C).

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NOTE: Home heating oils commonly carry the same No. 1 and No. 2 grade designations as Diesel fuel and often are used interchangeably with those grades of Diesel. Some home heating oils, however, do not contain the necessary additives to provide proper engine operation. It is also illegal in many countries to utilize these oils for over-the-road use when their cost does not include applicable road taxes.

The chart of components which follows will assist in determining which part changes are required to implement these field conversions. Refer to the individual pump specification to identify which standard components have a low viscosity fuel replacement.

LOW VISCOSITY FUEL CAPABILITY CONVERSION PARTS

REMOVE	INSTALL	DESCRIPTION	MODEL TYPE			
			DB	DB2	DB4	DM
20511	20803	Transfer Pump Blades	X	X	X	X
20512 (O' size)	20804	Transfer Pump Blades	X	X	X	X
16753	18958	Transfer Pump Liner	X			
21232	22988	Transfer Pump Liner		X	X	X
11620	29709	Governor Thrust Washer	X	X		
23272	20222	Governor Thrust Washer		X		X
19860	23859	Governor Thrust Washer			X	
21522	24691	Drive Shaft Thrust Washer		X		
26468	26358	Drive Shaft Thrust Washer			X	
26469	26361	Shaft Retaining Ring			X	
10213	29138	Drive Shaft	X	X		
21519	28573	Drive Shaft		X		
23364	24108	Drive Shaft		X		
23452	26110	Drive Shaft		X		
26179	26238	Drive Shaft		X		
26386, 24623	26538	Drive Shaft (Ref. S.B. 419)		X		
28825	23820	Drive Shaft		X		
29783	27639	Drive Shaft		X		
30941	30940	Drive Shaft		X		
30500	31325	Drive Shaft		X		
19870	33817	Rotor Retainer (Note 1)		X		
32859	33818	Rotor Retainer (Note 1)		X		

NOTE 1: P/N's 33817 and 33818 can be used only in pump models with Pressure Compensating Transfer Pumps – Ref. S.B. 444A. These rotor retainers have a notch on the outside diameter to distinguish them from P/N's 19870 and 32859.

ADDITIONAL PARTS FOR APPLICATIONS
EQUIPPED WITH SPEED DROOP GOVERNORS

REMOVE	INSTALL	DESCRIPTION	MODEL TYPE			
			DB	DB2	DB4	DM
12214	20224	Pivot Shaft	X	X	X	X
12358	20225	Linkage Hook Link	X	X	X	X
21201	20214	Governor Weight	X	X		
19858	28974	Governor Weight			X	X
22284	23858	Governor Weight			X	X
29135	30800	Governor Weight			X	
28089	28681	Governor Weight Retainer		X		
29294	29296	Governor Weight Retainer (spline)		X		
28370	28681	Governor Weight Retainer		X		
19893	23860	Governor Weight Retainer			X	X
15421	20219	Governor Arm	X	X		
24929	20219	Governor Arm	X	X		
29060	20956	Governor Arm			X	X
21312	14483	Governor Thrust Sleeve	X	X		

Identification

Identify each pump which is converted for low viscosity fuel operation by stamping "LVFC" (Low Viscosity Fuel Components) on the nameplate below the pump model number.

Warranty

Conversions for low viscosity fuel operation are made at the request and expense of the customer and as such, Stanadyne will not accept warranty claims for these modifications.

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Revision	Date	Changes
1	12/90	Defined fuel usage for both standard and low viscosity components. Added conversion parts chart.
2	1/93	Updated conversion parts chart, changed nameplate identification from "SB 125" to "LVFC".
3	6/93	Updated conversion parts chart and revised fuel usage recommendations.
4	1/98	Updated conversion parts chart.

APPENDIX C

Airport Fueling System Interview Guide

Airport____________________________
Date______________________________
Contact Name______________________
Phone_____________________________
Email _____________________________

Airport Fueling System Interview Guide

1. How are fuels currently delivered to the airport (e.g., pipeline, truck, barge)? If pipeline, is it multi-product or dedicated jet?
    a. Jet fuel
    b. Diesel fuel for airside vehicles
    c. Gasoline for airside vehicles
    d. Avgas for general aviation aircraft
    e. Other fuels for airside vehicles (e.g., compressed natural gas, propane, biodiesel)
    f. What is the volume of each fuel type distributed on a maximum day? Annually?
    g. What is the typical daily consumption of each fuel type?
    h. How many suppliers for each fuel type?
2. How are fuels distributed to airside equipment?
    a. Jet and turboprop aircraft—hydrant or refueler vehicles
    b. GSE—pumping station or refueler vehicles
        i. Diesel
        ii. Gasoline
        iii. Other
    c. Other vehicles
3. How old is the oldest part of the fuel distribution system? When was the most recent substantial upgrade of the fuel distribution system?
4. Who operates the fuel distribution system(s)? How many companies dispense fuel to aircraft/GSE? Who can store fuel in tanks? Who owns each facility? Who controls each facility? What is length of lease and expiration date for each operator?
5. List number and volume of fuel storage tanks for each fuel at each fueling facility.
    a. Describe any equipment associated with fuel tanks like special gauging equipment, tank vent controls, etc.
    b. Size or capacity of filters and other equipment associated with fuel storage tanks (note filter type: pre-filters, clay treaters, micronic filters, filter/separators, other)
6. What is the average fuel inventory on hand for each fuel type?
7. How many gates are serviced at the airport?
    a. By the hydrant system?
    b. By the refueler vehicles?
    c. Total gates and hard stands serviced?
8. Approximately how many other vehicles (other than aircraft) or pieces of equipment are serviced at the airport?
9. How many vehicles are used in the fuel delivery process?
    a. Refueling vehicles
    b. Hydrant vehicles

Airport___________________________
Date_____________________________
Contact Name______________________
Phone____________________________
Email ____________________________

    c. Other vehicles

10. How many fueling operations are performed on an average day by type of equipment (e.g., aircraft/GSE)?
11. How many airlines are serviced by the jet fueling system?
12. How many companies other than airlines (e.g., service companies, FBOs) are serviced by the fueling system?
13. How many aircraft operations (i.e., flights) are conducted at the airport on an average day? Annually?
14. What are the materials of construction of a hydrant system's wetted parts for check valves, control valves, and piping?
15. What are the materials of construction for refueling trucks, tanks, valves, and piping?
16. What leak detection monitoring is employed for each fuel type?
17. What is the opinion of the primary jet fuel system operator on the use of alternative fuels and especially on replacing the current fuel with a drop-in alternative? Also explore concerns about safety, issues with fuel desegregation, defueling considerations, and other practical operating considerations.
18. What is the opinion of the station manager for one of the airlines with the greatest number of operations at the airport on replacing the current fuel with a drop-in alternative?
19. Is consumption subtracted from inventory and/or billed to customers in gross or net gallons? How is fuel consumption tracked? How do you control for taxation considerations?
20. Would you consider a single fuel for all airport uses?
21. Would you be able to (or be interested in) blending alternative fuel and jet fuel onsite? Do you have adequate tankage? What else needs to be considered?
22. Request **PFD** (process flow diagram), **P&ID** (piping and instrumentation diagram), schematic, and/or other facility drawing that includes tank size, material spec or materials takeoff, filter description, etc. Otherwise sketch diagram below of each fuel system showing approximate line length and pipe size (from fuel delivery, to storage tanks, to refueler vehicle/hydrant system, to aircraft). Note type of cathodic protection used for underground piping, tanks, and equipment.

General Notes

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Summary of Airport Fuel Distribution and Consumption

Airport____________________________
Date______________________________
Contact Name______________________
Phone_____________________________
Email _____________________________

Fuel Type	Fuel Receipt Method	Fuel Distribution Method	System Age (years)	Operator Name	Number of Tanks	Storage Capacity (gal)	Distribution Capacity (gal/day)	Number and Size (in.) of Transfer Pipes	Filter Type	Cathodic Protection Type	Leak Detection Type	Daily System Consumption (gal/day)	Average Inventory (gallons)	No. Gates, Vehicles, or Equipment Serviced	No. Vehicles Used	Daily Fueling Ops	Number of Airlines or Clients Served

Vehicles Fueled: For each type of fuel listed in the table, list a representative set of vehicles by type and engine/motor size and manufacturer.

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APPENDIX D

Summary of Emission Factors and Emission Indices

D.1 Sulfur Properties Relating to Diesel Fuel Combustion

Table D-1. EPA-estimated sulfur content of NONROAD diesel fuel, which is assumed in EDMS.

Study Year	Sulfur Content in Weight Percent (Soxbas) (48 States)
2006	0.2249
2007	0.1140
2008	0.0348
2009	0.0348
2010	0.0163
2011	0.0031
2012	0.0031
2013	0.0031
2014	0.0019
2015	0.0011

Table D-2. Assumed fraction of diesel fuel sulfur that is converted to particulate matter.

Years	Sulfur Conversion Efficiency (Soxcnv)
Through 2010	0.02247
After 2010	0.131

Sources:

- U.S. EPA. Diesel Fuel Sulfur Inputs for the Draft NONROAD2004 Model. April 27, 2004. http://www.epa.gov/OMS/models/nonrdmdl/nonrdmdl2004/sulfur.txt. Accessed January 30, 2009.
- U.S. EPA. Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling—Compression-Ignition NR-009c. April 2004.

D.2 Ground Support Equipment Emissions Scaling Factors

Table D-3: Emissions scaling relationships for nitrogen oxides, unburned hydrocarbons, and carbon monoxide. Source: Donohoo (2010).

Fuel Type	NOx	HC	CO
SPK	$E_{GSE-SPK-NO_x} = E_{GSE-diesel-NO_x} \cdot 0.87$	$E_{GSE-SPK-HC} = E_{GSE-diesel-HC} \cdot 0.55$	$E_{GSE-SPK-CO} = E_{GSE-diesel-CO} \cdot 0.61$
ULSJ	$E_{GSE-ULSJ-NO_x} = E_{GSE-diesel-NO_x} \cdot 0.84$	$E_{GSE-ULSJ-HC} = E_{GSE-diesel-HC} \cdot 0.90$	$E_{GSE-ULSJ-CO} = E_{GSE-diesel-CO} \cdot 0.66$
Blend (ULSJ with β%/100 SPK)	$E_{GSE-ALT-NO_x} = E_{GSE-diesel-NO_x} \cdot \left[0.87 \cdot \beta + 0.84 \cdot (1-\beta)\right]$	$E_{GSE-ALT-HC} = E_{GSE-diesel-HC} \cdot \left[0.55 \cdot \beta + 0.90 \cdot (1-\beta)\right]$	$E_{GSE-ALT-CO} = E_{GSE-diesel-CO} \cdot \left[0.61 \cdot \beta + 0.66 \cdot (1-\beta)\right]$

Table D-4. Emissions scaling relationships for sulfur oxides. Source: Donohoo (2010).

Fuel Type	SOx Through 2010 (soxbas from Table D.1)	SOx Post 2011
SPK	$E_{GSE-SPK-SO_2} = E_{GSE-diesel-SO_2} \cdot \frac{0.0015}{soxbas}$	$E_{GSE-SPK-SO_2} = E_{GSE-diesel-SO_2}$
ULSJ	$E_{GSE-ULSJ-SO_2} = E_{GSE-diesel-SO_2} \cdot \frac{0.0015}{soxbas}$	$E_{GSE-ULSJ-SO_2} = E_{GSE-diesel-SO_2}$
Blend (ULSJ with β%/100 SPK)	$E_{GSE-ALT-SO_2} = E_{GSE-diesel-SO_2} \cdot \frac{0.0015}{soxbas}$	$E_{GSE-ALT-SO_2} = E_{GSE-diesel-SO_2}$

Table D-5. Emissions scaling relationships for total PM. Source: Donohoo (2010).

Fuel Type	PM Through 2010	PM Post 2010
SPK	$E_{GSE-SPK-PM} = 0.48 \cdot E_{GSE-diesel-PM}$	$E_{GSE-SPK-PM} = 0.48 \cdot E_{GSE-diesel-PM}$
ULSJ	$E_{GSE-ULSJ-PM} = 0.48 \cdot E_{GSE-diesel-PM}$	$E_{GSE-ULSJ-PM} = 0.48 \cdot E_{GSE-diesel-PM}$
Blend (ULSJ with β% /100 SPK)	$E_{GSE-ALT-PM} = E_{GSE-diesel-PM} \cdot 0.48 \cdot \left(\beta + (1-\beta)\right)$	$E_{GSE-ALT-PM} = 0.48 \cdot E_{GSE-diesel-PM}$

Table D-6. Combustion CO_2 emissions. Source: Donohoo (2010).

Fuel Type	COMBUSTION CO_2 (Fuel in Kg, CO_2 in Kg)
SPK	$E_{GSE-SPK-CO_2} = \left(\text{Fuel burn}_{diesel}\right) \cdot 0.85 \cdot \left({}^{44}\!/_{12}\right)$
ULSJ	$E_{GSE-ULSJ-CO_2} = \left(\text{Fuel burn}_{diesel}\right) \cdot 0.86 \cdot \left({}^{44}\!/_{12}\right)$

D.3 Ground Support Equipment Fuel Use

The diesel fuel use was back-calculated from the estimated sulfur oxide emissions according to Equation D.1. Soxcnv is given in Table D.2. Soxbas is a function of the year of the study as given in Table D.1.

$$FuelBurn_{diesel} = \frac{grams(SO_2)}{(1-soxcnv) \cdot 0.01 \cdot soxbas \cdot 2} \qquad \text{Equation D.1}$$

D.4 Main Gas Turbine Emissions Scaling Factors

Table D-7. Fuel burn ratios. Source: Hileman et al. (2010).

Fuel Type	Fuel Burn Change (relative to Jet A)	Ratio to Jet A, Δ
Jet A	–0.5% to 0.5%	1.000
ULSJ	–0.8% to 0.2%	0.997
SPK	–1.6% to –2.3%	0.978

Table D-8. Fuel burn scaling relationships. Source: Donohoo (2010).

Fuel Type	Fuel Burn
SPK	$E_{AC-SPK-FuelBurn} = \Delta_{SPK} \cdot E_{AC-Jet-FuelBurn}$
ULSJ	$E_{AC-ULSJ-C\ FuelBurn} = \Delta_{ULSJ} \cdot E_{AC-Jet-FuelBurn}$
Blend (ULSJ with β%/100 SPK)	$E_{AC-ALT-FuelBurn} = E_{AC-Jet-FuelBurn} \cdot [\beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$
Blend (Jet A with τ%/100 SPK)	$E_{AC-ALT-FuelBurn} = E_{AC-Jet-FuelBurn} \cdot [\tau \cdot \Delta_{SPK} + (1-\tau)]$

Table D-9. Emissions scaling relationships for sulfur oxides, nitrogen oxides, and unburned hydrocarbons. Source: Donohoo (2010).

Fuel Type	SOx	NOx	HC
SPK	$E_{AC-SPK-SOx} = \Delta_{SPK} \cdot E_{AC-Jet-SOx} \cdot 0.022$	$E_{AC-SPK-NOx} = \Delta_{SPK} \cdot E_{AC-Jet-NOx}$	$E_{AC-SPK-HC} = \Delta_{SPK} \cdot E_{AC-Jet-HC}$
ULSJ	$E_{AC-ULSJ-SOx} = \Delta_{ULSJ} \cdot E_{AC-Jet-SOx} \cdot 0.022$	$E_{AC-ULSJ-NOx} = \Delta_{ULSJ} \cdot E_{AC-Jet-NOx}$	$E_{AC-ULSJ-HC} = \Delta_{ULSJ} \cdot E_{AC-Jet-HC}$
Blend (ULSJ with β%/100 SPK)	$E_{AC-ALT-SOx} = E_{AC-Jet-SOx} \cdot 0.022 \cdot [\beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$	$E_{AC-ALT-NOx} = E_{AC-Jet-NOx} \cdot [\beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$	$E_{AC-ALT-HC} = E_{AC-Jet-HC} \cdot [\beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$
Blend (Jet A with τ%/100 SPK)	$E_{AC-ALT-SOx} = E_{AC-Jet-SOx} \cdot [0.022 \cdot \tau\ \ \Delta_{SPK} + (1-\tau)]$	$E_{AC-ALT-NOx} = E_{AC-Jet-NOx} \cdot [\tau \cdot \Delta_{SPK} + (1-\tau)]$	$E_{AC-ALT-HC} = E_{AC-Jet-HC} \cdot [\tau \cdot \Delta_{SPK} + (1-\tau)]$

Table D-10. Emissions scaling relationships for carbon monoxide. Source: Donohoo (2010).

Fuel Type	CO
SPK	$E_{AC-SPK-CO} = \Delta_{SPK} \cdot E_{AC-Jet-CO}$
ULSJ	$E_{AC-ULSJ-CO} = \Delta_{ULSJ} \cdot E_{AC-Jet-CO}$
Blend (ULSJ with β%/100 SPK)	$E_{AC-ALT-CO} = E_{AC-Jet-CO} \cdot [\beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$
Blend (Jet A with τ%/100 SPK)	$E_{AC-ALT-CO} = E_{AC-Jet-CO} \cdot [\tau \cdot \Delta_{SPK} + (1-\tau)]$

Table D-11. Emissions scaling relationships for PMNV, PMS, and PMFO. Source: Donohoo (2010).

Fuel Type	PMNV (43%)	PMS (41%)	PMFO (16%)
SPK	$E_{AC-SPK-PMNV} = \Delta_{SPK} \cdot E_{AC-Jet-PMNV} \cdot 0.24$	$E_{AC-SPK-PMSO} = \Delta_{SPK} \cdot E_{AC-Jet-PMSO} \cdot 0.022$	$E_{AC-SPK-PMFO} = \Delta_{SPK} \cdot E_{AC-Jet-PMFO}$
ULSJ	$E_{AC-ULSJ-PMNV} = \Delta_{ULSJ} \cdot E_{AC-Jet-PMNV}$	$E_{AC-ULSJ-PMSO} = \Delta_{ULSJ} \cdot E_{AC-Jet-PMSO} \cdot 0.022$	$E_{AC-ULSJ-PMFO} = \Delta_{ULS} \cdot E_{AC-Jet-PMFO}$
Blend (ULSJ with up to 50% SPK)	$E_{AC-ALT-PMNV} = E_{AC-Jet-PMNV} \cdot [0.58 \cdot \beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$	$E_{AC-ALT-PMSO} = (E_{AC-Jet-PMSO} \cdot 0.022) \cdot [\beta \cdot \Delta_{SPK} + (1-\beta)\ \Delta_{ULSJ}]$	$E_{AC-ALT-PMFO} = E_{AC-Jet-PMFO} \cdot [\beta \cdot \Delta_{SPK} + (1-\beta) \cdot \Delta_{ULSJ}]$
Blend (Jet A with up to 50% SPK)	$E_{AC-ALT-PMNV} = E_{AC-Jet-PMNV} \cdot [0.58 \cdot \tau \cdot \Delta_{SPK} + (1-\tau)]$	$E_{AC-ALT-PMSO} = (E_{AC-Jet-PMSO} \cdot 0.022) \cdot [\tau \cdot \Delta_{SPK} + (1-\tau)]$	$E_{AC-ALT-PMFO} = E_{AC-Jet-PMFO} \cdot [\tau \cdot \Delta_{SPK} + (1-\tau)]$

Table D-12. Emissions scaling relationships for total PM. Source: Donohoo (2010).

Fuel Type	PM-TOTAL	PM-TOTAL
SPK	$E_{AC-SPK-PM} = \Delta_{SPK} \cdot E_{AC-Jet-PM} \cdot (0.24 \cdot 0.43 + 0.022 \cdot 0.41 + 0.16)$	$E_{AC-SPK-PM} = \Delta_{SPK} \cdot E_{AC-Jet-PM} \cdot 0.27222$
ULSJ	$E_{AC-ULSJ-PM} = \Delta_{ULSJ} \cdot E_{AC-Jet-PM} \cdot (0.43 + 0.022 \cdot 0.41 + 0.16)$	$E_{AC-ULSJ-PM} = \Delta_{ULSJ} \cdot E_{AC-Jet-PM} \cdot 0.59902$
Blend (ULSJ with up to 50% SPK)	$E_{AC-ALT-PM} = E_{AC-Jet-PM} \cdot \{[(\beta \cdot \Delta_{SPK}) \cdot (0.58 \cdot 0.43 + 0.022 \cdot 0.41 + 0.16)] + [((1-\beta) \cdot \Delta_{ULSJ}) \cdot (0.43 + 0.022 \cdot 0.41 + 0.16)]\}$	$E_{AC-ALT-PM} = E_{AC-Jet-PM} \cdot \{[(\beta \cdot \Delta_{SPK}) \cdot 0.41842] + [((1-\beta) \cdot \Delta_{ULSJ}) \cdot 0.59902]\}$
Blend (Jet A with up to 50% SPK)	$E_{AC-ALT-PM} = E_{AC-Jet-PM} \cdot \{[(\tau \cdot \Delta_{SPK}) \cdot (0.58 \cdot 0.43 + 0.022 \cdot 0.41 + 0.16)] + [(1-\tau) \cdot (0.43 + 0.022 \cdot 0.41 + 0.16)]\}$	$E_{AC-ALT-PM} = E_{AC-Jet-PM} \cdot \{[(\tau \cdot \Delta_{SPK}) \cdot 0.41842] + [(1-\tau) \cdot 0.59902]\}$

Table D-13. Combustion CO_2 emissions indices. Source: Hileman et al. (2010).

Fuel Type	Combustion CO_2 (g CO_2/MJ)	Specific Energy (MJ/Kg)
Jet A	73.2	43.2
ULSJ	72.9	43.3
Diesel	72.6	41.8
SPK	70.4	44.1

Handbook for Using AFIT, the Alternative Fuels Investigation Tool

Companion to

ACRP Report 46

AIRPORT COOPERATIVE RESEARCH PROGRAM 2011

CONTENTS

CHAPTER 1

Introduction

This handbook is designed to help airports, fuel suppliers, and other interested parties evaluate the costs and benefits of using an alternative jet fuel at an airport. The alternative fuels considered are an ultralow sulfur (ULS) jet fuel and synthetic paraffinic kerosenes (SPKs). SPKs include Fischer-Tropsch fuels and hydroprocessed renewable jet fuel created from feedstocks such as algae and palm oils. The handbook is a guide to using the Alternative Fuels Investigation Tool (AFIT) and interpreting the results. More detailed information about using alternative fuels at an airport can be found in the technical report for ACRP Project 02-07, under the same cover as this handbook and available on the TRB website (www.trb.org) by searching "ACRP Report 46." The report provides additional detail on alternative fuels transport and use, emission impacts, equipment modification considerations, and the use of AFIT. AFIT has been developed to estimate costs associated with the introduction of an alternative fuel and associated emissions reductions. AFIT does not provide a cost–benefit metric. Deciding whether to introduce an alternative fuel to a specific airport is a complex decision and is beyond the scope of this research and the AFIT software tool. It must also be noted that AFIT, in its present configuration, is only for analyzing alternative jet and ground support equipment (GSE) fuels and is not intended for a total fuels analysis including natural gas, compressed air, biodiesel, or electric power.

1.1 Why Should an Airport Consider Using an Alternative Jet Fuel?

Fuel prices and price volatility, local air quality, and greenhouse gas (GHG) emissions are among the issues airports face as a result of the fuel consumed by airports and airlines. The cost of fuel is a significant budget item for airports and especially airlines, and wide swings in the price of fuel complicate financial and operational planning. Alternative fuels are now recognized as one option for expanding total fuel supply, reducing reliance on a single resource, and potentially stabilizing fuel prices.

Emissions from fuel combustion are an airport's primary contribution to air pollution. These emissions are expected to increase, following the growth in fuel use as airports expand capacity to meet increasing demand for air travel, unless steps are taken to reduce them. Airports require new strategies for mitigating these impacts on their communities, and one such strategy is to use alternative fuels in place of conventional fuels.

Global climate change is now widely viewed as a significant, serious environmental threat, and aviation sources have limited opportunities for reducing their GHG emissions. Alternative fuels represent one potential strategy for airports to address their GHG emissions compared to other industries and reduce their carbon footprints.

Using alternative jet fuel in place of conventional jet fuel (Jet A) offers a variety of environmental and operational benefits. A "drop-in" alternative jet fuel—that is, one that could be accommodated at an airport with little or no modification—would allow an airport to readily make such a change. Drop-in, low-sulfur alternatives to Jet A can also be used to fuel diesel powered equipment. This offers the possibility that GSE as well as aircraft could use the same fuel, simplifying fuel distribution and reducing the amount of fuel handling equipment.

Alternative jet fuel may soon be available to airports. ULS jet fuel and SPK are the leading candidates for near-term use. The purpose of this handbook and the accompanying AFIT tool is to assist airport managers in deciding whether to use alternative fuels by quantifying the costs and benefits of using them.

1.2 What Are the Benefits of Using an Alternative Jet Fuel?

Alternative jet fuels have the potential to

1. Stabilize or lower total fuel costs,
2. Increase the planning flexibility airports need to reduce emissions,
3. Diversify supply options, and

4. Reduce the amount of equipment needed to distribute fuel on the airport.

Also, since SPK fuels can be produced from a wide variety of non-petroleum feedstocks (e.g., coal, natural gas, biomass, renewable oils, and waste products), they may be produced at a cost advantage compared to Jet A. SPK fuel also reduces particulate matter (PM) and sulfur oxide (SO_x) emissions.

Using alternative jet fuel can also reduce pollutant emissions that impair air quality as well as those considered GHG emissions. Reduced emissions can potentially reduce any known health impacts of airport operations on employees and adjacent communities. However, when considering GHG emission impacts, the feedstock and fuel production process must be considered to account for life-cycle emissions.

A significant share of GSE operating at most airports uses diesel fuel. Since jet fuel is similar to diesel, GSE can also use alternative jet fuel. Fueling GSE with ULS or SPK jet fuel would achieve many of these benefits and reduce emissions and fuel handling costs.

1.3 Are There Regulatory Considerations Involved?

The American Society of Testing and Materials (ASTM) determines the requirements that jet fuel must meet for physical properties, chemical content, contaminant limits, and overall performance requirements. ASTM 1655D is the current fuel specification and enumerates all of the jet fuel requirements. ASTM is currently assessing whether SPK fuels should be certified for commercial aircraft use. It is anticipated that ASTM will certify SPK fuels in up to a 50% blend with conventional fuels in 2011. The Commercial Aviation Alternative Fuels Initiative (CAAFI) has a goal of obtaining ASTM certification for a 100% SPK fuel by 2013. SPK fuels are considered to be drop-in replacement fuels since they could be handled, distributed, and used at airports with a minimum of modification to existing equipment. Only drop-in fuels are considered in this handbook.

Sulfur in fuel results in emissions of both SO_x and PM, and removing sulfur from fuels reduces fuel combustion emissions. For this reason, the U.S. Environmental Protection Agency (U.S. EPA) sets maximum limits on the sulfur content of fuels. The EPA has already reduced the allowable sulfur content of diesel fuel for on-road vehicles and has regulations in place to phase in restrictions on the sulfur content of diesel for off-road vehicles, including GSE. Removing sulfur from Jet A to produce a ULS jet fuel will significantly reduce PM and SO_x emissions from aircraft as well as GSE using that fuel. Note that conventional Jet A does not have stringent sulfur limits and cannot be used in GSE since the fuel would exceed the allowable sulfur content for off-road vehicles.

SPK fuel also reduces PM and SO_x emissions and potentially improves fuel economy due to its higher energy content per unit weight. While ULS jet fuel comes from conventional petroleum, SPK fuels can come from a variety of sources. When considering GHG emission impacts, the feedstock and fuel production process must be considered.

1.4 What Are the Costs of Using an Alternative Jet Fuel?

Alternative jet fuels, just as Jet A, must be transported from a fuel production facility to an airport via multiple transportation links. A likely sequence includes transportation from a production plant to a storage facility, where the fuel is accumulated until sufficient quantities are ready to be shipped a considerable distance via barge, marine tanker, or pipeline. The fuel would likely be received at another tank farm from which it would be sent to the airport via truck or rail.

Somewhere along the way it is necessary to blend SPK alternative fuel with conventional jet fuel to produce a blended fuel acceptable to airlines, ASTM, and airports. This could occur at the fuel production facility, one of the storage facilities, or the airport. Once on the airport, the fuel can be distributed using existing tanks, pumps, and hydrants or trucks. ULS jet fuel or blended alternative fuel with sufficiently low sulfur content can also be used in GSE and other diesel equipment. This would allow the airport to remove existing diesel storage and handling equipment, reducing maintenance and fuel handling costs. Costs related to transportation links, equipment modification requirement costs, and fuel costs are captured in AFIT to determine the cost of using an alternative jet fuel at an airport.

At present, diesel fuel that is used in GSE is taxed by state and local authorities. Any alternative fuel that is used to replace diesel would also be subject to this tax. This change is not captured in the AFIT tool since there should be zero cost difference.

1.5 Who Should Use the Handbook?

This handbook describes the use of AFIT, an automated computational methodology for conducting a cost–benefit analysis. The analysis is intended to help airports and others consider whether to use an alternative jet fuel. It is most useful as a screening tool to help the user identify cost considerations and develop an initial estimate of environmental benefits.

The handbook guides the AFIT user in evaluating the costs of acquiring, transporting, distributing, and using an alternative jet fuel as well as evaluating environmental benefits. It was designed with airports in mind but would be useful for anyone interested in alternative fuel use at airports. For example, an alternative jet fuel producer can use AFIT to develop a marketing approach for working with an airport. A fuel service company could use it to better understand the process and costs involved in acquiring and transporting an alternative jet fuel from a production site to an airport. An environmental analyst could use it to evaluate the degree to which emissions could be mitigated through the use of alternative jet fuel.

1.6 What Is Required for Using AFIT?

AFIT is a 32-bit Windows native application that runs on Microsoft Windows 2000, XP, Vista, or 7.

AFIT uses relatively simple, readily available data to quantify alternative fuel transportation and equipment modification costs. Fuel costs are determined using inputs related to fuel use quantity, transportation sequence, and handling requirements. To determine environmental benefits, AFIT requires a baseline emissions inventory from FAA's Emissions and Dispersion Modeling System (EDMS) as an input.

AFIT produces a report enumerating the costs and potential savings that can come from using alternative jet fuel and summarizes changes to an airport's emissions inventory. Additional details on using AFIT are presented in the following sections of the handbook.

1.7 What Data Will Be Needed to Use AFIT?

The user will need to be familiar with the airport's current fuel usage, either annually or monthly, for both diesel and Jet A. The user will also need to be familiar with price per gallon paid for each. AFIT has default fuel price settings based on typical prices paid throughout the United States and averaged. Appendix B in this handbook also lists several sources for fuel information. The user also has to determine whether the study is for alternative fuels to be run through existing equipment or whether the alternative fuel is part of a significant expansion to the airport where new construction will be required. The user also must select the type of alternative fuel to be considered in the study and should be familiar with types of fuel available and costs at the producer.

Familiarity with the current costs of fuel delivery will also be helpful. Storage, flowage, throughput, and other fuel handling per-gallon costs of existing fuels and those expected for the alternative fuel are also helpful. AFIT supplies default costs, but they are averaged from airports across the United States. Knowledge of the current GSE fleet and suppliers of parts and service will be needed to estimate change-out costs. Access to past construction estimates and project documents or current contact with construction companies and fuel supply vendors will improve the accuracy of estimates. As the alternative fuel replaces diesel fuels, removal and decommission costs of the diesel system will also need to be estimated.

If emissions analysis will be conducted, access to the latest EDMS study will be needed. EDMS details appear below.

1.8 What Is EDMS?

EDMS is a combined emissions and dispersion model for assessing air quality at civilian airports and military air bases. The model was developed by the Federal Aviation Administration (FAA) in cooperation with the United States Air Force (USAF). The model is used to produce an inventory of emissions generated by sources on and around the airport or air base and to calculate pollutant concentrations in these environments. More information regarding the current version of EDMS (5.1.2) (including the User Manual and ordering information) can be found in FAA's EDMS website (http://www.faa.gov/about/office_org/headquarters_offices/aep/models/edms_model).

1.9 What Is an EDMS Study?

An EDMS study is an airport emissions inventory computed from user inputs by the EDMS software. An EDMS study can contain multiple scenarios and multiple airports and can span multiple years. For each scenario-airport-year combination, the user can define operations for aircraft, GSE, roadway vehicles, parking facilities, stationary sources, and training fires.

1.10 Does AFIT Contain EDMS and Why Is EDMS Needed?

- AFIT does not contain EDMS.
- AFIT analyzes aircraft and GSE information from an existing EDMS study to estimate a baseline emissions inventory.
- The baseline inventory is adjusted by AFIT and is not intended to match the EDMS inventory.
- It then computes the airport emissions as though an alternative fuel was used at the airport. AFIT is designed to evaluate the costs and benefits of using an alternative jet fuel at a single airport.
- Therefore, only one scenario-airport-year EDMS set of inputs can be analyzed at a time by AFIT.

1.11 Can an Old EDMS Study Be Used as an AFIT input?

Any study created using EDMS version 5.0 or later can be used regardless of the year modeled. If the EDMS study contains multiple scenarios, airports, or years, AFIT will import emissions from the first scenario-airport-year combination.

CHAPTER 2

Conducting a Cost–Benefit Analysis of Alternative Jet Fuel Use

2.1 Cost–Benefit Analysis Assessment Process

Making provision for or switching entirely over to an alternative jet fuel carries with it a variety of costs. Modifications to equipment and airport infrastructure and their corresponding cost estimates should all be included in the cost–benefit comparison analysis. It is also possible that adopting a single fuel source for aircraft and diesel engine GSE will reduce cost where a new airfield or significant expansion of an existing airfield is involved.

AFIT is a software cost and benefit calculation tool and is offered to assist users with the complex calculations required to determine costs and emissions reductions. Users can either provide custom inputs based on their own circumstances and requirements or opt for default input values provided in AFIT. Research into typical costs for delivery, storage, blending, filtering, and on-site equipment upgrades and replacements produced a range of expected values likely in the switch to an alternative fuel. These default values are offered as guides to the user. AFIT displays conversion costs both in terms of per-gallon of fuel consumed and total cost.

AFIT consists of five tabs, or information areas:

1. General setup information—monthly fuel usage, fuel price, and airport fuel conversion type.
2. Fuel economics—fuel transport, storage, and blending information.
3. Equipment costs—GSE part replacements for filters, seals, and fuel pumps (which may be required); avoided capital investment cost of a diesel fueling station in the case of airport expansion or new facility construction.
4. Emissions—emissions affecting air quality as well as life-cycle greenhouse gas emissions; both are provided for the current fuel and the alternative fuel.
5. Report—fuel and equipment cost and emissions comparison results.

AFIT displays baseline and alternative fuel cost and emission estimates and the relative change between them at the top of each tab, keeping a rolling update as users enter values in the lower portions of each tab. The user is able to determine the relative cost changes and compare them to the relative emission reduction benefit for use in deciding the merits of a switch to an alternative fuel. AFIT does not answer the question of whether alternative fuel use is the right decision. It simply compares the costs and emissions with and without a drop-in alternative fuel.

AFIT is designed to analyze drop-in fuel use in either existing fuel delivery systems, where no additional or new fuel delivery upgrades are planned, or in cases where a new airfield or significant expansion of the existing fuel delivery system is planned.

2.2 Using AFIT

AFIT is available on the CD enclosed with this handbook. AFIT can be run to conduct a complete cost and emission reduction benefit assessment. To estimate costs, the user needs information on current fuel usage, fuel prices, airport fueling infrastructure, and the ground support equipment that would use the fuel. To estimate emissions reductions, the user needs to have an EDMS run with an emissions inventory. If an EDMS run is not available, the tool can still be used to estimate the change in costs.

Download and Launch the Software

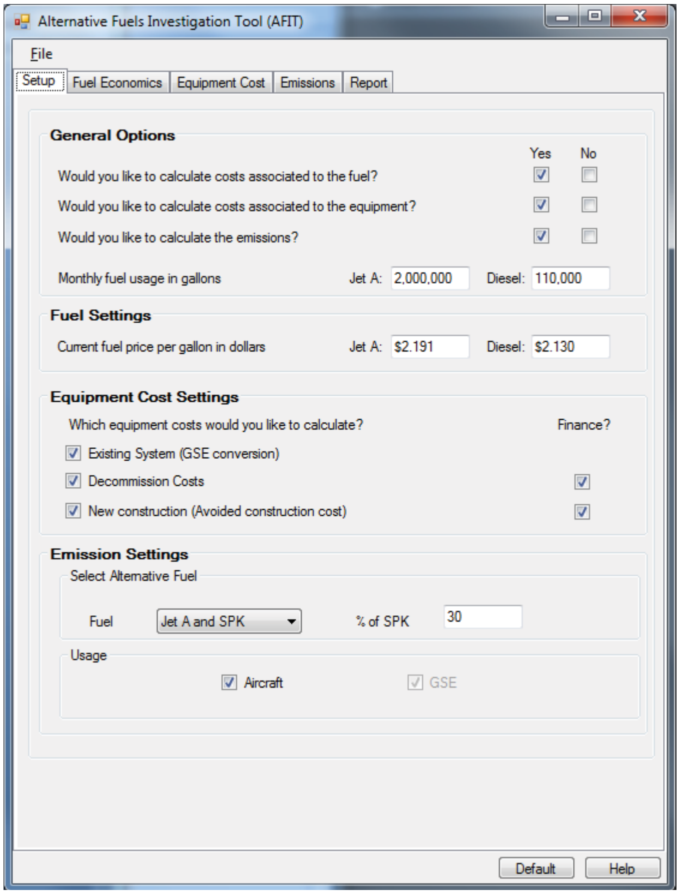
Copy the AFIT Installer file folder to your computer. Double click the installer to install AFIT on your computer. Follow the instructions, clicking “Next” to complete the installation. Find the folder titled “AFIT” on your computer’s start menu (typically under “All Programs”) and launch the application.

Upon opening AFIT the user is presented with the "Setup" tab and can see the other four tabs, or sections of the analysis tool, that group input and output of similar type. The "Setup" tab collects basic information about the user's monthly fuel consumption, price paid, and fuel scenario.

Setup

The "Setup" tab, Figure 1, allows the user to select the type of analysis: fuel costs, equipment costs, and/or emissions (selecting or not selecting these fields gives or restricts the user's access to the associated parts of AFIT), the alternative fuel composition that will be analyzed, and where it will be used. The alternative fuel composition options are (1) JET A + SPK, (2) ULSJ, and (3) ULSJ + SPK. Due to ULS standards, the Jet A + SPK fuel composition cannot be used in the GSE and can only be used in aircraft. The user selects the blend percentage for the alternative fuel (50% is the maximum blend percentage for alternative fuel in this version of AFIT).

In this tab, the user also inputs monthly fuel-use information for Jet A and diesel in terms of consumption and price. Enter whole gallons (decimal places are not critical) for the average fuel consumed in a month. If consumption statistics are listed in barrels, the conversion factor for barrels to gallons is 42 gallons/barrel. (Multiply barrels used by 42 to get gallons used.) These inputs are only used for estimating monetary costs; they are not used for the emissions calculations, which will be discussed below. Enter the current price for Jet A and diesel fuel. As broad price swings can occur over the course of a year, selecting a yearly average or another suitable price approximation representative of typical values is suggested. Several sources exist to help the user with fuel price estimates. Appendix B contains a list of sources where the AFIT user can find current and historical fuel price information.



General Options

	Yes	No
Would you like to calculate costs associated to the fuel?	☑	☐
Would you like to calculate costs associated to the equipment?	☑	☐
Would you like to calculate the emissions?	☑	☐

Monthly fuel usage in gallons Jet A: 2,000,000 Diesel: 110,000

Fuel Settings

Current fuel price per gallon in dollars Jet A: $2.191 Diesel: $2.130

Equipment Cost Settings

Which equipment costs would you like to calculate?	Finance?
☑ Existing System (GSE conversion)	
☑ Decommission Costs	☑
☑ New construction (Avoided construction cost)	☑

Emission Settings

Select Alternative Fuel

Fuel: Jet A and SPK % of SPK: 30

Usage

☑ Aircraft ☑ GSE

Figure 1. "Setup" tab.

Default values exist in AFIT if the user does not know the input values for the "Setup" tab. Clicking the "Default" button in the lower right corner will import default values. The analyst must provide airport fuel-consumption statistics; otherwise, a default value of zero will be used. Fuel prices for Jet A and diesel reflect representative values of the fall of 2008; updated values can be found on the EIA website at http://www.eia.doe.gov/oil_gas/petroleum/info_glance/petroleum.html.

Three "Equipment Cost Settings" options are presented on the "Setup" tab. These allow the user to determine whether separate (possibly existing) diesel fuel facilities are to be used or whether fuel supplied to GSE and other diesel equipment will use the jet fuel supply system. These fields activate other functions and calculations in AFIT to help guide the user through the analysis process.

- Click the "Existing System" box if the alternative fuel will be delivered to and through the existing fueling system only. After clicking, a check mark should appear. No additional fuel delivery equipment will be purchased or installed.
- Click the "New Construction" box if new diesel fueling and delivery equipment will be constructed and installed. After clicking, a check mark should appear. Typically this includes fueling pumps, storage tanks, fueling-island concrete, piping, valves, and so on.
- Click the "Decommission Cost" box if diesel fueling equipment will be removed or taken out of service.

If the user supplies no information, upon clicking to navigate to another tab, the software will ask the user if default values should be used. If "no" is selected, other fields are left open for user input values. Selecting "yes" will insert appropriate fields with default values. There is also a "Finance" option. Since decommissioning costs and new construction can be quite expensive, the ability to calculate typical financing costs over a period of payments is enabled by clicking the finance check box.

Within the “Setup” tab, the user also selects the fuel composition being examined. Within the “Alternative Fuel Composition” box, the user selects the primary fuel—ULS Jet or SPK. The blend percentage determines the amount of alternative fuel that is being used—values between 0% and 50% are available. The user has two check boxes to select the fuel composition that is being blended with the alternative. The user should select “Jet A” if he or she is interested in examining a blend of SPK fuel with conventional jet fuel. The user should select ULSJ if the user is interested in examining either ULS jet fuel or in examining a blend of SPK fuel with ULS jet fuel. Because conventional jet fuel is not allowed for use in GSE, the AFIT tool will only examine GSE emissions if the ULSJ box is selected. The user selects the fuel being used in the aircraft and GSE by selecting the appropriate boxes underneath “Aircraft Fuel” and “Ground Support Equipment Fuel.” If the user had previously selected “Jet A,” then the AFIT tool would automatically select “ULS Diesel” for the “Ground Support Equipment Fuel,” and the “Alternative” option would not be available.

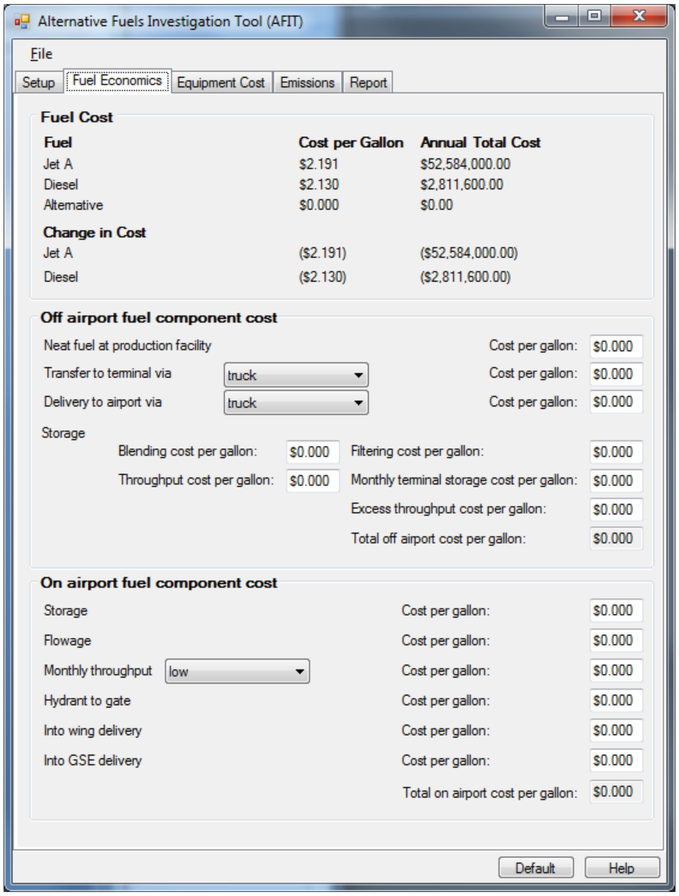
Fuel Economics

The “Fuel Economics” tab, Figure 2, captures all the costs associated with production and transportation of the alternative fuel from its production source to the wing of the plane and GSE. Production cost is entered as the purchase price of the alternative fuel from the production facility.

Fuel delivery is broken down into “off airport” and “on airport” components. Off airport includes shipment from production to the airport fence line. On airport captures costs from the fence to the aircraft and GSE. These include airport costs such as storage, flowage, volume throughput charges, and so on. Delivery is typically by pipeline, rail car, barge, or truck. Selecting one of these modes inserts a default cost, or the user can supply the user’s own by typing it into the field. The default costs are truck, $0.35; barge, $0.05; dedicated pipeline, $0.02; and rail, $0.10 (all per gallon). There is no default cost for “other” in this version of AFIT. To enter any of the above default costs, select a mode of transportation and then click default at the bottom of the tab, and the cost will be entered in the field. If an airport operator is buying an alternative fuel “at the fence,” then by entering zeros for off-airport costs, AFIT will reflect the price at the airport.

The user enters values appropriate to the airport in the analysis, or typical average cost-per-gallon estimates can be input by clicking the default button in the bottom right corner.

These various off-airport and on-airport handling costs are added to the production cost, and new totals are calculated by AFIT and displayed at the top of the tab in the section called “Fuel Cost.” The user-entered Jet A and diesel fuel prices are shown, as is the estimated alternative fuel price based on user inputs lower down on the tab. Annual total fuel cost estimates are shown, as is the cost difference between Jet A and diesel and the alternative fuel.



Fuel Cost

Fuel	Cost per Gallon	Annual Total Cost
Jet A	$2.191	$52,584,000.00
Diesel	$2.130	$2,811,600.00
Alternative	$0.000	$0.00
Change in Cost		
Jet A	($2.191)	($52,584,000.00)
Diesel	($2.130)	($2,811,600.00)

Off airport fuel component cost

Neat fuel at production facility — Cost per gallon: $0.000
Transfer to terminal via: truck — Cost per gallon: $0.000
Delivery to airport via: truck — Cost per gallon: $0.000
Storage
Blending cost per gallon: $0.000
Throughput cost per gallon: $0.000
Filtering cost per gallon: $0.000
Monthly terminal storage cost per gallon: $0.000
Excess throughput cost per gallon: $0.000
Total off airport cost per gallon: $0.000

On airport fuel component cost

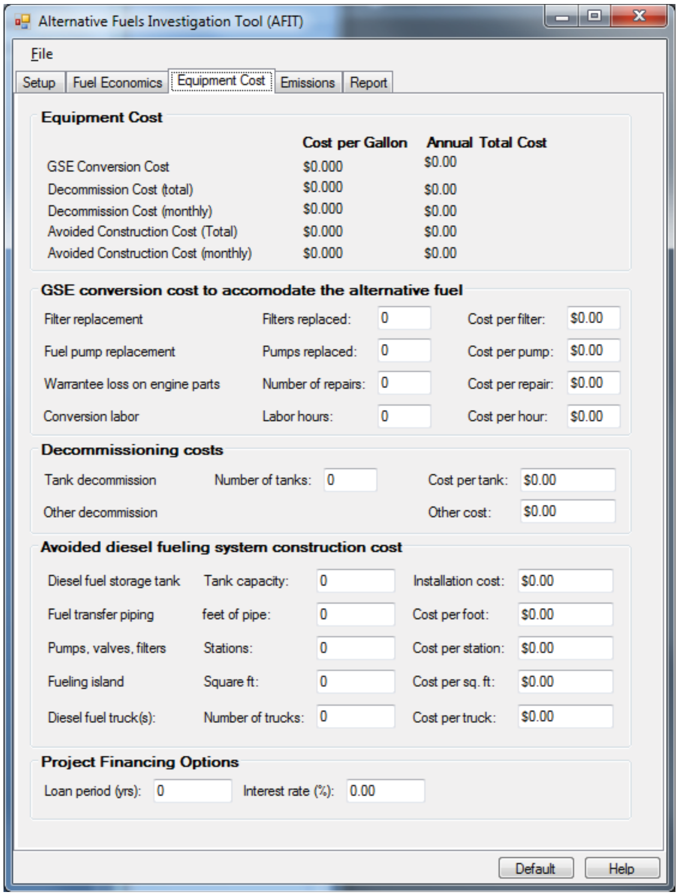
Storage — Cost per gallon: $0.000
Flowage — Cost per gallon: $0.000
Monthly throughput: low — Cost per gallon: $0.000
Hydrant to gate — Cost per gallon: $0.000
Into wing delivery — Cost per gallon: $0.000
Into GSE delivery — Cost per gallon: $0.000
Total on airport cost per gallon: $0.000

Figure 2. “Fuel Economics” tab.

Equipment Cost

The “Equipment Cost” tab, Figure 3, captures the costs associated with changes to the aircraft and GSE that accompany a change in fuel. It also captures the avoided fueling infrastructure costs associated with using the alternative fuel in both aircraft and diesel engine GSE and the decommissioning costs of taking existing diesel fueling equipment out of service.

AFIT assumes that the alternative fuel has been certified for aircraft use. As a result there are no equipment costs associated with aircraft, which should be a valid assumption for 50-50 alternative fuel blends. Higher alternative fuel concentrations could require replacement of aircraft seals due to reduced fuel aromatic content or a decrease in required maintenance due to reduced sulfur content.



Equipment Cost

	Cost per Gallon	Annual Total Cost
GSE Conversion Cost	$0.000	$0.00
Decommission Cost (total)	$0.000	$0.00
Decommission Cost (monthly)	$0.000	$0.00
Avoided Construction Cost (Total)	$0.000	$0.00
Avoided Construction Cost (monthly)	$0.000	$0.00

GSE conversion cost to accomodate the alternative fuel

Filter replacement	Filters replaced:	0	Cost per filter:	$0.00
Fuel pump replacement	Pumps replaced:	0	Cost per pump:	$0.00
Warrantee loss on engine parts	Number of repairs:	0	Cost per repair:	$0.00
Conversion labor	Labor hours:	0	Cost per hour:	$0.00

Decommissioning costs

Tank decommission	Number of tanks:	0	Cost per tank:	$0.00
Other decommission			Other cost:	$0.00

Avoided diesel fueling system construction cost

Diesel fuel storage tank	Tank capacity:	0	Installation cost:	$0.00
Fuel transfer piping	feet of pipe:	0	Cost per foot:	$0.00
Pumps, valves, filters	Stations:	0	Cost per station:	$0.00
Fueling island	Square ft:	0	Cost per sq. ft:	$0.00
Diesel fuel truck(s):	Number of trucks:	0	Cost per truck:	$0.00

Project Financing Options

Loan period (yrs): 0
Interest rate (%): 0.00

Figure 3. "Equipment Cost" tab.

The "Equipment Cost" tab captures the costs associated with upgrades and replacements necessary on certain GSE. Rubber seals, fuel filters, fuel pumps, possible warrantee losses, and the labor associated with replacements are captured here. Quantities and costs of each and the labor required to perform installations and other maintenance must be estimated.

While GSE conversion costs add to the price of the alternative fuel, in the case of a new airfield or expansion of existing facilities, a single fuel source for both aircraft and GSE allows an airport to avoid construction cost for diesel fueling facilities. If the user selected the "New Construction" box on the "Setup" tab, these fields will be active for data entry.

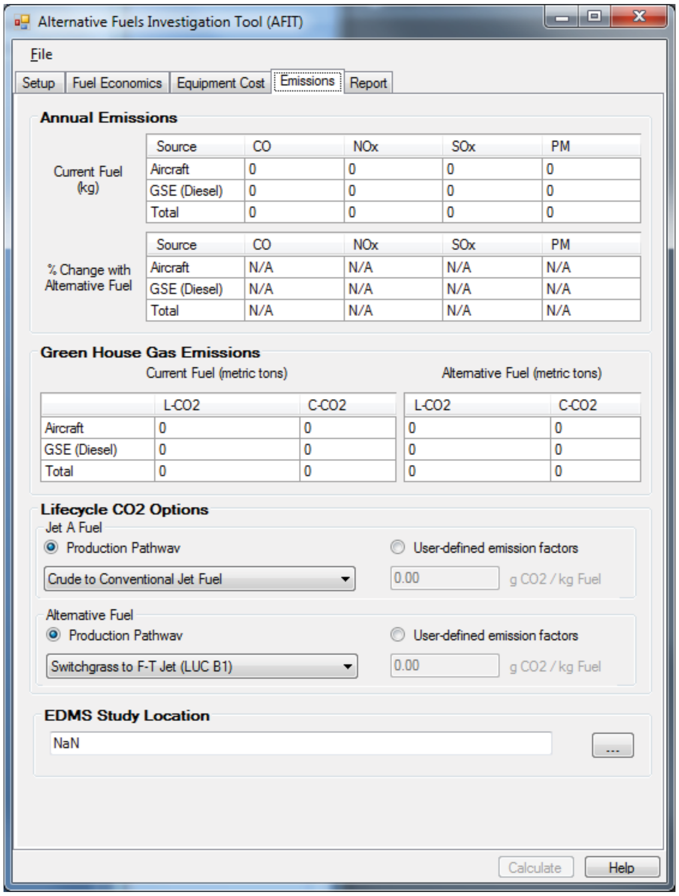
Typical diesel fuel delivery infrastructure, equipment, and fabrication costs are represented in this section of the tab. If the user has not checked the "New Construction" box on the "Setup" page, these fields will not be accessible. The user will input construction cost estimates to compute avoided diesel fueling equipment and construction costs. Cost totals are represented at the top of the tab in both total single year expensed cost and monthly costs if the project is financed over several years and a period of payments is selected by the user.

Emissions

The "Emissions" tab, Figure 4, captures the changes in emissions that may result if the airport switches to an alternative jet fuel. It is also where the user must have access to EDMS reports and software.

The user must locate an existing EDMS study to form the basis for the baseline in the AFIT study. It is important to note that the emissions displayed are adjusted for this analysis and are not intended to match the EDMS results.

To determine the life-cycle emissions of a fuel, a specific feedstock and production pathway must be selected from the list of potential alternative jet fuels using the pull-down menu. The life-cycle emissions are provided in the form of ranges to give the user a sense of the emissions that may result from each alternative fuel. The user can also input custom emission factors for another fuel (if it is not on the list) by selecting the "User-defined emission factors" radio button. Additional details on life-cycle emissions can be found in Appendix D.



Annual Emissions

Current Fuel (kg)

Source	CO	NOx	SOx	PM
Aircraft	0	0	0	0
GSE (Diesel)	0	0	0	0
Total	0	0	0	0

% Change with Alternative Fuel

Source	CO	NOx	SOx	PM
Aircraft	N/A	N/A	N/A	N/A
GSE (Diesel)	N/A	N/A	N/A	N/A
Total	N/A	N/A	N/A	N/A

Green House Gas Emissions

	Current Fuel (metric tons)		Alternative Fuel (metric tons)	
	L-CO2	C-CO2	L-CO2	C-CO2
Aircraft	0	0	0	0
GSE (Diesel)	0	0	0	0
Total	0	0	0	0

Lifecycle CO2 Options

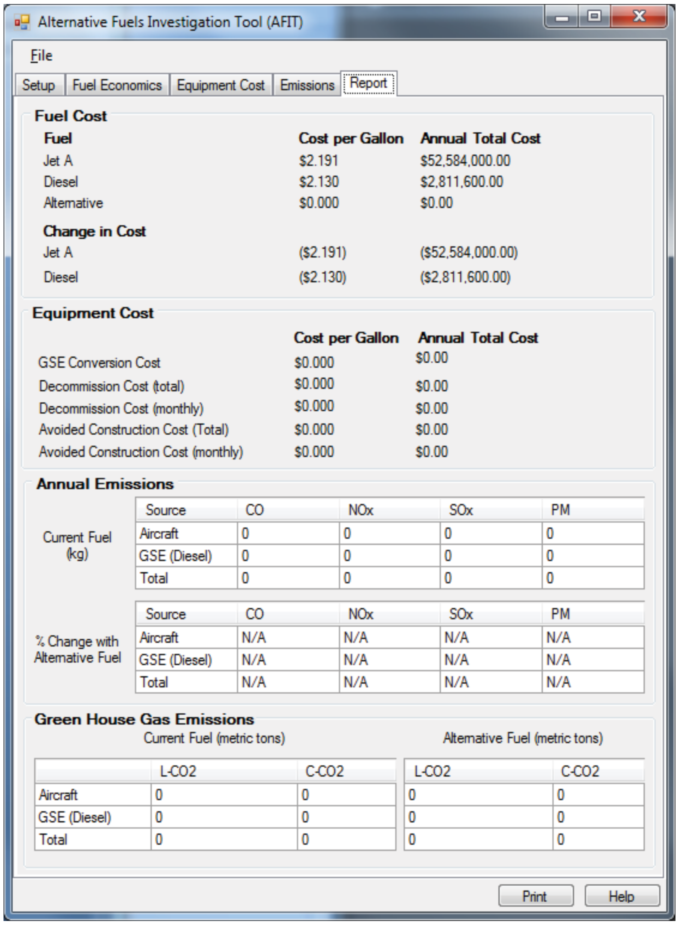
Jet A Fuel
● Production Pathwav
○ User-defined emission factors
Crude to Conventional Jet Fuel
0.00 g CO2 / kg Fuel

Alternative Fuel
● Production Pathwav
○ User-defined emission factors
Switchgrass to F-T Jet (LUC B1)
0.00 g CO2 / kg Fuel

EDMS Study Location

NaN

Figure 4. "Emissions" tab.



Fuel Cost

Fuel	Cost per Gallon	Annual Total Cost
Jet A	$2.191	$52,584,000.00
Diesel	$2.130	$2,811,600.00
Alternative	$0.000	$0.00
Change in Cost		
Jet A	($2.191)	($52,584,000.00)
Diesel	($2.130)	($2,811,600.00)

Equipment Cost

	Cost per Gallon	Annual Total Cost
GSE Conversion Cost	$0.000	$0.00
Decommission Cost (total)	$0.000	$0.00
Decommission Cost (monthly)	$0.000	$0.00
Avoided Construction Cost (Total)	$0.000	$0.00
Avoided Construction Cost (monthly)	$0.000	$0.00

Annual Emissions

Current Fuel (kg)

Source	CO	NOx	SOx	PM
Aircraft	0	0	0	0
GSE (Diesel)	0	0	0	0
Total	0	0	0	0

% Change with Alternative Fuel

Source	CO	NOx	SOx	PM
Aircraft	N/A	N/A	N/A	N/A
GSE (Diesel)	N/A	N/A	N/A	N/A
Total	N/A	N/A	N/A	N/A

Green House Gas Emissions

Current Fuel (metric tons)

	L-CO2	C-CO2
Aircraft	0	0
GSE (Diesel)	0	0
Total	0	0

Alternative Fuel (metric tons)

	L-CO2	C-CO2
Aircraft	0	0
GSE (Diesel)	0	0
Total	0	0

Figure 5. "Report" tab.

Report

The "Report" tab, Figure 5, compiles the information input by the user, calculated by AFIT, and derived from EDMS to represent, on a single page, the comparison in costs to deliver an alternative drop-in fuel and the reduced emissions that result.

The user can view the summary cost and emissions data for comparison. This tab also permits the user to print reports to capture cost and emissions estimates for comparison.

CHAPTER 3

Evaluating the Results of an Alternative Jet Fuel Cost–Benefit Analysis

3.1 Emissions

AFIT reports out two categories of pollutants on the "Emissions" tab—criteria pollutants and life-cycle greenhouse gases. The emission changes are compared to Jet A in the aircraft and ULS diesel in the GSE.

Carbon monoxide (CO), nitrogen oxides (NO_x), SO_x, and PM with a diameter of 2.5 micrometers or less ($PM_{2.5}$) are criteria pollutants.[1] These pollutants are broken out by source (aircraft or GSE) and fuel (current or alternative) in the "Emissions" tab. The emissions reflected in the "Current Fuel" table have been adjusted from the EDMS run used as an input file for this analysis. The emissions in the "Alternative Fuel" table reflect the computed emissions from the specific fuel blend entered in the "Setup" tab. If the alternative fuel is not used in GSE or aircraft, the emissions will be unchanged from the baseline (current fuel) emissions. The emission values shown for alternative fuels include the change in fuel use that results from an alternative fuel.

The GHG emissions from aircraft and GSE are reported in two separate categories—combustion CO_2 and life-cycle CO_2e (LC CO_2e). Combustion CO_2 changes by fuel type based on the amount of fuel consumed and the relative carbon content of the fuel. This is the amount of CO_2 emitted due to combustion and is typically the value included in an airport's GHG inventory or carbon footprint. LC CO_2e reflects the GHG emissions (carbon dioxide, nitrous oxide, and methane) created during the production of the fuel as well as the combustion CO_2. This illustrates the total GHG impact from using a particular fuel. The changes in life-cycle emissions will, in general, dwarf any changes in combustion emissions, and these changes are due to the details of fuel production, as is discussed briefly in Appendix D.

3.2 Costs

Specific costs associated with the introduction of an alternative fuel depend on individual airport considerations. AFIT was developed to accommodate most possibilities. AFIT is designed to collect standard fuel-related costs such as

- The fuel—the purchase of the product itself, likely from the production facility;
- Transportation to the airport—via pipeline, rail, barge, truck;
- Storage—in nearby facilities such as a fuel terminal and on the airport property;
- Fuel handling—blending, filtering and other fees; and
- On- and off-airport costs—reflecting inside- and outside-airport perimeter differences.

Annual and monthly consumption amounts for both Jet A and diesel fuels are also relevant since fuel suppliers modify fee structures depending on volume and infrastructure cost scale with volume-related measures (e.g., a 2-million-gallon storage tank costs more to build and maintain than a 1-million-gallon tank). This also enables conversion of raw costs to cost per gallon for comparison to Jet A and diesel.

Upgrades to GSE seals, gaskets, filters, pumps, and so on and the labor to perform installation are collected. Some discretion should be used with respect to equipment upgrades since some portion may occur during normal maintenance intervals. There is also the possibility that certain warrantees may be voided, and consideration for these costs must be made. Based on conversations with experts in the field, there appears to be a risk that if you put jet fuel into a diesel engine without first getting the manufacturer's approval, you then run the risk of voiding your warranty. Simply put, jet fuel certification covers jet engines. It does not automatically cover diesel engines. While there may not be an issue with the GSE engine warranty, this represents a potential cost that has not yet been completely

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[1] The AFIT tool was based on the best data that was available at the time of AFIT publication. However, additional testing of the emissions from alternative fuel combustion was ongoing at that time, and additional work was being devoted to estimating life-cycle greenhouse gas emissions.

resolved. By definition, a “drop-in” fuel is fully compatible with aircraft engine specifications, and it is assumed that no aircraft-related costs are incurred. It is anticipated that GSE upgrade costs will be expensed in the year in which they are incurred, for accounting purposes; however, a fundamental determination must be made regarding capital costs or the avoidance of them. AFIT is able to collect cost estimates in cases where the fuel will be dispensed through existing equipment and infrastructure at the airport and in situations where substantial new infrastructure development will be undertaken, such as with a new airport or a major expansion of the current facility. The reason this is important is that an alternative fuel compatible with both aircraft and GSE would reduce costs since two fueling systems would be replaced by a single system. AFIT is constructed to accommodate both circumstances and converts monthly capital financing charge estimates into a per-gallon fuel cost estimate.

AFIT converts and sums all costs into a per-gallon estimate for comparison with existing Jet A and diesel usage. Monthly and annual cost data are provided to assist with tracking and accounting. The analyst can input various costs and quantities of equipment affected, and AFIT updates the cost-per-gallon estimates, which can be compared to existing fuel costs.

AFIT intentionally does not provide a cost and benefit calculation as that is the purview of the analyst. It is designed to assist with categories of likely costs and also provides default estimates should the user not have specific data pertinent to the user’s facility. These estimates were collected from a range of sources and represent an approximation for use only when airport-specific values are not available.

3.3 Health Benefits from Improved Air Quality

Atmospheric $PM_{2.5}$, a criteria air pollutant that has been linked to respiratory illnesses and premature mortality, results from primary PM emissions as well as emissions of NO_x, SO_x, and unburned hydrocarbons. These latter pollutants, which are referred to as secondary PM precursors, are transformed in the atmosphere into aerosol PM, also referred to as secondary PM. Secondary PM is significantly more prevalent on a mass basis than primary PM. Emissions from aircraft, GSE, and other equipment and vehicles around an airport contribute to both primary and secondary atmospheric PM. The alternative fuels considered in AFIT have the potential to reduce $PM_{2.5}$ through a reduction in both primary PM and SO_x, which yields health benefits. The report includes an analysis of the impact of using both ULS and SPK blends on the air quality in the region surrounding Atlanta Hartsfield International Airport.

3.4 Making the Decision to Use an Alternative Jet Fuel

The analysis conducted by AFIT is meant to inform the user about the potential economic costs and changes in emissions that could result from switching to an alternative fuel. The results are best viewed as a screening assessment of whether an airport should consider an alternative jet fuel for use in aircraft and/or diesel-engine GSE. If the emission reduction benefits identified by AFIT are significant enough for the airport to seriously consider using an alternative fuel, a more-detailed engineering study will be required to fully quantify all costs.

APPENDIX A

Cost–Benefit Computations

AFIT is designed to assist fuel analysts in determining costs associated with introducing an alternative fuel and benefits as measured by reduced emissions. It is not a cost–benefit tool offering the analyst the decision to use an alternative fuel or not. To this end, AFIT is structured around two cost and one benefit computation pages or tabs.

Fuel Economics Costs

Fuel economics costs consist of off-airport (costs outside the airport perimeter fence) and on-airport costs (costs incurred inside the perimeter fence). These include transportation and storage and storage-related costs (filtering, blending) and, in the case of off airport, the cost of the alternative fuel. Costs are entered as a per-gallon charge, and AFIT sums them, using monthly gallons-consumed information, into a total monthly cost estimate for each cost component.

The calculations are simple addition, multiplication, and division operations producing per-gallon and total costs in dollars for user reference to current monthly costs.

Equipment Costs

There are three groupings on this tab.

1. GSE conversion costs to ready the equipment for the alternative fuel;
2. Decommissioning costs to remove the diesel-related tanks, piping, and equipment; and
3. Avoided construction costs of a new diesel facility in cases where significant expansion or new facilities associated with airport expansion required them.

All costs should be entered per unit. For example, if the GSE fleet requires 200 filters to be replaced, then enter 200 and the cost per filter, for example $10.00, and AFIT will calculate the cost to convert into the cost per gallon and the annual cost of replacement. A simple financing cost calculation is also supplied for the avoided diesel fueling system construction costs since these costs are likely to be significant and financed over time.

Emissions

Baseline emissions are imported from an EDMS study. AFIT calculates the new inventories based on the fuel selected and the equipment at the airport. Differences are displayed on the emissions and report tabs for the analyst to use for further consideration in whether to adopt an alternative fuel.

APPENDIX B

Sources of Data

Some data needed for the fuel comparisons can be found easily. Other information, such as transportation costs (pipeline, truck, barge, rail, etc.) and storage and blending fees depend on the facility and businesses involved. Fuel information is provided below. The AFIT software provides the typical cost range for the various handling fees.

Fuel

Gasoline and Diesel
EIA gasoline and diesel prices:
http://tonto.eia.doe.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm
U.S. Gulf Coast No. 2 Diesel Low Sulfur Spot Price FOB (cents per gallon)
http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=rdlusg&f=d
IATA Jet Fuel Price Monitor
http://www.iata.org/whatwedo/economics/fuel_monitor/index.htm
ATA Jet Fuel Price Statistics
http://www.airlines.org/Energy/FuelCost/Pages/MonthlyJetFuelCostandConsumptionReport.aspx

Alternative Fuel Price Estimates at the Producer

Many reports (e.g., Hileman et al., 2009) provide estimates of the economic costs of producing fuel, but these values are in terms of the fuel producer. This should not be confused with the price that would be paid by a fuel consumer. The price paid by a consumer will be set by the prevailing market price for conventional jet fuel. Assuming that the fuel producer can create its alternative jet fuel at a cost that is less than the prevailing price of conventional jet fuel, it will sell it at the market price of conventional jet fuel to maximize profits. However, if the fuel producer and fuel buyer go into a long-term contract, then the fuel producer may sell its product at a discount to conventional jet fuel. Because of this, AFIT has a default assumption that the price of the alternative fuel is assumed to be 90% of conventional jet fuel.

Transportation and Storage Costs

These costs are not collected and posted conveniently on any single website. The cost ranges provided in AFIT were collected by reviewing financial filings, regulatory requirements, and other legal and non-legal documents and sources. Pipeline, barge, truck, and rail costs vary widely depending on a multitude of factors. The Energy Information Association (EIA) is a large repository of useful information and can be found at http://www.eia.doe.gov/.

New Diesel Fueling Station Costs

Construction costs vary depending on region, project type, preexisting arrangements, and so on, but the RSMeans Building Construction Cost Data manual is an excellent source for the latest industry standards. The 2008 edition was used for this version of the handbook. A 2010 version of the manual is now available.

Equipment Costs

GSE equipment replacement costs vary widely depending on the equipment on site, its age and condition, onsite inventory, mechanical skill level of employees, and other factors. Fleet and equipment managers currently maintaining the equipment will likely be able to find the best cost data with their current suppliers.

APPENDIX C

Glossary, Acronyms, and Abbreviations*

ACRP	Airport Cooperative Research Program
AFIT	Alternative Fuels Investigation Tool
ASTM	the American Society of Testing and Materials
CAAFI	the Commercial Aviation Alternative Fuels Initiative
CO	carbon monoxide
CO_2	carbon dioxide
Drop In	a fuel that can be mixed in with existing fuels in the system with no deleterious effect
EDMS	Emissions and Dispersion Modeling System
EPA	the Environmental Protection Agency
FAA	Federal Aviation Administration
GHG	greenhouse gas
GSE	ground support equipment
Jet A	conventional jet fuel
LC	life cycle
LC CO_2e	life-cycle CO_2 emissions
NO_x	nitrogen oxides
PM	particulate matter
SO_x	sulfur oxide
SPK	synthetic paraffinic kerosene
ULSJ	ultralow sulfur jet fuel
USAF	United States Air Force

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*Definitions of key terms necessary to using AFIT; a more extensive glossary is included in the report.

APPENDIX D

Life-Cycle Greenhouse Gas Emissions

To accurately assess the impact of fuel combustion on global climate change, one must consider the full fuel life cycle, from feedstock extraction through fuel combustion. If one only considers combustion, then for the fuels considered here (conventional jet fuel, SPK, and ULSJ fuel) the emissions of an alternative fuel will vary by less than 4%, and this is true regardless of the feedstock used to create the fuel (petroleum, natural gas, coal, or biomass) or how the fuel is processed. It is only from a life-cycle standpoint that one can see that biofuels offer the potential to reduce aviation's impact on global climate change. Biofuels can lessen aviation's production of greenhouse gases because the biofuel feedstock was created by photosynthetic reaction of water with carbon dioxide; thus, if atmospheric carbon dioxide was used to grow the biomass, then the combustion of the biofuel results in the carbon dioxide being returned to the atmosphere from which it came and there is zero net emissions of carbon dioxide into the atmosphere from fuel combustion. This is not true for fossil fuel combustion, where the fuel feedstock contains carbon that has been sequestered from the atmosphere for millions of years. Further background information and guidance on creating a life-cycle GHG inventory can be found within AFLCAWG (2009).

The life-cycle GHG emissions from a variety of potential alternative jet fuels are plotted in Figure 6; these data are from the analysis of Stratton et al. (2010). These results include an assessment on the anticipated impact of variations in feedstock properties and process efficiencies on life-cycle GHG emissions as well as an analysis of the impacts of land-use changes. Five life-cycle steps were considered: feedstock recovery (e.g., mining, farming, pumping), feedstock transportation, feedstock processing (e.g., gasification, F-T synthesis, refining), transportation (of finished fuel), and fuel combustion. Because of the increased energy intensity of feedstock extraction, unconventional petroleum fuels (oil sands and oil shale) have increased life-cycle carbon dioxide emissions relative to fuels created from crude oil. A ULS fuel has a slight increase in life-cycle carbon dioxide emissions because of the additional processing (i.e., refining) that is necessary to desulfurize the fuel. To achieve emissions comparable to conventional fuels, F-T fuels must either use carbon capture and sequestration (CCS) or incorporate biomass. Without CCS, F-T fuels from coal will have roughly twice the life-cycle carbon dioxide emissions. Hydroprocessed renewable jet (HRJ) fuels have emissions that are highly dependent on the feedstock that is being used, with emissions from either land-use change dominating (Table 1).

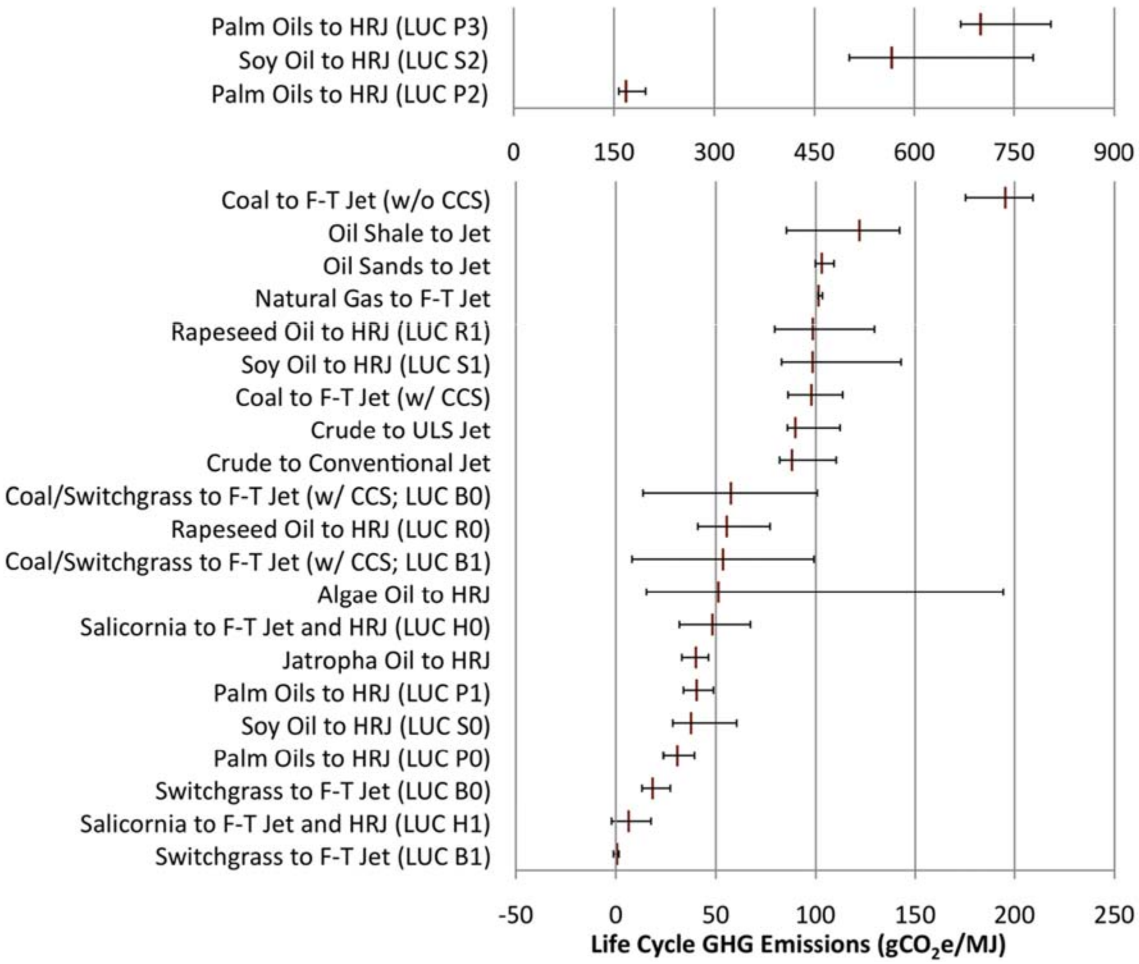

Figure 6. Life-cycle greenhouse gas emissions from a variety of potential alternative fuel pathways that could result in SPK, ULS, or conventional fuels [from Stratton et al. (2010) with permission].

Table 1. Land-use change scenarios explored for HRJ pathways [from Stratton et al. (2010) with permission].

Land-Use Change	Scenario 0	Scenario 1	Scenario 2	Scenario 3
Switchgrass	None	Carbon depleted soils converted to switchgrass cultivation	n/a	n/a
Soy oil	None	Grassland conversion to soybean field	Tropical rainforest conversion to soybean field	n/a
Palm oil	None	Logged-over forest conversion to palm plantation field	Tropical rainforest conversion to palm plantation field	Peatland rainforest conversion to palm plantation field
Rapeseed oil	None	Set-aside land converted to rapeseed cultivation	n/a	n/a
Salicornia	None	Desert land converted to *Salicornia* cultivation field	n/a	n/a

References

AFLCAWG (Aviation Fuel Life Cycle Assessment Working Group). *Framework and Guidance for Estimating Greenhouse Gas Footprints of Aviation Fuels.* Air Force Research Laboratory Technical Report, AFRL-RZ-WP-TR-2009-2206, April 2009. http://web.mit.edu/aeroastro/partner/reports/proj28/greenhs-gas-ftprnts.pdf. Accessed March 31, 2010.

Hileman, J., D. Ortiz, J. Bartis, H. M. Wong, P. Donohoo, M. Weiss, and I. Waitz. *Near-Term Feasibility of Alternative Jet Fuels.* Jointly published by the RAND Corporation (Report No. TR-554-FAA) and the Partnership for AiR Transportation Noise and Emissions Reduction (Report No. PARTNER-COE-2009-001), 2009. http://web.mit.edu/aeroastro/partner/reports/proj17/altfuelfeasrpt.pdf. Accessed March 31, 2010.

Stratton, R., H. M., Wong, J. Hileman. *PARTNER Project 28 Report: Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels, Version 1.0.* Partnership for AiR Transportation Noise and Emissions Reduction Report No. PARTNER-COE-2010-001, 2010. http://web.mit.edu/aeroastro/partner/reports/proj28/. Accessed March 31, 2010.

Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation