An Overview of Aviation Fuel Markets for Biofuels Stakeholders

Carolyn Davidson, Emily Newes, Amy Schwab, and Laura Vimmerstedt

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List of Acronyms and Abbreviations

AEO	Annual Energy Outlook
CO_2	carbon dioxide
EIA	U.S. Energy Information Administration
EISA	Energy Independence and Security Act
FAA	Federal Aviation Administration
FBO	fixed-base operator
FT	Fischer-Tropsch
GHG	greenhouse gas
HEFA	hydroprocessed esters and fatty acids
MJ	megajoule
n.d.	no date
NREL	National Renewable Energy Laboratory
PADD	Petroleum Administration for Defense Districts
WTI	West Texas Intermediate

Executive Summary

This report is intended for biofuels stakeholders who are interested in, but unfamiliar with, the U.S. aviation industry and, in particular, the aviation fuel market. It provides an overview of the state of the aviation fuel industry, targeting background information for evaluating the potential of biofuels in aviation. This scope includes trends in jet fuel price, airline responses to fuel price increases and volatility, and environmental goals for aviation fuels in relation to the potential for biofuels. The overview of the aviation fuel industry includes production, distribution, and consumption of aviation fuel, and it outlines players in the aviation fuel supply chain.

Jet fuel has accounted for approximately 10% of U.S. petroleum refinery production for the past two decades. Production is concentrated by company and geographic region, with Exxon Mobil, Chevron, and BP among the top producers and Texas, Louisiana, and California among the top producing states. Refiners' decisions about jet fuel production volumes encompass purchasing capital equipment, selecting crude oil, and producing the desired type and quantity of products. Biomass-based jet fuel production at scale would need to enter this supply chain.

Distribution of jet fuel in the United States primarily involves transport from the Gulf Coast to other regions. Transportation of refined petroleum products (which include jet fuel) is accomplished via pipeline (60%), ocean-going tankers and barges on inland waterways (30%), tanker trucks (5%), and rail (5%). At each airport, fuel supply chain organization and fuel sourcing could differ with regard to the role of oil companies, airlines, airline consortia, airport owners and operators, and airport service companies.

Major jet fuel purchasers are airlines, general aviation operators, corporate aviation, and the military, with most of the jet fuel in the United States being used for domestic, commercial, and civilian flights carrying passengers, cargo, or both. Commercial aviation fuel efficiency has improved dramatically over time, largely due to aircraft and engine upgrades and operational and air traffic control improvements. This has resulted in an overall decline in U.S. jet fuel consumption during the past decade.

The report addresses historical and projected fuel price trends, as well as airline strategies to mitigate price risk. Jet fuel prices generally correlate with prices of crude oil and other refined petroleum products, such as diesel. Increasing prices and the persistent price volatility of jet fuel markets impact airline industry finances in the United States. Jet fuel represents the single largest operating expense for airlines (approximately one-third of airline operating costs), and fuel price increases are not readily passed on to consumers.

Airlines use various strategies to manage aviation fuel price uncertainty, including financial hedges, increased vertical integration, and adjustments in aircraft utilization and size. Investments in alternative aviation fuel could be a mechanism to diversify exposure to the price of petroleum. While the first set of strategies aims to manage the current petroleum-based aviation fuel price, the use of alternative aviation fuel would serve to diversify the fuel mix. If a diversified fuel mix were to decrease fuel price volatility or reduce long-term fuel price increases, potential benefits include reduced hedging costs, increased price certainty, and lessened fuel costs. This diversity could allow airlines to become more consistently profitable

and to make other investments in their business. The potential of biofuels to reduce fuel price volatility or long-term fuel price increases is not evaluated here.

The report outlines the environmental basis for considering biofuels for aviation, but it does not quantify the environmental effects of different options or otherwise evaluate these opportunities. The aviation industry has established goals to mitigate its greenhouse gas emissions for a variety of reasons, notably regulatory and financial risks. These goals target carbon neutral growth starting in 2020.

Biofuels have potential to meet aviation industry needs, possibly including managing risks of upward fuel price trends and fuel price volatility and risks associated with greenhouse gas emissions. The aviation industry has taken steps to explore this potential through participation in alternative aviation fuel research, development, and demonstration. Initial steps toward using biojet include development of standards. Biofuels that currently have ASTM standards for aviation use include fuels based on two processes: Fischer-Tropsch (FT) and hydroprocessed esters and fatty acids (HEFA). Standards development is underway for other processes, and biofuels are being used in demonstration flights.

The aviation fuels market could use biofuels to reduce greenhouse gas emissions and mitigate long-term upward price trends, fuel price volatility, or both. This report offers a background on the aviation industry, primarily for biofuels stakeholders with an interest in environmental, economic, and financial potential.

Table of Contents

List of Figures

List of Tables

1 Introduction

Biofuels—fuels made from biomass—for aviation fuel markets could have the potential to address needs and objectives of both biofuels and aviation stakeholders. This report is intended to provide a snapshot of the aviation industry and its fuel market for biofuels stakeholders who may be unfamiliar with the U.S. aviation sector but are interested in whether and how biofuels might enter the aviation fuel market. The report does not assess the technical aspects or production potential of biofuels for aviation, nor does it address in detail other alternative aviation fuels or combinations of biofuels with fossil fuels.

Biofuels have potential to meet aviation industry needs, possibly including managing risks of upward fuel price trends and fuel price volatility and risks associated with greenhouse gas (GHG) emissions. The aviation industry has taken steps to explore this potential through participation in alternative aviation fuel research, development, and demonstration. Through these activities, additional potential benefits of biofuels have been identified, such as chemical properties that could improve fuel performance or complement other alternative fuels. Public and private initiatives have targeted goals for biofuels in aviation, including support of national goals, a Federal Aviation Administration volumetric goal, and goals of the Commercial Aviation Alternative Fuels Initiative (CAAFI), as described in the Farm to Fly report (U.S. Department of Agriculture et al. 2012). The CAAFI summarizes actions that the aviation industry might take to advance development of aviation biofuels (Miller and Heimlich 2013). The International Air Transport Association regularly tracks the status of alternative aviation fuels (International Air Transport Association 2013).

For the biofuels industry, aviation fuel markets could provide an outlet for biofuels producers that might be attractive relative to current markets. Today, the single largest domestic biofuel is ethanol, which is blended into motor gasoline for cars and trucks. However, ground transportation biofuel markets face declining gasoline sales, limits on ethanol blending in gasoline, market risks for higher ethanol blends and hydrocarbon fuels, and competition from non-liquid fuels (natural gas, battery-electric, or fuel-cell hydrogen-powered vehicles). Aviation fuel markets are likely less vulnerable to competition from non-liquid fuels (U.S. Department of Agriculture et al. 2012) because the benefits of greater energy density of liquid fuels are substantial in aviation due to the energy efficiency implications of hauling the fuel itself and the physical constraints of airplane design and performance. Another feature of aviation fuel markets that is relevant to biofuels producers is the concentration of jet fuel demand at major airport hubs (U.S. Department of Agriculture et al. 2012). This concentration could simplify supply chain control and logistics, potentially facilitating biofuels supply to these locations, although possibly also raising concerns about market power of the fuel purchasers. The challenges to biofuels entering aviation fuel markets are numerous and significant and include business and financial risks of delivering a specialized, highly regulated fuel at a competitive price to a financially volatile industry. Neither these potential benefits nor the challenges are assessed in detail in this report. The CAAFI provides guidance about the development of this business, including airline requirements for fuels purchases and discussion of business risks (Miller and Heimlich 2013).

It could be technically feasible for the U.S. biofuels industry to grow sufficiently to supply a significant share of U.S. jet fuel and to diversify its production into the jet fuel market. The biofuels industry as well as government efforts are pursuing growth strategies; for example, the

U.S. Department of Energy's Multi-Year Program Plan (Bioenergy Technologies Office and Energy Efficiency and Renewable Energy 2013) provides one summary of a government biofuels program. Policy and technology progress could influence the future development of the U.S. biofuels industry. The Energy Independence and Security Act of 2007 (EISA) established a target of 36 billion gallons per year (860 million barrels) of renewable liquid transportation fuel in the United States by 2022 (U.S. Congress 2007). New technology could enable an advanced biofuels industry based on conversion of cellulosic biomass. Products of an advanced biofuels industry could include hydrocarbons that can be integrated into existing petroleum-based jet fuel delivery systems (Bioenergy Technologies Office and Energy Efficiency and Renewable Energy 2013).

Jet fuel has accounted for approximately 10% of U.S. petroleum refinery production for the past two decades after a generally increasing trend from the 1950s through the 1980s (Energy Information Administration 2012b, Table 5.8). Production and consumption of jet fuel have both decreased in the past decade, and the decrease in consumption, even as total domestic air miles have continued to increase is due to increased fuel efficiency (Energy Information Administration 2013f; Research and Innovative Technology Administration 2013).

Increasing prices of jet fuel and continued price volatility pose challenges for the U.S. airline industry, with real prices nearly tripling from approximately $1.30/gallon in 2000 to approximately $3.00/gallon in 2012 (Research and Innovative Technology Administration 2013). Prices are sufficiently volatile that many airlines seek to mitigate fuel price risks through various financial measures, such as fuel price hedging. In addition to the challenge of increasing and volatile fuel prices, the aviation industry faces environmental concerns associated with aviation fuel, including air quality impacts and GHG emissions. Concerns about climate change have prompted regulatory measures in Europe and industry commitments to reduce emissions (Meltzer 2013). The use of biofuels could help address these concerns.

Using biofuels for aviation has the potential to offer a new market for the biofuels industry, while easing financial and environmental challenges in the aviation industry. The overall market size and the structure of the aviation fuel supply chain shape the opportunity for biofuels. Understanding the basics of current production, distribution, and consumption of aviation fuel could help analysis of whether and how biofuels could be used. In addition, effects of biofuels on price and price volatility in the aviation fuel market would be a critical consideration for their adoption. This report provides a background on these topics. It offers an overview of the aviation fuel market (Section 2), including basic information for considering biofuels entry into the aviation fuel market: an overview of production, distribution, and consumption in the current aviation fuel industry, as well as descriptions of market participants. The report addresses historical and projected jet fuel price trends (Section 3), as well as airline strategies to mitigate to price risk (Section 4). It outlines the financial and social basis for interest in biofuels in aviation (Section 5), but it does not address the technical, economic, or market potential of biofuels in that market. It also does not evaluate costs and benefits of biofuels for aviation, which would include environmental as well as financial and economic metrics. The conclusions (Section 6) offer perspectives on the opportunities and challenges outlined in the report.

2 Overview of the Aviation Fuel Industry

The aviation fuel industry in the United States includes production, distribution, and consumption that together support aviation operations as summarized in Table 1. This section describes the participants and operations of these systems of production (Section 2.1), distribution (Section 2.2), and consumption (Section 2.3). These participants and operations could adopt or potentially be affected by the adoption of biofuels in aviation fuel markets.

Table 1. Operational Characteristics of the U.S. Airline Industry

Characteristic	Number	Year of Data	Location of Data in Source
Major air carriers	19	2011	Table 1.2
Certificated airports	547	2011	Table 1.3
Air carrier aircraft	7,028	2011	Table 1.13
Departures	9,345,013	2012	Table 1.37
Enplaned revenue passengers	685,102,804	2012	Table 1.37
Revenue short tons	12,144,337	2012	Table 1.37

Source: Research and Innovative Technology Administration 2014a

2.1 Production of Jet Fuel

The United States produces more than 22 billion gallons of jet fuel annually. Total domestic biofuel production for all uses is on the same order of magnitude as jet fuel production. Domestic biofuel production in 2012 was equivalent to 1.24 quadrillion Btu (14 billion gallons) or 43%, based on energy content, of the aggregate U.S. airlines' jet fuel product supplied (Energy Information Administration 2014b).[1]

The aviation fuel market includes jet fuel and aviation gasoline. Jet fuels are classified into two types: kerosene-type (carbon number distribution between 8 and 16) and naphtha-type (carbon number distribution between 5 and 15). Jet A and Jet A-1, kerosene-type jet fuels, are the fuel types most commonly used in commercial aviation and are produced to an international specification (Chevron Global Aviation 2006). JP-8 is used for military operations and is similar to Jet A-1, although many military operations are beginning to switch to commercial jet fuel (Wood 2013). Jet B and JP-4 are classified as naphtha-type jet fuels and are not used as widely as their kerosene-type counterparts. Aviation gasoline is also used in smaller aircraft, but it comprises only about 1% of the total aviation fuel market (Federal Aviation Administration 2013). Biofuel standards for aviation fuels target kerosene-type jet fuel, hereafter referred to as biojet.

Crude oil[2] is processed into various products at petroleum refineries, with shares of production shown in Figure 1. Heavy crude oil (with greater shares of higher carbon number compounds) is generally less expensive to purchase than light crude but requires more expensive processing to produce higher-value, lower-carbon-number products, such as jet fuel. Various types of

[1] Product supplied is considered a proxy for total consumption and will be discussed further in Section 2.3.
[2] Crude oil naturally varies in composition, with regard to the distribution of molecules by carbon number, the types of hydrocarbons (e.g., alkanes), and the presence of elements other than hydrogen and carbon, such as oxygen and sulfur.

equipment are used to process crude petroleum into desired products. Refiners must make decisions about purchase of crude oil and capital equipment, as well as operational decisions about which processes to run and at what capacity. These decisions take into account price and chemical characteristics of different available crude oils, the cost of running different equipment, and the cost of investing in new equipment. Biojet production would involve similar decisions and at large scales could affect the operations of existing refineries in their production of conventional jet fuel.

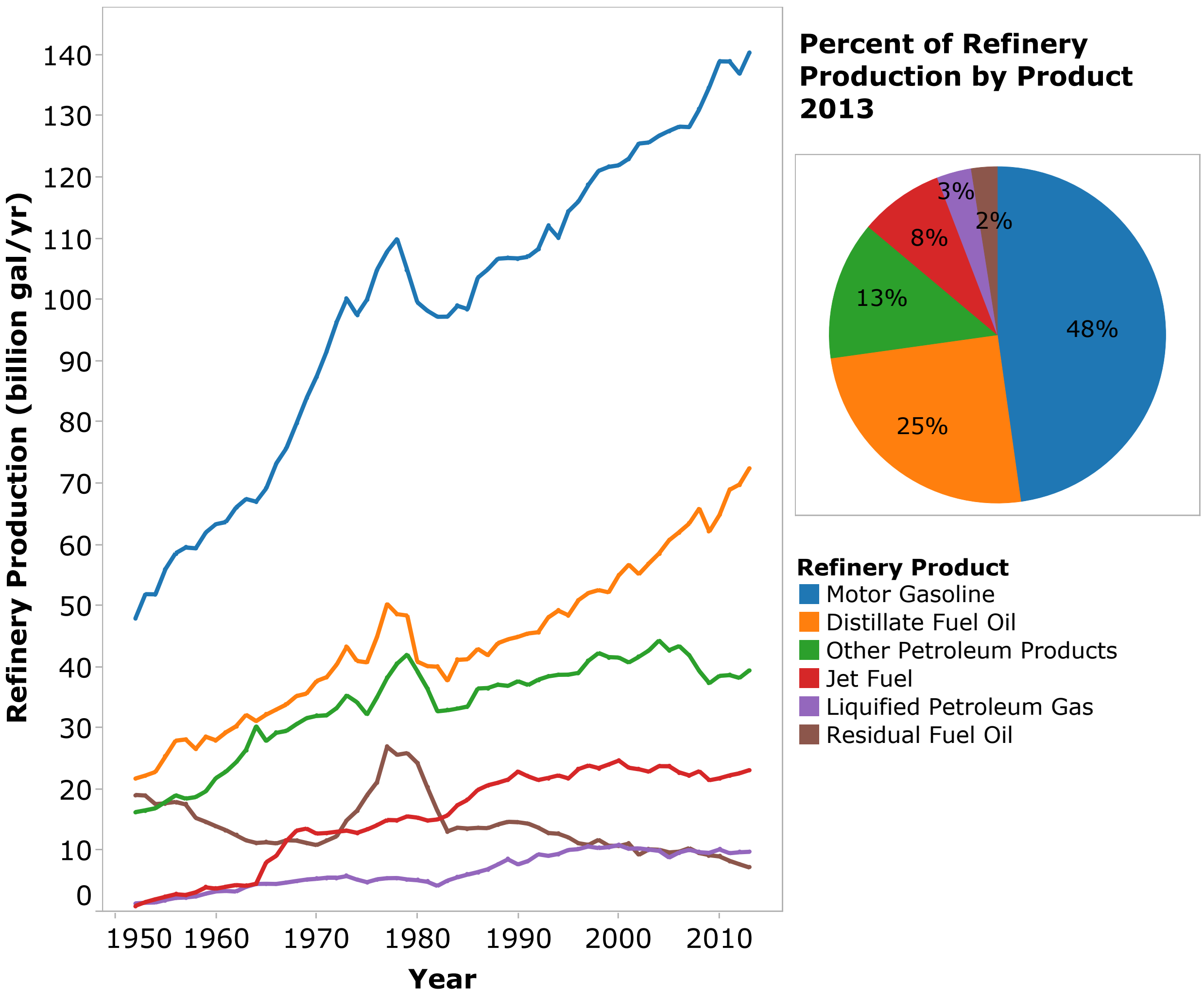

Figure 1. Historical trends and current share of refinery production by product in the United States

Source: Energy Information Administration 2014, Table 3.2

Note: Data were converted from thousand barrels/day to billion gallons/year.

The top five U.S. refiners by jet fuel production are Exxon Mobil, Chevron, BP, Valero, and Marathon Petroleum Group, which together account for roughly 50% of total U.S. jet fuel production (Figure 2). In many cases, the energy company refines jet fuel from crude oil and distributes the jet fuel to consumers.

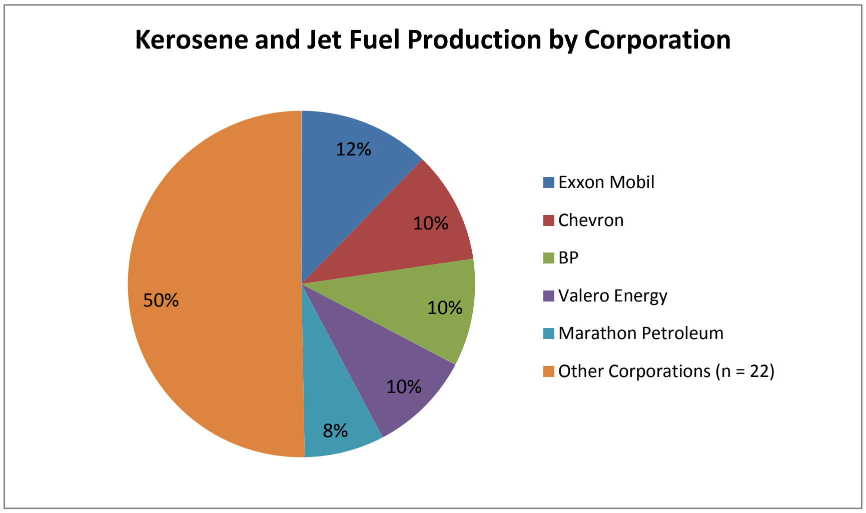

Figure 2. Percent of jet fuel supplied by companies in the United States

Source: Energy Information Administration 2012a

In other cases, oil companies work with distributors or marketers to supply fuel to buyers; for example, Shell works with Eastern Aviation Fuels (Eastern Aviation Fuels, Inc. 2010). In addition, there are several independent suppliers of aviation fuels (e.g., Epic Aviation, Avfuel, and Chemoil Aviation). Morgan Stanley, who had historically dealt with futures and derivatives and not fuel on a physical basis, began selling and trading fuel on a physical basis in 1986; in 2003, United Airlines chose to use Morgan Stanley to supply all of its jet fuel (Davis 2005). Distribution of jet fuel is discussed in Section 2.2.

As of 2012, the total capacity for kerosene-type jet fuel production in the United States was just less than 23 billion gallons per year, with the largest output from the Gulf Coast regional Petroleum Administration for Defense District (PADD), given the high refinery capacities located in Texas and Louisiana (Figure 3). In many states, the production of jet fuel comprises a large portion of total refinery products output (Figure 4). The geographic pattern of biofuel production is different from jet fuel production because biorefineries are located near their biomass resource base, primarily in the Midwest.

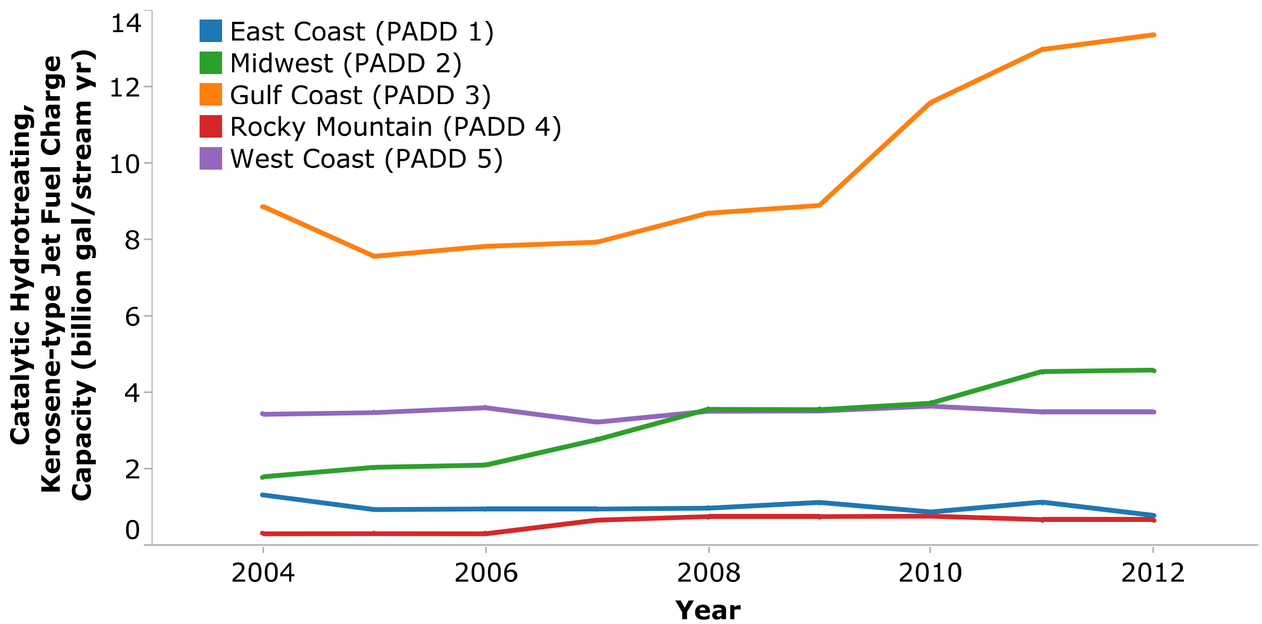

Figure 3. Jet fuel charge capacity by PADD, 2004–2012

Charge capacity refers to the "input (feed) capacity of the refinery processing facilities."
Source: Energy Information Administration 2013d

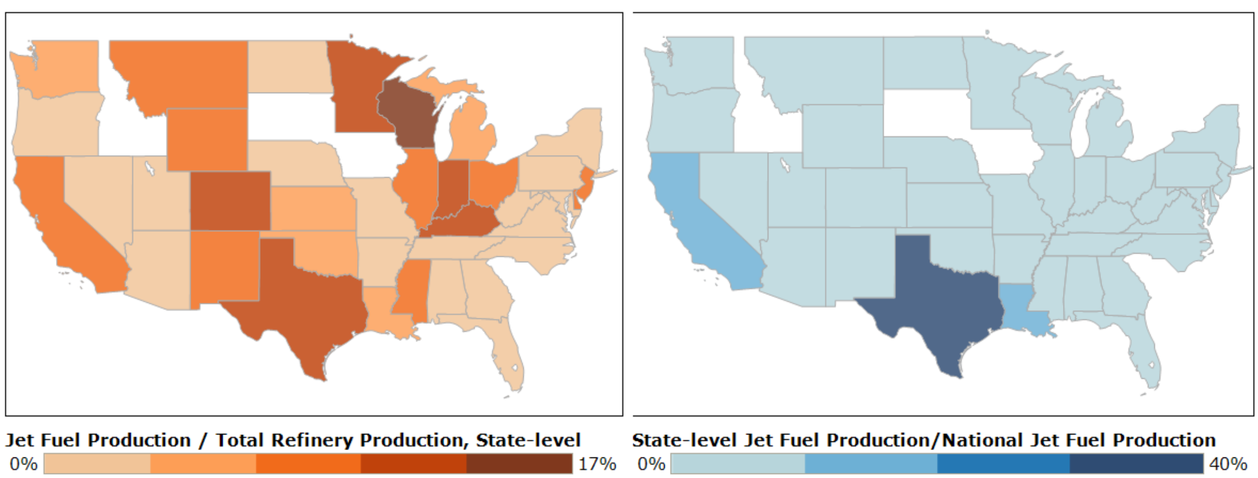

Figure 4. Percent of state-level refinery production dedicated to jet fuel (left) and percent of total jet fuel produced by each state (right) in 2012

The color white indicates those states without jet fuel production, according to the U.S. Energy Information Administration (EIA).

Source: Energy Information Administration 2013d

2.2 Distribution of Jet Fuel

The crude oil transport and jet fuel distribution system provides the critical links between import or crude oil extraction locations, refinery locations, and jet fuel consumption. For the potential entry of biofuels into the jet fuel distribution system, important considerations include overall geographic patterns of production and consumption, fuel compatibility with distribution system components, non-fuel contamination, cross-contamination among different fuels, and logistical considerations for fuel handling during transfer and blending. Insertion points of biocrude or biofuel into the jet fuel supply chain, and compatibility with that supply chain, would determine how easy or difficult it might be to enter into the distribution system. Section 5.2 provides information regarding some of these biofuel-specific issues.

In general, for petroleum products, import, extraction, and refining are all concentrated in the Gulf Coast, although development of resources in the northern plains and Canada, as well as other domestic resources, has shifted the geographic distribution of import and extraction. Jet fuel consumption is distributed across the country, concentrated at major urban airports. The transportation networks that are used to connect import or extraction to refining and refining to consumption reflect these historical patterns, and they are adapting to new resource locations. Use of biojet would rely upon, and influence the future development of, these networks.

Crude oil can be transported long distances to refineries. The majority of jet fuel (62%) is refined within the PADD where it is used, so most cross-region transport occurs as crude oil before refining (Energy Information Administration 2013e; Energy Information Administration 2013b). Figure 5 shows an example of crude oil flows among PADDs for 2012 and demonstrates that the only major exporting region is PADD 3.

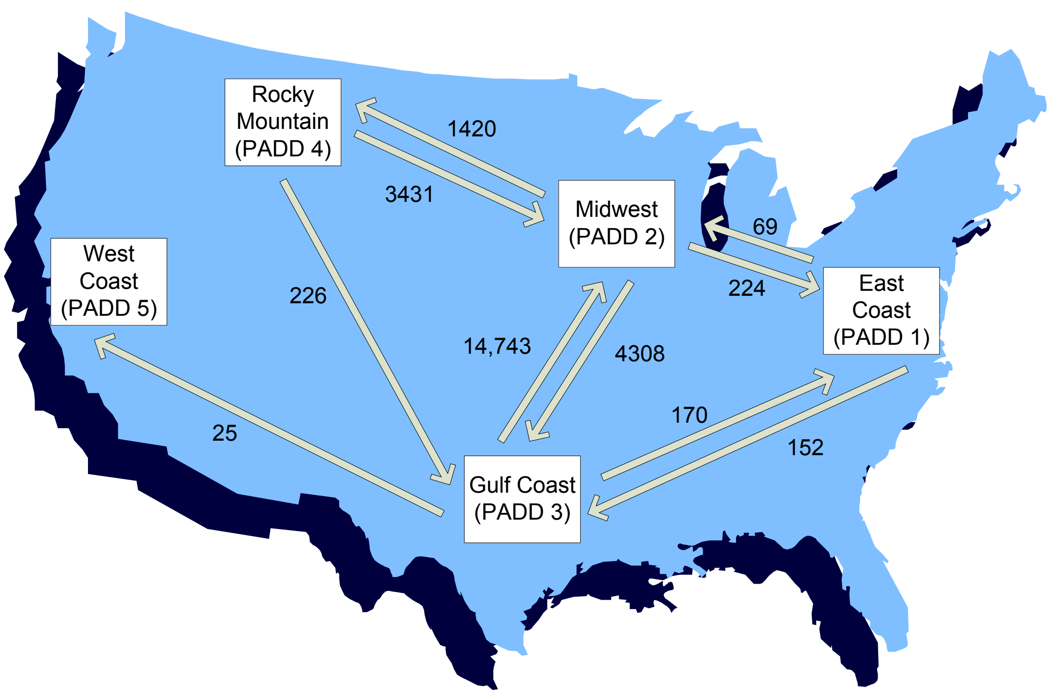

Figure 5. Crude oil movements (million gal) by PADD in 2012

Source: Energy Information Administration 2013b

For the 38% of jet fuel production that is not refined within the PADD where it is used but is imported and exported across regions, jet fuel distribution data for the United States is shown in Figure 6. Export by PADD is shown in the top panel, with much larger exports occurring from the Gulf Coast than any from other region. For the top four exporting regions, destination of the export (importing region) is shown by PADD in the lower four panels. These data are plotted at the monthly level, which shows seasonal volatility as well as other month-to-month volatility, such as inventory or production variations. Transportation routes largely flow from the Gulf Coast to other regions, highlighting the national importance of Gulf Coast refineries.

Many of the largest jet-fuel-producing refineries are located near large airports. After being refined from crude oil, jet fuel is typically transported to airports in batches (tenders[3]), which can regularly exceed 400,000 gallons. The fuel can be shipped directly from the refinery to the airport fuel storage facility, though often it is stored in an intermediate storage facility. Jet fuel is more likely transported from the intermediate storage facility via a dedicated jet-fuel pipeline or tanker truck. Smaller airports are more likely than larger ones to rely tanker trucks. Due to their large volume, the majority of tenders are transported by pipeline (Chevron Global Aviation 2006).

Various means are used to transport crude oil and refined petroleum products, including liquid jet fuel. Transport of refined petroleum products occurs via pipeline (63%), water carriers (26%), tanker truck (5%), and rail (5%) (Research and Innovative Technology Administration 2014a). Jet fuel falls within the refined petroleum product, but data are not available on the share of jet transport by transportation method and by leg (refinery to intermediate storage, storage to airport). Figure 7 provides an overview of select transportation networks and destinations, showing pipelines and navigable waterways, as well as refineries and airports. The figure also includes select data on biomass resources that could be converted to biomass-based aviation fuel, illustrating that the geographic locations of these resources differ from the locations of the current fuel system.

[3] Tenders can originate from one refinery or multiple refineries operated by multiple companies whose products meet the same specifications.

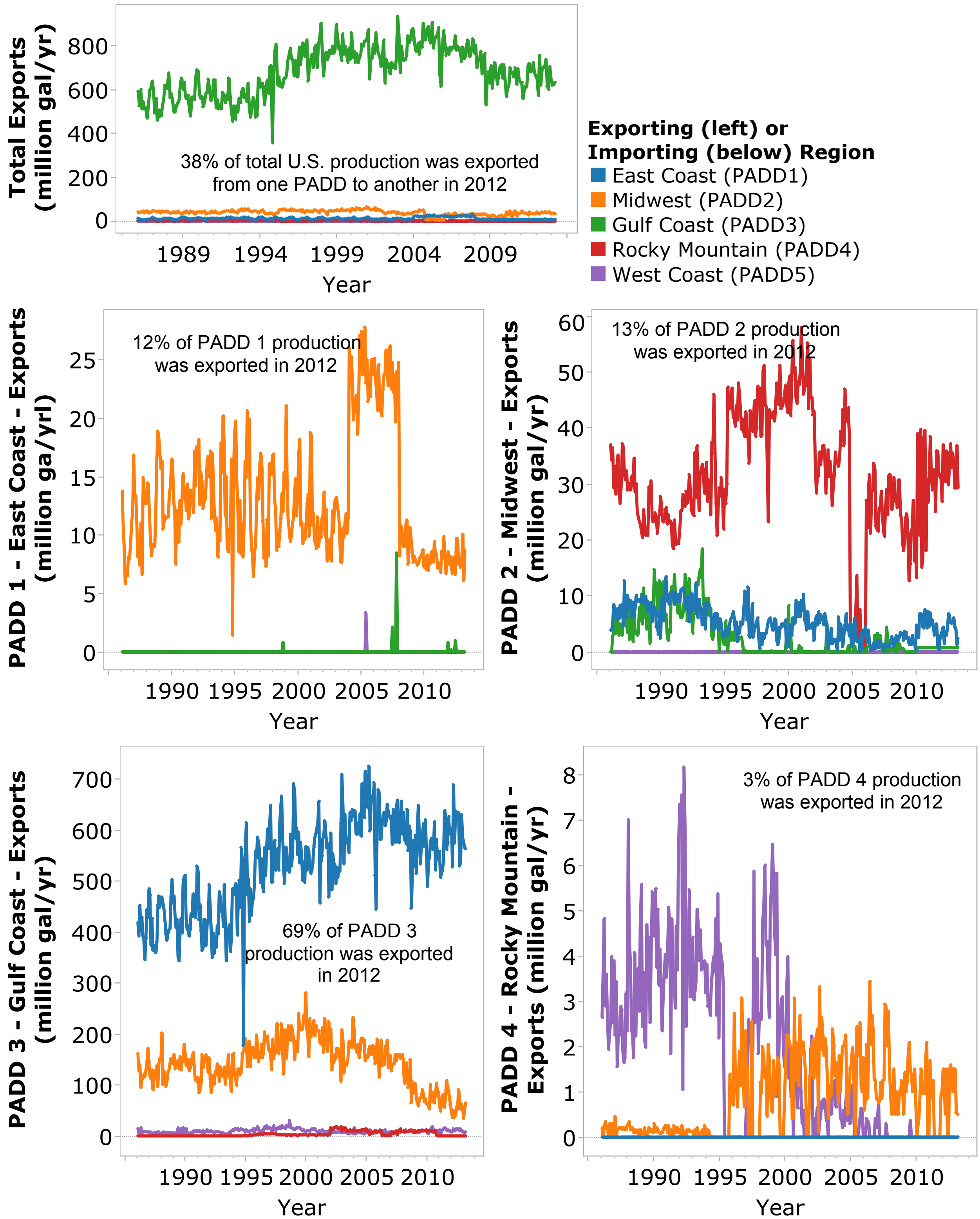

Figure 6. Kerosene-type jet fuel transported between PADDs by pipeline, tanker, and barge

Y-axes have different scales.

Source: Energy Information Administration 2013b

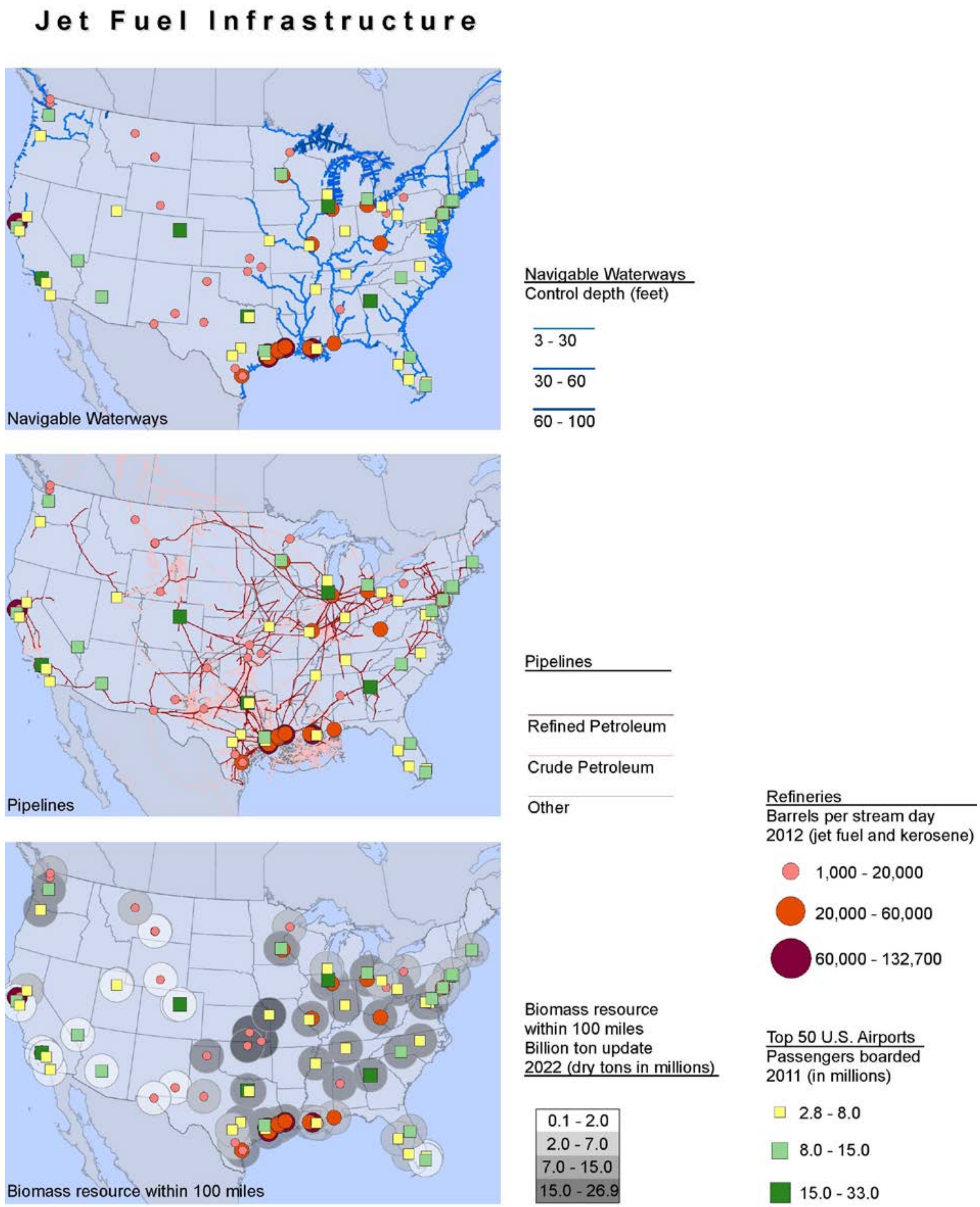

Figure 7. Refineries, crude, refined petroleum pipelines, waterways, airports, and biomass resources in the United States

Sources: Homeland Security Infrastructure Program 2012; Research and Innovative Technology Administration 2014a, Table 1-44; Energy Information Administration 2013d; U.S. Department of Energy 2013

Pipelines are the least expensive and most commonly used method to transport refined petroleum products (Research and Innovative Technology Administration 2014a) and by far the dominant method for jet fuel delivery to airports (Airlines for America 2014d). Typically, pipelines are owned by different entities than refineries. While in some cases pipelines are specifically designated for jet fuel, typically they are multiproduct pipelines that handle a wide variety of liquid petroleum products (Sera 2009). Pipeline routes are determined based on demand patterns; routes are shown in Figure 7. Increased crude oil production in the United States in the last several years has filled most pipelines to capacity. Building new pipeline infrastructure is a lengthy and expensive process; as a result, new crude oil supply often relies on existing rail and waterway infrastructure. Rail carloads of petroleum increased 40-fold between 2008 and 2013 (Association of American Railroads 2013).

Barges and oceangoing vessels are also used to transport petroleum products. When pipeline transport is not an option, barges on waterways are the second-most efficient and cost-effective means to transport refined petroleum products; one 15-barge tow can carry as much cargo as 216 rail cars or more than 1,000 trucks (Toohey 2013). Roughly one-quarter of refined petroleum product ton-miles are transported by water carriers (Research and Innovative Technology Administration 2014a). Barge transportation relies on the U.S. inland waterways transportation system, an 11,000-mile network that includes 27 waterways operated and maintained by the U.S. Army Corps of Engineers. Private barge carriers contract with refineries to transport refined petroleum products (including jet fuel). Barge transport is particularly prevalent for jet fuel in New England (Gibbs 2012). Figure 7 displays the U.S. inland waterway network.

Refined petroleum products transported by rail use specialized tank cars typically owned by independent, private tank car supply and service companies, rather than by common carriers (railroad owners) or fuel companies (Union Tank Car Company 2013; TTX Company 2013).

Generally, tanker trucks only transport jet fuel from intermediate storage facilities to airports—typically smaller airports—because this mode is only economical when transport quantities are small (Janić 2011).

As jet fuel is received in storage, it is filtered and tested according to ATA Spec 103 ("Standard for Jet Fuel Quality Control at Airports") protocols for several potential contaminants, including water and particulates. At some large commercial airports, fuel can be transported to gates via underground pipelines and dispensed through a hydrant system. Another alternative to refuel aircraft is to transport fuel to the waiting aircraft. The fuel is again filtered as it is released into the hydrant system or into the fueling trucks, and another filtration occurs as the fuel is dispensed into the aircraft fuel tanks (Chevron Global Aviation 2006, pp.74–76).

Before the 1980s, the distribution and storage of fuel at major airports was handled by major oil companies, many times with their own distribution systems to service specific concourses. This setup was monopolistic, prevented airlines from seeking new sources of fuel, and resulted in higher costs for the airlines. In the mid-1980s, many airlines formed consortia to seek a more competitive option. New joint ventures purchased the oil company distribution systems at some airports, leased the property and right-of-ways from the airport authority, financed the acquisitions and improvements, and managed the fuel infrastructure and operations. Joint venture members split the cost of acquiring, maintaining, and operating the infrastructure based on each member's consumption (Sturtz and Smith 2010).

Airlines typically prefer to source their fuel through contracts with fuel suppliers that deliver fuel to an airport's fuel farm. Fuel farms are managed by fixed-base operators (FBOs),[4] on behalf of airports or airlines (Airport Cooperative Research Program 2012). At large hub airports, airlines purchase separate tenders from more than one supplier, partially to reduce risk arising from supply interruptions (e.g., natural disasters and fuel infrastructure problems). In general, contracts have a length of 1–2 years and specify the delivery point, volume, and price (Miller and Heimlich 2013).

This section has summarized the transportation systems that biojet would need to enter to serve aviation markets, with the exact transportation implications of biojet influenced by overall geographic patterns of production and consumption, compatibility and insertion point decisions, contamination risks, and logistical considerations.

2.3 Consumption of Jet Fuel

As was discussed in Section 2.1, domestic production of jet fuel topped 22 billion gallons in 2012. However, the consumption of jet fuel can vary, depending on imports and exports of the fuel. Table 2 contains a summary of jet fuel production, product supplied, and consumption by major players in the last 10 years. Domestic fuel consumption by U.S. carriers was just over 17 billion gallons in 2012 (Research and Innovative Technology Administration 2013). Jet fuel purchasers include airlines, FBOs, airport owners and operators, corporations with flight departments, operators of crop dusters and helicopters, and the military. Airlines and other users at airports are, by far, the largest buyers of jet fuel. Figure 8 shows jet fuel consumption for major consumers. The domestic and international classifications include U.S. carriers with at least $20 million in revenue per year, so these data do not include general aviation or corporate aviation. Therefore, the totals are lower than what is reported by the EIA as product supplied, which is considered a better estimation of overall consumption (Energy Information Administration 2014a).

[4] Fixed-base operators are airport service centers responsible for aircraft services, such as passenger handling, aircraft fueling, parking, maintenance, charters, rentals, flight training, and de-icing.

Table 2. Comparison of Jet Fuel Production, Product Supplied, and Consumption, 2003–2012

Year	Jet Fuel Production (billion gallons)	Jet Fuel Product Supplied (billion gallons)	Jet Fuel Consumption (billion gallons)
2003	22.812	24.195	22.559
2004	23.714	25.055	23.723
2005	23.697	25.739	23.877
2006	22.703	25.032	23.967
2007	22.196	24.871	24.132
2008	22.887	23.651	22.976
2009	21.407	21.358	21.137
2010	21.734	21.947	21.371
2011	22.210	21.851	21.449
2012	22.548	21.492	20.611

Source: Research and Innovative Technology Administration 2013b; Defense Logistics Agency 2013; Energy Information Administration 2014b; Energy Information Administration 2013d

Historically, the airline industry has been the largest consumer of U.S. jet fuel—with domestic, commercial flights accounting for over half of consumption. During the past decade, jet fuel consumption has decreased by around 18% for both the military and domestic flights, but consumption for international flights has increased by around 28% (Figure 8).

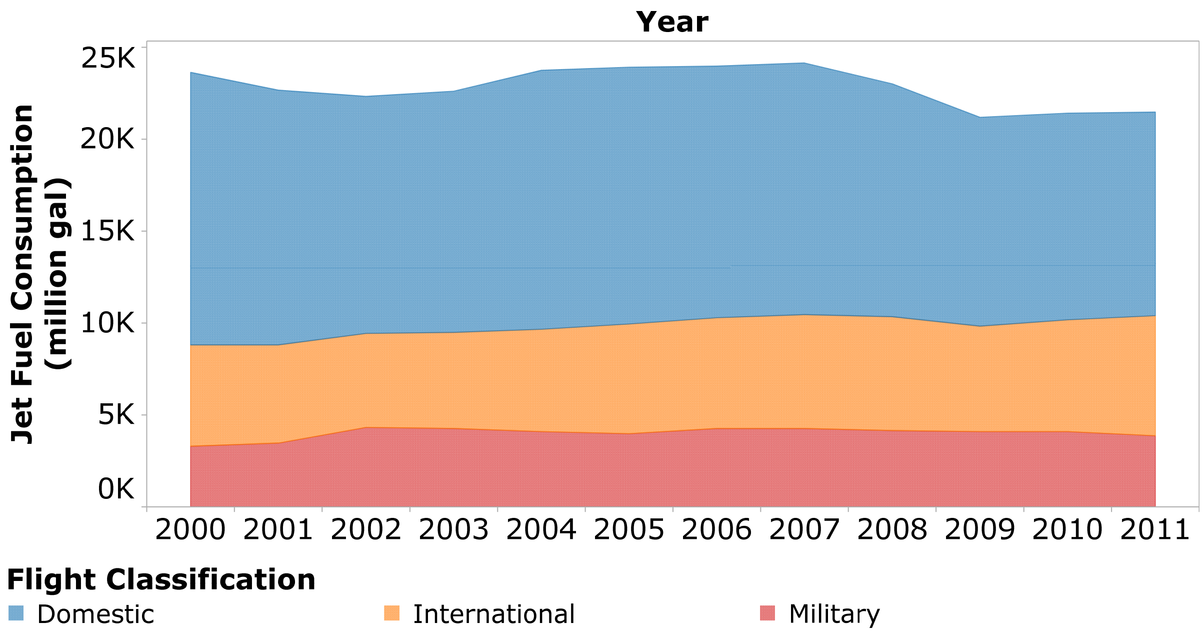

Figure 8. Total U.S. aviation fuel consumption by flight classification, 2000–2012

Source: Research and Innovative Technology Administration 2013b; Defense Logistics Agency 2013[5]

[5] The reported amount of consumption of jet fuel by the military is approximate because fuel can be taken out of storage at any time.

Data on jet fuel usage by airport show the geographic distribution of the potential target market for biojet. Figure 9 shows Jet A dispensed to all users (commercial, non-commercial, passenger, freight) by airport for select airports. Related estimates can also be made using either public sources (Research and Innovative Technology Administration 2014b; Research and Innovative Technology Administration 2014c) or private sources (e.g., "PlaneStats by Oliver Wyman." 2014).

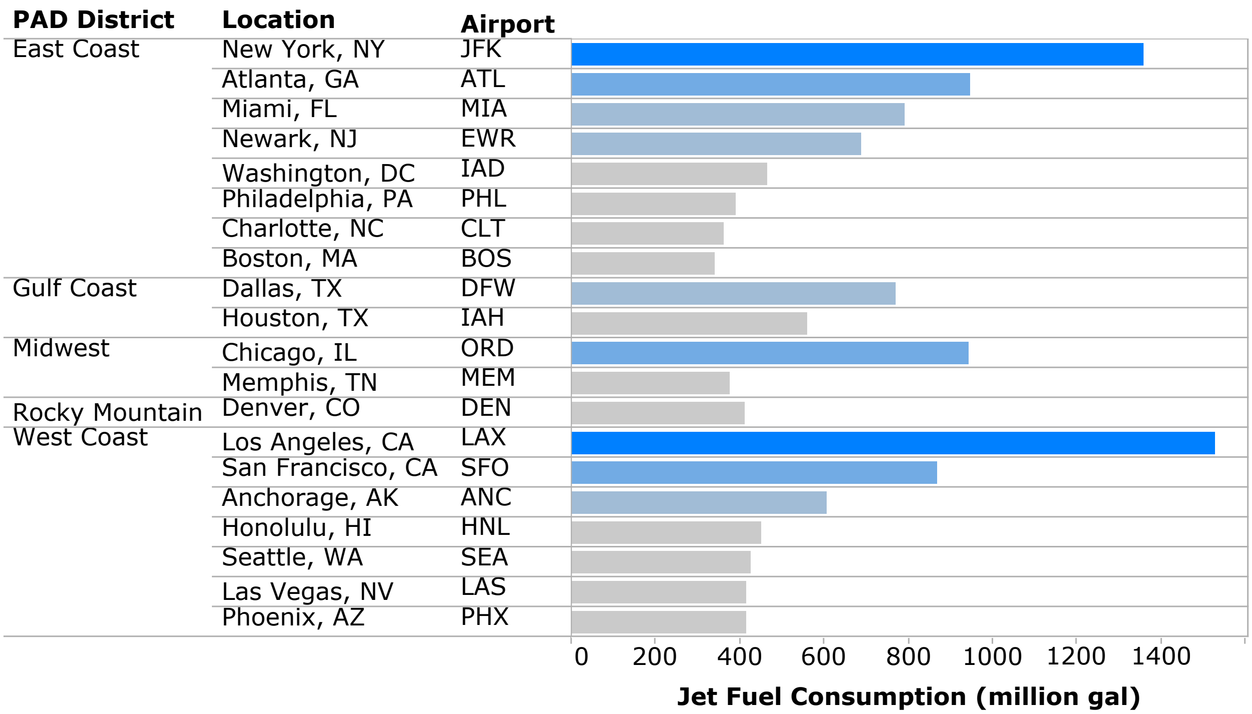

Figure 9. Jet fuel consumption (Jet A) dispensed by airport in 2012 for selected airports

Source: Airlines for America Unpublished

Aviation energy efficiency has improved during the past 20 years, with greater improvements domestically than internationally. Metrics of energy efficiency include (1) aircraft miles flown per gallon, which improves as more efficient aircraft enter the fleet and can be measured in seat-miles per gallon and (2) energy intensity per passenger, which depends on both the efficiency of the aircraft and the share of seats that are filled and is measured in British thermal units per passenger-mile (Figure 10).[6] Aircraft fleet upgrades and advanced flight logistic enhancements enabled these improvements over the last 10 years as empty seats were reduced and aircraft fleets modernized. As airlines worked to fill planes, aircraft load factors (ratio of passenger-kilometers to available-seat-kilometers) increased from an industry-wide average of 63% in 1990 to 81% in 2011 (Research and Innovative Technology Administration 2014a). Despite improved fuel efficiency, total fuel costs have continued to increase (Figure 11).

[6] Data are for U.S.-owned carriers only.

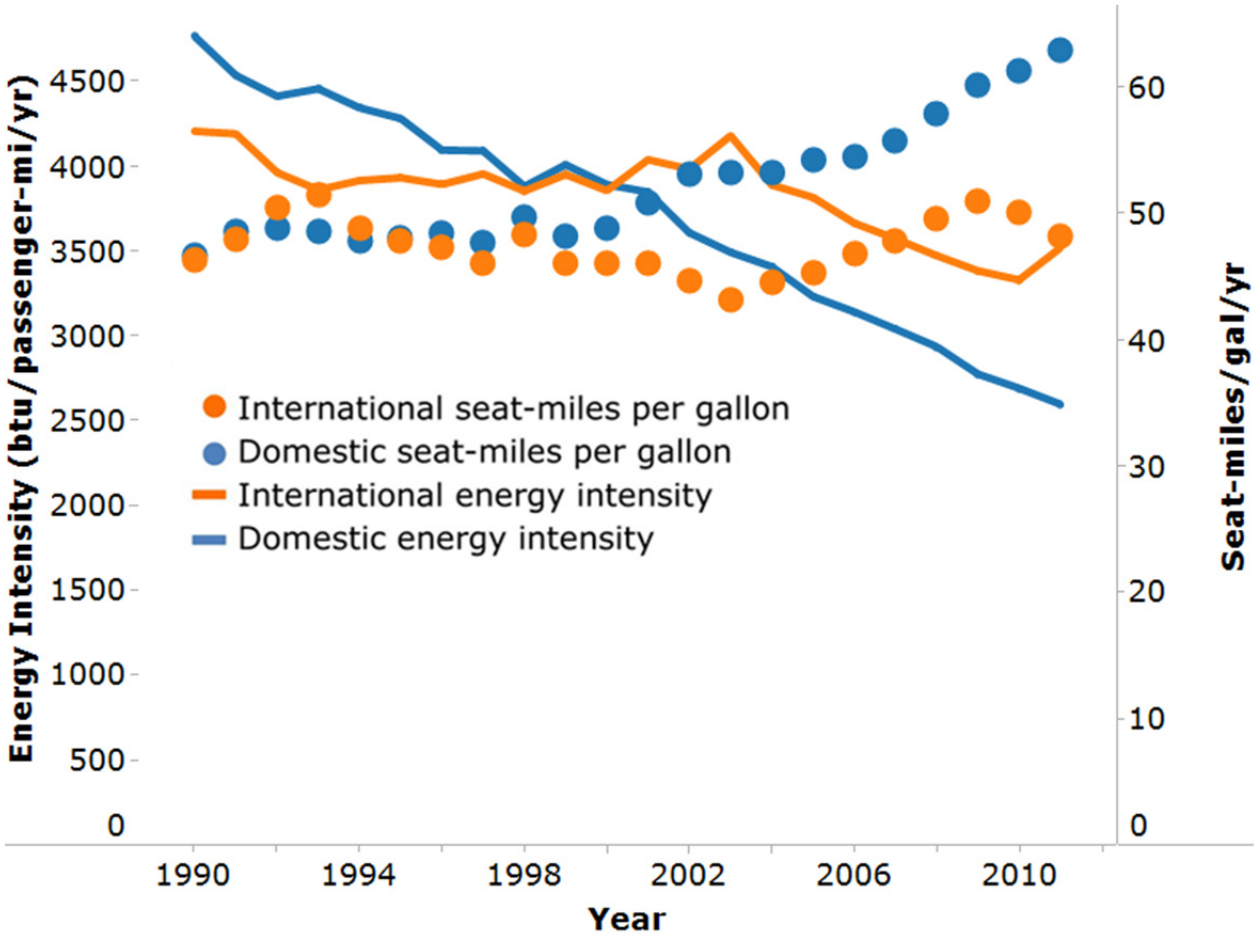

Figure 10. Energy efficiency metrics, 1990–2010

Source: Research and Innovative Technology Administration 2013a, Table 4-21

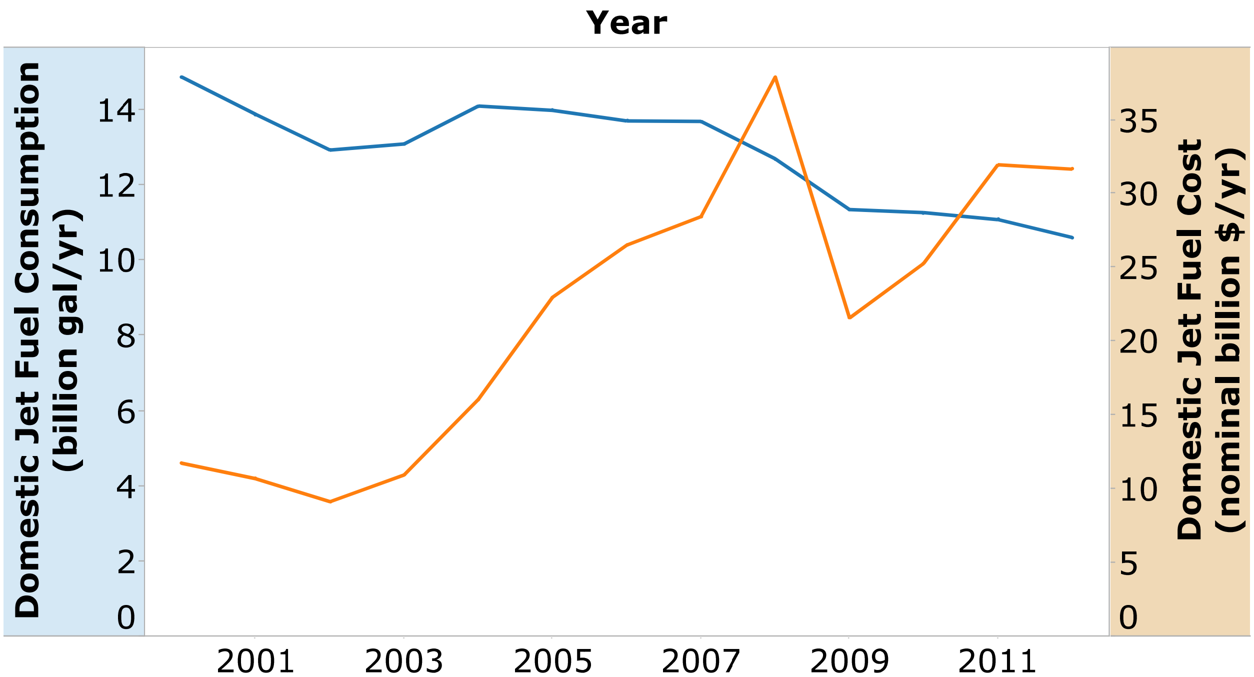

Figure 11. Aviation fuel cost and consumption for domestic travel, 2000–2012

Source: Research and Innovative Technology Administration 2013b

Figure 12 shows varying projections for consumer demand and fuel consumption, as forecasted by the EIA's Annual Energy Outlook (AEO) and the Federal Aviation Administration (FAA). While both exhibit increasing trends, the FAA forecasts are higher.

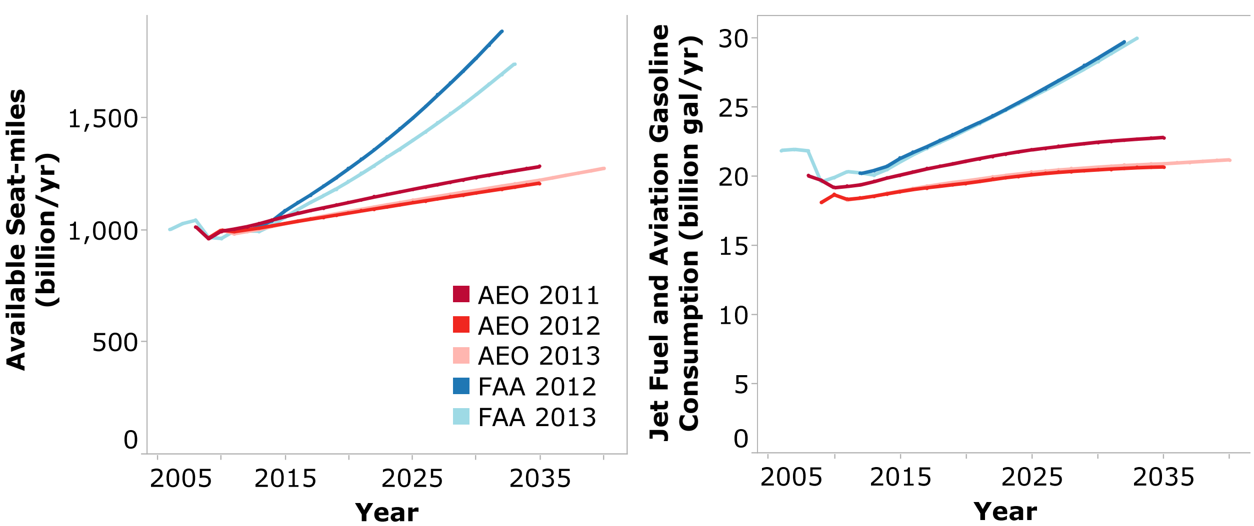

Figure 12. Comparison of projections for available seat-miles and fuel consumption from the Federal Aviation Administration (FAA) and the Energy Information Administration (AEO)

Sources: Federal Aviation Administration 2013; Energy Information Administration 2013b

3 Jet Fuel Prices

Competitiveness of biojet with conventional jet fuel prices is critical to the prospects of biofuels for aviation. Historically, jet fuel price increases and volatility have both posed challenges for the U.S. aviation industry, raising the possibility that biofuels might help address one or both of these challenges.

Jet fuel prices are higher than crude oil prices and generally correlate with crude oil price trends. Real jet fuel price increased from approximately $1.10/gallon in 2000 to approximately $2.90/gallon in 2012 (2013 dollars) (Energy Information Administration 2014c). Shorter-term fluctuations in the price of jet fuel are highly correlated with movements in the price of Number 2 heating oil and diesel (Figure 13). Commodity markets rely on Number 2 heating oil as the benchmark for jet fuel because it is publicly traded. As a result, when the price of heating oil increases, the price of jet fuel increases. Jet fuel prices are projected to increase steadily over the next few decades (Figure 14). While the FAA (2013) does not project large increases, the AEO (2013a) projects a doubling to tripling of nominal jet fuel prices by 2040—which would have serious implications for airline fares and, likely, profitability.

In addition to long-term prices trending upward, crude oil price and refined petroleum product prices are volatile. That is, while the mean trends upwards, there is a large variation around the mean. Oil price volatility is often attributed to supply factors: unplanned refinery outages (natural and human-caused disasters),[7] pipeline problems, political instability in oil producing regions, limited spare production, and diversion of oil to the Strategic Petroleum Reserve (PR Newswire 2013). Overall, jet fuel price is determined by spot market prices, the terms of purchase contracts, and the location of the purchase. Other determining factors include outside influences, such as refinery shut downs; sudden, localized changes or seasonal shifts in demand; interruptions in supply (e.g., natural disasters); and market speculation and environmental regulations. For example, oil supply disruptions because of hurricanes Katrina and Rita in 2005 prompted many refiners to raise production of gasoline, increasing the price of jet fuel (Airlines for America 2014a). Some recent increases in U.S. jet fuel prices may be a result of closing refineries (particularly Northeast refineries) that were key suppliers to East Coast hubs, as well as competition, at the margin, for refinery capacity with other refined petroleum products (Energy Information Administration 2011).

Various studies have explored price volatility in general and volatility of jet fuel prices in particular. Lee and Zyren (2007) and Regnier (2007) found that prices of crude oil, and even more so petroleum products, were more volatile than other products sold by U.S. producers.

[7] Many conventional refineries are located in areas prone to natural disasters (i.e., the Gulf Coast [Airport Cooperative Research Program 2012]). In August 2012, a fire shut down California's second-largest refinery for 6 months, prompting the shipment of 120,000 tons of fuel per month from South Korea to the West Coast ("Tesoro to Ship Jet Fuel From Asia to U.S. West Coast" 2012).

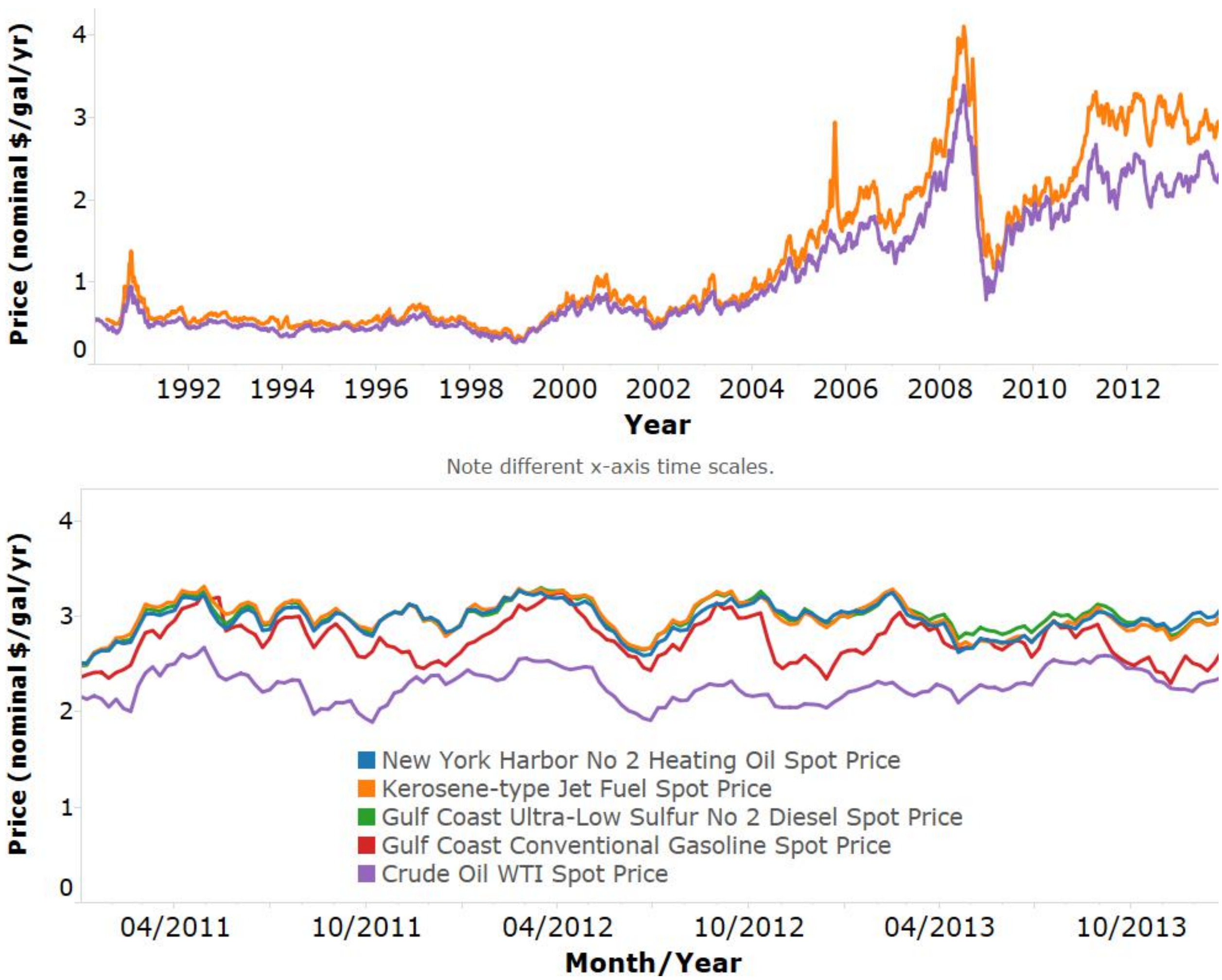

Figure 13. Spot prices for Gulf Coast kerosene-type jet fuel and West Texas Intermediate (WTI) crude oil, 1990–2013 (top) and spot prices for a various petroleum products, 2011–2013 (bottom)

Source: Energy Informaton Administration 2014c

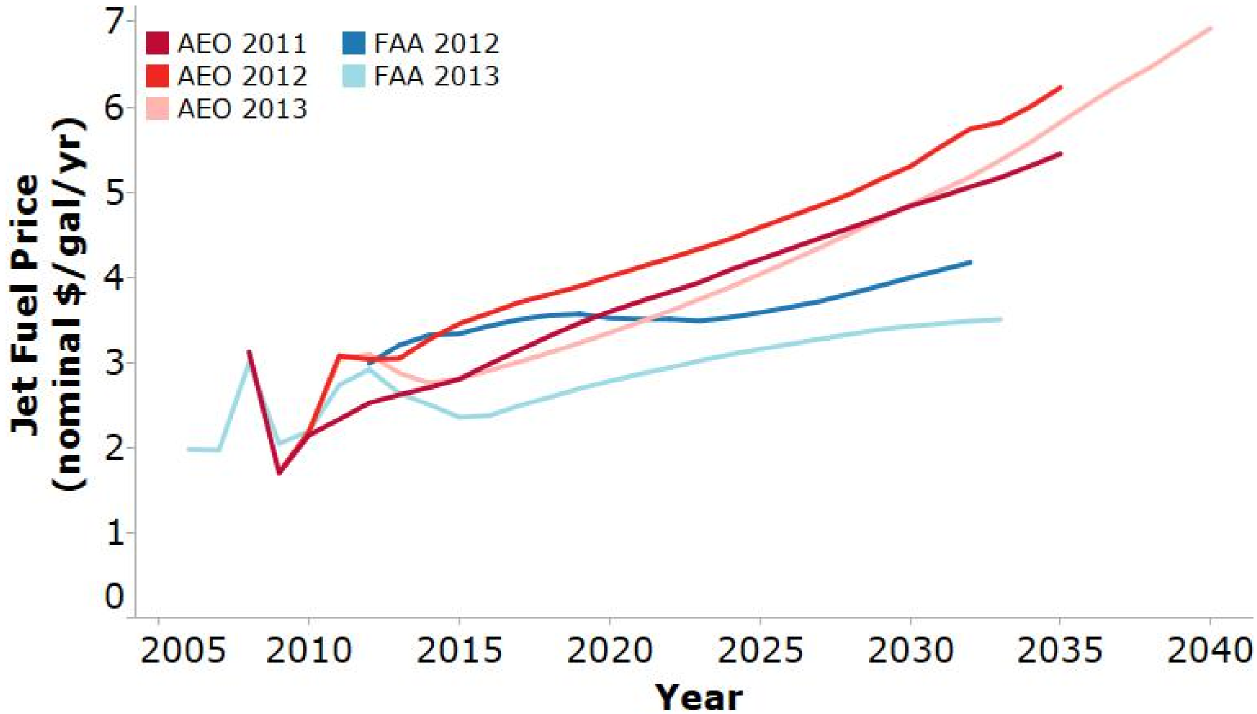

Figure 14. Comparison of projections for jet fuel price from the Federal Aviation Administration (FAA) and the Annual Energy Outlook (AEO)

Sources: Federal Aviation Administration 2013; Energy Information Administration 2013b

Bacon and Kojima (2008) undertook a statistical analysis to explore whether mean prices remain constant over time and to examine the variance of crude oil and specific oil products in different periods using daily, weekly, and monthly price indices. While jet fuel pricing patterns were found to correlate closely with other petroleum product prices, jet fuel prices were found to be slightly less volatile than gasoline prices but more volatile than heating oil and diesel prices.

Projections to characterize expected volatility do not exist, though it is unlikely that jet fuel volatility will noticeably decrease and more likely that the industry will continue to face the need to manage this risk. It is possible introducing alternative fuels in large amounts could reduce price volatility, and this potential is currently under investigation.

Jet fuel price volatility and the long-term trend of price increases are a business challenge for the entire aviation industry, affecting operations of both airports and airlines. Jet fuel price volatility has prompted airlines to pursue financial risk management measures, such as jet fuel hedging, as discussed in the next section. These challenges have also greatly affected medium and small airports.

U.S. air carriers respond to increases in jet fuel prices by changing their schedules in the short-term or changing their fleet in the long-term (Spitz and Berardino 2011). Jet fuel accounts for the single-largest direct operating cost (International Air Transport Association 2010); Airlines for America estimated that every $1/barrel increase in the price of oil represents $425 million in additional expenses for the airline industry (PR Newswire 2013). Passing on higher fuel costs to customers is difficult for airlines. An extensive literature review commissioned by the

International Air Transport Administration found that demand for air travel has been consistently price-elastic[8]—that is, an increase in ticket price will result in a decrease in the number of tickets sold (InterVISTAS Consulting Inc. 2007). This effect is largest for a single airline seeking to increase its ticket prices while others are not. Local and regional flights are more price-elastic than longer flights because substitute transportation exists. If airline fares increase across a broad range of markets (routes and carriers) by the same amount, for example through the imposition of a tax, air travel has been found to be inelastic (Smyth and Pearce 2008; Jung and Fujii 1976; InterVISTAS Consulting Inc. 2007).

Carter et al. (2006a) found that the industry under-invested in growth opportunities during periods of particularly high and volatile prices. When fuel prices are high, airlines face compressed operating margins with which to cover both operating costs and fixed costs. During periods of unexpected high fuel price, some airlines sell assets, often at a discount, to raise revenue.

Airports are affected by the fuel price impact on airlines. When jet fuel prices spike (as was the case in 2008[9]), airports see changes that affect operating budgets and capital improvement programs. The data show that price spikes could affect air service at smaller airports more drastically than larger airports. One possible reason for the inequity in impact could be that demand patterns change more drastically at smaller airports, as people choose to drive to larger airports with cheaper fares (Spitz and Berardino 2011). Another reason could be that carriers consolidate their route offerings due to increased jet fuel prices (Carey 2013).

[8] In the literature, route elasticities range from -1.2 to -1.5. A price elasticity greater than 1 in absolute value indicates price elasticity (InterVISTAS Consulting Inc. 2007).
[9] The price spike in 2008 was a result of a combination of factors: stagnant oil supply, rapidly increasing demand from non-OECD economies (especially China), depreciation of the U.S. dollar, and financial speculation (Hamilton 2009).

4 Risk Mitigation and Airline Fuel Prices

Companies pursue varying strategies to mitigate the risks imposed by fuel-price volatility in order to reduce exposure to the uncertainty surrounding fuel costs. The CAAFI found that it is unlikely that biojet would be valued for hedging, at least initially, because of its small market size and lack of price history. The CAAFI publication also discusses structuring biofuels contracts with price floors and price ceilings for risk mitigation (Miller and Heimlich 2013).

To mitigate jet fuel price risk, consumers can conduct business as usual, employ financial tools, dynamically adjust capacity, or index shipping charges to fuel prices. In one particular instance, Delta Air Lines purchased a refinery. Financial tools may be used to establish a hedging strategy that consists of a set of financial instruments. A hedge establishes a fixed or capped cost through a commodity swap or option.[10] For example, if an airline buys a fuel swap and jet fuel price decreases, the airline would have to pay an above-market rate for fuel. If the same airline buys a call option and jet fuel price increases, the airline would obtain a return on the option based on the price difference, which would aid in offsetting the actual cost of fuel. Financial instruments that target jet fuel specifically are not available, so prices of other petroleum product commodities are used. However, hedging can be fairly risky; it necessitates a large amount of capital to finance the initial transaction costs and is betting on the future price of jet fuel (Airlines for America 2014a). Nearly all airlines hedge for next-year fuel cost or have fuel cost pass-through agreements with major airline partners or charter arrangements. Typically, hedges contract two to three years forward. Jet fuel hedging may result in a 5% to 10% increase in firm value by allowing it to re-invest funds during periods of high jet fuel price. Extremely high fuel prices often require non-hedged airlines to liquidate assets at below-market prices; hedged firms then grow in value as they are in a position to purchase the discounted assets (D. A. Carter, Rogers, and Simkins 2006b).

[10] Swaps are used when a company would like to lock in a price for a specific commodity. That company can purchase a swap so that a different party will assume the liability of the variable market or index price. A call option represents the right to purchase a specific quantity of a commodity, at a specified price. A put option is the right to sell a specific quantity of a commodity at a specified price.

Figure 15 highlights the differences among airlines’ hedging strategies and differences between 2003 and 2012. More airlines hedged more of their fuel purchases in 2003 than in 2012. Figure 16 shows fuel cost trends and net profits and losses for seven major U.S. airlines.

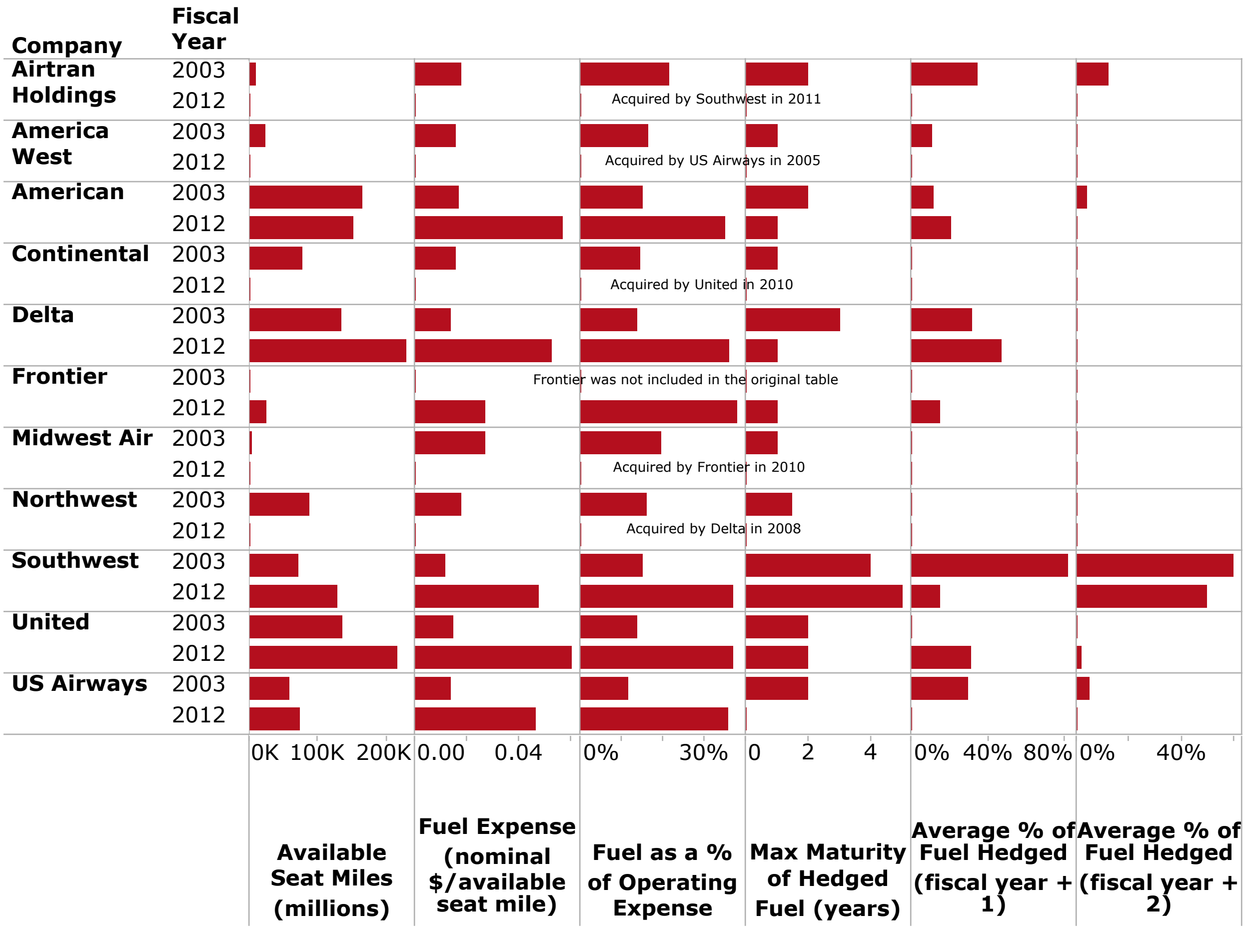

Figure 15. Airline fuel expense and hedging summary, fiscal year 2003 versus 2012

Sources: D. Carter, Rogers, and Simkins 2004; Companies’ 10-k 2013

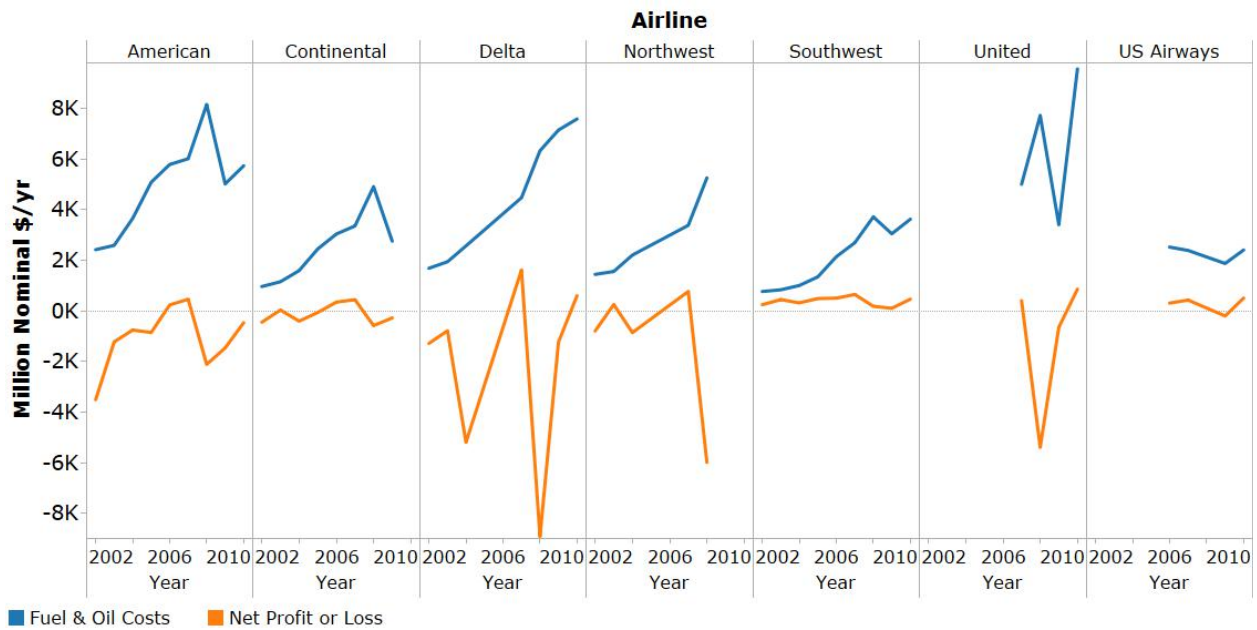

Figure 16. Fuel and oil costs versus profits for U.S.-based airlines, 2002–2010

Missing data represent either bankruptcies or mergers.

Source: AirlineFinancials.com LLC 2013

U.S. airlines typically base their hedging strategies on prices of crude oil or the chemically similar Number 2 heating oil (Westbrooks 2005). Hedging strategies vary by carrier. Alaska Airlines and Southwest Airlines engage in aggressive financial hedges, but United Airlines hedges on a more limited basis (Figure 15). From 2003 to 2012, the nominal fuel expense per seat mile doubled because of the increase in the share of overall operating costs of the airlines that was attributed to fuel costs (Figure 16).

Employing a different method for hedging against volatile prices, a wholly owned subsidiary of Delta Air Lines purchased the Trainer refinery in Pennsylvania from Phillips 66, becoming the first airline to invest in a refinery (See text box, next page). This move was largely motivated by forecasted East Coast jet fuel supply shortages. Currently, refined petroleum products move from the Gulf Cost to the Northeast via the Colonial Pipeline, which has limited capacity to accept increased shipments (Energy Information Administration 2011). By purchasing the refinery, Delta Air Lines hoped to transport less expensive petroleum by rail from the Midwest (which is oversupplied with petroleum from North Dakota's Bakken formation), refine it at Trainer near Philadelphia, and distribute it to airports throughout the Northeast (CAPA Centre for Aviation 2013).[11]

[11] The increase in domestic petroleum production enabled by hydraulic fracturing and the resulting oversupply existing in the Midwest has increased the demand for East Coast refining capacity. This strategy marks a change for a region that had witnessed several refinery closures, or threatened closures, during 2012 (Ailworth 2013; Ailworth 2012).

A physical hedge such as this mitigates some risks while posing others, such as the low liquidity of owning real property and the relative inflexibility of the refining capacity available at that particular refinery, which may be optimized to particular types of crude oil.

Quote Describing Delta Air Lines' Trainer Refinery Purchase
(Delta Air Lines, Inc. 2012, pp. 4-5):

Because global demand for jet fuel and related products is increasing at the same time that jet fuel refining capacity is decreasing in the U.S. (particularly in the Northeast), the refining margin reflected in the prices for jet fuel has increased. Our wholly-owned subsidiaries, Monroe Energy, LLC and MIPC, LLC (collectively, "Monroe"), acquired the Trainer refinery and related assets located near Philadelphia, Pennsylvania in June 2012 as part of our strategy to mitigate the increasing cost of the refining margin[1] we are paying.

Refinery Acquisition. Monroe invested $180 million to acquire the refinery from Phillips 66. Monroe received a $30 million grant from the Commonwealth of Pennsylvania. The acquisition includes pipelines and terminal assets that allow the refinery to supply jet fuel to our airline operations throughout the Northeastern U.S., including our New York hubs at LaGuardia and John F. Kennedy International Airport ("JFK"). Prior to the transaction, Phillips 66 had shut down operations at the refinery.

Refinery Operations. The facility is capable of refining 185,000 barrels of crude oil per day.[1] In addition to jet fuel, the refinery's production consists of gasoline, diesel and refined products ("non-jet fuel products"). Production at the refinery restarted in September 2012. BP is the primary supplier of crude oil used by the refinery under a three year agreement. We are also exploring other sources of crude oil supply, such as bringing supply to the refinery by rail from the Bakken oil field in North Dakota.

Strategic Agreements. Under a multi-year agreement, we are exchanging a significant portion of the non-jet fuel products with Phillips 66 for jet fuel to be used in our airline operations. Substantially all of the remaining production of non-jet fuel products is being sold to BP under a long-term buy/sell agreement effectively exchanging those non-jet fuel products for jet fuel. Our agreement with Phillips 66 requires us to deliver specified quantities of non-jet fuel products and they are required to deliver jet fuel to us. If we or Phillips 66 do not have the specified quantity and type of product available, the delivering party is required to procure any such shortage to fulfill its obligation under the agreement. Substantially all of the refinery's expected production of non-jet fuel products is included in these agreements.

5 Environmental Concerns and Aviation Biofuels

The effect of transportation fuel choices on the overall well-being of the nation is an important attribute of different transportation energy future scenarios, but markets only partially reflect the social welfare effects of these choices.[12] A substantial literature gives estimates of a few of the externalities associated with fuel choice: criteria air pollutants and precursors, GHG emissions, and energy security. While these issues are pertinent to the aviation industry, they are beyond the scope of this report. Instead, this section briefly addresses airline industry goals to reduce emissions, which have spurred interest in biojet, and it summarizes the status of those fuels.

5.1 Commitments to Reduced Emissions

The aviation industry faces regulatory risks associated with GHG emissions, which may support a business case for a reduction in emissions. The European Union's carbon tax on air transport is an example of a recent increase in regulatory costs associated with GHG emissions. By limiting emissions now, the industry could potentially avoid added regulatory- or climate-change-driven costs in the future. In addition, the implementation of climate change strategies by the airline industry may be attractive to customers and/or investors. Finally, protecting the environment could be seen as being socially responsible (Heeres et al. 2011).

In 2008, the international aviation sector—including the major U.S. airlines as represented by Airlines for America—committed to reducing carbon emissions through technology (including biofuels), improving operational practices, and improving infrastructure in the near and long term (Air Transport Action Group 2010). These commitments are part of an overall aviation sector policy strategy perspective, as described by Airlines for America (Airlines for America 2014b). Specific targets and pathways to achieve targets include:

1. Increasing fuel efficiency by an annual average of 1.5% per year on a revenue ton mile basis through 2020—this will largely come from replacing old aircraft with new, more efficient aircraft
2. Capping net carbon emissions at the 2020 level—emissions the industry is unable to reduce will be offset by "economic" measures (e.g., voluntary purchase of carbon offsets)
3. Committing to net carbon emissions that are one-half of 2005 levels by 2050—the industry seeks to achieve this reduction through a combination of advanced technology and large volumes[13] of biofuels.

[12] In economics, social welfare is the sum of the economic well-being of all individuals. Markets are good at setting prices that optimize social welfare for some types of goods and services but not for other types. One category of market failure is called externalities—costs or benefits of economic activity that are external to markets and thus not possible to buy or sell. In the transportation fuels case, markets may be expected to face limits in their ability to value public goods, such as a healthy environment and a secure energy supply.
[13] The Air Transport Action Group (2009) estimates that 50% of jet fuel used by commercial flights could be biomass-based by 2040.

Figure 17 shows an emissions trajectory consistent with these goals. These targets would build on historical improvements in energy efficiency. For example, during the period 1958–2010, advances in airline efficiency, logistics, and load factor have improved the fuel burned per seat-mile by 50%.

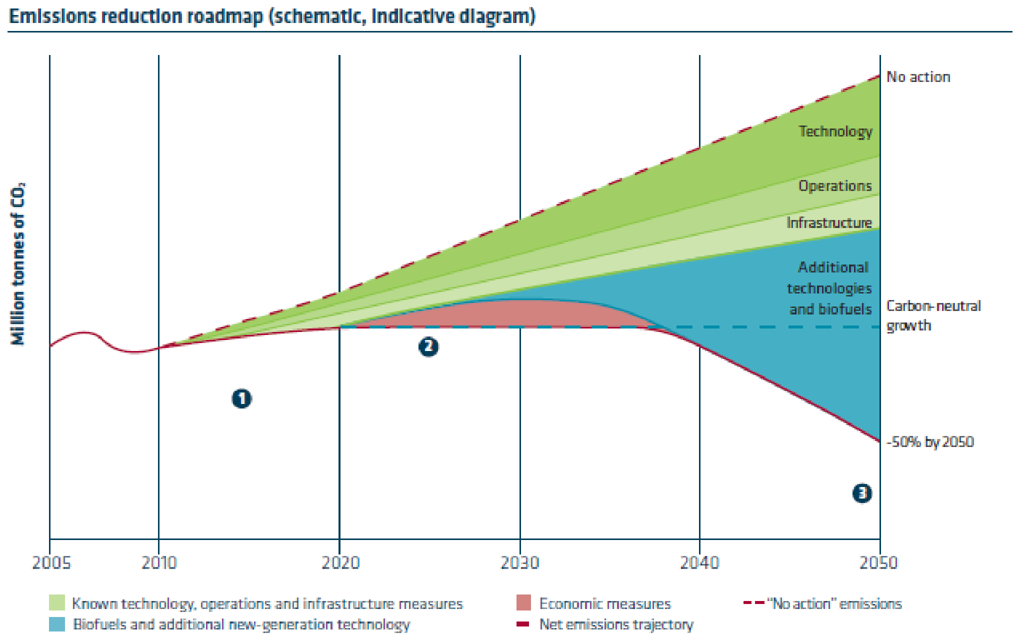

Figure 17. Aviation industry emissions targets and measures to achieve

Source: Air Transport Action Group 2010

The CAAFI provides an example terms sheet that notes documentation of GHG emission reduction as a key sustainability criterion to include in alternative aviation fuels contracts (Miller and Heimlich 2013), and the CAAFI also provides guidance on sustainability criteria (Commercial Aviation Alternative Fuels Initiative 2013).

5.2 Relative Emissions of Aviation Biofuels

Biojet is a key component of a proposed strategy to reduce the GHG emissions that are associated with aviation. Airlines also seek potential reductions in emissions associated with local air quality impacts, such as particulate matter, through these fuels (Airlines for America 2014c). Large-scale use of biofuels would require development of production capacity, infrastructure, and logistics to support their inclusion in the fuel supply chain. Two production processes are approved for biojet production, and biojet has been used in both commercial and military applications.

The aviation industry identifies biofuels as part of a strategy to reduce GHG emissions because of the estimated potential for advanced biofuels to reach lower life cycle GHG emissions than conventional jet fuel. The extent of the potential emission reduction depends on the details of the fuels to be compared; life cycle analyses of conventional and biojet fuel have been conducted, although this area of research is relatively new, methodologically diverse, and can produce a wide range of resulting values. Conventional and biojet have both been incorporated into the

Greenhouse gas, Regulated Emissions, and Energy use in Transportation (GREET) model, as described in Elgowainy et al. (2012) and Han (2013). Biomass feedstocks considered in GREET include corn stover, other cellulosic biomass, such as switchgrass, and bio-oils (from soybeans, palm, rapeseed, jatropha, camelina, and algae). Three different biomass-to-biofuel conversion pathways currently are included: a Fischer-Tropsch (FT) process for converting cellulosic biomass; a pyrolysis process for converting corn stover; and conversion of bio-oils using a HEFA process, also known as hydrotreated renewable jet fuel processes.

Stratton et al. (2010) compared life cycle GHG emissions from a baseline conventional jet fuel to GHG emissions from jet fuel produced from a wide range of biomass feedstocks that included switchgrass, corn stover, soy oil, palm oil, rapeseed oil, jatropha oil, algae oil, and salicornia. These include feedstocks suitable for domestic cultivation in the United States, as well as palm and salicornia, which would primarily be cultivated internationally in warmer climates. Stratton et al. (2010) selected baseline jet fuel transportation and recovery emissions of 87.5 grams of carbon dioxide-equivalent per megajoule (gCO_2e/MJ), calculated from the weighted average for crude oil entering U.S. refineries in 2005. The baseline emissions associated with processing were based on projected 2015 crude oil characteristics. The study explored a low and a high case for emissions of conventional jet fuel based on varying these choices, with the low at 92% of the baseline and the high at 125% of the baseline (R. Stratton, Wong, and Hileman 2010).

In addition to considering a range of biomass feedstocks, Stratton et al. (2010) examined a range of assumptions about soil carbon and direct land use change; indirect land use change was not considered. The greatest reductions in life cycle GHG emissions were found for biojet produced from switchgrass using the FT process and from salicornia using both FT and HEFA. For the switchgrass pathway, life cycle biojet emissions were estimated at 20% of baseline conventional jet fuel without considering effects on soil carbon and -2% of baseline with effects on soil carbon. For the salicornia pathway, life cycle biojet emissions were estimated at 55% of baseline conventional jet without considering carbon sequestration and 7% with carbon sequestration. The highest estimated life cycle increase in GHG emissions was found when peatland rainforest was assumed to be converted to palm oil plantations. When that direct land use change assumption was applied to the pathway involving palm oil feedstock conversion to HEFA, estimated life cycle GHG emissions were estimated at 7.98% of baseline conventional jet. Table 3 summarizes estimated life cycle GHG emissions for some of the pathways in Stratton et al. (2010) and shows the low and high ranges that were reported from alternate assumptions.

Table 3 also shows an estimate from Shonnard et al. (2010), who used the baseline conventional jet GHG emissions of 88 gCO_2e/MJ from Skone and Gerdes (2008) (also based on 2005 life cycle data). They compared this baseline to HEFA production from a camelina feedstock, and they estimated a 75% reduction in life cycle GHG emissions, not including indirect land use change.[14] Table 3 shows the sensitivity of this estimate to alternate methods for allocating emissions.

[14] For consistency within Table 3, all values are relative to the 87.5 gCO_2e/MJ baseline.

Table 3. Relative Life Cycle GHG Emissions from Conventional Jet and Biojet Fuels, Normalized to Conventional Jet Emissions Rate[a]

Fuel, Feedstock, and Assumptions	Baseline[b]	Low	High	Notes[c]
Conventional Jet (Crude Oil)	**1.00**	**0.92**	**1.25**	**1.00 = 87.5 gCO_2e/MJ**
Biojet				
Switchgrass, without soil carbon	0.20	0.14	0.30	FT
Switchgrass, with soil carbon	-0.02			FT
Corn Stover, without soil carbon	0.10			FT
Corn Stover, with soil carbon	0.16			FT
Forest Residue	0.14			FT
Soy Oil, no LUC	0.42	0.31	0.68	HEFA
Soy Oil, grassland conversion	1.12	0.93	1.62	HEFA
Soy Oil, tropical rainforest conversion	5.70	6.45	8.85	HEFA
Palm Oil, no LUC	0.26	0.34	0.44	HEFA
Palm Oil, logged forest conversion	0.45	0.37	0.54	HEFA
Palm Oil, tropical rainforest conversion	1.75	1.90	2.21	HEFA
Palm Oil, peatland rainforest conversion	7.98	7.60	9.16	HEFA
Salicornia	0.35	0.55	0.76	HEFA + F-T
Salicornia, with carbon sequestration	-0.22	0.07	0.37	HEFA + F-T
Camelina, energy allocation	0.26			HEFA (Shonnard, Williams, and Kalnes 2010)
Camelina, mass allocation	0.23			HEFA (Shonnard, Williams, and Kalnes 2010)
Camelina, displacement allocation	-0.19			HEFA (Shonnard, Williams, and Kalnes 2010)

LUC = direct land use change; HEFA = hydroprocessed esters and fatty acids, also called hydrotreated renewable jet

[a] 1.00 = 87.5 gCO_2e/MJ

[b] GHG emissions relative to baseline; Shonnard et al. (2010) did not include land use change. Stratton et al. (2010) applied displacement allocation wherever possible, followed by energy allocation where possible, and mass allocation for remaining processes.

[c] Values are from Stratton et al. (2010) unless otherwise noted.

For conventional jet fuel, the source of the crude oil influences life cycle GHG emissions primarily due to variation in recovery, transportation, and quality characteristics that influence processing requirements. For biojet, the greatest impact on life cycle emissions (not considering land use change or operations) is generally from biomass feedstock production, which is also called feedstock recovery. The second largest impact is generally from biomass-to-biofuel conversion processing (R. Stratton, Wong, and Hileman 2010; Shonnard, Williams, and Kalnes 2010). Avoiding unfavorable land use changes is essential to reducing GHG emissions relative to conventional jet fuel. Stratton et al. (2011) review sources of variability in life cycle GHG emission estimates. This section emphasizes life cycle GHG emissions reduction potential; for consideration of additional metrics of sustainability, such as air pollution effects, soil and water effects, solid or liquid wastes, biodiversity, and land-use changes, see Williams et al. (2009).

5.3 Certification and Demonstration of Biojet

Aviation fuels must be certified before they can be used in aircraft. They need to comply with internationally recognized standards, such as ASTM International. The ASTM approval process is a multi-year, multi-million dollar process (Rumizen 2013). Two different conversion technologies have already been certified with ASTM standards. In 2009, ASTM International approved standards for alternative fuels use in aviation through the FT process, which can convert renewable feedstock or fossil fuel sources to jet fuel (Enright 2011). In 2011, the production of jet fuel from HEFA was added to the standard under D7566-11. The standard states that these fuels, which may be biomass-based, can be used in commercial aviation in up to a 50/50 blend with petroleum-based jet fuel, which is certified through ASTM Standard D1655 (approved in 1959). Multiple task forces are working on certification of other conversion processes through Standard D7566 (SkyNRG 2013). Two task forces operating in ASTM address alcohol-to-jet processes: synthetic paraffinic kerosene and synthetic aromatic kerosene. Certification is expected in 2014 for synthetic paraffinic kerosene and in 2015 for synthetic aromatic kerosene. A third task force is working to certify the hydrotreated-depolymerized-cellulosic-jet pathway, using a pyrolysis process, and anticipates approval in 2015. A fourth is working on the direct-sugars-to-hydrocarbons process to produce an additive that could be added to jet fuel (at 5%–10% by volume). A fifth addresses the FT process that includes aromatics (SkyNRG 2013). In addition, Boeing announced that it is considering the use of renewable diesel as a blend stock for jet fuel. It has filed with ASTM to either alter the D7566 standard or create an annex for the HEFA standard, and it hopes to have the approval by the end of 2014 (Sapp 2014).

Expanding on the approved feedstock list, various biomass resources could be used to produce jet fuel substitutes. These include lignocellulosic material such as wood waste, crop residues, and dedicated energy crops, as well as lipid feedstock, such as vegetable and waste oils, grease, animal fat, and algae. Milbrandt et al. (2013) reviewed related literature and evaluated the technical and economic feasibility of biomass-based diesel and jet fuel production and use in the United States. They found that technologies exist to convert biomass to jet fuel; however, the production capacity is currently small, and production costs are not well known, especially for less-developed processes. Although Milbrandt et al. (2013) found that renewable diesel demand is expected to increase, due in part to its low sulfur content, renewable jet fuel is not expected to expand unless its production proves cost-competitive with fossil fuels.

Once it is produced, biojet would need to be transported, stored, and dispensed for use at the airport. Aviation fuels produced from non-petroleum sources could use much of the same infrastructure that is already in place for conventional aviation fuels, if the fuels are compatible and can be introduced effectively into the supply chain. Specific chemical compatibility, regulatory, and logistical issues may pose challenges for biofuels entering particular parts of the system, such as the need for large batches in pipelines and the regulatory constraints on mixing biojet with jet fuel upstream of the blending location. Figure 18 shows blending with conventional jet fuel after production, although biofuel or bio-based blendstock could also be produced in existing petroleum refineries.

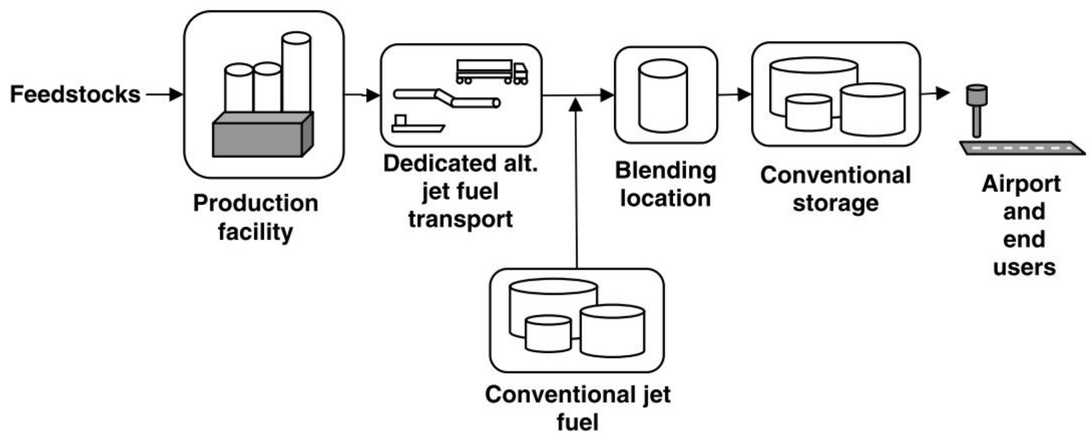

Figure 18. Biojet supply chain

Source: Airport Cooperative Research Program 2012

Biofuel has been used in both commercial and military aviation on a small scale. Hammel (2013) provides a list of biofuel procurement and test flights in the commercial aviation industry. As of March 2013, more than 20 routes of commercial flights had used biofuels as a portion of their fuel source, and the number of flights that have used biofuels continues to increase ("Flights that have been fuelled by biofuels," 2013). In addition, the U.S. Department of Defense collaborates with the commercial aviation industry on alternative aviation fuels (Airlines for America 2010). It has made numerous purchases of biomass-based aviation and diesel fuel for various reasons, including national security, possibly motivated by regulations of carbon emissions by aircraft and possibly to hedge against future price increases of petroleum-based fuels (Rogers 2012). The U.S. Navy has made development of biofuels a key part of its research and development with a goal to sail an alternative energy "Great Green Fleet" by 2016 and increase alternative fuels (including biofuels) to 50% of Navy afloat operations by 2020, including naval aviation. The purchases made by the Department of Defense through the beginning of 2012 are shown in Table 4. For reference, total military purchases of aviation fuel are represented in Figure 8.

The Department of Defense can provide contracts with terms of up to 5 years for alternative fuels (currently defined as fuels derived from natural gas, coal, or biomass). However, contracts to date have generally only been for 1-year terms. Industry experts have informed the Department of Defense that 5-year contracts are "not sufficient to stimulate the private capital market or potential alternative fuels suppliers to construct or expand production facilities…purchase contracts of at least 10 years in duration could potentially stimulate additional capital investment in alternative fuels production beyond the small volumes currently planned in response to commercial demand" (Operational Energy Plans and Programs 2012). The length of the contract term is only one of many factors that prospective investors would assess in their evaluation of financial risk and return.

Biojet is considered an important part of the aviation industry's GHG emission reductions strategy. Using it to reach a GHG emissions goal of 2050 emissions at one-half of the 2005 level would involve significant development of standards and regulatory approvals, feedstocks, conversion facilities, transportation infrastructure, and logistics, as summarized above. Initial use of biojet has proceeded in commercial and military applications.

Table 4. Biojet and Alternative Jet Fuel Contracts Executed by the U.S. Department of Defense

Date	Vendor	Fuel	Gallons	$ Total	Contract Term	Fuel Type
Alternative Fuels (Biomass-based)						
Aug 31 2009	Sustainable oils	Camelina JP-5	40,000	2,644,000	Seven months	Aviation
Aug 31, 2009	Solazyme	Algae F-76	20,055	8,574,022	Two-time delivery for testing	Distillate
Sept 1, 2009	Solazyme	Algae JP-5	1,500	223,500	One-time delivery on May 28, 2010 for testing	Aviation
Sept 15 2009	UOP (Cargill)	Tallow JP-8	100,000	6,400,000		
Sept 15, 2009	Sustainable oils	Camelina JP-8	100,526	6,715,137	Indefinite quantity/delivery; POP* ends Oct 30 2010	Aviation
June 29, 2010	Sustainable oils	Camelina JP-5	150,000	5,167,500	2010–2012, delivered Q1 2012	Aviation
July 26, 2010	Sustainable oils	Camelina JP-8	34,950	1,349,070	One-time delivery on May 28, 2010 for testing	Aviation
Aug 4, 2010	Sustainable oils	Camelina JP-8	19,672	759,339	Ends Jan 30, 2011	Aviation
Aug 31, 2010	Sustainable oils	Camelina JP-8	100,000	3,490,000	Indefinite quantity /delivery; POP ends Oct 30, 2010	Aviation
Aug 31, 2010	UOP (Cargill)	Tallow JP-8	100,000	3,240,000	Indefinite quantity /delivery; POP ends Oct 30, 2011	Aviation
Sept 10, 2010	Solazyme	Algae F-76	75,000	5,640,000	Indefinite quantity/delivery; one potential delivery	Distillate
Aug 26, 2011	Solazyme	Algae F-76	75,000	4,600,000	Indefinite quantity/delivery; one potential delivery	Distillate
Sept 23, 2011	Gevo	Alcohol to JP-8	11,000	649,000	Delivery period: Sep1, 2011 through Jan 30, 2013	Aviation
Sept. 30 2011	UOP	Bio JP-8	4,500	148,500		Aviation
Nov 30, 2011	Dynamic fuels (Tyson+Syntroleum), Solazyme	Tallow & Algae JP-5 Tallow and Algae F-76	350,000	12,037,500	Delivery period : Jan 1, 2012 through May 1, 2012	Aviation
Feb 2, 2012	Albemarle	Cobalt n-Butanol to Jet Fuel	55	245,000		Aviation

Date	Vendor	Fuel	Gallons	$ Total	Contract Term	Fuel Type
Alternative Fuels (Not Biomass-based)						
June 6, 2007	Equilon	Natural gas to aviation kerosene	315,000	1,075,694		Aviation
June 26, 2008	SASOL	Coal to aviation kerosene	60,000	225,000		Aviation
July 3, 2008	SASOL	Coal to aviation kerosene	335,000	1,306,500		Aviation
Sept 30, 2009	PM Group	Natural gas to diesel	20,000	140,000		Distillate

*POP = period of performance

Source: (Kiefer 2013; Staff Writer 2009; Defense Logistics Agency 2010; Defense Logistics Agency 2011b; Defense Logistics Agency 2011a)

5.4 Analytic Gaps

Others have comprehensively assessed overall research, development, and deployment needs for biojet and alternative aviation fuels (Midwest Aviation Sustainable Biofuels Initiative 2014; Commercial Aviation Alternative Fuels Initiative 2014; Commercial Aviation Alternative Fuels Initiative 2013; Mineiro et al. 2014). Analytic gaps in the literature on the potential role of biomass- or non-petroleum-based jet fuels as an alternative to conventional kerosene-based jet fuel are highlighted here, with a focus on market potential and comprehensive benefits analysis. These areas have been identified as topics for potential future research. This list, which includes interrelated issues, is not comprehensive of the research, development, and deployment needs discussed elsewhere, nor does it suggest priorities or recommend a sequence in which to address the gaps.

5.4.1 Market Potential

- The business case for biojet in general and also for particular pathways is not well established and may rely upon non-financial factors, such as environmental regulation. Additional research could be done to assess biojet market potential, by pathway, with consideration of users' and investors' perspectives, regulatory requirements, and policy goals.
- Related to the above assessment of market potential, there is a need for comparative analysis of jet fuel costs versus alternative jet fuel costs. This analysis could include current and projected costs, airline costs of managing volatility through hedging and other means, and airline management of regulatory risks. Harmonization of past analyses that are divergent could aid understanding. Airline perspectives on these issues would be informative.
- Additional analysis could support improved understanding of interactions between biojet markets and other markets, including biofuels for ground transportation in both gasoline and ultra-low-sulfur diesel fuel markets. This analysis could help clarify the opportunity for biofuels in the aviation fuel market. For example, HEFA-derived fuel likely can be sold more profitably into ultra-low-sulfur diesel markets than aviation markets (Midwest Aviation Sustainable Biofuels Initiative 2013; Quantas Airways Ltd. et al. 2013).
- Little understanding exists regarding the extent to which alternative jet fuels have the potential to mitigate jet fuel price volatility. In particular, given a relatively nascent market, there is little understanding of the price volatility of alternative jet fuels and the degree to which this will, or will not, correlate with jet fuel price volatility. A future area of research could evaluate the historical degree of volatility, as well as sources of volatility for other biofuels, and could apply relevant lessons to alternative jet fuels.

5.4.2 Comprehensive Benefits Analysis

- Identify and evaluate the environmental and social benefits of alternative jet fuel relative to conventional jet fuel.
- Evaluation of the full supply chain (from feedstock to finished fuel) for multiple prospective pathways is incomplete and could benefit from further analysis. Such evaluation could fill in a broader set of dimensions beyond fuel testing/certification, technoeconomic, logistics, and market considerations.

In addition, several datasets that are not collected or not readily available to the public would aid the analysis:

- Tracking chemical and physical characteristics of conventional jet fuel in sufficient spatial and temporal detail to ensure that blending with biojet will meet specifications would facilitate planning for blending logistics.
- While actual jet fuel contracts are likely unavailable due to their proprietary nature, it would be helpful to gain a clear understanding of their terms, particularly the signing parties and the length of contracts.[15]
- Data on movement of jet fuel from the refinery to airports would allow a better understanding of the status quo in order to identify least-cost logistics for biojet.

[15] Miller and Heimlich (2013) provide an overview of the basic components included in a jet fuel contract.

6 Conclusions

This report provides an overview of the aviation industry and its fuel market. Biofuel stakeholders are the intended audience. The report characterizes the state of the U.S. aviation fuel industry in terms of the major suppliers and buyers, the fuel transportation infrastructure, production and consumption, and geospatial distribution.

The communities of fuel suppliers and fuel consumers are important stakeholders for biofuel market entry. If biofuels enter the aviation fuel market, they would need to use portions of the aviation fuel transportation infrastructure. Significant market entry of biojet would impact geospatial flows of aviation fuels.

Fuel efficiency in aviation has improved significantly, especially for the U.S. industry, due to both airplane technology advancements and logistical enhancements. Continued improvement in fuel efficiency will be critical to meeting the long-term goals of the aviation industry to curtail GHG emissions. The industry sees biojet as an important complement to continued efficiency improvement in its strategy to meet these long-term goals.

Aviation fuel price accounts for such a large share of aviation costs that managing price increases and price volatility is an ongoing challenge. Whether biofuels could help mitigate either of these concerns is a question for further exploration.

An opportunity might exist for biofuels penetration into the aviation fuel market on an environmental basis and possibly on an economic basis. Initial steps toward greater use of biojet have been taken, in the form of ASTM standards for two fuel production pathways and small-scale use of biofuels in both commercial and military applications. Further analysis could explore the potential of biofuels in aviation fuel markets to help meet aviation industry goals.

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