SUSTAINABLE ALTERNATIVE JET FUELS

Contents

EXECUTIVE SUMMARY

Overview

Sustainable Alternative Jet Fuel (SAJF) is a general term for non-petroleum-based jet fuels. SAJFs have been around since 2008 and stem from the International Air Transportation Association's (IATA) initiative to mitigate CO2 emission from air transportation and address the global challenge of climate change. Deployment of SAJF low carbon fuels is one part of their four-pillar approach to reduce CO2 emissions by 50% (2005 levels).

In order for a jet fuel to be considered a SAJF, it must meet three key requirements; 1) the fuel must be sustainable (avoiding depletion of natural resources), 2) alternative (i.e. not a conventional fuel, and produced in an alternative matter via thermochemical, biochemical, and catalytic production processes), and 3) it must be a "drop in jet fuel blend", which can be interchangeable/blended with conventional jet fuel. A drop-in fuel blend does not require adaptation of the aircraft or engine fuel systems and can be used "as is" on turbine powered aircraft. The fuel typically comes in the form of a 30/70 blend with 30% SAJF and 70% conventional Jet A.

There are currently five approved types of SAJF available for production today (breakout below).

1. HEFA – SPK (98% of current production; 42% in 2022)
    1. Feedstock: Plant and animal fats, oils and greases
    2. Up 50% HEFA blended with Jet-A
    3. Example: World Energy produces this type of fuel at their Paramount, CA facility and uses tallow (a rendered form of beef fat)
2. FT – SPK and FT - SPK/A (0% of current production; 47% in 2022)
    1. FT and FT/A are similar methods and typically referenced as single category (FT)
    2. Based on biomass such as municipal solid waste (MSW), wood and energy crops and coal
    3. Up to 50% FT blended with Jet-A
    4. Example: Fulcrum produces this type of fuel and uses municipal solid waste (waste products collected from landfills).
3. ATJ -SPK (2% of current production; 5% in 2022)
    1. Based on starches, sugars, cellulosic biomass (ethanol based)
    2. Up to 50% ATJ blended with Jet-A
    3. Example: Gevo who's plant is located in Luverne, MN, uses corn starch and sugar cane. They have a strategic partnership with Avfuel for 1m gallons by 2020.
4. HFS -SIP (0% of current production; 0% in 2022 - production costs are too high to be competitive)
    1. Based on sugars
    2. Up to 10% HFS blended with Jet-A
    3. There are currently no companies using this method today.

Production

Currently there are only a handful of facilities globally able to produce SAJF. In the US, the largest producer currently is World Energy. Total production is currently about four million gallons per year and is almost exclusively being used in commercial aviation by United Airlines. Production levels are small compared to 17.9 billion gallons of Jet A used for US commercial aviation.

In Europe, the only real producer of SAJF is Neste who has not been released information on specific production amounts. Steve Csonka, president of CAAFI, believes they could be producing in similar capacity to World Energy, but will have capacity to produce more in the future.

While current production is minimal, several US companies have announced plans to produce SAJF in the future. Below is a breakout of these companies and includes details on production capacity, expected production based on offtake agreements, and fuel type. Note the difference in capacity is typically taken up by more profitable biodiesel production.

Estimated SAJF Production (2018-2022)								
			2018		2020		2022	
	Publicly Listed	Fuel Type	Actual	Capacity	Expected	Capacity	Expected	Capacity
World Energy	No	HEFA-SPK	4	40	4	40	30.6	306
Fulcrum Bioenergy	No	FT-SPK	0	0	10.5	10.5	43.5	43.5
Gevo	Yes	ATJ-SPK	0.1	0.1	1	1	1	10
LanzaTech	No	ATJ-SPK	0	0	0	0	10	10
Red Rock Biofuels	No	FT-SPK	0	0	6	15	6	15
SG Preston	No	HEFA-SPK	0	0	0	0	14	240
Total US			**4.1**	**40.1**	**21.5**	**66.5**	**105.1**	**624.5**

<u>Demand Drivers and Challenges</u>

Demand for SAJF is in large due to the environmental benefits associated with the fuel. As a key part of IATA's four pillar approach, the goal of SAJF is to reduce net life cycle CO2 emission and enhance the sustainability of aviation.

While the altruistic benefit of wanting to help the environment has driven initial demand, there have been a number of challenges for SAJF. These include 1) price, 2) policy hurdles, 3) supply chain issues, and 4) discrepancy on life-cycle emissions savings. The price of SAJF makes it difficult to justify a business case and thus limited commercial use has been driven from the vantage of being a good steward for the environment. Further detail on demand drivers and challenges are discussed below.

Price

SAJF fuels are expensive relative to traditional Jet A and have been the primary challenge. According to a study from the US Department of Energy's Lawrence Berkeley National Laboratory, the average price of alternative jet fuel alone falls around $16/gallon. However, SAJF is blended with Jet-A, which costs around $4.67/gallon. A 30/70 blend of SAJF/Jet A could result in a price of $8.07/gallon to the end user. Estimated ranges include $8-11 per gallon depending on SAJF type and blend.

The interest in SAJF has varied over the past decade with the price of oil. The price gap is less when oil is $130/barrel as opposed to $50-60/ barrel at present. Policy changes and supply chain hurdles could also help narrow the price gap and are discussed below.

Policy Hurdles

In general, there are two main policy issues related to SAJF and include 1) RFS (Renewable Fuel Standard Program) and 2) LCFS (Low-carbon fuel standard).

The RFS program was designed to mandate certain production levels of renewable fuels, which should increase demand for SAJF. However, in the past few years the EPA has loosened the standard, and exemptions from the program have increased from eight refineries to now 31. As a result, over 2 billion gallons were lost and not reallocated to capable companies. The Advanced Biofuels Association and Growth Energy have both sued the EPA for its wrongdoing, resulting in two ongoing court cases that may compromise EPA's ability to offer exemptions.

LCFS created a secondary market for carbon credits that initially made it more cost efficient to produce SAJF. However, today only two states, California and Oregon, are implementing LCFS programs, and carbon is only around $190 per metric ton and has not been impactful. The policy also includes some nuances in how different fuel types are created that favor diesel fuel and make producing SAJF a little less attractive to biodiesel fuels.

The culmination of these regulations with trade tensions from China have decreased the demand for biofuels such as ethanol and will likely have a similar impact on producers entering the SAJF market.

Supply Chain

When compared with traditional jet fuel delivery, SAJF has to deal with a number of issues including where to blend, store, and transport the product.

- Existing supply routes are available for Jet-A through pipelines and rail which are the most cost-efficient methods of transporting fuel. However, none of these currently exist for SAJF and batch delivery by truck is the only option.
- Blending fuels can also be cumbersome as this cannot be done via "splash blending" at the fuel truck and refineries are required to bring in certified jet fuel and receive a certification post blending to ensure fuel meets ASTM D1655 requirements.
    - The amount of testing restricts where the product can be blended at and will typically be done at the refinery

Unclear Environmental Benefit

It is important to note the actual tailpipe emissions of SAJF are nearly identical to Jet A (about 1-2% less) and the benefit of reduced carbon emissions comes via a lifecycle assessment or "well-to-wake" analysis. The lifecycle assessment measures carbon used from equipment needed to grow crops, transport raw material, refine, distribute, and in air use of SAJF vs traditional jet fuel. The process involved with producing SAJF reduces carbon emissions by using existing carbons in the air to grow and produce crops that serve as the fuel base. By using these feedstocks, no additional carbon is pulled out of the ground to produce fuel. As an example, the CAAFI estimates that on a 1,000 nautical mile mission using SAJF produced by World Energy could result in an 18% reduction of CO_2 emissions on a lifecycle basis.

While life cycle carbon savings are a key demand driver, it is also somewhat of a challenge as the exact calculations of these savings can be very subjective. The calculation is specific to each producer's feed stock, refining process, and transportation methods**.** Finding these details has proven extremely difficult and may be needed in order for SAJFs to be more widely accepted in the industry.

Social and Economic Benefit

Social and economic benefits include the creation of new industry related jobs, promoting economic development, and improving air quality.

No in-depth studies on the economic benefit of SAJF has been conducted, but as a rule of thumb one might point to similar studies for ethanol in, which a ratio of gallons to jobs created has been set. If you look at those assumptions, every 100m gallons produced supports roughly 3,200 additional jobs. In general, biorefineries support a variety of economic sectors: manufacturing, transportation, service, and agriculture.

Trade Association

- International Air Transport Association (IATA); President: Alexandre de Juniac
- International Civil Aviation Organization (ICAO) (CORSIA initiative); President: Olumuyiwa Benard Aliu
  Commercial Aviation Alternative Fuels Initiative (CAAFI); President: Steve Csonka
- National Business Aviation Association (NBAA); President: Edward Bolen
- National Air Transportation Association (NATA); President: Gary Dempsey
- General Aviation Manufactures Association (GAMA); Chairman: Mark Burns President of Gulfstream
    - Bombardier's David Coleal (Business Aircraft President) chairs the Environment Committee

OVERVIEW

Background

Sustainable Alternative Jet Fuel (SAJF) is a general term used to describe the class of non-petroleum-based jet fuels that are being pursued by the aviation industry today. Alternative fuels are a part of the four pillars approach the aviation industry is taking to cut CO2 emissions by 2050.

What Makes Jet Fuel SAJF?

1) **Sustainability:** This is defined as something that can be continually and repeatedly resourced in a manner consistent with economic, social and environmental aims. Specifically, something that conserves an ecological balance by avoiding depletion of natural resources and mitigates contribution to climate change. For example, excess animal fats and newly grown crops can be used as the main source for the fuel, thus avoiding any depletion of natural resources.
2) **Alternative:** SAJF is created an alternative manner (via thermochemical, biochemical, and catalytic production processes), and is produced from non-petroleum sources with feedstocks ranging from cooking oil, plant oils, solid municipal waste (trash), waste gases, sugars, purpose-grown biomass and agricultural residues, among others.
3) **Jet Fuel:** SAJF must be produced to the requirements established and approved by the industry in ASTM D7566[1], meets the technical and certification requirements for use in turbine-powered aircraft engines and is re-identified as meeting the ASTM D1655[2] standard.

SAJF will not be used exclusively on its own and will be blended with Jet-A (30/70). Blending limits are to ensure the appropriate level of safety and compatibility with the aircraft fueling systems and to meet the density requirements of ASTM D1655. SAJF must also be identified as a drop-in fuel, which means that it is completely interchangeable and compatible with conventional fuel.

Trade associations around the world have been working since 2009 to support the development of SAJF:

- International Air Transport Association (IATA); President: Alexandre de Juniac
- International Civil Aviation Organization (ICAO) (CORSIA initiative); President: Olumuyiwa Benard Aliu
  Commercial Aviation Alternative Fuels Initiative (CAAFI); President: Steve Csonka
- National Business Aviation Association (NBAA); President: Edward Bolen
- National Air Transportation Association (NATA); President: Gary Dempsey
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On February 24, 2008, a Virgin Atlantic B747 became the first airplane flown by a commercial airline to fly on a blend of conventional jet fuel and sustainable alternative jet fuel. Since then SAJF was used in just 3,000 total flights by 2013, and over 100,000 flights by the end of 2018.[3]

It has had issues commercializing due to the high cost associated with producing and purchasing the product, the unclear CO2 savings that the product offers, and logistical issues with the supply chain.

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[1] ASTM D7566 – Specification for Aviation Turbine Fuel Containing Synthesized Hydrocarbons
[2] ASTM D1655 – Standard Specification for Aviation Turbine Fuel
[3] https://www.iata.org/pressroom/pr/Documents/saf10-infographic.pdf

Industry Wide Push

The creation of SAJFs stems from the International Air Transportation Association's (IATA) initiative to mitigate CO2 emission from air transpiration and address the global challenge of climate change. The goals are stated in Figure 1 and the 4-pillar strategy to accomplish them is listed below.

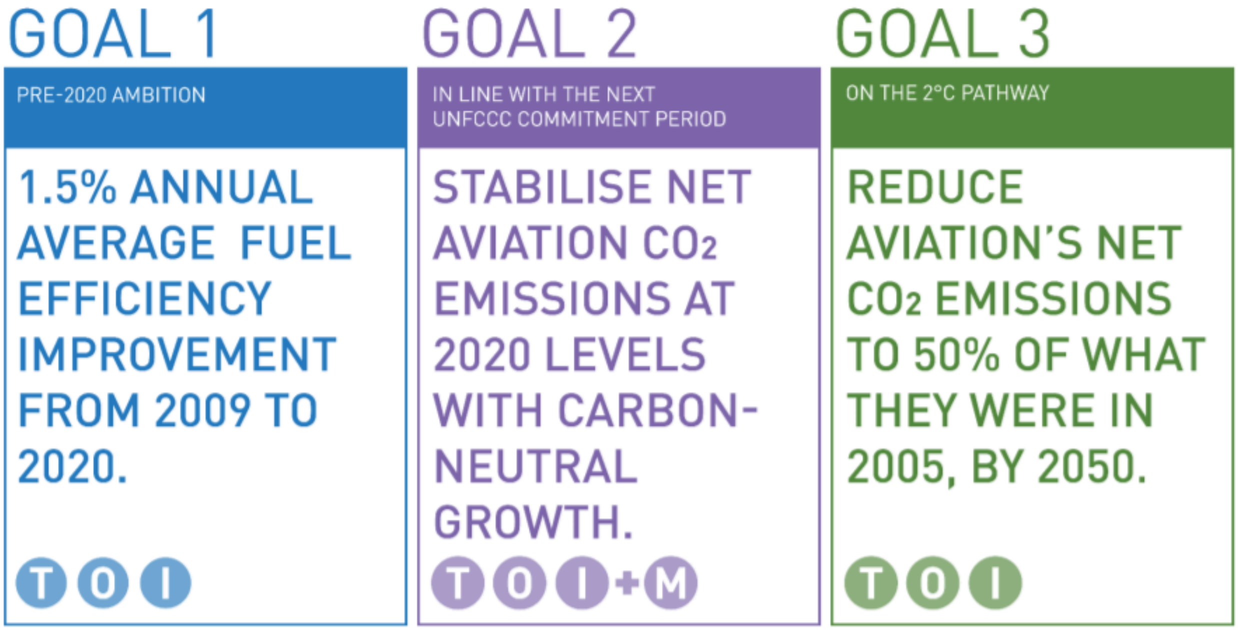


Figure 1 Aviation Carbon Emission Goals

The industry also adopted a 4-pillar strategy to accomplish these goals. They are as follows:[4]

1) Technology: New technology, including the deployment of **sustainable alternative fuels**
2) Operations: More efficient aircraft operations
3) Infrastructure: Improvements, including modernized air traffic management systems
4) A single Global Market-Based Measure (GMBM) to fill the remaining emission gap

Notice in bold, the deployment of sustainable alternative fuels is a key component of the technology pillar. The aviation industry is the only industry to have developed internationally agreed carbon emission reduction standards for both aircraft and operators. The single largest potential reduction in aviation greenhouse gas (GHG) emissions is sustainable alternative fuels.

Similarly, business aviation, which makes up 2% of all aviation, has adopted these same standards, and is committed towards adopting SAJF in the near future. This segment of aviation is partnering with authorities in Europe and North America to develop, certify and commercially implement such fuels within the next few years.[5] Many business aircraft owners and corporate flight departments have said they are prepared to pay a premium to have SAJF in their aircrafts.[6]

In 2016, the International Civil Aviation Organization (ICAO), adopted a set of goals and strategies to reduce carbon emissions called the Carbon Offsetting and Reduction Scheme for International Aviation

[4] https://www.iata.org/pressroom/facts_figures/fact_sheets/Documents/fact-sheet-climate-change.pdf
[5] https://gama.aero/wp-content/uploads/GAMA-IBAC-Joint-Position-on-Business-Aviation-Tackling-Climate-Change-1.pdf
[6] https://www.greenaironline.com/news.php?viewStory=2597

(CORSIA) which has been generally accepted by all aviation worldwide.[7] CORSIA aims to stabilize net CO2 emissions from international civil aviation at 2020 levels. The scheme works in three phases and aims to cut carbon emissions by 70% based on individual operator growth by 2035, where the plan will be reevaluated.[8] The use of SAJF will be a key component in this plan.

Influential Policies

Renewable Fuel Standard (RFS)

Congress adopted the RFS program 2005, which is a national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil or jet fuel. The Environmental Protection Agency (EPA) is charged with implementing and enforcing its requirements. Obligated parties are refiners or importers of gas or diesel fuel. This is done by producing renewable fuels and blending them into transportation fuel, or by purchasing Renewable Identification Numbers (RINs) to meet an EPA-specified Renewable Volume Obligation (RVOs).

Small refineries may be granted temporary exemption from RVOs if they can demonstrate that compliance with RVOs would cause the refinery to suffer disproportionate economic hardship. In the early years of RFS exemptions, 2013-2015, 8 refineries applied and received them. Under the Trump administration, the EPA approved 19 exemptions for 2016 and 35 for 2017 in private, erasing over 2 billion gallons worth of RFS blending obligations for 2016 and 2017.[9] As a result, there are two ongoing lawsuits that could inhibit EPA's ability to offer exemptions in the future.

In terms of ongoing litigation, first is The Advanced Biofuels Association (ABFA), which petitioned the US court of appeals for the District of Columbia Circuit on September 5, 2018. The ABFA accused the EPA of issuing over 25 "disproportionate hardship" waivers to large, multi-billion-dollar refining companies behind closed doors without accountability for their decision making.[10] This has caused the RINs value to drop significantly in recent years, disincentivized blending, caused economic harm to ABFA's members, and posed a threat to the integrity of the RFS program at large.[11]

The second lawsuit comes from Growth Energy, the leading biofuel trade association in the US, which also petitioned the court of appeals for the District of Columbia Circuit on February 2, 2019. They sued the EPA for the denial of agency records, regarding small refinery exemptions. The EPA failed to explain the increase or account for or reallocation of renewable fuel obligations from the RFS program and refused to take up the issue of small refinery exemptions in its 2019 RVO rulemaking.[12]

In June of this year, member companies and organizations from the ABFA sent a letter to Assistant EPA Administrator Bill Wehrum to urge the Agency to finalize provisions to remove unnecessary regulatory barriers to produce certain advanced biofuels. ABFA President Michael McAdams noted this as a way to "create the opportunity for American companies to generate significant quantities of cellulosic fuels, including renewable jet fuel."[13] The EPA has yet to act on this letter.

[7] Carbon Offsetting and Reduction Scheme for International Aviation – Source: http://caafi.org/resources/pdf/1.9_Policy_Discussion.pdf

[8] https://aviationbenefits.org/environmental-efficiency/climate-action/offsetting-emissions-corsia/corsia/corsia-explained/

[9] https://biofuels-news.com/news/rfs-integrity-act-to-address-problems-with-small-refinery-exemptions/

[10] https://www.epa.gov/sites/production/files/2018-05/documents/aba_18-1115_pfr_05012018.pdf

[11] http://advancedbiofuelsassociation.com/blog/abfa-files-lawsuit-against-epa-challenging-rfs-small-refinery-exemptions/

[12] https://growthenergy.org/2019/02/11/growth-energy-files-federal-lawsuit-against-epa-on-small-refinery-exemptions/

[13] http://advancedbiofuelsassociation.com/blog/biofuels-industry-stakeholders-call-on-epa-to-remove-rfs-regulatory-barriers/

Amid these issues, on August 9, 2019, the EPA granted 31 additional exemptions for small refiners that were received for 2018, which could eliminate an estimated 1.43 billion gallons of biofuel demand in the US. This is 4 less exemptions than last year but still more than expected. Many entities throughout the biofuels industry responded, including the national Biodiesel Board (NBB) which pointed towards President Trump caving to pressure from the oil industry and allowing his EPA to dismantle the RFS program, which will force biodiesel producers out of business and undermine the farm economy.[14]

In addition to this, the demand for corn-based ethanol has dropped significantly amidst the EPA exemptions and trade tensions between China. China is estimated to need 15 million metric tons (5.02 billion gallons[15]) of ethanol annually by 2020 and the US was expected to fill most of this demand. As US and China spar over trade terms, other ethanol-producing nations like Brazil appear to be more likely beneficiaries of this need.[16]

As a result, the price of corn and ethanol have plummeted significantly in the last couple months, with ethanol hitting a five-year low. Ethanol has dropped from \$1.59 on July 12th, to \$1.30 (-18.2%) today, while corn has dropped from \$4.50 per bushel to \$3.24 (-28%) in the same time frame.[17]

The culmination of events has had a direct impact on companies in the biofuels industry. Green Plains, one of the world's largest ethanol producers, reported a \$45 million second quarter loss and estimated that is lost 24 cents on every gallon of ethanol produced. Similarly, Archer Daniels Midland Co., another top ethanol producer, is separating its ethanol-producing dry mills into a stand-alone business it could sell or spin off.

With the biodiesel and SAJF industries being so closely related, the shift in demand and price of biodiesel will have similar impacts on SAJF and the ability for it to gain popularity. Politics will be influential in the acceptance of SAJF, especially in the early stages of development. It is evident in the past year that the actions of groups throughout the biofuel industry have not changed the EPA's plans, and it is likely that it will stay that way through the remainder of Trump's presidency.

Low Carbon Fuel Standard (LCFS)

The LCFS is a rule enacted to reduce carbon intensity in transportation fuels as compared to conventional petroleum fuels. The first low-carbon fuel standard mandate in the world was enacted by the California Air Resources Board (CARB) in January 2011. This established a "cap-and-trade" method of providing incentives for companies to pursue renewable fuel sources.

In short, refineries are required to track their fuels carbon intensity through a system of "credits" and "deficits." Credits are generated from fuels with lower carbon intensity, and deficits from higher carbon intensity. A fuel provider must have credits equal to, or greater than, the number of deficits. If the company is not able to meet these standards, they are able to purchase credits from companies who are over on an open market, and vice-versa, sell the credits if they've obtained additional.[18]

To date, there are only two states with LCFS programs; California and Oregon. This provides additional incentive to sell alternative fuels in these states. More states are planning to follow. Washington has

[14] https://biofuels-news.com/news/epa-grants-31-small-refinery-exemptions-leaving-biofuels-industry-reeling/
[15] Conversion rates: https://ethanolrfa.org/wp-content/uploads/2015/12/Fuel-Ethanol-Trade-Measurements-and-Conversions_RFA.pdf
[16] https://www.wsj.com/articles/ethanol-hits-five-year-low-as-stocks-rise-11565796465
[17] Ethanol- https://markets.businessinsider.com/commodities/ethanol-price; Corn- https://markets.businessinsider.com/commodities/corn-price
[18] https://stillwaterassociates.com/lcfs-101-a-beginners-guide/

pending legislation that could take place as early as 2021, and New York is in talks of creating a Low Carbon Fuel program like California's. British Columbia also has an LCFS program currently in place, but the credits are currently not interchangeable with American credits.[19]

It was not until 2018 that alternative aviation fuels were eligible to receive these credits as a part of these programs.[20] Although company's may now receive credits for producing SAJF, there is evidence that the production of biodiesel fuels create more credits which in turn creates additional money for the producing companies compared to SAJF.[21] Changes to this could increase incentives for SAJF production and even the playing field.

The price of per credit has risen steadily over the past 3 years. The average price in 2017 was $89/MT (Metric ton of CO2), the average price in 2018 was $160/MT[22], and the current price for a credit is around $194.53/MT (Metric ton of CO2).[23] The total value of LCFS credits generated in the past two years has reached about $1 billion per year.[24] As of January 31, 2019, there are 322 registered parties a part of the program, up from 274 in May 2018.[25] From this, it is expected that the average price per credit and the total parties involved will continue to increase moving forward.

It's worth noting that in Europe a similar strategy is being used effectively to even the playing field between renewable and non-renewable producers. The system requires producers to hold credits for each ton of CO2 produced. In 2017, the European Union decided to reduce the number of credits in the system by 24% each year for five years starting in 2019. This has caused the price of credits to increase more than 5 times their value in 2017. As a result, it now costs industrial polluters almost as much to use coal as it does to use cleaner natural gas.[26]

SAJF Types (Pathways)

Progress on developing sustainable fuels has been ongoing for the last decade. There are now five different pathways approved by the aviation industry and available to producers to convert different feedstocks into jet fuel (with several other pathways under review). A pathway is an approved process to make SAJF. Below is the list of approved alternative fuel production pathways to date.

HEFA-SPK (HEFA): Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene

- Industry Approval Date: July 2011
- Blend Limitation: Up to 50%
- Feedstocks: Plant and animal fats, oils and greases (FOGs).
- Known Producers: World Energy
- Announced Producers: SG Preston

FT-SPK or FT-SPK/A (FT): Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK and FT-SPK/A are relatively the same and will be addressed as just FT throughout the report)

- Industry Approval Date: September 2009 / November 2015
- Blend Limitation: Up to 50%

[19] https://www.act-news.com/news/california-leads-with-low-carbon-fuel-standard-programs/
[20] https://ww2.arb.ca.gov/news/carb-amends-low-carbon-fuel-standard-wider-impact
[21] https://ww3.arb.ca.gov/fuels/lcfs/dashboard/creditpricecalculator.xlsx
[22] https://ww3.arb.ca.gov/fuels/lcfs/credit/20190108_deccreditreport.pdf
[23] https://ww3.arb.ca.gov/fuels/lcfs/credit/lrtweeklycreditreports.htm
[24] https://stillwaterassociates.com/lcfs-101-an-update/
[25] https://ww3.arb.ca.gov/fuels/lcfs/lcfs.htm
[26] https://www.wsj.com/articles/once-unpopular-carbon-credits-emerge-as-one-of-the-worlds-best-investments-11565515800

- Feedstocks: Biomass such as municipal solid waste (MSW), agricultural and forest wastes, and wood and energy crops and non-renewable feedstocks such as coal and natural gas.
- Known Producers: No known producers
- Announced Producers: Red Rock Biofuels, Fulcrum Bioenergy

ATJ-SPK (ATJ): Alcohol to Jet Synthetic Paraffinic Kerosene

- Industry Approval Date: April 2016
- Blend Limitation: Up to 50%
- Feedstocks: Starches, sugars, cellulosic biomass
- Known Producers: Gevo
- Announced Producers: LanzaTech

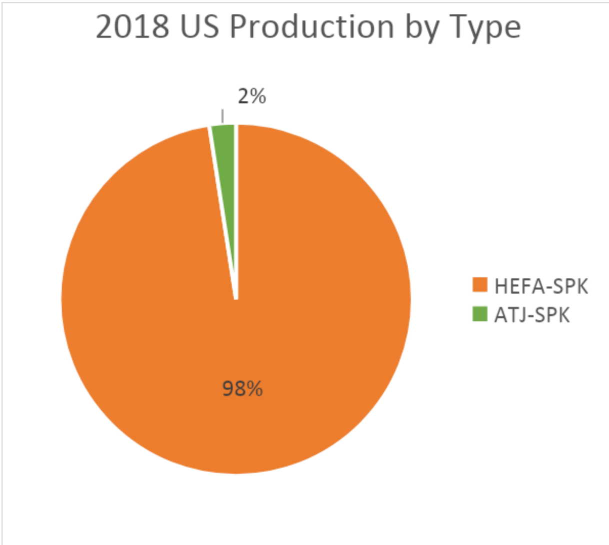
HFS-SIP (HFS): Hydroprocessed Fermented Sugars to Synthetic Isoparaffins

- Industry Approval Date: June 2014
- Blend Limitation: Up to 10%
- Feedstock: Sugars.
- Known Producers: No known producers
- Announced Producers: No announced producers[27]

Figure 2 and 3 are the current and estimates on 2022 production capacity by type in the United States. The primary process today is HEFA at 98%. This has been the only type that has been commercially available. ATJ follows up at 2%, with only 100,000 gallons being produced in the last year. In the upcoming years, the balance will shift slightly, with HEFA moving to about 88% of total production capacity by 2022 and FT moving to 9%. This shift is mainly due to Fulcrum Bioenergy facilities that will be appearing in the next 3 years that utilize the FT method in their production. Note this is related to the production capacity and not announced offtake agreements, which are discussed in Figures 4 ,5 & 6.

The appeal to these two production methods versus the others are influenced primarily by projected total production cost. Other reasons may include access to feedstock and the higher blend (50%) associated with FT, HEFA, and ATJ. It's also worth noting that there is no evidence of HFS being used now or in the future because production costs are too high to be competitive.

[27] http://www.caafi.org/focus_areas/fuel_qualification.html



[28]

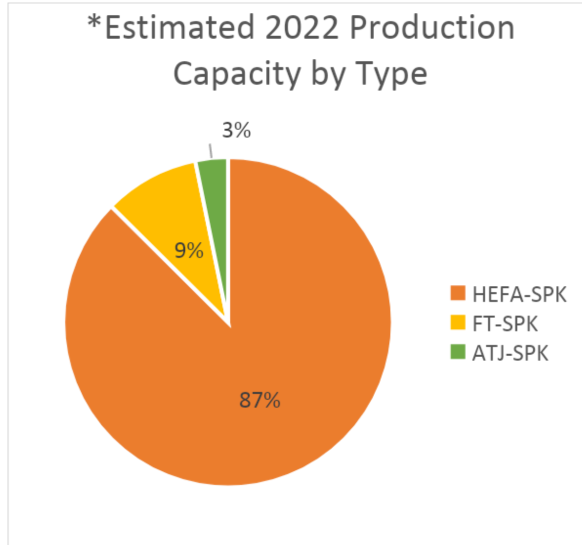


Figure 4 - 2018 US Production Method Breakout

Figure 5 - Estimated 2022 Production Method Breakout

Size

Currently, there are few facilities globally able to produce SAJF. In the last couple of years, it is estimated that about 4 to 5 million gallons of SAJF were produced per year in the world, almost entirely produced by World Energy (formally Altair),[29] this compares to 95 billion gallons produced globally for commercial airlines.[30]

According to Steve Csonka, executive director of the CAAFI, airlines worldwide have made commitments for the purchase of more than 250 million gallons of SAJF annually, and production could reach that level by the end of 2022.[31] This will be driven by US and European refineries making a push for the commercial development of SAJF.

European SAJF is being driven by four companies that will produce the fuel commercially by 2022. Neste leads the way with current production levels measurable to World Energy, and future capacity to produce up to 356 MGY by 2022. Total, SkyNRG, and LanzaTech will also be operational with capacity to produce 165, 32 and 90 MGY respectively in the next five years.

US Key Players

Below is the list of companies that currently, or are expected to, produce alternative jet fuels in the United States by 2022 based on news and offtake agreements, followed by key statistics.

Offtake agreements have been key in driving the production of SAJF. They provide guaranteed product demand and revenues to cover their debt. Without offtake agreements, companies struggle to start operations and secure financing. They have become necessary for a company to begin production. Additional information on these companies can be found in the "Key Players" section of the analysis.

World Energy

- Headquarters: Boston, MA

[28] http://www.caafi.org/activities/pdf/Offtakes_News_October2018.pdf
[29] https://www.ainonline.com/aviation-news/business-aviation/2019-05-18/bizav-makes-strides-sajf-utilization
[30] https://www.statista.com/statistics/655057/fuel-consumption-of-airlines-worldwide/
[31] https://www.travelweekly.com/Travel-News/Airline-News/Sustainable-fuel-taking-off

- Year Founded: 1999
- Offtake Agreements: 0 (estimated 30.6 MGY based on current production levels)
- 2022 Capacity: 306

The first company to commercially produce SAJF and was in a 3-year agreement with United Airlines to supply up to 5 MGY that spanned from 2016-2018 (only 4 million was purchased from United in 2018). The company has commitments to sell an undisclosed amount of SAJF to World Fuel and Gulfstream for the next 3 years.

Fulcrum Bioenergy

- Headquarters: Pleasanton, CA
- Year Founded: 2007
- Offtake Agreements: 177.5 million gallons per year (MGY)
- 2022 Capacity: 43.5 MGY

Offtake agreements to supply Cathay Pacific 37.5 MGY,[32] United Airlines 90 MGY,[33] and AirBP 50 MGY[34] all over the next 10 years. The company had plans to open 7 facilities by 2022 but will have just to 2 facilities capable of producing 43.5 MGY.

SG Preston

- Headquarters: Philadelphia, PA
- Year Founded: 2012
- Offtake Agreements: 14 MGY
- 2022 Capacity: 240 MGY

Offtake agreements with JetBlue and Qantas to supply 10 and 4 MGY respectively for the next 10 years beginning in 2020.[35]

LanzaTech

- Headquarters: Skokie, IL
- Year Founded: 2005
- Offtake Agreements: 10 MGY
- 2022 Capacity: 10 MGY in the US (100 MGY globally by 2025)

Offtake agreement with ANA, a Japanese Airline, to purchase an undisclosed amount of SAJF beginning in 2021.[36] This is expected to take up full capacity of the Georgia refinery.

Red Rock Biofuels

- Headquarters: For Collins, CO
- Year Founded: 2011
- Offtake Agreements: 6 MGY
- 2022 Capacity: 15.1 MGY

[32] http://fulcrum-bioenergy.com/partners/cathay-pacific/
[33] http://fulcrum-bioenergy.com/partners/united-airlines/
[34] http://fulcrum-bioenergy.com/partners/bp-air/
[35] https://sgpreston.com/news-detail/26 - https://sgpreston.com/news-detail/25
[36] https://www.ana.co.jp/group/en/pr/201906/20190614.html

Offtake agreements with FedEx and Southwest to supply 3 million gallons of alternative fuel to each company per year for 7 years, starting in 2020.[37]

Gevo

- Headquarters: Englewood, CO
- Year Founded: 2005
- Offtake Agreements: 1 MGY
- 2022 Capacity: 10 MGY

Announced a commitment to have Avfuel become their exclusive distributer of SAJF. Terms with Avfuel allow them to purchase up to 1 MGY over the next 5 years, starting in 2020.[38]

Estimated US Production

It is important to note that some of the numbers in Figure 4 represent the capacity to produce alternative jet fuel. While all these companies will have the facilities in place to produce SAJF, majority of them produce multiple resources, such as diesel fuel and naphtha. For an example, Red Rock Biofuels plans to produce 15.1 MGY in sustainable alternative fuel, but will dedicate 40% of production to diesel fuel, 20% to naphtha, and the remaining 40% to alternative jet fuels.[39] For that reason, the expected production numbers are also provided, which is based purely on the offtake agreements.

Notice in Figure 4 that even at the base capacity (expected production), the production value is estimated to increase by over 5x its current value by 2020, and over 25x its current production value by 2022. The current production of commercial jet fuel in the United States is about 17.9 billion gallons per year[40]. This is expected to grow roughly 4% annually through 2030.[41] This means US jet fuel consumption will be about 20 billion gallons per year in 2022. At max capacity (624.5 MGY), SAJF production would make up just 3.1% of commercial jet fuel production in the US.

	2018		2020		2022	
Company	**Actual**	**Capacity**	**Expected**	**Capacity**	**Expected**	**Capacity**
World Energy*	4	40	4	40	30.6	306
Fulcrum Bioenergy**	0	0	10.5	10.5	43.5	43.5
SG Preston	0	0	0	0	14	240
LanzaTech	0	0	0	0	10	10
Red Rock Biofuels	0	0	6	15	6	15
Gevo	0.1	0.1	1	1	1	10
Total	**4.1**	**40.1**	**21.5**	**66.5**	**105.1**	**624.5**

Figure 4 - US SAJF Production (millions of gallons per year)

**World Energy estimations are based on operating at current capacity level (10%). – they will likely continue to increase production*

***Fulcrum is estimated to be producing at full capacity based on offtake agreements*

[37] https://www.energy.gov/sites/prod/files/2019/04/f61/Woody%20Biomass%20Biorefinery%20Capability%20Development_EE000DPA2.pdf
[38] https://www.avfuel.com/Details-Page/ArticleID/400/AVFUEL-ARRANGES-SUSTAINABLE-ALTERNATIVE-JET-FUEL-SAJF-SUPPLY-AGREEMENT-WITH-GEVO
[39] https://ucanr.edu/sites/swet/files/221271.pdf
[40] https://www.statista.com/statistics/197690/us-airline-fuel-consumption-since-2004/
[41] http://www.caafi.org/activities/pdf/9_Transportation_Issues_September2017.pdf

Figure 5 is a breakout of expected SAJF production in 2022 based on current offtake agreements. This is accompanied by Figure 6, which categorizes production by type with orange representing companies that use the FT pathway, blue representing HEFA, and green representing ATJ.

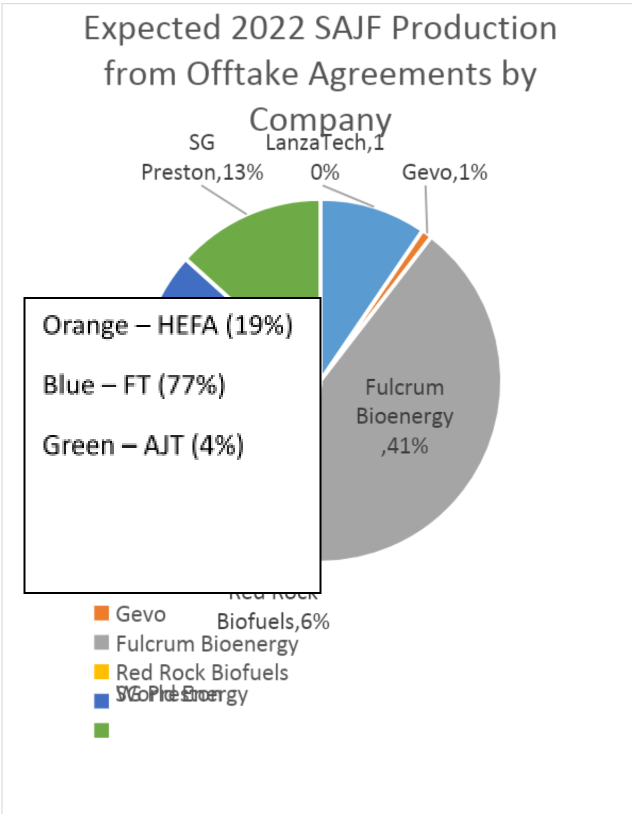
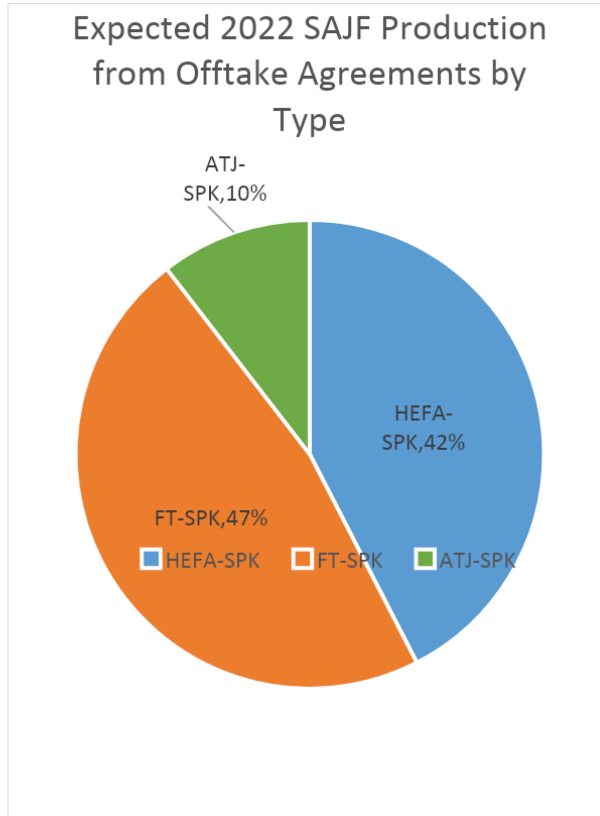


Figure 5 - Expected SAJF Production by Producer



MARKET DEMAND

Demand Drivers

To properly assess the demand for alternative jet fuel in the market, it's important to understand the objectives of SAJF. According to the Business Aviation Guide to the use of SAJF, the three main objectives are:

1) Reduce net life-cycle CO2 emissions from aviation operators
2) Enhance the sustainability of aviation by being superior to petrol-based jet fuel in environmental, social and economic aspects
3) Enable drop-in jet fuel production from multiple feedstocks and conversion processes, so no changes are required in aircraft or engine fuel systems, distribution infrastructure or storage facilities. As such, SAJF can be mixed interchangeably with existing jet fuel

Industry Wide Push

As stated in Figure 1, the aviation industry has adopted a set of goals set forth by the ICAO called CORSIA which targets reducing carbon emissions by 2050:

1) 1.5% annual average fuel efficiency improvement from 2009 to 2020
2) Stabilize net aviation CO2 emissions at 2020 levels with carbon-neutral growth
3) Reduce Aviation's net CO2 emissions to 50% of what they were in 2005, by 2050

Additionally, the industry also adopted a four-pillar strategy to accomplish these goes. The deployment of sustainable alternative fuels is included in the technology pillar and recognized as one of the largest potential reductions in GHG emissions.

The aviation industry is the only industry to have developed internationally agreed carbon emission reduction standards for both aircraft and operators. A list of trade associations committed to the reduced carbon emissions is listed below. Their commitment to these goals will have a great impact on the development of future sustainable fuels and drive their acceptance into the industry.

Trade Association

- International Air Transport Association (IATA); President: Alexandre de Juniac
- International Civil Aviation Organization (ICAO) (CORSIA initiative); President: Olumuyiwa Benard Aliu
  Commercial Aviation Alternative Fuels Initiative (CAAFI); President: Steve Csonka
- National Business Aviation Association (NBAA); President: Edward Bolen
- National Air Transportation Association (NATA); President: Gary Dempsey
- General Aviation Manufactures Association (GAMA); Chairman: Mark Burns President of Gulfstream
  - Bombardier's David Coleal (Business Aircraft President) chairs the Environment Committee

In November of 2009, the business aviation community, with of GAMA representing the manufactures and IBAC representing the operators, adopted the same three goals. Since then, efforts have been made to make this product more readily available, and many business aircraft owners and corporate flight departments have even said they are prepared to pay a premium to have SAJF in their aircrafts.[42]

[42] https://www.greenaironline.com/news.php?viewStory=2597

For example, Gulfstream has used a 30/70 blend of SAJF at its Savannah headquarters since 2012. Since 2016, the company has flown more than 920,000 miles on it, saving 870 metric tons of carbon dioxide. Gulfstream also announced that they will offer SAJF this year to customers using their Long Beach facility.[43]

While business aviation is making a push for the acceptance of alternative jet fuels, they only make up about 2% of all aviation. Participation from commercial airlines could be more influential on a large scale moving forward. Offtake agreements will be key in driving the production numbers of new companies entering the space.

Other notable participation in the industry includes a $30 million-dollar investment from United Airlines into an up-and-coming refinery, Fulcrum Bioenergy, which will eventually supply the company with 90 million gallons per year. Similarly, Cathay Pacific made an equity investment in the same company in 2014 and entered a long-term jet fuel supply agreement with Fulcrum for 375 million gallons per year.

Lifecycle GHG Emission Reduction

The greatest appeal to SAJF is the theoretical impact it can have on GHG emissions, which align with the industries push for carbon reduction. The tailpipe emissions from SAJF is nearly identical to Jet-A (within 1-2%). The key when analyzing the impact this product can have comes from the life-cycle analysis (well-to-wake). This life cycle analysis measures how much carbon is used at each stage in the production, transportation and use of the product, and is typically measured using the GREET model (Greenhouse gases, Regulated Emissions, and Energy us in Transportation).

Actual emissions of SAJF and Jet-A are difficult to measure, and the research on the two have been scarce and are highly subjective. The reduction from lifecycle emissions comes from the recycled use of carbon that has already been introduced into the biosphere. SAJF feedstocks pull CO2 out of the atmosphere through photosynthesis rather than pulling additional carbon out of the ground to produce fuel. Figure 7 below provides a visual of this process.

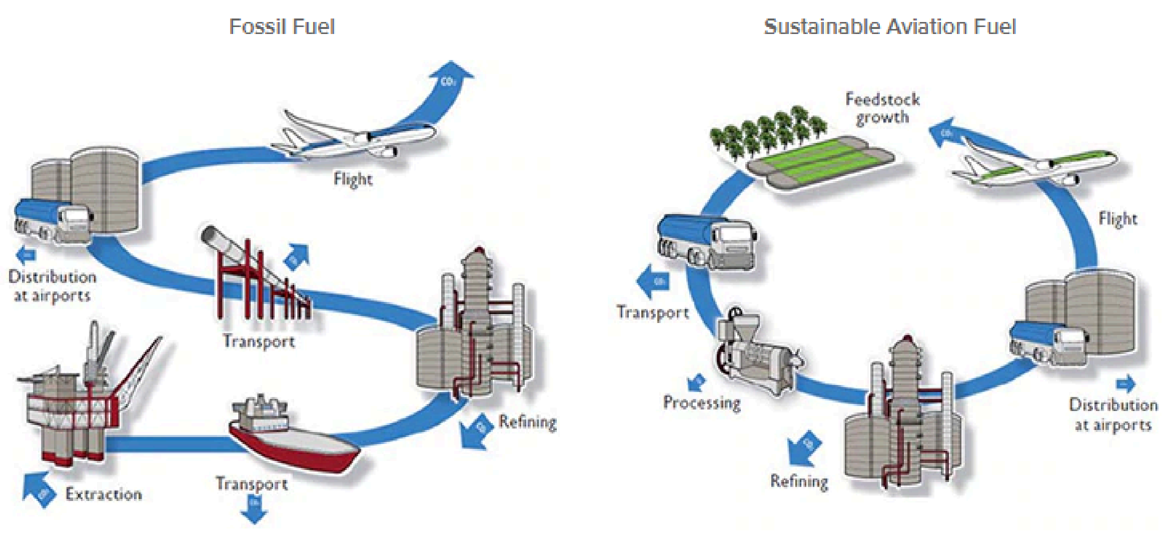


Figure 7 - Life Cycle (Well-To-Wake)

Theoretically, the use of unblended alternative jet fuel can reduce the overall carbon emissions compared to conventional jet fuel by 47-90% (Figure 8). The net reduction is much less than this. Most

[43] https://www.gulfstreamnews.com/news/gulfstream-reinforces-commitment-to-sustainable-alternative-jet-fuel-with-first-sale-to-customer

end-users will use some blended component of SAJF, most commonly 30/70. For an example, a large-cabin modern business jet on a 1,000-mile mission might burn enough fuel to produce approximately 22,787 lbs. of CO2. If such a flight were to use SAJF (HEFA pathway) produced by the World Energy in California at a blend of 30% SAJF to 70% conventional Jet-A fuel, the same mission would result in a net reduction of CO2 emissions of approximately 4,100 lbs. (18%) on a lifecycle basis.[44] While the company advertises a 60% reduction to CO2 emissions, the company really only saves 18%. Figure 8 below provides further insight into the realized CO2 reductions for the major players in the market.

Company	Pathway	CO2 Reduction (unblended)	**30/70 Blend level CO2 Reduction**	Max Blend Level (50/50) CO2 Reduction
LanzaTech	ATJ	90%	**27%**	45%
Fulcrum Bioenergy	FT	80%	**24%**	40%
World Energy	HEFA	60%	**18%**	30%
Red Rock Biofuels	FT	50%	**15%**	25%
Gevo	ATJ	50%	**15%**	25%
SG Preston	HEFA	47%	**14.1%**	23.5%

FIGURE 8 - ESTIMATED BLENDING REDUCTION FROM MAJOR PLAYERS

The framework is currently being set up for a third party to come in and reevaluate the emission reduction for each company. For example, the RSB (Roundtable on Sustainable Biomaterials) has scored the fuels coming out of the World Energy Paramount facility and accurately recorded the savings on a life-cycle basis. This will become common practice in the upcoming years with entities like the ISCC (International Sustainability & Carbon Certification) and RSB qualifying each pathway. There is one catch, they cannot do this until the plant is fully operational. Each of the other company's carbon savings should be taken with caution until they are fully operational and approved by one of these entities.

Figure 9 uses the GREET model (Greenhouse gases, Regulated Emissions, and Energy use in Transportation) and analyzes carbon reduction at each stage in the of the production, transportation and use of the product. The red bar represents the net emissions from each fuel type and feedstock used, and the red number represents net emissions savings. Notice, the difference between SAJF and Jet-A is the use of biogenic CO2 in the fuel, which represents fuel that is made from CO2 already introduced to the atmosphere. For this reason, the tailpipe emissions are entirely negated, and the net emissions are going to be measured by the "well-to-pump."

[44] https://www.ebaa.org/app/uploads/2018/05/14271-BBA-Business-Aviation-Guide-to-SAJF-A4_MAY-2018_PROOF.pdf

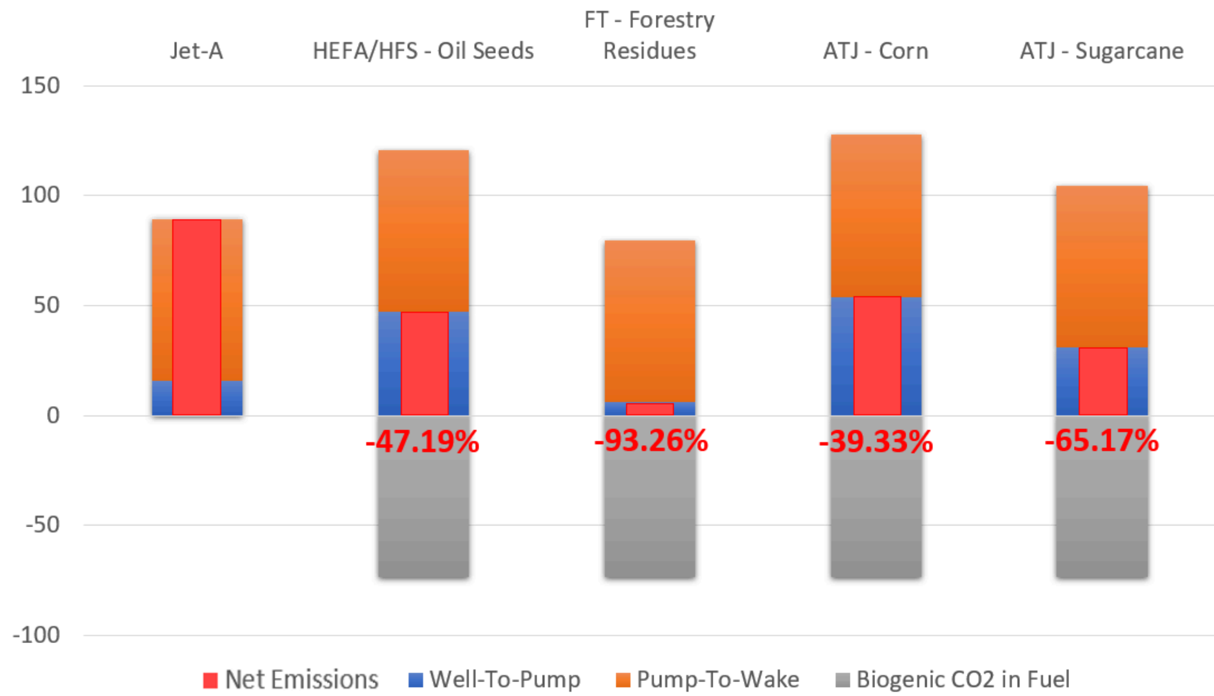


Figure 9 - SAJF Net Emissions Compared to Jet-A

It is important to note that while producers have cited carbon emissions to be reduced over 80% over their lifecycle, research has proven difficult to support these claims, with companies having no concrete research over these savings. This information will vary depending on the crops grown for the feedstock and the equipment and transportation methods that each individual farmer uses to harvest and transfer their feedstock to refineries.

In addition to reducing carbon emissions, burning SAJF creates less air pollution and increases air quality in areas surrounding airports. Burning the product alone reduces emissions of oxides of sulfur, which is a precursor for secondary particulate matter. SAFJ blends typically contain lower levels of aromatics, which improves combustion characteristics, and have shown general reductions in aerosol emissions, particles, and black carbon.[45]

Sustainable Feedstocks

Feedstocks are the building blocks, or necessary carbon sources, for SAJF production. Fuel producers convert a variety of carbon sources from nature or waste streams into hydrocarbons suitable for jet fuel. Below are the feedstock categories that can be used in SAJF production.[46]

[45] https://www.virent.com/news/virent-bio-jet-provides-more-than-50-reduction-in-particulate-matter-emissions/
[46] http://www.caafi.org/focus_areas/feedstocks.html

Fats, oils, and greases (FOGs)			
Oil Seeds (camelina, rapeseed)		Wastes/Industrial (tallow/lard, grease)	Algae/Aquatic Species (cyanobacteria)
Cellulose			
Woody (sawdust)	Grasses (switchgrass, perennial)	Residues (corn stover, grain hulls, forest residues)	Other (Brassicaceae, fungi)
Carbohydrates/Sugars			
Crop Sugars (sugar beet, sugar cane)		Industrial (food processing, whey)	
Industrial Waste Streams			
(food waste, municipal solid waste)			

FIGURE 10 - FEEDSTOCK SOURCE CATEGORIES

Currently, inedible tallow is the primary feedstock used by the only commercial SAJF production facility in the US, World Energy, but dedicated oilseed crops and other feedstocks such as residues are anticipated to be in use soon. Near-term commercial scale feedstocks are likely to be sourced from existing wastes and residues, as these feedstocks are often low-cost and readily available.

Novel purpose-grown crops like oilseeds, perennial grasses, and starchy or sugary crops, will take longer to deploy at large scales, particularly to avoid existing food crops. However, a great deal of work is underway to develop viable non-food crops that can be worked into existing rotations and follow periods to add to farmer revenue without replacing current production of food, feed, and fiber.

Fats, oils, and greases (FOGs)

Industrial FOGs are desirable in that they utilize existing, low- or no-cost wastes to produce SAJF and require no land use change.

Industrial FOGs, like brown and yellow grease (trap grease and used cooking oil, respectively), can also be converted to produce SAJF. Other waste FOGs include beef tallow, poultry fat, and hog fat. There is limited availability of waste FOGs to produce SAJF, as a large amount of the available supply is used for biodiesel production. This limited supply imposes an upper bound on potential production volumes.

Cellulose

Cellulose is the substance that makes up most of a plant's cell walls and is the most abundant organic compound on earth. Cellulosic feedstocks are non-food based and include crop residues, forestry residues, and dedicated energy crops. They are either waste products or purposefully grown energy crops harvested from land not suitable for other crops. These are anticipated to grow soon.

Carbohydrates/Sugars

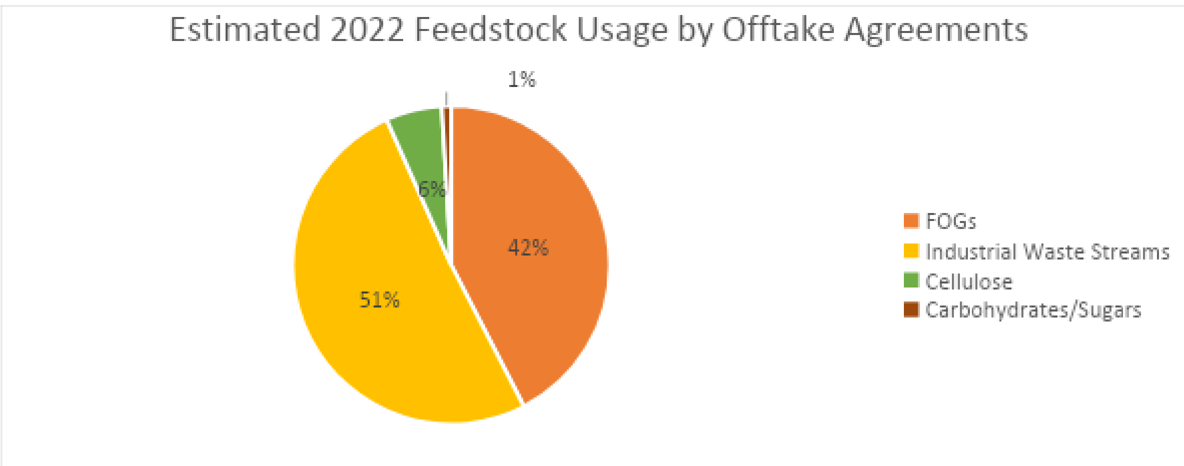
Starch- and sugar-based feedstocks are considered due to the easy extraction and fermentation that allows for large scale fuel production.[47] Currently, starchy and sugary crops will take longer to deploy at large scales, particularly given the desire to avoid existing food crops.

[47] https://afdc.energy.gov/fuels/ethanol_feedstocks.html

Industrial Waste Streams

Municipal solid waste (MSW) offers many benefits for SAJF production, including the emissions benefits achieved by removing lignocellulosic waste from landfills that would otherwise release methane when decomposing. Waste-based fuel producers can even earn credits for keeping waste out of the landfill. MSW can be converted for SAJF production from wholesale gasification and processing of the separated out lignocellulosic components from the larger MSW batch. While wholesale gasification is a simpler process, it releases carbon that would otherwise be hidden in plastics and other long-lived materials. Processing separated components may have a better GHG footprint, but this presents logistical challenges as well as the potential recycling revenues associated with separation.[48]

Figure 11 is the estimated 2022 feedstock usage from offtake agreements. Leading all feedstocks is the use of industrial waste streams (51%), driven by FT production from Fulcrum and LanzaTech which uses these as a primary resource in their production. This is followed by FOGs (42%), driven by HEFA production from SG Preston and World Energy. Cellulose (6%) and Carbohydrates/Sugars (1%) complete the graph, each source has one company with low capacity planning on utilizing these feedstocks.



[49]

Figure 11 - SAJF Production Capacity by Feedstock

Economic Benefits

Additional feedstock production has the potential to create jobs in rural areas where economic opportunities may be limited. This is because demand for additional energy crop production as well as its transport stimulates the rural economy as additional revenue is generated for local businesses. This also can improve the US energy security, as jobs created in rural America for feedstock production are difficult to outsource.

While there have been concerns raised about feedstock production conflicting with food, feed, and fiber production, more recent work suggests there can be synergies between food production and bioenergy crop production. This is in part due to potential added revenue streams for farmers and increased diversity of farm products, but also because valuable feedstock crops can enable investment in technology and infrastructure for food production. Several examples of SAJF focused feedstock development at various locations around the world are demonstrating the potential for growing

[48] http://www.caafi.org/focus_areas/feedstocks.html
[49] http://www.caafi.org/activities/pdf/Offtakes_News_October2018.pdf

feedstocks in ways that do not compete with food production, therefor creating benefits in society without consequences such as food shortages.[50]

Although there have been no direct studies done on the economic impact of increased SAJF production, the biodiesel industry is closely related market that has had similar studies done. According to "The Economic Impact of Biodiesel," every 100 million gallons of biodiesel production supports roughly 3,200 jobs.[51] Additionally, biorefineries support a wide variety of economic sectors, including manufacturing, transportation, service, and agriculture.

Challenges

Price

Costs for SAJF are difficult to determine, as it is not a readily available commodity, and contracts for purchase of volumes of fuel do not usually disclose the price. Existing analysis should be treated with caution as assumptions generally overestimate yields and underestimate capital costs, resulting in wide ranges for cost estimates.[52]

In a recent study by the US Department of Energy's Lawrence Berkeley National Laboratory,[53] the cost of alternative jet fuel alone is around $16/gallon.[54], compared to $4.68[55] for Jet-A. The study showed that all five current SAJF production pathways could create fuel products competitive with conventional fuel prices. To do this, producers would need to convert the leftover biomaterial from the pathway process into a profitable byproduct.

Using $16/gallon as a base for the cost of all SAJF, the actual cost realized for products blended 50/50 is $10.34/gallon. The actual cost realized for products blended 30/70 (most common) is $8.07/gallon. In general, the end user should expect to pay anywhere from $8-11 when purchasing SAJF.

The price point of SAJF has been the main contributor to slow growth and low acceptance in the market. In general, the price per barrel of oil influences the price of Jet-A and more particular, the industry participation for a viable path to SAJF. When the price is anywhere north of $130/barrel, the aviation industry is more likely to participate in the adoption and use of SAJF, and the alternative fuel can be cost competitive in the market. Historically speaking, this has only happened for a brief period in 2008. Today, the average cost is around $50-60/barrel, causing each pathway to struggle.

The inclusion of LCFS credits into renewable aviation fuels creates another way to offset the price difference. Although the credits have not been as appealing as they had initially thought, it may be a viable option if coupled with some factors mentioned prior.

Supply Chain Logistics

In general, availability is the most pressing issue that has hindered the widespread adoption of SAJF for aviation. The products are not yet available in quantities large enough to serve the entire aviation community.

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[50] http://www.caafi.org/focus_areas/feedstocks.html

[51] https://www.regi.com/blogs/blog-details/resource-library/2019/02/15/the-economic-impact-of-biodiesel

[52] https://www.ainonline.com/aviation-news/business-aviation/2019-05-18/bizav-makes-strides-sajf-utilization

[53] "Techno-economic analysis and life-cycle greenhouse gas mitigation cost of five routes to bio-jet fuel blendstocks" Source - https://www.ainonline.com/aviation-news/business-aviation/2019-05-18/bizav-makes-strides-sajf-utilization

[54] https://www.sciencedaily.com/releases/2019/03/190319083920.htm

[55] Average Price in the US as of 8/12/19 (subject to change)- Source: https://www.airnav.com/fuel/report.html

Issues include the logistics in the supply chain, dealing with blending, storing and transporting the product. There is an array of considerations for a prospective supplier to consider: where to source both the SAJF and jet fuel products, where these products will be stored, and what point are they blended and tested, to whom these products will be delivered.

To be successful, SAJF supply chains need to be optimized, including reducing costs, technology uncertainty and risks, and increasing yields of both feedstocks and fuel production processes, as well as improving the collection, storage, densification, and pretreatment of biomass and municipal solid waste, and optimizing its transport to conversion facilities.[56] A brief visual of the different supply chain elements is offered in Figure 12.

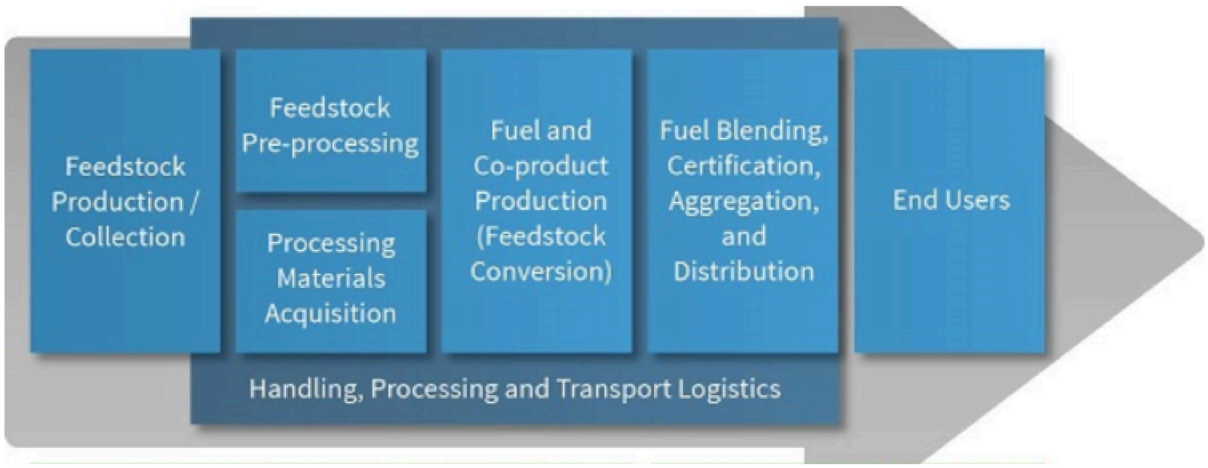

FIGURE 12 - SUPPLY CHAIN

Feedstock Production

Feedstock is harvested, collected, and stored until it is transferred to a feedstock processor at a pretreatment and/or densification facility.

Feedstock Pre-processing and Material Acquisition

In some cases, feedstocks must be pretreated before being transported to the biorefinery. For example, oilseeds may be crushed to extract vegetable oil, [57] municipal solid waste may be separated into lignocellulosic, recyclable, and non-usable fractions. In addition, biorefineries must acquire any additional materials other than feedstocks that are needed for conversion (hydrogen, catalysts, etc.).

Fuel and Co-product Production

Feedstock is converted into an alternative jet fuel blending component that fulfills the requirements of a relevant jet fuel specification according to ASTM.

Fuel Blending, Certification, Aggregation, and Distribution

The SAJF must be blended within the maximum allowable levels and be certified as compliant under industry standards, following which the fuel can be made available for use as jet fuel.

Handling, Processing, and Transport Logistics

[56] http://www.caafi.org/focus_areas/supply_chain.html
[57] Refers to plant dry matter and is the most abundantly available raw material on Earth for production of biofuels

Throughout the supply chain, there are logistics to be addressed for handling, processing, and moving materials from one stage to the next. This has been a real issue with driving down the cost and will be addressed in the next section.

Fuel End Use

Airlines and the military are the primary end users of aviation fuels. For airlines, alternative jet fuel end-use distribution happens at the airport.[58]

Handling, Processing, and Transport

One of the major issues logistically with the supply chain today is the handling, processing and transportation of SAJF to airport facilities. Drop-in SAJF is generally considered interchangeable with existing petroleum-based jet fuel. However, there are challenges associated with integrating SAJF into the existing petroleum jet fuel transport and distribution infrastructure. The challenges are related to geographical concentration of production, constraints of existing infrastructure, and tracking SAJF through the supply chain to ensure blending requirements are met.

Traditional Jet Fuel Delivery Approaches[59]

To understand the issues related with this, we need to understand the traditional approach. Jet fuels are transported in batches via pipelines, marine vessels, and road tankers. The batches are often stored in intermediate bulk oil storage facilities (between the refinery and airport) and are usually transported to the airport via pipeline due to their large volume. There are dedicated pipelines used solely for the transport of jet fuel, but it can also be transported in multi-product pipelines that handle a variety of liquid petroleum products.

The most efficient and cost-effective means to transport jet fuel to an airport is using a pipeline. This is followed by barges on waterways, rail using specialized tank cars, and tanker trucks respectively. To date, the only evidence of SAJF transportation is through tanker trucks, the least efficient and highest costing method.

Airports that produce a high turnover of jet fuel on a daily basis usually have three or more storage tanks: one tank is used as a receiving tank and accepts new fuel loads; a second tank acts as a holding and settling tank to allow time for contaminants to settle; and the third tank is called the operating tank from which fuel is drawn for daily use. From these storage tanks, fuel is either piped to an underground hydrant fuel system or is loaded into a refueler truck for its delivery to an airplane.

Constraints[60]

Currently, there is little infrastructure in place to transport finished SAJF to end-users. The current differences in the geographic location of conventional jet fuel production and SAJF production may pose challenges for SAJF entry into the existing jet fuel distribution system. Additionally, companies may have issues meeting minimum batch requirements since the market is so new.

Whether or not a sufficient SAJF supply can be delivered to airports via rail or marine vessels also remains a question. If the fuel is delivered through infrastructure not currently in use, then additional hookups will be necessary. For example, if an airport currently receives conventional jet fuel through a pipeline from a refinery and starts to receive SAJF by railroad, then a hookup, such as a fuel truck,

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[58] http://www.caafi.org/focus_areas/supply_chain.html
[59] http://www.caafi.org/activities/pdf/9_Transportation_Issues_September2017.pdf
[60] http://www.caafi.org/activities/pdf/9_Transportation_Issues_September2017.pdf

between the railroad car and the pipeline is required. In this case, terminal ramps and access roadways must then be designed to accommodate heavy fuel truck movements.

Blending Issues

Other issues include regulations in terms of the blending and tracking of alternative fuel. SAJF must be approved in terms of ASTM 1556 before blending and following blending to ensure safe use within the aircraft. Splash blending (blending done in fuel truck) will not be allowed due to regulatory issues.

SAJF can be delivered to the airports as a blended or non-blended product. If the product is blended, the product may come with some blend-level uncertainty due to unintentionally blending between unblended SAJF with blended SAJF which would result in the product being above the certified blending limit. If the product is unblended, then the product must be blended on sight, which could create challenges with infrastructure at airports, forcing them to dedicate tanks for blending or adding infrastructure. Currently, the most likely solution is to have producers blend the fuel at their refinery and have it ready for pick up and distribution to avoid any addition cost to the producer.

Solutions

Ideally, the industry will be able to establish designated pipeline routes that create the most efficient and cost-effective means to transport SAJF. Entry into existing pipelines may also be a viable solution once more of the market is aware of the product. Finding ways around these issues will be key in driving down production and distribution costs. Since the market for SAJF market is very new, many producers rely on few suppliers to distribute the product. Below are examples of how companies supply SAJF today.

Gevo and Avfuel

On July 1, 2018, Avfuel, a leading global supplier of aviation fuel and services, became the official distributer of Gevo. Avfuel has turned their attention to infrastructure and logistics behind where the SAJF will be blended, from where and to whom the product can be transported, and how great of a reach the company's network can have in the coming years.[61]

As of right now, there has only been evidence of distribution in two separate occasions for business aviation. The first was to Business Jets Fuel Green: A Step Toward Sustainability event at Van Nuys Airport[62] and the second was supplied to the EBACE[63] (European Business Aviation Convention & Exhibition) Fueling the Future event. In both cases, Avfuel blended the concentrated SAJF product with Jet-A at an Avfuel facility and delivered the final product to the event where FBOs were able to purchase the product.

Fulcrum and Partners[64]

Fulcrum will sell unblended product to Air BP and World Fuel in exchange for blending, certification and delivery of the fuel to commercial and military aviation customers. This will model Avfuel's approach, where the distributor takes care of the blending and delivery. There is no evidence if a pipeline or truck will be used, or of the cost associated with this distribution channel.

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[61] https://www.avfuel.com/Details-Page/ArticleID/400/AVFUEL-ARRANGES-SUSTAINABLE-ALTERNATIVE-JET-FUEL-SAJF-SUPPLY-AGREEMENT-WITH-GEVO

[62] http://www.avfuel.com/Details-Page/ArticleID/440/AVFUEL-SUPPLIES-FIRST-FULL-LOAD-OF-SUSTAINABLE-ALTERNATIVE-JET-FUEL-FOR-BUSINESS-AVIATION-AT-VAN-NUYS-EVENT

[63] https://www.avfuel.com/Details-Page/ArticleID/485

[64] http://fulcrum-bioenergy.com/partners/world-fuel-services/

Acceptance in the Industry

The high price, undeveloped supply chains, and the overall lack of awareness throughout the industry has caused for a slow acceptance of SAJF. Many operators still believe that the fuels might not be good for their engines, while others may have not been aware that the product existed, because it has not been readily available.[65] While this has inhibited the acceptance thus far, there are organizations, particularity business aviation, trying to make a push for awareness of the product.

In January, the business aviation industry came together at California's business aviation hub Van Nuys Airport for "Business Jets Fuel Green: A Step Towards Sustainability." SAJF was available to the business aviation community on a trial basis, with World Fuel and Avfuel supplying four FBOs on the field with more than 14,000 gallons of blended SAJF. To further demonstrate the fuel's acceptability, several aircraft operators sent aircrafts to provide demonstration flights. Gulfstream, which has used World Energy's SAJF 30/70 blend since 2012, dispatched a G280 demonstrating the high performance possible with SAJF.

Similarly, on May 20, 2019, a record number of 23 aircrafts arrived at Geneva Airport in Switzerland for the annual European Business Aviation Convention & Exhibition (EBACE) using alternative fuels. EBACE is a premier event and the annual meeting place for the European business aviation community. Over 400 exhibiting companies are in attendance, with about 13,000 aviation professionals. The event clearly demonstrated that SAJF is safe and does not impact aircraft performance, offers benefits to the airport and the community, and it reflects the commitment by business aviation to aircraft carbon reduction.[66]

[65] https://www.ainonline.com/aviation-news/business-aviation/2019-05-21/business-aircraft-operators-need-demand-biofuel

[66] https://ebace.aero/2019/latest-news/fuelling-the-future/

KEY PLAYERS

World Energy[67]

- Website: http://www.worldenergy.net/
- Headquarters: Boston, MA
- CEO: Gene Gebolys
- Year Founded: 1999
- Employees: 49
- Facilities: Rome, GA; Camp Hill, PA; Natchez, MS; Galena Park, TX; Hamilton, ON Canada
- SAJF Production Facilities: Paramount, CA
- Capacity: 306 MGY (2022)
- Feedstock: Inedible Tallow
- Pathway: HEFA-SPK
- Claimed Emission Reduction: 60%

World Energy is a private company, and is one of America's largest suppliers of biodiesel, offering over 200 million gallons of annual biodiesel production. World Energy recently acquired Altair, who had supplied United airlines roughly 15 million gallons in SAJF since 2016. World Energy plans on expanding the Paramount facility to roughly 306 MGY in capacity by 2022.

In late July, World Energy supplied EgyptAir in the current longest flight using a SAJF blend produced in their Paramount facility.[68] The fuel was distributed by Epic Fuels, a fuel provider with over 8,000 locations which will likely play an increasing role in the acceptance of the alternative fuel.

Fulcrum Bioenergy[69]

- Website: http://fulcrum-bioenergy.com/
- Headquarters: Pleasanton, CA
- CEO: E. James Macias
- Year Founded: 2007
- Employees: 40
- SAJF Production Facilities: Sierra, NV (2020); Gary, Indiana (2022)
- Capacity: 43.5 MGY
- Feedstock: MSW (Municipal Solid Waste)
- Pathway: FT-SPK
- Claimed Emission Reduction: 80%

Fulcrum is a private company, making low-carbon, low-cost, transportation fuels from household garbage. Utilizing trash as a feedstock, Fulcrum is diverting large volumes of waste from local landfills are reducing greenhouse gas emission by more than 80%. They currently have offtake agreements with Cathay Pacific for 37.5 MGY, United Airlines for 90 MGY, and World Fuel Services for 50 MGY. Fulcrum will have 2 facilities operational by 2022 with capacity of 43.5 MGY. They had announced plans to have 7

[67] http://www.worldenergy.net/about-us/
[68] https://egyptindependent.com/egyptairs-newest-dreamliner-records-worlds-longest-sustainable-flight/
[69] http://fulcrum-bioenergy.com/

facilities operational by 2022 with capacity of about 190.5 MGY which will likely be built in the years following.

SG Preston

- Website: https://sgpreston.com/home
- Headquarters: Philadelphia, PA
- CEO: Randy Delbert LeTang
- Year Founded: 2012
- Employees: Unknown
- SAJF Production Facilities: Lawrence County, OH (2021)
- Capacity: 240 MGY
- Feedstock: Non-edible oilseeds
- Pathway: HEFA-SPK
- Claimed Emission Reduction: 47%

SG Preston is a private Philadelphia-based bioenergy leader committed to the science of solving global energy challenges sustainably. They are currently building a facility in Lawrence County, Ohio that will be operational by 2021 with capacity for 240 MGY of sustainable fuel. Currently, 14 MGY of SAJF is planned to be produced.

Red Rock Biofuels[70] [71]

- Website: https://www.redrockbio.com/
- Headquarters: Fort Collins, CO
- CEO: Terry Kulesa
- Year Founded: 2011
- Employees: 52
- SAJF Production Facilities: Lakeview, OR (2019)
- Capacity: 15.1 MGY
- Feedstock: Forest residues, corn stover, bagasse, switchgrass, and algae
- Pathway: FT-SPK
- Claimed Emission Reduction: 50%

Red Rock Biofuels is a private company that is positioned to be a leading producer of drop-in, renewable, low carbon jet and diesel fuels. They plan to convert 136,000 tons of waste woody biomass into 15.1 MGY of renewable fuels per year, 6 of which will be dedicated to SAJF. They have offtake agreements with Southwest and FedEx for 3 MGY respectively.

[70] https://www.redrockbio.com/lakeview-site.html
[71] https://www.energy.gov/sites/prod/files/2019/04/f61/Woody%20Biomass%20Biorefinery%20Capability%20Development_EE000DPA2.pdf

Gevo[72]

- Website: https://gevo.com/
- Headquarters: Englewood, CO
- CEO: Patrick R. Gruber
- Year Founded: 2005
- Employees: 74
- SAJF Production Facilities: Luverne, MN; Silsbee, TX
- Capacity: 10 MGY[73]
- Feedstock: Corn Starch and Sugar Cane
- Pathway: ATJ-SPK
- Claimed Emission Reduction: 50%

Gevo (NASDAQ: GEVO) is a public company that specializes in renewable technology, chemical products, and next-generation biofuels. Gevo has one of the few ASTM specified low carbon alternative jet fuels that can be used commercially. There Luverne facility will be operational in 2022 and have the capacity for 10 MGY of sustainable jet fuel. Currently, they have a commercial supply agreement with Avfuel, a leading global supplier of aviation fuel and services, which allows them to purchase up to 1 million gallons of SAJF per year.[74]

LanzaTech[75]

- Website: https://www.lanzatech.com/
- Headquarters: Skokie, IL
- CEO: Jennifer Holmgren
- Year Founded: 2005
- Employees: 130
- SAJF Production Facilities: Soperton, GA
- Feedstock: MSW (municipal solid waste), organic industrial waste, agricultural waste
- Pathway: ATJ-SPK
- Claimed Emission Reduction: 90%

LanzaTech is a private biotech company founded in New Zealand, which focuses on converting carbon emissions to useful products, including fuel. They are currently in production of a facility in Georgia, which will have capacity to produce 10 MGY by 2022. The company also plans on having three UK plants running by 2023, with capacity to produce up to 100 MGY in total.

[72] https://gevo.com/jet-fuel/
[73] https://gevo.com/technology/
[74] https://www.biofuelsdigest.com/bdigest/2018/06/21/gevo-signs-supply-agreement-for-alcohol-to-jet-fuel-with-avfuel/
[75] https://www.lanzatech.com/