Sustainable Aviation Fuel:

Greenhouse Gas Reductions from Bay Area Commercial Aircraft

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Prepared for:

Bay Area Air Quality Management District

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List of Terms and Acronyms

ACRONYM	DEFINITION
AQMP	Air Quality Management Plan
AFI	Aviation Facilities, Inc.
ASTM	ASTM International
ATAG	Air Transport Action Group
CARB	California Air Resources Board (Also "ARB")
BAAQMD	Bay Area Air Quality Management District
CAAFI	Commercial Aviation Alternative Fuels Initiative
CI	Carbon Intensity
CJF	Conventional Jet Fuel
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalents
CORSI	Carbon Offsetting and Reduction Scheme for International Aviation
CEC	California Energy Commission
DPM	Diesel Particulate Matter
EPA	U.S. Environmental Protection Agency
FOGs	Fats, Oils and Greases
GHGs	Greenhouse Gases
GPY	Gallons per Year
HAP	Hazardous Air Pollutants
HEFA	Hydroprocessed Esters and Fatty Acids
ICAO	International Civil Aviation Organization
ICCT	International Council for Clean Transportation
IBAC	International Business Aviation Council
KM SFPP	Kinder Morgan Santa Fe Pacific Pipeline
LCFS	Low Carbon Fuel Standard (California)
LTOs	Landings and Take Offs (Aircraft)
MJ	Megajoule
NAAQS	National Ambient Air Quality Standards
NO_x	Oxides of Nitrogen
OAK	Oakland International Airport
PM / $PM_{2.5}$	Particulate Matter / PM smaller than 2.5 microns in size
RD	Renewable Diesel
RFS	Renewable Fuel Standard (federal)
SFBAB	San Francisco Bay Air Basin
SAF	Sustainable Aviation Fuel
SFO	San Francisco International Airport
SJC	San Jose International Airport
SIP	State Implementation Plan
SO_x	Sulfur Oxides
UA	United Airlines
UFP	Ultrafine Particles
W2W	Well-to-Wheels

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Executive Summary

Sustainable aviation fuel (SAF) is a drop-in replacement for conventional jet fuel (CJF) that can significantly reduce full-fuel-cycle greenhouse gas (GHG) emissions from jet aircraft engines. Currently, SAF is required to be blended with CJF, at up to 50 percent SAF by volume. Of the seven certified processes to produce SAF, one pathway (hydroprocessing of esters and fatty acids, or HEFA) currently accounts for more than 95 percent of the SAF used in commercial aviation. Neat SAF produced using the HEFA process currently reduces full-fuel-cycle GHG emissions from jet aircraft by approximately 60 percent compared to using baseline CJF. SAF that will be available in the near future (from HEFA or other pathways) will likely provide even greater GHG-reduction benefits.

The world's commercial aviation sector contributes roughly two-to-three percent of combustion-related GHG emissions. In California's Bay Area (greater San Francisco-Oakland), aviation contributes about six percent of transportation-related GHG emissions. Compared to surface (ground and water) transportation modes, the aviation sector presents greater challenges to decarbonize. Commercial aviation companies have made important strides to reduce carbon emissions through aircraft fleet efficiency improvements, but SAF has emerged as the leading approach to further reduce GHG emissions from jet aircraft.

There are currently four LCFS-certified "pathways" to produce SAF; all four use the HEFA process and animal tallow feedstock at World Energy's biorefinery in Paramount, CA. These pathways provide full-fuel-cycle GHG reductions ranging from 52 to 73 percent relative to baseline CJF. Although SAF must currently be blended with CJF (having higher carbon intensity), each SAF gallon ultimately displaces one CJF gallon, and therefore provides GHG reductions based on the relative carbon intensities of the two neat fuels.

SAF blends can also improve local ambient air quality, especially within airport boundaries and adjacent areas in close proximity to large numbers of jet "Landing and Take Off" (LTO) events. Specifically, SAF blends can significantly reduce direct aircraft emissions of fine particulate matter (PM), sulfur oxides (SOx) and carbon monoxide (CO). Although more studies are needed, displacing neat CJF with SAF blends also appears to reduce black carbon emissions and provide beneficial alterations of ultrafine particle emissions from jet engines. Based on studies to date, it appears that SAF does not significantly change NOx emissions from the jet engines, and therefore it does not seem to advance ozone-reduction strategies in the Bay Area or other urban areas.

A few million gallons of neat SAF are being used in the U.S. today. The largest SAF volumes are being dispensed in California at Los Angeles International Airport (LAX) and San Francisco International Airport (SFO), which have become proving grounds for SAF use in North America. SAF-fueled jet departures at these airports accelerated in 2019, when SAF became active as a credit-generating fuel under California's landmark Low Carbon Fuel Standard (LCFS) program.

While the societal benefits offered by SAF are compelling -- and demand from airlines is growing – currently this "premium" jet fuel is neither available nor affordable for wide-scale use. It costs at least two times as much to produce SAF compared to CJF, using the leading HEFA pathway and assuming a typical SAF yield of less than 15 percent, with renewable diesel (RD) being the dominant co-product. While the SAF yield can be increased up to 50 percent, this entails greater incremental cost and appears to compromise the market value of the overall biofuel products (RD and SAF, plus renewable naphtha and propane).

An equally important market barrier is that, once produced, a gallon of neat SAF's current market value in California is about eight percent lower than a gallon of RD, even though they are co-produced from the same feedstock and HEFA process. Consequently, SAF producers are likely to continue gearing their biofuel production to maximize the yield of RD – the more valuable co-product – unless and until SAF becomes a more highly valued biofuel (monetarily, environmentally, or both).

This combination of higher cost / lower market value has implications on airlines that purchase SAF. Supplies can be constrained, and incremental fuel cost can be high. Airlines using SAF at San Francisco International Airport (SFO) reportedly pay a premium of about $1.25 per gallon, under a best-case scenario that includes buydown of SAF costs using LCFS credits as well as "RIN" values under the federal Renewable Fuel Standard (RFS). Nonetheless, demand for SAF has been fairly strong in California – specifically at SFO and LAX. Roughly five million gallons of SAF blends (30 % SAF / 70% CJF appears to be typical) were dispensed at these two airports in 2019.

Despite higher costs to produce and purchase SAF, the industry and its airline customers anticipate major growth. Based on known "offtake" agreements, at least 350 million gpy of neat SAF will be produced and available for dispensing at U.S. airports by the 2023 timeframe. It is not yet known if that will continue to be dispensed into aircraft at or below a 50/50 ratio, as the blending requirement is largely a safety precautionary measure. In fact, aircraft flights have been successfully and safely demonstrated on neat SAF.

SFO – the nation's seventh busiest airport – has been a world leader to foster large-scale use of SAF. For several years, the airport has been working with its airline partners to test SAF blends and develop innovative ways to increase supply, while lowering costs. Under a Memorandum of Understanding (MOU) with airlines as well as SAF providers, SFO has established the goal to procure and dispense enough neat SAF within three to five years to displace about two percent of its CJF use (30 million gallons per year), and 17 percent (300 million gallons per year) within about a decade. While this near-term goal may have been significantly set-back by the unprecedented COVID-19 pandemic, it is too soon to know the impact on meeting the longer-term goal (a decade out).

Oakland International Airport (OAK) is the other Bay Area airport that has made progress to pilot test the benefits of SAF blends in commercial aviation. At least six million gallons per year of neat SAF have been committed to FedEx and Southwest Airlines for dispensing out of the OAK fuel farm facility. There appears to be significant synergy between SFO, OAK and SJC to share delivery and storage logistics for large-scale

SAF usage in the Bay Area, as SFO has invited both airports to join its MOU and interdisciplinary Stakeholder Working Group (SWG).

Over the longer term (about a decade), industry estimates indicate that one to six billion gallons of neat SAF may be available for the U.S. commercial aviation sector. This will be supplied by a combination of key existing SAF producers (primarily World Energy and Neste) as well as newcomers to SAF production such as Fulcrum BioEnergy, Red Rock Biofuels, Phillips 66 and others. The vast majority of this appears likely to be targeted for consumption in California, due to monetary incentives offered under the LCFS. A significant portion – perhaps half or more – may be used in the Bay Area at SFO and OAK, with potential synergy for use at SJC.

A high-level estimate was performed to roughly calculate the full-fuel-cycle GHG reductions that could be realized by widely using SAF blends at the three largest Bay Area airports. The assumptions were that pre-pandemic demand will return for jet fuel at SFO, OAK and SJC; and that 100 percent of the flights at all three airports will use SAF blends instead of neat CJF. A range of blends – SAF5, SAF25, and SAF50 – were evaluated. It is estimated that GHG reductions from SAF blends would range from 0.47 million metric tons per year (SAF5) up to 4.7 million metric tons per year (SAF50), based on 2019 emissions estimates. Notably, these combined GHG reductions reflect emissions from all fuel loaded at these three Bay Area airports, i.e., they are not constrained to reductions that would occur within BAAQMD boundaries.

A similar analysis was performed to estimate criteria pollutant emission reductions that could be realized within BAAQMD boundaries under the same SAF blend deployment scenarios. For the best-case scenario, it is estimated that displacing all CJF use at the three major airports with a SAF50 blend could provide reductions in CO emissions of 2.27 tons per day, SOx emissions of 0.39 tons per day, and PM10 emissions of 0.28 tons per day.

A number of challenges and barriers exist that currently hinder SAF producers from providing commercial aviation operations at SFO and other California airports with the large volumes they ultimately seek. The three key (related) impediments under current dynamics are 1) higher cost/price of SAF relative to CJF; 2) reduced value of SAF on a per-gallon basis compared to its more-dominant co-product RD (which disfavors gearing the production process for a higher SAF yield versus RD); and 3) federal and state policies that generally favor using limited biofuel resources to decarbonize surface transportation more than the aviation sector.

A fourth impediment has been the global COVID-19 pandemic, which has dramatically decreased aircraft departures at large coastal airports (nearly 70 percent at SFO at its peak), thereby greatly reducing demand for CJF and lessoning the need for airlines to continue switching to SAF blends.

A fifth impediment is the potential for California to be "outcompeted" for limited available SAF supplies, because other nations (or even regions of the U.S.) now offer – or may offer in the near future -- more favorable incentives and/or policies, which could make it increasingly difficult for airlines serving the Bay Area to procure large volumes of the fuel.

To address these barriers currently impeding wider-scale use of SAF at Bay area airports – thereby helping to achieve its GHG-reduction objectives for the commercial aviation sector -- the BAAQMD may wish to further develop and implement the following actions, in conjunction with various stakeholders.

- Engage with CARB and other relevant state or federal agencies about how to 1) improve the relative value of SAF through changes in the monetization metrics of key programs (LCFS, Cap and Trade, RFS2, etc.), and 2) generally modify California's GHG-reduction policies to more favorably treat SAF production and/or end use.

- Further evaluate the pros and cons of channeling more types of support (policy, incentive funding, permitting requirements, etc.) towards SAF as the leading available strategy to further decarbonize the Bay Area's aviation sector.

- Consider exploring new pilot program incentives for SAF production and end use, based on air qualify benefits associated with reducing criteria pollutants and air toxics in DAC / EJ areas near Bay Area airports.

- Consider creative methods to incentive larger-scale production and use of SAF, such as fast-track permitting and/or CEQA approval for new biofuel production facilities or conversion of conventional refineries to biorefineries.

- Commission a study (e.g., using the UC system) that corroborates and further quantifies SAF's effects on criteria and toxic air pollutants from commercial aircraft, which can help ensure that grant funding achieves its intended use (i.e., to reduce surplus, quantifiable emissions.

- Establish (or join existing) regular working groups with SFO and other major Bay Area Airports (OAK, SJC) to monitor SAF-related progress, developments and status of key impediments (including Covid-19 impacts).

SAF Potential for Reducing GHG Emissions at Bay Area Airports

1. Background / Introduction

1.1. Commercial Aviation Market and Contributions to GHG Inventories

Global aviation entails nearly 32,000 aircraft from 1,300 airlines that annually carry about 4.4 billion passengers covering 45,000 routes. Worldwide, commercial aviation (passenger and freight airlines) consume as much as 90 billion gallons of jet fuel annually, while emitting an estimated 918 metric tons of CO_2 (about 2.4 percent of global CO_2 emissions from fossil fuel use).[1] Relative to 2016, it has been projected (pre-pandemic) that international air traffic at North American airports will grow annually by an average of 2.7 percent over the next two decades. International flights at airports in Asia and the Middle East are expected to experience even greater annual growth,[2] with average global air traffic expected to increase as much as 4 to 5 percent annually.[3]

Collectively over the last decade, U.S. commercial airlines annually consumed an average of about 20 billion gallons of Jet Fuel A (also called conventional jet fuel, or CJF). Total CJF consumption in 2018 was nearly 27 billion gallons across all U.S. aviation uses.[4] The Department of Energy has projected that the CJF market in the U.S. will reach 54 billion gallons per year by 2040.[5]

At San Francisco International Airport (SFO) -- the largest airport in the San Francisco Bay Area -- airlines annually dispense approximately one billion gallons of CJF, with 2019 reaching about 1.2 billion gallons.[6] No public records were found for typical annual volumes of CJF dispensed at the other two large commercial aviation airports in the Bay Area, Oakland International (OAK) and San Jose International (SJC). Simplistically using greenhouse gas (GHG) emissions data provided by Bay Area Air Quality Management District staff (BAAQMD) associated with Landings and Take-Offs (LTOs)[7] – reported as metric tons of CO_2 equivalent ("$MTCO_2e$") – rough estimates for annual CJF dispensing at the other two airports have been derived proportionally, using the ratio of SFO's fuel use (the lower end, at 1 billion gallons per year) to its LTO GHG emissions. Table 1 summarizes estimated volumes of CJF dispensed at these three airports (see the * in the table).

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[1] International Council on Clean Transportation, "CO2 Emissions from Commercial Aviation: Fact Sheet, September 2019, https://theicct.org/sites/default/files/ICCT_CO2-commrcl-aviation-2018_facts_final.pdf.

[2] Haldane Dodd, Air Transport Action Group, "Aviation's Climate Action Plan," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.

[3] Dr. Alan H. Epstein (Prat & Whitney) and John Mandyck (United Technologies Corporation), "The Future of Sustainable Aviation: Betting on Jet Propulsion and Lower Net Carbon Fuels," Power Point presentation, 2016, http://naturalleader.com/wp-content/uploads/2016/10/UTC-7612-FutureSustainableAviationWhitePaper_3.pdf.

[4] Energy Information Administration, Table F1: Jet fuel consumption, price and expenditure estimates, 2018, https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_fuel/html/fuel_jf.html&sid=US.

[5] U.S. Department of Energy, Bioenergy Technologies Office's Efforts on SAJF,: presentation by Jonathan Male to CAAFI General Meeting, December 4, 2018, http://www.caafi.org/resources/pdf/1.2_Value_Proposition.pdf.

[6] Personal communication to GNA from Erin Cooke of San Francisco International Airport, September 2020.

[7] Notably, SFO operates many more long-haul flights than OAK and SJC, and thus dispenses greater volumes of CJF on a per-flight basis. Using a simplistic ratio of LTO GHG emissions does not capture this difference. However, GNA has received corroboration from knowledgeable sources that this rough approximation (as noted in Table 1 below) is reasonably accurate.

Table 1. Estimated annual dispensing of CJF (Jet A) at three largest Bay Area airports

Bay Area Airport	LTO CO_2 Emissions (mtCO2e/yr)	% of Total	Estimated Jet A Use (gal/yr)	Source of Estimate
San Francisco Int'l (SFO)	1,332,084	71.8	1 billion	Cited by SFO officials
Oakland Int'l (OAK)	334,029	18.0	251 million	CO_2e emissions (from LTOs) relative to SFO
San Jose Int'l (SJC)	188,270	10.2	141 million	
Totals	**1,854,383**	**100.0**	**1.4 billion**	

LTO GHG Source: "2019 Large Jet Aircraft GHG Emissions" (BAAQMD – Base Year 2011), provided by BAAQMD staff, July 2020.

*This is a rough approximation; GHG emissions are from LTO events and may not include general or business aviation flights. SFO's annual fuel demand (used to estimate OAK and SJC) entails all fuel dispensed at SFO, most of which is combusted beyond the Bay Area. Consequently, it is possible that these estimates understate or overstate dispensing CJF dispending at any of these three airports.

As shown in the table, based on GHG (CO_2e) emissions from aircraft during LTO events, roughly 1.4 billion gallons per year of Jet A fuel (CJF) are collectively dispensed at these major Bay Area airports (pre-pandemic). SFO, OAK and SJF account for about 72, 18 and 10 percent of this CJF use, respectively.

1.2. Initiatives to Reduce Aviation-Related GHG Emissions

U.S. Federal and International

About a dozen years ago (2008-2009), the commercial aviation sector joined the business aviation sector in efforts to significantly reduce aircraft emissions of CO_2 and other GHGs, to mitigate the industry's contributions to climate change. Drivers for these initiatives primarily came from the U.S. Federal Aviation Administration (FAA), the International Civil Aviation Organization (ICAO), the General Aviation Manufacturers Association (GAMA), the International Business Aviation Council (IBAC), the International Air Transport Association (IATA), the Air Transport Action Group (ATAG), and other organizations. ICAO in particular has been a major drive to reduce aviation-related GHG emissions (see for example https://www.icao.int/environmental-protection/Pages/ClimateChange_ActionPlan.aspx).

While there are some differences and nuances in the goals of these various organizations, there are key common elements, such as those codified in a joint November 2009 press release[8] calling for adoption of specific initiatives and goals, which included the following:

- Phasing in of carbon-neutral growth
- Annual improvements in fuel efficiency
- A 50 percent reduction in total carbon emissions by 2050, relative to 2005

In 2015, the FAA and other federal agencies joined with aviation companies and stakeholders to adopt the *United States Aviation Greenhouse Gas Emissions Reduction Plan.* This collaboration was designed to help U.S. commercial aviation achieve the "aspirational goal" of carbon-neutral growth by 2020, using

[8]General Aviation Manufacturers Association and the International Business Aviation Council, "Global Business Aviation Community Announces Commitment On Climate Change," press release, November 24, 2009, https://gama.aero/news-and-events/press-releases/global-business-aviation-community-announces-commitment-on-climate-change/.

2005 as the baseline year. The plan included specific approaches to reduce the carbon footprint of U.S. aviation, including support to develop and deploy "sustainable alternative jet fuels with lower life-cycle GHG emissions than conventional petroleum fuel."[9]

The next year these initial efforts in the U.S. were combined with similar goals of the international aviation industry, resulting in adoption of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). CORSIA is a global market-based initiative that seeks to mitigate annual increases in total CO_2 emissions from international civil aviation. (Note: CORSIA does not specify mitigating CO_2e emissions.) Using emissions offsets as the basic approach to reducing CO_2 emissions, CORSIA focuses on civil aviation flights that depart in one country and arrive in a different country. The objective is to aggressively reduce aircraft-related GHG emissions below baseline levels, while also considering "special circumstances and respective capabilities" of different countries and airlines.[10]

CORSIA's initial "monitoring, reporting and verification" phase took effect in 2019. As of mid-2020, 82 countries (acknowledged as "Member States") are participating in this voluntary "pre-phase" of CORSIA. Under CORSIA's voluntary pre-phase, all ICAO Member States that operate international flights track and report CO_2 emissions from their international flights. CORSIA's "first phase" begins January 1, 2021; it will require covered aviation operations to begin offsetting GHG growth when operating on covered routes. By 2035, CORSIA requires substantial GHG offsets through this market-based system (with recent adjustments due to the COVID-19 pandemic).

One key way for commercial airlines to achieve their CORSIA offsetting requirements is to use a "CORSIA eligible" fuel, which includes sustainable aviation fuel (SAF) that meets certain certification criteria.[11] CORSIA's route-based approach applies to aircraft operators that annually emit more than 10,000 metric tons of CO_2 during international flights. (Globally, the average commercial aviation flight in 2018 emitted an estimated 24 metric tons of CO_2.[12]) Operators with lower annual emissions on international flights can still participate in the market-based program to monitor and trade their international CO_2 emissions. An in-depth discussion about CORSIA and its specific requirements involving SAF is beyond the scope of this memo; details can be found at the ICAO Environment website.[13]

Largely in response to the initial actions of 2009 and then subsequent adoption of CORSIA, the world's major commercial aviation companies have made tangible accomplishments to reduce GHG emissions over the last decade. In the U.S., major airlines are driven to reduce GHG emissions by at least two

[9] U.S. Government, "United States Aviation Greenhouse Gas Emissions Reduction Plan," submitted to the International Civil Aviation Organization, June 2015.
[10] Timothy Obitts, Chief Operating Officer and General Counsel, National Air Transportation Association, "Green Aviation: Funding and Regulatory Drivers," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.
[11] Federal Aviation Administration, "ICAO and Alternative Jet Fuels," presentation by Dr. James I. Hileman, July 29, 2020, accessed from CAAFI website at http://www.caafi.org/resources/pdf/CAAFI_Webinar_CORSIA_Eligible_Fuels_07_29_2020.pdf.
[12] International Council on Clean Transportation, "CO2 Emissions from Commercial Aviation: Fact Sheet, September 2019, https://theicct.org/sites/default/files/ICCT_CO2-commrcl-aviation-2018_facts_final.pdf.
[13] See https://www.icao.int/environmental-protection/Pages/A39_CORSIA_FAQ2.aspx).

separate (but related) needs: 1) to achieve corporate sustainability goals (including CORSIA); and 2) to avoid regulatory restrictions on future air traffic growth (e.g., adoption of indirect source rules focused on airports). Additionally, airlines are driven to reduce or offset GHG emissions to help passengers "feel better" about the environmental implications of their air travel (especially discretionary).

State of California

GHG-reduction efforts in California are driven by the California Global Warming Solutions Act of 2006 (the Act), which was born out of Assembly Bill 32. The Act calls for the California Air Resources Board (CARB) and other State agencies to adopt sweeping efforts to reduce GHG emissions emitted from "all sectors of the economy." Specific strategies are laid out in California's 2017 Climate Change Scoping Plan (soon to be updated), which specifically targets a 40 percent reduction in GHG emissions by 2030, relative to the 1990 baseline. Given that California's transportation sector contributes about 40 percent of the State's GHG emissions (2017 inventory[14]), the Scoping Plan makes it a high priority to rapidly reduce GHG emissions for all modes of transportation, including aviation.

In 2009 under the umbrella of AB 32, CARB adopted the landmark Low Carbon Fuel Standard (LCFS) program, as one pillar of California's efforts to decarbonize the state's vast transportation sector. Using a combination of market pull and regulatory requirements, CARB designed the LCFS to systematically reduce the average carbon intensity (CI) of mainstream transportation fuels, with certain exceptions.

Originally, CARB excluded aviation fuel from participating under the LCFS. However, in 2018 CARB approved amendments that (among other things) allowed producers of low-carbon aviation fuels to voluntarily "opt into" the LCFS. This meant that renewable jet fuel dispensed at California airports could start generating valuable LCFS credits, as long as the fuel's life-cycle "pathway" has an CARB-certified CI rating below that of CJF. CARB set-up declining CI "benchmarks" for CJF, specifically to enable the calculation of credits that can be generated by voluntarily substituting low-CI "alternative jet fuel" (AJF).[15] According to a coalition of SAF producers, CARB's actions to add SAF into the LCFS "firmly established" California as America's "leading SAF state from both a supply and demand standpoint," and also put it "in the top tier of locations globally supporting the expansion of SAF."[16]

Under the LCFS regulation, AJF does not necessarily refer to renewable or "sustainable" jet fuel. CARB defines AJF as "a drop-in fuel, made from petroleum or non-petroleum sources, which can be blended and used with conventional petroleum jet fuels without the need to modify aircraft engines and existing fuel distribution infrastructure." As these words indicate, AJF does not need to be made from renewable, sustainable feedstock to generate LCFS credits.[17] However, the practical implication is that AJF now

[14] See https://ww2.arb.ca.gov/ghg-inventory-graphs.
[15] CARB, "Low Carbon Fuel Standard Basics," https://ww2.arb.ca.gov/sites/default/files/2020-06/basics-notes_1.pdf.
[16] Letter to CARB from Graham Noyes (Noyes Law Corporation), representing the "SAF Producer Group," September 21, 2020, provided to GNA from a leading SAF producer.
[17] CARB, "Low Carbon Fuel Standard Basics Proposed New Temporary Pathway: Alternative Jet Fuel," July 31, 2019, https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/fuelpathways/comments/ajf_temp.pdf.

generating credits under the LCFS is essentially synonymous with SAF (also see the discussion in Section 2.1).

Section 2.3 of this report further defines and describes SAF's GHG-reduction benefits, by key variables. Section 7 provides CARB's CI benchmark curve and discusses the relative value of LCFS credits generated with SAF used for aviation versus renewable diesel used for ground transportation.

Bay Area Air Quality Management District

In April 2017, BAAQMD approved its 2017 Clean Air Plan. The Plan's overarching objective is to "lead the (Bay Area) to a post-carbon economy, to continue progress toward attaining all State and federal air quality standards, and to eliminate health risk disparities from exposure to air pollution among Bay Area communities." The Plan includes a comprehensive strategy of 85 proposed control measures to simultaneously reduce ozone and fine particle pollution, reduce air toxics, and meet the State's long-term GHG reduction targets. [18]

Aviation contributes about six percent of the Bay Area's transportation-related GHG emissions. For all transportation sources (ground, air and marine), the Plan prioritizes reducing emissions of GHGs, criteria pollutants, fine particulate matter, and toxic air contaminants. It seeks to decrease fossil fuel combustion, and increase use of renewable energy (including development of local production capacity). The Plan notes that "by 2050, Bay Area industries will need to be powered by renewable electricity wherever feasible with renewable fuels making up the difference." Noting that CJF is considered a "hard-to-replace" and/or "specialty" fuel, the Plan acknowledges that oil companies will likely continue to supply liquid aviation fuel, but it will need to transition to renewable, non-petroleum forms (i.e., SAF).

In fact, as one of many potential future control measures for mobile sources, the Plan calls out increased use of SAF to help simultaneously achieve climate change goals and ambient air quality goals. Specifically, Transportation Control Measure (TCM) TR17 calls for BAAQMD to "work with the appropriate partners to increase the use of cleaner burning jet fuel and low-NOX engines in commercial jets arriving and departing the Bay Area." [19]

Additional localized efforts to reduce aviation-related GHG emissions within the BAAQMD's jurisdiction are discussed in the context of the Bay Area's three major airports (see Section 7.1).

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[18] Bay Area Air Quality Management District, "Final 2017 Clean Air Plan, adopted April 19, 2017, http://www.baaqmd.gov/~/media/files/planning-and-research/plans/2017-clean-air-plan/attachment-a_-proposed-final-cap-vol-1-pdf.pdf?la=en.

[19] Bay Area Air Quality Management Plan, "Draft 2017 Clean Air Plan: Spare the Air, Cool the Climate;" presentation to Board of Directors by Henry Hilken, Director of Planning and Climate Protection, March 1, 2017, http://www.baaqmd.gov/~/media/files/board-of-directors/2017/bod_presentations_030117-pdf.pdf?la=en.

2. SAF Description and Characteristics

2.1. General Description, Basic Production Processes

Broadly defined, SAF[20] refers to certified distillate aviation fuels "produced sustainably from renewable resources (in whole or in part)."[21] More technically, SAF is "drop-in" alternative aviation fuel produced using a renewable pathway approved by ASTM International (ASTM), which ensures key standards are met for fuel quality, sustainability, safety and performance characteristics. Specifically, ASTM D7566 ("Specification for Aviation Turbine Fuels Containing Synthesized Hydrocarbons") sets requirements for 100 percent (neat) SAF, as well as blended portions. First published in 2009, ASTM D7566 includes a series of annexes that lay out the most-current requirements for SAF to be deemed a drop-in substitute for CJF.

Table 2 lists all seven SAF-production pathways (by annex number) approved under ASTM D7566 and/or ASTM D4054 (the fast-track process recently enacted). Annex 2, the "HEFA SPK" pathway (hydro-processing of fats and oils) has been, and continues to be, the dominant method to produce SAF. In fact, this pathway is estimated to account for more than 95 percent of the SAF that has been used in commercial aviation, to date.[22] Section 4 discusses specific producers using this dominant pathway.

Table 2. ASTM D7566 and D4064 (fast-track) approved pathways for SAF

Technology Code	Pathway Code ASTM Annex	Feedstock	Max Blend %	Status
Fischer-Tropsch Synthetic Paraffinic Kerosene	FT SPK **A1**	All biomass and household waste	50%	Approved 2009 (ASTM D7566), currently no technical barriers to widespread implementation. Commercial facilities starting production in 2020-2021.
HEFA Synthetic Paraffinic Kerosene	**HEFA SPK** **A2**	Renewable fat, oil and grease	50%	Approved 2011 (ASTM D7566), **Commercially produced/supplied at scale**
Hydroprocessed Synthesized Isoparaffins	HFS-SIP **A3**	Sugars	10%	Approved 2014 (ASTM D7566), currently no technical barriers to widespread implementation.
FT Synthesized Paraffinic Kerosene plus Aromatics	FT-SPK/A **A4**	All biomass and household waste	50%	Approved 2015 (ASTM D7566), currently no technical barriers to widespread implementation.
Alcohol to Jet Synthetic Paraffinic Kerosene	ATJ-SPK **A5**	Sugars, biomass, waste gases	50%	Approved 2016 (ASTM D7566), commercially produced/supplied at low volume.
Catalytic Hydrothermolysis Synthesized Kerosene	CH-SK or CHJ **A6**	Renewable fat, oil and grease	50%	Approved 2020 (ASTM D7566), currently no technical barriers to widespread implementation.
Synthesized Paraffinic Kerosene from HC-HEFA	HC-HEFA SPK **A7**	Renewable fat, oil and grease	10%	Approved, first pathway under ASTM D4054 fast track review process

Source: Inputs from ASTM Inter'l; table reproduced from Atlantic Council, "Sustainable Aviation Fuel Policy in the United States: A Pragmatic Way Forward, by Fred Ghatala, April 2020 and Green Car Congress, https://www.greencarcongress.com/2020/05/20200514-ihi.html.

[20] SAF is also commonly called "sustainable alternative jet fuel" (SAJF), "renewable jet fuel" (RJF), and "alternative jet fuel."
[21] Commercial Aviation Alternative Fuels Initiative, "Glossary," http://www.caafi.org/resources/glossary.html.
[22] Atlantic Council, "Sustainable Aviation Fuel Policy in the United States: A Pragmatic Way Forward, by Fred Ghatala, April 2020.

Regardless of the production pathway, before SAF can be used in U.S. aircraft, it must be blended with CJF and certified under ASTM D7566 as well as D1655 ("Standard Specification for Aviation Turbine Fuels"). SAF blends that meet ASTM D1655 "can be handled in the same fashion as the equivalent refined D1655 aviation turbine fuel," [23] so it can be inserted into a manifold upstream via an on-airport hydrant system, or directly into an aircraft. (In addition, ASTM D4054 encumbers a fast-track evaluation process to determine if emerging alternative jet fuels are equivalent to CJF.)

Currently, the maximum amount of SAF allowed under the dominant HEFA pathway (and most others) is 50 percent by volume. As described below by the Air Transport Action Group (ATAG), the 50 percent blending limit was adopted as an initial precautionary safety measure, but it is not likely to cap long-term use of SAF.

Definition: *drop-in jet fuel blend:*

A substitute for conventional jet fuel that is completely interchangeable and compatible with conventional jet fuel when blended with conventional jet fuel. A drop-in fuel blend does not require adaptation of the aircraft/engine fuel system or the fuel distribution network, and can be used "as is" on currently flying turbine-powered aircraft.

-CAAFI, http:// www.caafi.org/resources/glossary.html

> *"The reasons for the current blend limits are to ensure the appropriate level of safety and compatibility with the aircraft fueling systems (mainly due to the level of aromatics which are necessary for the different systems). It is, however, likely that higher blend limits will be approved in the future."*[24]

In fact, aircraft have been flown on 100 percent SAF, such as demonstration flights by Boeing and Airbus. And, jet engine OEM Rolls-Royce announced in late 2020 that it will "ground test" SAF100, "to determine whether the unblended biofuel can be used in its next-generation engine technology."[25] Currently, SAF is blended with at least 50 percent CJF largely as a precautionary measure. As noted, ASTM is the organization that sets standards for aviation fuels, and it appears to be actively working towards testing and verifying the safety of higher blend limits. More information about ASTM's process to maintain the safety of aircraft fuels, including SAF, can be obtained from ASTM's website.[26]

Notably, it appears that blends well below 50 percent may be leading the early years of SAF usage. Supplies of neat SAF are constrained, and it is a premium-priced fuel even when blended at 50 percent (see Section 7). Used in blend ratios well below the current 50 percent limit, SAF can still provide significant GHG reductions (proportional to the blend ratio). As further discussed, some early-adopter airlines are commonly using SAF in a 30 percent blend with CJF, and some may be using lower percentage

[23] ASTM, "Active Standard ASTM D7566," https://www.astm.org/Standards/D7566.htm.
[24] Air Transport Action Group (ATAG), "Beginner's Guide to Sustainable Aviation Fuel," Edition 3, November 2017, https://aviationbenefits.org/media/166152/beginners-guide-to-saf_web.pdf.
[25] Opisnet.com, "Rolls-Royce to Ground Test 100% SAF in Next-Generation Engines, reporting by Aaron Alford, November 16, 2020,
[26] For example, see ASTM's brochure "Keeping Aircraft Safe," https://www.astm.org/ABOUT/OverviewsforWeb2014/AviationOverviewSept2018.pdf.

blends.[27] Blending to low SAF levels extends the limited SAF supply and makes it more affordable. Although blending results in proportionally lower GHG-reduction benefits (as further evaluated), it is noteworthy that each gallon of neat SAF provides a certain GHG reduction benefit, regardless of the ratio at which it ultimately gets blended.

2.2. Performance and Combustion

As summarized by the National Renewable Energy Laboratory, jet fuels are "mostly defined in terms of required performance properties." Per the ASTM approval process and pathways noted above, all jet fuels (fossil or renewable) are required to meet specifications for parameters that include: (1) minimum energy density by mass, (2) maximum allowable freeze point temperature, (3) maximum allowable deposits in standard heating tests, (4) maximum allowable viscosity, (5) maximum allowable sulfur and aromatics content, (6) maximum allowable amount of wear in standardized test, (7) maximum acidity and mercaptan concentration, (8) minimum aromatics content, (9) minimum fuel electrical conductivity, and

Table 3. Comparison of typical CJF to SAF (neat, HEFA pathway) for key properties

Key Fuel Properties	Typical Measured Values	
	Conventional Jet Fuel* (CJF)	Sustainable Aviation Fuel (SAF)
Density (kg/m3)	800	772
Flash point (deg C)	42	47
Total aromatic content (%)	15%	0.10%
Freeze point (deg C)	-40	-50
Specific Energy (MJ/kg)	43	44
Sulfur content (ppm)	700	< 1
Derived Cetane number	46	60
Source: Neste communication to GNA (citing CRC and AFRL reports, Jan. 2020) ***Jet A**		

(10) minimum allowable flash point.[28]

The net result is that SAF is substantially similar to CJF, and provides excellent overall properties for use as a safe, high-performance substitute jet fuel. In fact, as shown in Table 3, SAF produced by the dominant HEFA pathway offers certain combustion characteristics that are advantageous over CJF for operating aviation

[27] Notably, it appears to be rare for SAF to be directly delivered to aircraft. More typically, SAF gets to the airport fueling system through a pipeline or local fuel farm / hydrant system (which has lifecycle GHG benefits vs. delivering by tanker), where it may be further blended with CJF before being dispensed into individual aircraft.
[28] National Renewable Energy Laboratory, "Review of Biojet Fuel Conversion Technologies," Wei-Cheng Wang, Ling Tao, Jennifer Markham, Yanan Zhang, Eric Tan, Liaw Batan, Ethan Warner, and Mary Biddy, NREL Technical Report NREL/TP-5100-66291, July 2016.

engines. These include a higher cetane number, lower aromatic content, and lower sulfur content[29] – all of which help to contribute to SAF's lower GHG and criteria pollutant emissions profiles (see Section 2.4) and higher performance. Notably, while SAF's lack of aromatics help provide its good emissions profile, it also raises materials compatibility issues, which is one key reason that ASTM currently requires SAF to blended with CJF.[30]

Although HEFA-SPK SAF has a slightly greater fuel density by mass than CJF, its volumetric energy density is about 4 percent lower than CJF. This means that (all else being equal) SAF use could result in proportional reductions in aircraft flying range compared to burning CJF. However, the lower volumetric energy density only impacts aircraft that are flying on (or close to) a fuel capacity limit. That rarely happens in practice, as aircraft are more typically limited by maximum takeoff weight (MTOW) restrictions.[31]

Major jet engine manufacturers like Pratt & Whitney (a United Technologies company) have clearly sanctioned use of SAF blends in their engines, while also noting important challenges that need to be overcome to achieve wide-scale use (limited supply, high costs).[32] Notably, the Sustainable Aviation Fuel Users Group (SAFUG), formed in September 2008, includes "25 members airlines (representing 33% of commercial aviation fuel demand)" and five "affiliates" organizations from the aviation industry (Boeing, Airbus and Embraer). Reportedly, SAFUG members including the airlines and manufacturers have signed a sustainability pledge acknowledging that advancing and adopting SAF is "a key driver to a carbon neutral industry."[33]

In sum, SAF is not only a drop-in replacement for CJF; in several important ways it is a superior jet fuel.

2.3. Carbon Intensity, Effects on Life-Cycle GHG Emissions and Sustainability

SAF's primary environmental benefit is that it provides a cost-effective, compelling in-sector GHG-reduction strategy for airlines and aircraft OEMs alike (consistent across turbine and piston types). A commonly cited figure is that neat SAF can reduce lifecycle GHG emissions by "up to 80 percent" compared to petroleum-based CJF.[34] However, as further described below, SAF's actual GHG-reduction benefits depend on the specific production pathway and feedstock type. Notably, on a *per-gallon basis*

[29] Pearlson, M. N., "A Techno-Economic and Environmental Assessment of Hydroprocessed Renewable Distillate Fuels," Master of Science, Massachusetts Institute of Technology, 2007.
[30] For additional information, see IATA's "Fact Sheet 2 - Sustainable Aviation Fuel: Technical Certification," https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-technical-certifications.pdf.
[31] Personal communication to GNA from CAAFI, September 2020.
[32] Dr. Alan H. Epstein (Prat & Whitney) and John Mandyck (United Technologies Corporation), "The Future of Sustainable Aviation: Betting on Jet Propulsion and Lower Net Carbon Fuels," Power Point presentation, 2016, http://naturalleader.com/wp-content/uploads/2016/10/UTC-7612-FutureSustainableAviationWhitePaper_3.pdf.
[33] International Civil Aviation Organization, "Sustainable Aviation Fuel User Groups (SAFUG)," https://www.icao.int/environmental-protection/GFAAF/Pages/Project.aspx?ProjectID=13.
[34] This "up to 80 percent" is frequently cited by fuel producers, end users, SAF proponents, and in aviation sector publications. For example, see the commentary from Neste at https://www.aviationpros.com/gse/fueling-equipment-accessories/fuel-distributors-suppliers-manufacturers/article/21144761/neste-north-america-now-is-the-time-to-let-sustainable-aviation-fuel-take-off.

the GHG reductions for a given type of neat SAF are independent of the degree to which it is ultimately blended with CJF.

In California where SAF use is strongest, CARB measures the GHG-reduction potential of all transportation fuels by their carbon intensity (CI) value (in grams of carbon dioxide equivalent per mega Joule, or

Table 4 All Current LCFS-Certified Pathways for Alternative Jet Fuel (SAF), as of August 2020

Fuel Producer / Production Location	Feedstock / Pathway Process	Location of Feedstock	Carbon Intensity (gCO_2e/MJ)
AltAir LLC (World Energy) Paramount, CA	Animal Fat (Tallow) / Hydrotreatment using natural gas, grid electricity and hydrogen	Colorado	23.93
		Canada	25.08
		North America	37.13
		Australia	42.91
		Avg CI (Unweighted)	**32.26**

gCO_2e/MJ). The baseline aviation fuel to which SAF is compared for relative GHG emissions is CJF, which currently has a CI value of 89.37 gCO_2e/MJ.

Starting in late 2019 and culminating in June 2020, one company and biofuels facility – World Energy's Paramount, California plant – certified four distinct (but similar) Tier 2 production pathways for SAF ("Alternative Jet Fuel" using CARB's nomenclature). As shown in Table 4, all four pathways entail hydrotreatment of tallow feedstock (animal fat from cattle and poultry). The CI ratings range from 23.93 to 42.91 gCO_2e/MJ. One key CI determinant is the geographical location of the feedstock, and how far it must be shipped to reach World Energy's Paramount biofuels plant in Southern California. The average CI of World Energy's four CARB-certified pathways is 32.26 gCO_2e/MJ (unweighted for production volumes). Notably, this is almost identical to the volume-weighted average CI for renewable diesel (RD) transacted under the LCFS program in 2019. This reflects the fact that SAF is co-produced with RD, using the same feedstocks and hydrotreatment process -- although it is not incentivized at the same rate as RD (see Section 4).

As indicated, the CI ratings for currently available SAF sold under a CARB-certified pathway (i.e., being supplied today by World Energy's Paramount biorefinery) range from 42.91 gCO_2e/MJ down to 23.93 gCO_2e/MJ.[35] <u>In this comparison, neat (100 percent) SAF provides reductions in carbon intensity ranging</u>

[35] California Air Resources Board, "LCFS Current Pathways as of April 2020," downloaded from https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm.

from 52 to 73 percent, relative to baseline CJF. Notably, World Energy is working on HEFA pathways with feedstocks other than tallow that may eventually achieve "carbon negative" CI values.[36]

It is important to stress that these potential GHG reductions associated with using SAF are based on the CI values of unblended (neat) SAF. As noted, ASTM requirements currently limit SAF content to 50 percent (or less) by volume, blended with CJF. Moreover, blends well below 50 percent SAF are being used to extend limited supply of neat SAF. Thus, accounting of actual GHG reductions from SAF use must consider the degree to which each neat gallon is blended. (See the analysis in Section 7.)

For SAF from not-yet-certified pathways (i.e., SAF not supplied by World Energy), CARB staff has established "temporary" CI ratings. To build-up these temporary CI values, CARB used "the most conservative data from LCFS certified renewable diesel pathways that produce (SAF) as a co-product."[37] Pending full pathway certification by the producer, some SAF supplied to airlines at Bay Area airports has been assigned CARB's temporary CI of 50 gCO2e/MJ; this provides about a 44 percent GHG reduction for each gallon of neat SAF relative to CJF.[38]

It appears that the GHG-reduction benefits of SAF may increase as new production pathways and feedstocks become commercialized and/or greater utilized. The International Council on Clean Transportation (ICCT) notes that SAF produced through "advanced fuel conversion processes" such as gasification and cellulosic alcohol-to-jet "can deliver 80% to 90% reductions in fuel carbon intensity, and their production could be greatly increased in the upcoming decades."[39] A recent publication by the National Academy of Sciences indicates that SAF's fuel-fuel-cycle GHG-reduction benefits may be even greater:

> *The potential GHG emissions reduction benefits from using (SAF) could be significant when compared to conventional jet fuel, and in some cases could exceed 100% (e.g., with biochar sequestration, or avoidance of other GHGs associated with the feedstock).*[40]

This concurs with World Energy management's previously noted statement that they are working on "negative carbon" pathways for the SAF they produce in Paramount, California – using the well-established and proven HEFA pathway. In addition, the ICAO cites at least three carbon-negative "CORSIA eligible" SAF pathways that use Fischer-Tropsch and Alcohol-to-Jet processes.[41] Again, these estimated

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[36] World Energy's Bryan Sherbacow, personal communication to Jon Leonard of GNA, August 2020.
[37] California Air Resources Board, "Low Carbon Fuel Standard Proposed New Temporary Fuel Pathway: Alternative Jet Fuel," July 31, 2019, https://ww3.arb.ca.gov/fuels/lcfs/fuelpathways/comments/ajf_temp.pdf.
[38] California Air Resources Board, "Low Carbon Fuel Standard Proposed New Temporary Fuel Pathway: Alternative Jet Fuel," July 31, 2019, https://ww2.arb.ca.gov/sites/default/files/classic//fuels/lcfs/fuelpathways/comments/ajf_temp.pdf.
[39] International Council for Clean Transportation, "Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities," January 2019, https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf.
[40] National Academy of Sciences, "Sustainable Alternative Jet Fuels and Emissions Reduction: February 2019 Factsheet," summary of ACRP Web-Only Document 41, accessible from www.trb.org/main/blurbs/179509.aspx.
[41] International Civil Aviation Organization, CORSIA Default Life Cycle Emissions Values for CORSIA Eligible Fuels, November 2019, https://www.icao.int/environmental-protection/CORSIA/Documents/ICAO%20document%2006%20-%20Default%20Life%20Cycle%20Emissions.pdf.

potentials for carbon reduction refer to use of SAF in its neat form, as a drop-in unblended replacement for CJF. Under current ASTM requirements, for any production pathway SAF must be blended with CJF for safety and general precautionary reasons. This also improves economics and extends the limited supply of SAF.

Several key mechanisms are in place to ensure that SAF used in California (as well as Oregon) is produced using sustainable, environmentally sound pathways. First, the LCFS and its counterpart in Oregon encourage "good behavior" by suppliers throughout the entire feedstock and supply chain processes for their biofuel products. This is because low CI values associated with sustainable pathways generate the highest credit values. Second, there are enforcement mechanisms in place to ensure sustainability. CARB has taken aggressive action to monitor the origins of biofuels (SAF, RD and others) dispensed in California. Reportedly, the agency has hired large numbers of third-party certifiers around the world, who help ensure sustainable sourcing for imported biofuels that generate credits under the LCFS, while also corroborating CI ratings for steps in the process that occur abroad. These actions by CARB have helped keep SAF and RD out of California if they have not been produced sustainably.[42]

Section 4 further discusses the implications of the relative CI ratings for CJF and SAF, in terms of potential GHG emissions in the Bay Area, and how they can impact the price of SAF blends to end users.

2.4. Effects on Aircraft Emissions of Criteria and Hazardous Air Pollutants

In addition to strong GHG-reduction benefits, substituting SAF blends for neat CJF can provide important improvements in ambient air quality. As noted above, SAF's high cetane number, lack of aromatic hydrocarbons and near-zero sulfur content generally help reduce aviation engine emissions of criteria pollutants and toxic air contaminants. A key Airport Cooperative Research Program (ACRP) study was conducted in 2018-2019 to assess the status of knowledge regarding emission reductions achievable by using SAF blends in commercial aircraft. Known as ACRP 02-80, the study was sponsored by the National Academy of Science and its Transportation Research Board. Under this study, the selected expert (Booz Allen Hamilton) collected, reviewed, and compiled data from emissions tests sponsored by a large government-industry-academia consortium. The results were derived from analysis using an Aviation Environmental Design Tool considering data from "representative airports" across various operational characteristics and fleet mixes (i.e., the numbers of jet, turboprop, and/or piston aircraft).[43]

In 2019, a "final" version of the ACRP 02-80 report was completed and issued as "Web-Only Document 41" (aka ACRP 41). This report included a second phase of ACRP 02-80 that further analyzed data compiled in the initial phase. This second part analyzed other blend levels of SAF (as low as 5%), and also explored

[42] Personal communications from state officials and SAF producers to GNA, July 2020.

[43] National Academies of Sciences, Engineering, and Medicine 2018, "*State of the Industry Report on Air Quality Emissions from Sustainable Alternative Jet Fuels*," **(Phase 1 of ACRP 02-80)**, Washington, DC: The National Academies Press, April 2018, https://doi.org/10.17226/25095, https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4238.

SAF benefits related to ultra-fine particles (UFP) in terms of particle mass (nvPM mass) and particle number (nvPM #).

Using the new analysis, the report authors developed "uncertainty in impact factors" for the emissions reductions found under Phase 1. The study reported important reductions in CO, SOx and PM emissions from jet aircraft fueled with SAF blends, although it found that no statistically significant NOx emissions

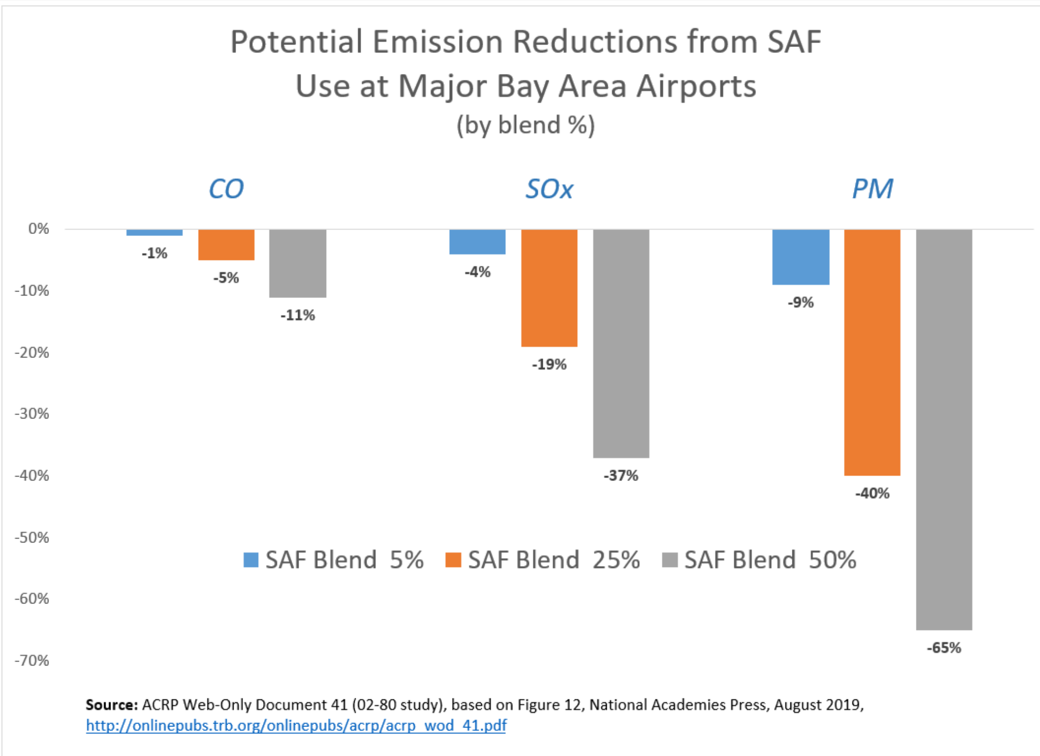

Figure 1. ACRP findings on potential criteria pollutant reductions from using SAF blends (see text reference)

reductions are realized. Figure 1 summarizes key findings for reducing these pollutants as a function of SAF blend percentage. These results are specific to airports that have a high percentage of turbine jets (relatively few piston engine aircraft), as is the case for the Bay Area's three largest airports. In Section 7.2, these emissions reduction factors are applied to quantify potential SAF-related reductions in criteria pollutant emissions at SFO, OAK and SJC.

In a separate "Fact Sheet"[44] that addresses the entire ACRP 02-80 study, the authors summarized estimated emission reductions from using SAF at "12 representative airports," paraphrased as follows.

[44] National Academy of Sciences, "Sustainable Alternative Jet Fuels and Emissions Reduction: February 2019 Factsheet," summary of ACRP Web-Only Document 41, accessible from www.trb.org/main/blurbs/179509.aspx.

SAF blends:

- Significantly reduce emissions of PM and sulfur oxides
- Achieve "moderate" reductions of carbon monoxide and unburned hydrocarbons"
- Reduce emissions of "ultrafine particles, not just the regulated larger particles"
- Minimally reduce, or have no effect on, emissions of NOx and hazardous air pollutants (HAPs)

The study notes that "these reductions could give airports flexibility to grow under their State Implementation Plan (SIP) constraints." For example, one key element of the BAAQMD's work to reduce local particulate matter emissions in the Bay Area is to prepare an "abbreviated" SIP that addresses EPA "planning requirements" associated with $PM_{2.5}$ attainment.[45] Expanded use of SAF feeds into the objectives of such a plan.

As one means to facilitate this process, the ACRP 02-80 study authors developed "a simplified tool that will allow airports to easily estimate emission reductions from use of (SAF) at their airport." As is further described in Section 6.1, SFO is already using significant volumes of SAF blends. While airport staff have not yet applied this tool to estimate the associated emissions reductions, they are using an internal methodology for this purpose, based on other industry data and within the framework of SFO's annual Climate Action Plan.[46]

[45] BAAQMD, "Particulate Matter Planning Activities," https://www.baaqmd.gov/plans-and-climate/air-quality-plans/current-plans.

[46] Personal communication from Erin Cooke and John Galloway (Environmental Dept at SFO) to GNA, telephone interview, August 12, 2020.

3. Emergence as a Leading Approach to Reduce Aviation-Related GHG Emissions

3.1. Previous Efforts Focused on Airline Fleet Efficiency

Historically, U.S. commercial airlines have focused on fuel efficiency improvements to reduce their aircraft fleet GHG emissions. Primarily, they have increased aircraft fuel economy by upgrading to newer planes (fleet modernization), and improving aerodynamics of in-use aircraft. Major GHG reductions have been achieved, but it appears this twin approach is now providing diminishing returns (see below). Consequently, the world's major aviation companies increasingly began to explore fuel-related strategies as a leading approach to reduce GHG emissions, beyond reductions enabled by fleet modernization.

As early as 2006, the U.S. Government began to take significant interest in SAF as a drop-in low-GHG replacement for CJF. Among the first steps taken was to form the Commercial Aviation Alternative Fuels Initiative (CAAFI) — a public-private partnership between the U.S. government, airlines, aircraft manufacturers, airports, and fuel producers. CAAFI was designed to lead SAF-related RD&D efforts, environmental assessments, commercialization efforts, fuel testing and other activities.

While test flights using SAF blends have been conducted in the U.S. for commercial, business and military aircraft for more than a decade, major momentum for SAF commercialization began about five years ago. A number of key SAF-related regulatory and sustainability initiatives have been adopted over the last half decade. Most of these are related to CORSIA, or at least complementary to its objectives. For example, in the 2010 timeframe FAA began "working to enable" U.S. aviation companies to consume one billion gallons per year of SAF blends by 2018.[47] Although that goal fell far short, the upshot in mid-2020 is that major commercial aviation companies in the U.S. and worldwide now seek to obtain and test SAF blends, to simultaneously comply with initiatives like CORSIA and achieve corporate sustainability goals.

SAF's emerging importance to reduce global aviation GHG emissions has been emphasized by the General Aviation Manufacturers Association (GAMA), acting jointly with the National Air Transportation Association and other stakeholders. In 2018 (and just updated for 2020), these stakeholders jointly produced a SAF use "guide,"[48] which includes the following sweeping statement (emphasis added):

> *"The single largest potential reduction in aviation's GHG emissions, and the key to reaching our goals for reducing them, will come about through the broad adoption of sustainable aviation fuel (SAF) in place of conventional jet fuel in use today."*

3.2. Current SAF Use at Demonstration Scale

NOTE: This report focuses on SAF use for commercial passenger aviation. However, it is important to note

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[47] Federal Aviation Administration, "Sustainable Alternative Jet Fuels," https://www.faa.gov/about/office_org/headquarters_offices/apl/research/alternative_fuels/.

[48] "Fueling the Future: Sustainable Aviation Fuel Guide, Edition 2, 2020, https://www.futureofsustainablefuel.com/guide.

that business aviation and commercial aviation also constitute important sectors for SAF adoption. In fact, some SAF stakeholders consider these smaller aviation sectors to be more ready and conducive to adopt SAF than the big passenger airlines, due to "a more extensive supply chain" that is less dependent on the fuel pipelines that are often used to supply jet fuel to commercial flights.[49]

> *"For mid- and long-haul flying, an energy transition away from fossil-based fuels and towards sustainable sources of liquid fuel is needed. Luckily, the industry has already been hard at work in this area. Over 200,000 commercial flights have now taken place since we gained certification for the use of sustainable aviation fuel in 2011. It is in regular use at five global airports, but the percentage of total fuel use is still very small."*
>
> *-Air Transport Action Group, September 2019*

Notwithstanding this significant progress to systematically shift commercial airlines over to SAF, worldwide use remains very limited (see ATAG callout quote). Moreover, at this relatively early stage it can be challenging to find verifiable information about specific volumes of SAF currently produced and consumed. The Rocky Mountain Institute estimated that during 2018, SAF constituted "less than 0.01% of global consumption" for aviation fuel, equating to "about 5 million gallons per year."[50] Neste Corporation, with the world's largest capacity to produce SAF and other biofuels for transportation, stated in 2018 that "a mere 6.6 million gallons" of SAF are produced annually "on a commercial scale" (globally).[51] Although the U.S. Energy Information Administration (EIA) does not report SAF production or consumption, EPA reports RFS RIN data, "which indicate that the United States consumed 2.4 million gallons" of neat SAF in 2019.[52] While 2020 RIN data are not yet complete, it appears that roughly 3.6 million gallons of neat SAF were produced through August 2020. [53]

Part of the uncertainty about actual SAF usage may involve inconsistent nomenclature. First, statements about SAF volumes often do not specify if they refer to neat (100 percent SAF), or to ASTM-compliant blends (up to 50 percent). Second, fuel producers tend to emphasize emerging or future production "capacity," rather than actual current production, with some exceptions. Similarly, end-users (airlines) tend to speak about future (and confidential) "commitments" to use SAF, rather than current actual use. Based on various public sources of information, a reasonable estimate is that roughly 8 to 9 million gallons per year of SAF blends are currently being dispensed in the U.S. commercial aviation sector, with typical blends constituting 30 percent SAF. This does not take into account the impact of Covid-19, which has resulted in major reductions of CJF use since Q1 of 2020, but may be reducing SAF blend use at a much lower rate.

[49] Personal correspondence to GNA from a SAF supplier for general and business aviation flights, October 2020.
[50] Craig Schiller, Rocky Mountain Institute, "Greening Aviation: Sustainability Takes Flight with Leading Airlines," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.
[51] Neste Corporation, "Renewable Jet Fuel, why does it cost more, August 30, 2018, https://www.neste.com/blog/aviation/renewable-jet-fuel-why-does-it-cost-more.
[52] National Renewable Energy Laboratory, "Renewable Hydrocarbon Biofuels," https://afdc.energy.gov/fuels/emerging_hydrocarbon.html.
[53] https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rins-generated-transactions

3.3. Key Drivers for Expanded Use

According to EIA's (pre-COVID) estimate, U.S. consumption of jet fuel will grow more than any other transportation energy source over the next 30 years, with the exception of electricity. EIA notes that increased demand for air transportation will "outpace" improvements in aircraft fuel efficiency.[54] In fact, the limits of using aircraft fuel efficiency improvement to offset growing jet fuel use – and therefore to mitigate aviation-related GHG emissions under CORSIA and other key initiatives -- is becoming a key driver for expanded SAF production and use. As many aviation stakeholders have noted – and common-sense dictates – it is harder to reduce GHG emissions from aircraft compared to key other modes of transportation, i.e., ground vehicles and water vessels. Especially notable is that combustion-free aircraft (e.g., powered with batteries and/or hydrogen fuel cells) are in the very early stages of research and development. Once prototypes are developed, the technology will need to overcome major safety barriers due to the nature of air travel. By contrast, "zero-emission" heavy-duty battery-electric and fuel cell platforms have now been conceptually proven for ground transportation applications, and their commercialization is progressing rapidly – as are government goals, incentives and requirements applied to them.

Notably, non-U.S. companies and governments are also keenly aware that SAF can provide hard-to-obtain GHG reductions in commercial aviation. While California currently offers the most-attractive market for SAF due to its LCFS program, this landscape may be changing as international aviation companies also seek to procure growing volumes of SAF. Other nations – particularly those in the European Union – already have favorable policies and may allow begin to "outpace" California as a market draw for SAF. This could make it increasingly difficult for airlines serving California airports – in particular SFO in the Bay Area -- to procure the large volumes of SAF they seek.

But for now, a key dynamic for SAF supply available at California airports relates to its close ties with RD production. A key question: is there greater potential societal benefit in maximizing SAF production to help decarbonize commercial aviation, while reducing volumes of co-produced RD for use in heavy-duty ground transportation? According to LCFS data for 2019, the volume of RD supplied for ground transportation applications in California currently exceeds the volume of SAF ("AJF") by a factor of approximately 300 to 1.[55] What is the future mix of these two renewable transportation fuel that will best and most cost effectively advance California's GHG-reduction goals, while accounting for the relative difficulty of decarbonizing the aviation sector? These complex questions are reportedly under discussion at high levels by CARB officials and state officials. Key overarching issues are further discussed in Sections 4 and 9.2.

[54]U.S. Energy Information Administration, "Annual Energy Outlook 2019 with Projections to 2050," January 4, 2019, https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf.
[55]CARB, Low Carbon Fuel Standard, Alternative Fuel Volumes and Credit Generation, averaging of Q3 and Q4 data, datasheet downloaded at https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm.

4. Supply Side: Feedstock, Producers, and Production Pathways

4.1. Feedstock Types

SAF (like the RD with which it is co-produced), can be made from a wide variety of non-petroleum renewable resources. Generally, feedstocks that can be used to produce SAF certifiable under ASTM D7566 fall in these categories:

- Fats, oils, and greases (FOGs),
- Carbohydrates/sugars (e.g., corn or sugarcane)
- Lignocellulosic (plant dry matter)
- Industrial wastes

One particular type of "FOG" – animal tallow from beef, sheep or chicken processing – is currently the leading feedstock used to co-produce RD and SAF. Animal tallow is fat (triglycerides) recovered by a rendering process. The animal residues are cooked, and the fat is recovered as it rises to the surface. Since animal tallow is a waste by-product, it is widely available in the U.S. as a relatively affordable feedstock. It can be harvested sustainably, as long as robust markets exist for meat and other animal products. While tallow dominates today, CARB has indicated that others (e.g., soybean oil) may be key feedstocks of the future for California's supply of both RD and SAF.

It is important to reiterate that the same feedstocks and process are currently used to co-produce RD and SAF. As described below, fuel producers control the relative yields of the two fuels, subject to limitations and tradeoffs. Additionally, the same feedstocks used to co-produce RD and SAF are also used to produce biodiesel. This general issue of feedstock competition as a potential barrier to wider use of SAF is further discussed in Section 9.2.

4.2. Production Processes and Pathways

As was described in Section 2.1, the current dominant method to produce SAF (as a co-product with RD) is "FOG" hydrotreatment (a HEFA process). Other SAF production pathways that have been approved under ASTM D7566 include -- but are not limited to -- 1) catalytic upgrading of sugars, 2) Fischer-Tropsch solid biomass-to-liquid 3) biogas-to-liquid, and 4) alcohol-to-jet. However, most of these other processes are not yet used to produce SAF (and RD) on a commercial scale.[56] As noted, neat SAF from any production pathway must be blended with conventional aviation turbine fuel and certified under ASTM D1655 before it can be dispensed into aircraft.

[56] National Renewable Energy Laboratory, "Renewable Diesel Fuel," Robert McCormick and Teresa Alleman, July 18, 2016, https://cleancities.energy.gov/files/u/news_events/document/document_url/182/McCormick___Alleman_RD_Overview_2016_07_18.pdf.

Importantly, the relative percentage varies for how much SAF these pathways produce. Subject to various limits and tradeoffs, producers can maximize the SAF yield relative to RD and other co-products. The International Council on Clean Transportation (ICCT) examined four processes and pathways to produce SAF, including the dominant HEFA pathway.[57] Figure 2 highlights "typical product slates" in terms of RD as the dominant co-product, with SAF being a sub-dominant co-product. Other subdominant co-products are renewable naphtha and propane. The first bar in the chart illustrates a typical product slate from a RD/SAF production facility using the HEFA process. As shown, this pathway produces about 75 percent of its total biofuel (by mass) as "Road fuels" (RD); "Jet fuel" (SAF) constitutes about 15 percent by mass. The remaining 10 percent are "Other products" (renewable propane and naphtha).

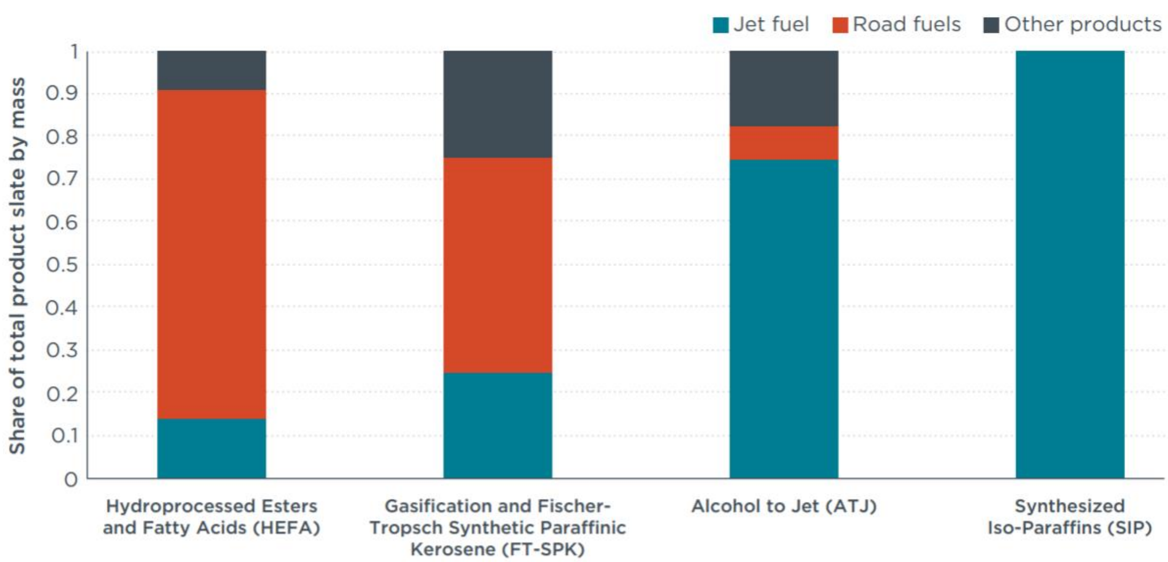

Figure 2. Typical product slates for SAF pathways (ICCT)

According to interviews with producers, this HEFA example reflects the high end of SAF yield that is regularly achieved today (up to about 15 percent by mass). In this case, the HEFA process has been geared towards producing RD for ground transportation as the dominant co-product. At this "typical" yield, SAF is reportedly produced at roughly the same cost as RD on a volumetric basis. However, the biofuel producer can choose to co-produce SAF at a much higher fraction of the product slate (up to about 50 percent). For example, as described below, producers can vary the type and/or loading of catalyst used during the HEFA process to increase the SAF yield (referred to below by its range of carbon atoms, C11 to C13), relative to the yield of RD (C14-C20) or the other co-products. (Note: they appears to be overlap

[57] ICCT, "Long-term aviation fuel decarbonization: Progress, roadblocks and policy opportunities," January 2019. https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf.

here; SAF is also listed today as being C8-16 or C8-18, with a significant percentage of molecules in the higher range.)[58]

> *"During hydroprocessing of triglycerides, the type of catalyst is one of the most important factors to determine the yield and composition of liquid products, such as green naphtha (C5-C10), green jet fuel (C11-C13), and green diesel (C14-C20), and even green liquid petroleum gas (LPG). A severe hydrocracking catalyst would lead to a high production of green naphtha whereas a mild-hydrocracking catalyst is prone to produce mainly green diesel. The reaction temperature plays an important role for the yield and quality of hydroprocessed oils as well."*[59]

Increasing the relative yield of SAF (and therefore reducing the RD yield) entails higher costs and other tradeoffs (see Section 8). Leading U.S.-based SAF producer World Energy confirms that its Paramount HEFA plant could produce SAF at 50 percent of the total yield. However, in current markets for biofuels, World Energy chooses to favor a high RD yield. Increasing the SAF yield requires "cracking" more longer-chain (C14+) RD molecules, which raises costs and may lower the overall biofuel yield. Moreover, SAF (and other lighter hydrocarbons that are increased) "trade at lower values" than RD. Thus, the aggregate value of the HEFA yield decreases.[60] Speaking about one specific HEFA pathway, Pearlson et al corroborate this by noting that choosing to maximize jet fuel production imposes higher costs "due to increased hydrogen use and decreased diesel and jet fuel yield."[61]

Notably, World Energy and other producers are continually seeking technological and economic solutions to improve their SAF yield, while minimizing such tradeoffs. If SAF becomes more valuable through technology, market and/or policy changes, producers will find it more attractive to increase the relative yield percentage for SAF.

Greater details about and repercussions of this differing value for SAF vs RD – and the tradeoffs associated with increasing the SAF yield – are discussed further in Section 8.

4.3. Major Producers and Production Volumes (Existing and Planned)

Figure 3, prepared by CAAFI as of June 2019, graphically depicts the location of the SAF production facilities in the U.S. that are commercially producing SAF today (green dots), under construction (blue dots), or planned (red dots).[62] As noted, the dominant current U.S. SAF production facility is World Energy's plant in Paramount, California. GEVO in eastern Texas is also producing commercial SAF, in small

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[58] Neste Corporation, personal communication to GNA, September 2020.
[59] "Hydroconversion of Triglycerides into Green Liquid Fuels," Rogelio Sotelo-Boyás, Fernando Trejo-Zárraga and Felipe de Jesús Hernández-Loyo, published October 2012, https://www.intechopen.com/books/hydrogenation/hydroconversion-of-triglycerides-into-green-liquid-fuels
[60] Personal communication from World Energy to GNA, August 2020.
[61] Matthew Pearlson, Wollersheim C, Hileman J.,"A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production," January 2013, https://onlinelibrary.wiley.com/doi/abs/10.1002/bbb.1378.
[62] CAAFI, "Current State of Alternative Jet Fuel Deployment," Power Point presentation, July 16, 2019, http://www.caafi.org/focus_areas/docs/Alternative_Jet_Fuel_Deployment_Status_July%202019.pdf.

volumes. Red Rock Biofuels (Nevada) and Fulcrum Bioenergy (Oregon) both anticipate bringing SAF production facilities online in late 2020 or early 2021. Within two years new SAF productions facilities in the Midwest and East Coast are expected to become operational from Gevo, Fulcrum Bioenergy, SG Preston, and Lanza Tech. (The information below is now becoming out of date, although -- as of this writing -- CAAFI has not updated the map version.)

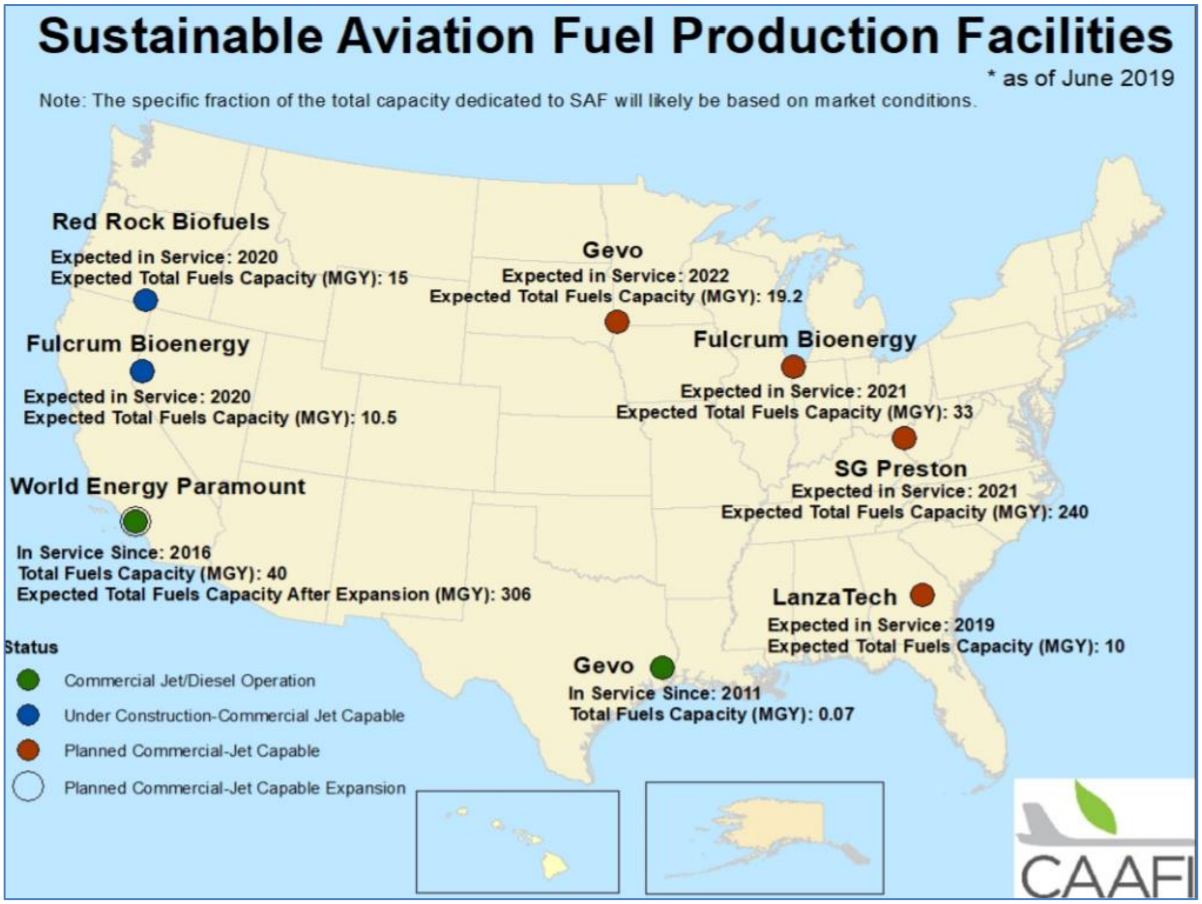

Figure 3. CAAFI's mid-2019 map of SAF production facilities (operating, under construction, and planned)

Other companies that produce (or plan to produce) SAF for U.S. commercial aviation include Neste and Velocys, which are both located outside the United States. Like World Energy, Neste is an important producer for SAF being dispensed at Bay Area airports. Neste, World Energy, Fulcrum and other key SAF producers (existing or planned) are further described below in the context of end use in the Bay Area.

Neste Corporation

Neste is the world's largest producer of biomass-based diesel (BBD) fuels used in high-horsepower compression-ignition engines for on-road and off-road transportation applications. Neste currently specializes – and leads the world in – producing RD via the HEFA pathway for heavy-duty ground transportation applications. In recent years Neste has increasingly focused on marketing and selling the co-produced kerosene jet fuel from this process, after upgrading it into ASTM-compliant SAF. Neste has branded this as Neste MY Renewable Jet Fuel™.

Currently, Neste has capacity at its three major production plants (Europe and Asia) to annually produce about 3.2 million tons (roughly 1 billion gallons) of biofuels for transportation. However, by expanding production capacity at Neste's Singapore biofuels, the company is in the process of increasing annual production capacity for all biofuel types by 50 percent, up to 4.8 million tons (about 1.6 billion gallons).

Currently, the vast majority of Neste's production capacity is dedicated to making RD for ground transportation. Only about 3.3 percent (~100,000 tons / 34 million gallons) of Neste's annual biofuel production capacity appears to be geared for making SAF. This capacity primarily exists at the Porvoo (Finland) production facility. However, as part of the Singapore plant expansion (to be completed in the 2023 timeframe), it appears that Neste is planning a 10-fold increase in its annual capacity to produce SAF (increasing from 100,000 to 1 million tons).[63] Neste is also conducting a feasibility study to potentially add major SAF production capacity at its Rotterdam biofuels production facility.[64]

It is important to note that these numbers refer to current and future production capacities, but not necessarily actual fuel production. Like the airline industry, Neste believes SAF has emerged as "the most effective method for decarbonizing aviation today." [65] However, as further described in Section 8.3, a gallon of RD currently has greater market value than a gallon of SAF. Ultimately, Neste (and other existing or potential SAF producers) will rely on dynamic market conditions to determine how much of their transportation biofuel production should be geared towards SAF vs RD.

Previously, Neste facilitated single test flights of its SAF blends with major airlines that include Qantas, Virgin Atlantic, JAL, KLM, Air New Zealand, and the U.S. Air Force. Neste now supplies (or expects to soon supply) SAF at a variety of airports around the world; U.S. locations include SFO, Chicago O'Hare and LAX.[66] In fact, as further discussed in Section 6, Neste is becoming a major supplier of SAF at SFO in the Bay Area. According to public statements, Neste's SAF product (RJF) "is already available at industrial scale," and "successful commercial use has been achieved." While Neste estimates that "widespread continuous use" of SAF is imminent, the company also stresses that this will require greater policy and stakeholder support.

World Energy

Boston-based World Energy is the U.S. leader for *actual production* of SAF, and possibly the world's leading producer. (Note: Neste does not disclose actual production volumes, but the company is "very confident" it has become the world's largest SAF producer.[67]) In March 2018, World Energy acquired all

[63] Neste Corp., "Neste's role in sustainable aviation," accessed July 2020, https://www.neste.com/companies/products/aviation/neste-my-renewable-jet-fuel.
[64] Neste Corp., personal communication to GNA, September 2020.
[65] Neste Corp., https://www.youtube.com/watch?time_continue=77&v=mOTp6x0LWFM.
[66] Lana Van Marter, Commercial Development Manager, Neste Corp., presentation at ACT Expo "Greening Aviation" session, April 26, 2019.6
[67] Neste Corp., personal communication to GNA, September 2020.

assets of AltAir's Paramount (California) biorefinery, for a cost that was reportedly $72 million.[68] Today, World Energy makes approximately 45 million gallons of BBD fuels, using four different CARB-certified HEFA pathways (refer back to Table 4). The bulk of the BBD fuel that World Energy produces at the Paramount plant is RD for ground transportation, which is primarily sold to big fleet customers like UPS.

No firm numbers are provided by World Energy, but it appears that SAF constitutes less than 10 percent of its current BBD production at the Paramount plant. Most of this (up to 5 million gallons per year) is purchased by United Airlines. In fact, World Energy has executed an agreement that makes United Airlines its exclusive SAF customer for U.S. based commercial passenger aviation. To date, most of the SAF that World Energy supplies to United Airlines is dispensed at nearby LAX. However, World Energy has also been supplying SAF to SFO "for many years," [69] and international airline SAF customers have included Singapore, Finnair and Air France.[70] Some (if not all) of World Energy's SAF currently going to SFO appears to be sold to international carriers like these, as well as cargo airlines (see Section 6).

In late 2018, World Energy announced a $350 million expansion of the Paramount biorefinery, which will increase annual production of all BBD fuels to 306 million gallons. World Energy notes that about half of this increased production capacity (150 million gallons per year) will be dedicated to SAF; the remainder will be for RD and renewable propane.[71] However – similar to the case with Neste's expanded production in Singapore – World Energy will rely on market dynamics (including but not limited to relative values) to guide the ultimate percentages of SAF, RD and renewable propane it produces at the Paramount production plant (see Section 8.3).

Apparently, World Energy will distribute at least some of this new, much-larger SAF production through its new partnership with a major, long-standing aviation fuel provider. In January 2020, World Energy and Shell Aviation jointly announced a collaboration to "develop a scalable supply" of SAF. The multiyear effort between the two companies will supply "up to one million gallons" of SAF to the SFO operations of Lufthansa Airlines (notably, not a North American airline, so this stays within World Energy's agreement with United Airlines). The SAF will be blended with CJF "at a ratio of up to 30%" into a CARB-certified low-CI aviation fuel. [72] Lufthansa has also partnered

Figure 4. World Energy's Paramount plant (photo by GNA)

[68] GreenAironline.com, "World Energy acquires AltAir's world-first commercial scale renewable jet fuel refinery," March 2018, https://www.greenaironline.com/news.php?viewStory=2465.
[69] Personal communication from World Energy to GNA, August 2020.
[70] Personal communication from Erin Cooke of SFO to GNA, September 2020.
[71] Biomass Magazine, "World Energy Invests $350M to Expand Paramount Biofuel Production, article by World Energy, October 4, 2018, http://biomassmagazine.com/articles/15699/world-energy-invests-350m-to-expand-paramount-biofuel-production.
[72] Shell Aviation, "Shell Aviation and World Energy Collaborate to Increase Supply of Sustainable Aviation Fuel," press release, January 7, 2020, https://www.shell.com/business-customers/aviation/news-and-media-releases/news-and-media-2020/shell-aviation-and-world-energy-collaborate-to-increase-supply-of-sustainable-aviation-fuel.html.

with Neste since 2011 to pilot SAF use in European commercial flights; the two companies announced further collaboration in October 2019.[73]

World Energy's SAF will also be used by Amazon Corporation, which has committed to achieve carbon neutrality by 2024. Reportedly, Amazon "aims to compete with FedEx and UPS in the logistics and shipping industry," and its emerging airline Prime Air has tested out SAF blends on at least two flights. In July 2020, Amazon announced that the company "has secured up to six million gallons" of blended SAF under a year-long procurement deal with World Energy as the fuel producer, and Shell Aviation as the supplier. Thus, it appears that Amazon Prime Air may be the largest offtake customer for SAF produced and supplied under the above-noted World Energy-Shell Aviation partnership. Amazon's press release is not clear whether the SAF it procures will be dispensed at one or more Bay Area airports. Notably, Amazon's major hub for air operations will be in Kentucky.[74]

Amazon states that the blended SAF it procures will reduce carbon emissions in the range of 20 to 22 percent.[75] As noted above, World Energy's approved LCFS pathways have carbon intensity (CI) values that range from 52 to 73 percent lower than the current CI of CJF. Assuming World Energy's best-case CI pathway for producing SAF, it can be deduced that Amazon will operate its cargo jets on a blend of about 30 percent SAF mixed with CJF, as follows:

SAF at -73% CI x 30% SAF blend = ~ -22% carbon emissions (full fuel cycle)

Based on this and the Lufthansa case described above, an approximate blend of 30 percent SAF / 70 percent CJF appears to be commonly used by World Energy's aviation customers. Notably, this is largely an academic estimate. Jet fuel is typically dispensed to aircraft using an underground common hydrant system, which "begins where fuel enters one or more tanks from an external source such as a pipeline, barge, rail car, or other motor fuel carrier."[76] This type of system is how SAF is now (or will be) introduced into the CJF supply at large airports like SFO. In this process, the SAF delivered by the supplier is blended into the hydrant system, and the percentage of SAF that ultimately reaches a given aircraft's fuel tanks may vary significantly.

Other Producers with Announced Plans or Potential to Supply Bay Area Airports

In addition to Neste and World Energy, other companies that currently produce SAF consumed at Bay Area airports – and/or have announced plans to build production facilities for this purpose – include Fulcrum BioEnergy, Red Rock Biofuels, SG Preston, and Phillips 66. Notably, two major domestic RD producers in the U.S. – Diamond Green Diesel and Renewable Energy Group – are likely working on their own efforts to produce and market SAF, which may ultimately be consumed at Bay Area airports.

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[73] Neste Corporation, "Neste and Lufthansa aim for a more sustainable aviation," press release, October 2, 2019, https://www.neste.com/releases-and-news/aviation/neste-and-lufthansa-collaborate-and-aim-more-sustainable-aviation.

[74] Amazon Corporation, "Promoting a more sustainable future for Amazon Air," The Amazon Blog, July 8, 2020, https://blog.aboutamazon.com/operations/promoting-a-more-sustainable-future-through-amazon-air .

[75] Amazon's web blog states "up to 20 percent;" the accompanying video on SAF states a 22 percent reduction.

[76] U.S. EPA, "Field-Constructed Tanks and Airport Hydrant Systems – 2015 Requirements, https://www.epa.gov/ust/field-constructed-tanks-and-airport-hydrant-systems-2015-requirements#ahs.

SAF producer developments relevant (or potentially relevant) to the Bay Area include:

- Red Rock Biofuels is building its production plant in Lakeview, Oregon. It will reportedly convert "136,000 tons of waste woody biomass into 15.1 million gallons/year of renewable fuels;" it's unclear how much will be RD for ground transportation versus SAF for aviation, but it appears that about 6 million gallons per year will be dedicated as SAF. Red Rock will focus on a Fischer-Tropsch pathway (FT-SPK) to make this biofuel.[77] It seems likely that a significant portion of this will be used at SFO and OAK.

- Fulcrum BioEnergy's plant near Reno, Nevada will be the nation's first commercial-scale plant to convert landfill waste into renewable fuel (RD as well as SAF). The resulting fuel will provide a "more than 80% reduction in lifecycle CO2 emissions." In 2014, Cathay Pacific made an undisclosed equity investment in Fulcrum.[78] In 2015, United Airlines made a $30 million equity investment in Fulcrum. Under the deal with United, Fulcrum will also build a SAF production facility in Gary, Indiana.[79] United Airlines has executed an offtake agreement with Fulcrum that appears to include up to 180 million gallons per year of SAF blends. It seems likely that a significant portion of this will be used for United's operations at SFO, or other Bay Area airports.

- Phillips 66's announced plans are of particular interest, to both SFO and the BAAQMD. Section 6 further discusses this case, in the context of SAF use at SFO.

- In the Pacific Northwest, the U.S. Department of Agriculture has joined with Alaska Airlines and SeaTac International Airport in an R&D project to convert local poplar trees to SAF. This type of alcohol-to-jet production pathway could eventually help bring SAF to the Bay Area. However, this process and project in particular do not yet appear to be producing significant volumes of SAF. [80]

4.4. Production Targets for Near and Longer Term

[77] Red Rock Biofuels, "Lakeview Project Summary," https://www.redrockbio.com/lakeview-site.html.
[78] Cathay Pacific, https://fulcrum-bioenergy.com/partners/cathay-pacific/.
[79] Ibid.
[80] Advanced Hardwood Biofuels Northwest, "Bridge to Biofuels: Renewable Biofuels and Biochemicals from Poplar Trees – Part 3 – Biojet Fuel, https://www.youtube.com/watch?v=pLye9duz1nU.

SAF Potential for Reducing GHG Emissions at Bay Area Airports

The Air Transport Action Group (ATAG)[81] considers SAF to be the key "long-term solution " for reducing commercial aviation GHG emissions, combined with "radical advances in technology."[82] As shown in Table 5, ATAG estimates that by 2025, the worldwide total "capacity of potential SAF production" will reach about 923 million neat gallons per year. (This is approximately equal to the current actual worldwide RD production). ATAG estimates it would take roughly twice that amount of SAF supply – about 1.85 billion neat gallons per year, or "around 2% of the overall jet fuel supply" – to "enable a tipping point in the supply / price balance, allowing more rapid deployment" of SAF. ATAG notes that this can only be achieved with "the right policy support."[83]

Table 5. ATAG Estimated SAF worldwide production capacity: mid-2020 and 2025

Parameter	2020 Estimated Actual	2025 ATAG: "Expected"*	2025 ATAG: Needed to "Enable Tipping Point" in Supply/Price
SAF Worldwide Production Capacity **(Neat)**	~6 to 7 Mgpy	923 Mgpy	1847 Mgpy
% of Current **CJF** Production	~0.01%	~1%	~2%
*SAF production plants and refineries "currently operating, under construction or advanced planning"			
Source: Air Transport Action Group (ATAG), May 2020 "Fact Sheet" on SAF (see text for full reference)			

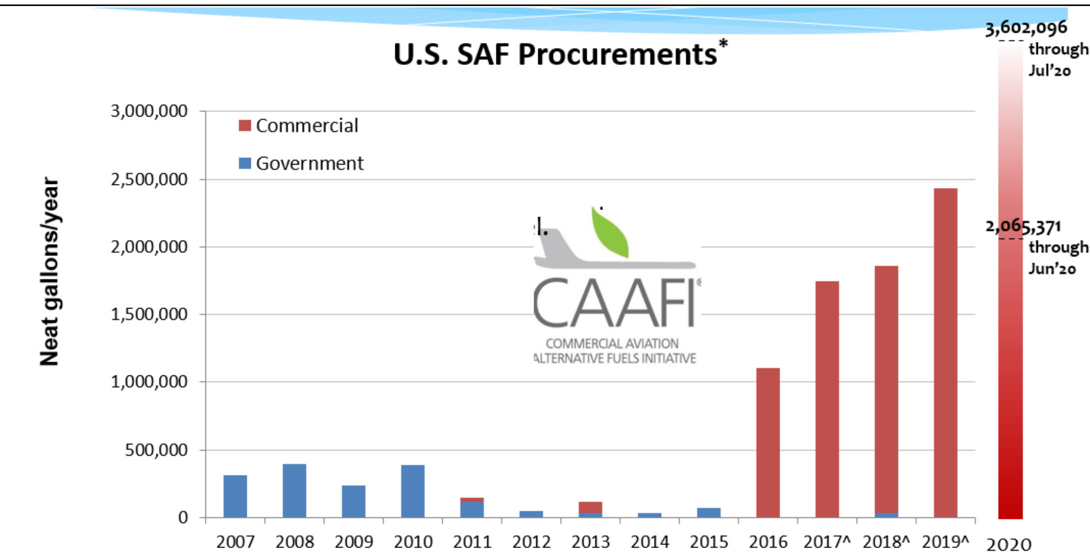
CAAFI, which leads a government-industry consortium to make SAF a widely used alternative to CJF in commercial aviation, estimates number that are in the same ballpark as ATAG. As of mid-2020, CAAFI reports that "several producers" plan to collectively produce approximately one billion gallons per year of neat SAF by 2026.[84] Blended at 30 percent SAF, this would result in more than three billion gallons of SAF fuel for use in the commercial aviation sector.

[81] ATAG (www.atag.org) "represents the entire aviation sector: airlines, airports, air traffic management organizations and the makers of aircraft and engines. It coordinates common industry positions on the sustainable future of air transport."
[82] ATAG, "Aviation Industry Welcomes Progress in CORSIA, Despite Global Emergency," press release, March 16, 2020.
[83]Air Transport Acton Group, "Aviation's Energy Transition, FACT SHEET #5," May 2020, http://www.caafi.org/resources/pdf/FACT_SHEET_5_Aviations_Energy_Transition.pdf.
[84]Personal communication from CAAFI to GNA, September 2020.

5. Demand Side: Commercial Aviation SAF Users

5.1. Overview

According to statistics provided (and continually updated) within ATAG's Aviation Benefits Beyond Borders report,[85] roughly 266,000 commercial flights have been operated (worldwide) on SAF blends since 2011. At least six airports "are currently regularly supplied with SAF," and at least nine airlines have arranged "significant off-take agreements" to purchase it. CAAFI calculates from actual SAF use reports that "procurements" of SAF have been steadily growing since 2016, especially in the commercial aviation sector. As shown in Figure 5, 2019 neat SAF procurements by U.S. airlines reached nearly 2.5 million gallons, and 2020 procurements are on track to exceed 4 million neat gallons.



Credit: FAA
*Reflects voluntarily reported data on use by U.S. airlines, U.S. government, manufacturers, other fuel users, and foreign carriers uplifting at U.S. airports.
^2017-2019 calculation includes reported EPA RFS2 RINs for jet fuel.

Source of graphic: CAAFI (slightly modified to fit document)

Figure 5. CAAFI's reported annual procurements of SAF for use at U.S. airports

5.2. Major Airlines Using SAF in California

Commercial Passenger Airlines

United Airlines is currently the largest user of SAF in North America, and possibly worldwide. United consumes about four billion gallons of CJF annually. CJF combustion makes up 99 percent of its carbon

[85] Aviation Benefits Beyond Borders, "Sustainable Aviation Fuel," accessed September 2, 2020, https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel.

footprint, which the airline has committed to reduce by 50 percent before 2050. To date, United has reduced GHG emissions by about 10 percent (relative to 2007 levels), but most of this was done through efficiency measures (e.g., a $2 billion investment per year to purchase more-fuel-efficient aircraft). Over the last five years, United has increasingly relied on fuel-related strategies to reduce aircraft-related GHG emissions. In March 2016, the airlines made its first flight on a SAF blend (LAX to San Francisco route). Since then, United has operated well over 4,000 flights on SAF blends, and it claims to currently consume as much as 50 percent of the U.S. SAF supply.[86]

United is now aggressively "scaling up biofuel use," to achieve its planned GHG reductions. This has necessitated active seeking of other SAF suppliers beyond Neste and World Energy, as well as investing in Fulcrum BioEnergy's greenfield production facility. United claims to have locked up "over half of the (airline) industry's biofuel commitments"[87] encumbered under offtake agreements, which it estimates at about 1.5 billion gallons over multiple years. Table 6 in the next subsection provides three different estimates for off-take agreements, including data provided by United Airlines.

As of July 2020, CAAFI indicated that United is "the only U.S. airline flying on SAF on a continuous basis."[88] However, that appears to be changing, with multiple airlines moving towards regular operation of certain flights on SAF blends. In fact, at least eight other passenger airlines are also testing SAF blends in flights departing from U.S. airports, including several that are operated out of SFO and other Bay Area airports. These include Alaska Airlines, American Airlines, and Cathay Pacific, which have joined United in striking deals with Neste and other suppliers for SFO flights. Section 6 further discusses various key Bay Area operations on SAF blends, in the context of the three major Bay Area commercial airports.

Commercial Cargo Airlines

Package and freight airlines have also initiated test programs to determine if SAF is an economically and technically feasible replacement for CJF. For example, in 2018 FedEx's "ecoDemonstrator" Boeing 777F became the company's first aircraft to fly on neat SAF. (Notably, this was a demonstration / R&D flight; use of neat SAF is not approved for commercial use in the U.S., primarily due to caution about materials compatibility issues that could compromise safety.) As further described, FedEx is now dispensing SAF blends at Bay Area airports, at demonstration scale.

Similar to the case with passenger airlines, use of SAF blends to date has primarily been a secondary strategy for package and freight airlines to reduce aviation-related footprints. FedEx and other carriers have achieved the bulk of their GHG reductions through efficiency improvements obtained via aircraft fleet modernization.[89] However, SAF is playing an increasing role in the sustainability strategies of cargo

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[86]Ibid.

[87]Aaron Stash, United Airlines Manager of Environmental Strategy and Sustainability, "Greening Aviation: Sustainability Takes Flight with United Airlines," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.

[88] CAAFI, "Current State of Alternative Jet Fuel Deployment," Power Point presentation, July 16, 2020, http://www.caafi.org/focus_areas/docs/Alternative_Jet_Fuel_Deployment_Status_July%202019.pdf.

[89]Allison Bird, FedEx, "Championing Sustainability in Air Freight," ACT Expo "Greening Aviation" session, April 26, 2019.

airlines. Amazon Prime, UPS and other cargo airlines are also testing and procuring SAF, with a focus on Bay Area airports (see Section 6).

5.3. Near-Term Expanded Use: Announced Offtake Agreements

At least nine airlines have negotiated "current forward purchase agreements" with SAF suppliers; these collectively encumber as much as 1.6 billion gallons of SAF over roughly a decade.[90] Table 6 summarizes three different sources that breakout rough estimates for airlines that have negotiated long-term off-take agreements, and their associated SAF producers/suppliers.

[90] Aviation Benefits Beyond Borders, "Sustainable Aviation Fuel," accessed September 2, 2020, https://aviationbenefits.org/environmental-efficiency/climate-action/sustainable-aviation-fuel.

Table 6. Estimated neat SAF volumes for announced commitments / offtake agreements

End User Airline *(Suppliers)*	United Airlines: Announced SAF Commitments	CARB: "Examples of Airline Partnerships with Producers"	CAAFI "SAF Offtake Agreements Beyond Numerous Demonstration Programs"
United ***(World Energy and Fulcrum BioEnergy)***	915 M gal (unspecified time)	• 5 mgpy from World Energy (unspecified time) • 90 to 180 mgpy (over 10 yrs) from Fulcrum	• 5 mgpy from World Energy (unspecified time) • 90 to 180 M gpy (10 yrs) from Fulcrum BioEnergy
Cathay Pacific ***(Fulcrum BioEnergy)***	375 M gal (unspecified time)	375 M gal (over 10 years)	• 37.5 M gpy (10 years)
JetBlue ***(SG Preston, Neste)***	99 M gal (unspecified time)	10 M gal (over 10 years)	• 10 M gal (10 years, JFK) • Unspecified volume from Neste
Quantas ***(SG Preston)***	40 M gal (unspecified time)	No information reported	• 4 M gpy (10 years, LAX)
Lufthansa / Austrian/ Brussels / Eurowings / Swiss ***(Gevo)***	40 M gal (unspecified time) for all	40 M gal (over 5 yrs) just for Lufthansa	• Unspecified volume from Neste for SFO operations
FedEx / Southwest ***(RedRock Biofuels)***	"Not publicly available"	• 3 mgpy for 8 yrs (Southwest)	• 3 M gpy each (7 yrs, Bay Area)
Air Canada / Japan / Alaska / KLM/ British Airways / Scandinavian / Delta ***(Neste, Other Suppliers)***	"Not publicly available"	• Unspecified small volumes	• KLM: 24 M gpy (10 years) • Delta: 10 M gpy (2022-23, term/blend unspecified) • Unspecified volume from Neste for SFO operations
Virgin Atlantic ***(LanzaTech/LazaJet)***	• No information	• No information	• 100 M gpy by 2023 from 4 facilities
Amazon Prime Air ***(World Energy)***	• No information	• No information	• 1.8 M g over 12 months
Air British Petroleum ***(Fulcrum BioEnergy, Neste)***	• No information	• No information	• 50 M gpy (over 10 years) from Fulcrum • Unspecified volume from Neste for SFO operations
American ***(Neste)***	• No information	• No information	• 9 M gal over 3 years (source for this is American Airlines)
Alaska ***(Neste)***	• No information	• No information	• Undisclosed volume /term (source for this is Neste)
Signature Flight Support ***(Neste)***	• No information	• No information	• 5 M gal / undisclosed term (source for this is Neste)

Source cited by UA: see text footnote, citing industry press releases and UA's assumptions for scale-ups
Source for CARB: https://ww3.arb.ca.gov/fuels/lcfs/lcfs_meetings/031717presentation.pdf
Source for CAAFI (except as indicated): "SAF offtake agreements," July 22, 2020 Power Point presentation provided to GNA by Steve Csonka of CAAFI

Like current use, it can be challenging to accurately tally how much SAF will actually be consumed in U.S. commercial aviation within the next few years, due to hazy terminology. As of mid-2020, CAAFI estimates that ">350 M gpy" of neat SAF are committed for near-term purchase under existing airline offtake agreements, "with more in development."[91]

[91] CAAFI, "U.S. SAF Procurements" as of September 16, 2020, Power Point slide provided by CAAFI to GNA.

6. A Closer Look: SAF Use at Major Bay Area Airports

6.1. San Francisco International Airport

San Francisco International Airport (SFO) is the nation's seventh largest airport for annual passenger throughput.[92] SFO is by far the largest airport in the Bay Area, annually serving roughly 58 million incoming and outgoing passengers with at least 58 different airlines. Each year, airlines operating at SFO dispense approximately one billion gallon of conventional jet ("Jet A") fuel.[93] (Notably, in 2019 this reached 1.2 billion gallons.[94] Of the three largest Bay Area commercial airports (SFO, OAK and SJC), nearly two-thirds of the annual landings and takeoffs (LTOs) occur at SFO, accounting for 72 percent of the GHG ("CO_2e") total emissions (Scopes 1, 2, and 3) at these three airports.[95]

SFO has adopted a five-year Strategic Plan that includes a goal to achieve "carbon neutrality" and reduce "SFO-controlled" (Scope 1, 2) GHG emissions by 50 percent. This feeds into California's overarching State policy to achieve a 40 percent reduction in all GHG emissions from a 1990 baseline by 2030. SFO notes that a key GHG-reduction strategy within its annual Climate Action Plan is to support its commercial aviation airline partners in obtaining and using SAF. In fact, SFO states that

> *"Aircraft are overwhelmingly the single largest source of emissions at SFO. To address this, SFO is leading the world's largest initiative to develop and deploy SAF at an airport. In FY 2020, SFO expects to be a leading airport for SAF deliveries, and is leading a coalition of airlines, fuel producers, and NGOs to expand SAF industry incentives and investment to drive the market in California and beyond."*[96]

SFO was one of the first airports in the world to recognize the potential of SAF as a clean alternative fuel for commercial aviation operations. In 2017, the SFO Airport Commission adopted an "Airport Policy on the Advancement" of SAF, to further explore SAF's potential to reduce aircraft-related emissions of GHGs, as well as criteria pollutants (specifically, particulate matter and sulfur oxides). By that same year, SFO had "facilitated a series of twelve SAF demonstration flights" in partnership with Singapore Airlines. SFO also began partnering with the City of San Francisco's Department of Environment to "carefully analyze the use and adoption of SAF in the context of international, federal, state and local sustainability and environmental requirements and best practices for organizational and infrastructure resilience."[97]

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[92] World Airport Codes, "US Top 40 Airports, https://www.world-airport-codes.com/us-top-40-airports.html.

[93] Erin Cooke, Sustainability Director, SFO, "Sustainable Aviation Fuel: State of the Industry and California's Emerging Opportunities," Power Point slide presentation, circa 2017 (undated).

[94] Personal communication to GNA from Erin Cooke, SFO, September 2020.

[95] Airport LTO and GHG data provided to GNA by BAAQMD via personal communication, July 2020.

[96] San Francisco International Airport, "Climate Action Plan 2019," https://www.flysfo.com/sites/default/files/media/sfo/community-environment/SFO_Climate_Action_Plan_FY19_Final.pdf.

[97] San Francisco International Airport, "Director's Recommendation: Adopt Airport Policy on the Advancement of Sustainable Aviation Fuels," Memorandum to Airport Commission, December 19, 2017.

SAF Potential for Reducing GHG Emissions at Bay Area Airports

In September 2018, SFO signed a memorandum of understanding (MOU) with four airlines (United, Alaska, American, and Cathay Pacific) and four fuel producers (Shell, Chevron, Neste and LanzaTech) to work cooperatively on expanding SAF use at the airport. According to SFO's press release, this agreement was "the first of its kind to include fuel suppliers, airlines, and airport agencies in a collaborative effort to accelerate the global transition to sustainable fuels."[98] SFO has since added Gevo, ANA and San Diego Airport to its list of MOU signatories, while continuing to court other parties.

In 2019 -- as an extension of previous collaborative work by SFO, airlines, and aviation partners -- SFO commissioned a "Sustainable Aviation Fuel (SAF) Feasibility Study." [99] This study provided new assessments regarding SAF's commercial feasibility, viability, and infrastructure needs at SFO. Key findings of the study are summarized (paraphrased) as follows:

- **Current supply chain** - SFO currently has approximately 750,000 bbls (31.5 million gallons) of fuel storage "available" for storing SAF. Additional storage volume is needed over the "medium to long term."
- **Multi-modal transport** - Trucking, pipeline, rail, and waterborne pathways exists at SFO for potential SAF delivery, although they are not yet "ideal" and/or fully suitable for transporting SAF.
- **SAF production and supply** – Supply of SAF available to SFO -- as well as means of SAF production -- are currently limited. However, significant growth for both production and supply is underway. Some involves expansion of foreign facilities, although imported SAF will be "more difficult to rely upon."
- **Potential storage and blending sites** - The study identified nine "short list" sites that need "infrastructure and supply chain modifications" to enable wider use of SAF at SFO. For the mid and long term, "existing refinery sites" were ranked the highest (based on criteria including site development, logistics, planning/permitting, environmental, community acceptance, and contingency/operational risk). Three Northern California refinery sites (Chevron in Richmond, PBF Energy in Martinez, and Phillips 66 in Rodeo) were noted for strong potential for both on-site production and storage in the future. (See the discussion below about Phillips' August 2020 announcement that it will "reconfigure" its Rodeo petroleum refinery into a biofuels production facility for RD and SAF, using a HEFA pathway.)
- **Funding Mechanisms and Support** – The study identified various state, federal and local sources of potential funding that can be used to help facilitate expanded use of SAF at SFO.

[98] San Francisco International Airport, "SFO Announces Landmark Agreement for Use of Sustainable Aviation Fuels," press release, September 5, 2018.
[99] San Francisco International Airport, "Sustainable Aviation Fuel Feasibility Study," Final Report, September 2019, provided to GNA by SFO staff, July 2020.

SAF Potential for Reducing GHG Emissions at Bay Area Airports

The SFO study identified "volume targets" for phasing in use of SAF to displace CJF, from the near term (3 to 5 years) into the long term (10+ years). As shown in Table 7, roughly within the next five years, the target for SFO is approximately 30 million "neat" (unblended) gallons per year of SAF; this equates to about 2 percent of current SFO CJF use (pre-pandemic). Over the mid-to-long term (5 to 10 years, and beyond), the target is approximately 300 million neat gallons of SAF per year; this is about 17 percent current CJF use. Notably, at the current ASTM-approved blend limit for SAF (50% SAF, 50% CJF), these volumes can be doubled to arrive at the targeted volumes of blended SAF. For a 30 percent SAF blend, these volumes can be tripled.

Table 7. Low/High SAF volume targets at SFO compared to CJF
Millions of gallons per year

	Short Term (3-5 yrs)		Mid Term (5–10 yrs)		Long Term (10+ yrs)	
Type of Aviation Fuel	**Low**	**High**	**Low**	**High**	**Low**	**High**
Conventional Jet Fuel	**1200**	**1400**		**1800**	**>1800**	
Sustainable Aviation Fuel (Neat*)	**0**	**30**		**300**	**>300**	
% SAF use of current CJF use	NA	2.1%		~16.7%		16.7%+ (?)
SAF Production Source	Existing and Planned Facilities (U.S., Global)		Demand / Price Induced (West Coast, Global)		Mainstream California Production	

Source: adapted from SFO "Sustainable Aviation Fuel Feasibility Study," September 2019 (Fig. 10, p. 17)
*Unblended (100%) SAF; at current ASTM-approved blend (50% SAF), these volumes can be doubled for useable SAF.

SFO's 2019 study identified likely sources of production for the targeted volumes of SAF over these same time periods. As indicated in the table, SFO's long-term plan is to transition toward getting all of its SAF from "mainstream California production" facilities.

Since the 2019 SAF study was commissioned, SFO has been implementing actions designed to make progressively larger SAF volumes available to its airline partners, under the airport's overarching "push towards net-zero carbon." In July 2020, SFO announced it joined with Neste Corporation to deliver an initial "batch" of SAF to select SFO airlines via an existing "multiproduct" pipeline. In an SFO / Neste press release, specific SAF quantities were not disclosed, but "high volumes" of SAF are reportedly already being transported via this system. In an August 2020 press release, Neste announced it is now supplying unspecified volumes of SAF blends to three airlines at SFO – Alaska, American and JetBlue -- as part of the umbrella MOU signed in 2018.[100]

Neste's raw biofuel product is shipped from its Porvoo (Finland) biofuels plant to Houston, where it undergoes final refining into SAF and RD. Neste uses Crowley to transport fully-conditioned and blended SAF from Houston to the Bay Area via a short-sea shipping tanker, where it is introduced into the pipeline

[100] Neste Corporation, "Neste to supply sustainable aviation fuel to three major U.S.airlines," press release of August 13, 2020, https://www.neste.us/www.neste.us/about-neste/news-inspiration/articles/Neste-supplies-sustainable-aviation-fuel-to-major-US-airlines.

that serves SFO's Fuel Farm.[101] Specifically -- based on detailed discussion from SFO's September 2019 "Feasibility" report about SAF – it appears that Neste's SAF is being delivered via part of the Kinder Morgan Santa Fe Pacific Pipeline (KM SFPP) network. Notably, only blended SAF (certified to ASTM 1655) can be introduced into the KM SFPP, which is regulated by the California Public Utility Commission. The KM SFPP also serves fuel farms at (or near) Oakland International Airport and San Jose International Airport.[102] (Extensive discussion of the KM SFPP's relevance as a potential SAF supply and distribution network for SFO -- as well as other parts of the Bay Area -- is provided in SFO's September 2019 SAF "Feasibility" Study.[103])

In mid-2020, Phillips 66 announced it will "reconfigure" its Bay Area refinery (Rodeo) to produce renewable fuels. As noted above, SFO's detailed SAF "Feasibility" study (September 2019) "short listed" this traditional petroleum refinery as one of several sites having good mid- and long-term potential for "storing, blending, and supplying SAF to SFO" (as well as other Bay Area airports, like Oakland International).[104] According to Phillips' press release, it will discontinue producing transportation fuels from crude oil, and transition the refinery to produce biofuels. Specifically, Phillips will co-produce RD, SAF and other products from feedstock that include used cooking oil, fats, greases and soybean oils. While not stated, this appears to be a HEFA pathway.

Phillips indicates that 1) the modified refinery will eventually produce 680 million gallons per year of these various renewable transportation fuels, although the SAF portion is not estimated. It states that the reconfigured Rodeo plant will become "the world's largest facility of its kind," with a total renewable fuel production "exceeding 800 million gallons per year when combined with the production of renewable fuels from an existing project in development." Production of RD, SAF and the other co-products is expected to begin in early 2024, "if approved by Contra Costa County officials and the Bay Area Air Quality Management District."[105]

It also appears that airlines seeking to use SAF at SFO may source it from Red Rock Biofuel's production plant in Oregon, once that facility is completed and starts production. Initially, it appears that Red Rock's SAF production will be used at Oakland International Airport (see below). SFO notes that "there will likely be opportunities to integrate supply chains, including blending and storage, with the supply to Oakland International Airport."[106]

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[101] San Francisco International Airport, "A Milestone for SFO: Neste Makes First Pipeline Delivery of Sustainable Aviation Fuel," joint press release with Neste Corp., July 7, 2020.
[102] According to Kinder Morgan (www.kindermorgan.com), its "Pacific Operations" pipeline network transports "more and one million barrels per day of gasoline, jet fuel, and diesel fuel" to western U.S. customers.
[103] San Francisco International Airport, "Sustainable Aviation Fuel Feasibility Study," Final Report, September 2019, provided to GNA by SFO staff, July 2020.
[104] See Table 6 on page 18 of SFO's 2019 SAF Feasibility study.
[105] Phillips 66, "Phillips 66 Plans to Transform San Francisco Refinery into World's Largest Renewable Fuels Plant, press release, August 12, 2020, https://www.wsj.com/articles/u-s-refiners-embrace-greener-fuels-11597251600.
[106] Ibid.

6.2. Oakland International Airport

Oakland International (OAK) is the second busiest airport in the Bay Area, and the fourth largest in California. This "primarily commercial service" airport serves more than "60 nonstop destinations on 14 different airline brands."[107] To date, it appears that use of SAF at OAK has been focused on FedEx's air cargo operations. Specifically, FedEx has announced plans to use up to three million gallons per year of SAF at its OAK air cargo hub. Additionally, but at least one passenger airline, Southwest, will also get SAF at OAK. Per CAAFI's estimate noted above, both FedEx and Southwest have signed offtake agreements with Red Rock Biofuels to each receive three million gallons per year of SAF, over seven years. Neat SAF supply will be shipped from the Red Rock refinery by truck or rail to a blending location and then "trucked to the Oakland International Airport fuel farm."[108]

The Red Rock SAF production plant in Lakeview was scheduled to begin operation in the Spring of 2020, but it appears to be significantly behind schedule.[109] Thus, it is not clear when FedEx and Southwest jets serving Oakland International will start using SAF blends from Red Rock Biofuels, but a start in 2021 seems likely.[110]

6.3. San Jose International Airport

San Jose International Airport (SJC) -- self-described as "Silicon Valley's Airport -- serves approximately 16 million passengers per year. Roughly, SJC is comparable to Oakland International in terms of market share for Bay Area passengers.[111] SJC has a "comprehensive" alternative fuels program that focuses on achieving GHG and criteria pollutant reductions, but this appears to be solely focused on ground transportation serving the airport. Based on extensive searching of SJC's website (mid-2020), the airport has not yet publicly announced plans to use SAF blends to reduce aviation-related GHG emissions. However, it is likely that SJC management is studying this potential, including possible synergy with SFO and/or OAK to support customer airlines in procuring SAF blends.

[107] Oakland International Airport, "About Oakland International Airport," https://www.oaklandairport.com/oakland-international-airport-goes-green-blue-natural-gas-buses/.

[108] Ibid.

[109] Red Rock Biofuels, presentation at ABLC Next by founder / CFO Jeff Manternach, October 2019, https://www.biofuelsdigest.com/bdigest/2020/01/12/from-woody-biomass-to-renewable-fuels-the-digests-2020-multi-slide-guide-to-red-rock-biofuels-lakeview-project/.

[110] Personal communication from CAAFI to GNA, September 2020.

[111] San Jose International Airport, "2019 Facts and Figures," https://www.flysanjose.com/sites/default/files/financial/activity_reports/2019%20Facts%20%26%20Figures.pdf.

7. High-Level Estimate of SAF-Related Emissions Benefits at Top Bay Area Airports

7.1. Greenhouse Gases

The BAAQMD maintains a district-wide GHG emissions inventory for a wide range of stationary and mobile sources, including aircraft. GHG emissions from aircraft are differentiated within the inventory by county and type of aviation (commercial, general, and military). Table 8 summarizes the direct GHG emissions (in metric tons CO2-equivalent) for the three major Bay Area airports for calendar year 2019, based on the emissions inventory.[112] These data represent estimated emissions occurring during the landing and takeoff (LTO) cycle, including flight from an altitude of approximately 2,300 feet[113] to ground level, on-ground taxi and idling, and take-off from ground level to 2,300 feet for commercial jet aircraft. The direct GHG emissions reported for each airport are translated into implied fuel consumption volumes using an emissions factor of 9.61 kgCO2e per gallon of CJF, derived from CARB's CA-GREET 3.0 model. This emissions factor is consistent with the emissions factors used in the BAAQMD GHG emissions inventory.

Table 8. Top BAAQMD airports: GHG emissions inventory from LTO events, and implied fuel consumption

Airport	Airport Type	Fuel/Engine Type	Direct GHG Emissions ($mtCO_2eq$ / year)	Implied Fuel Consumption During LTO Events (gal/year)
San Francisco International (SFO)	Commercial	Jet	1,332,084	138,650,209
Oakland International (OAK)			334,029	34,767,451
San José International (SJC)			188,270	19,596,156
			Total	**193,013,816**

Note: GHG emissions (and therefore implied CJF consumption) may not fully include business aviation or general aviation flights, which can entail a significant portion of total emissions and fuel demand. For example, business aviation reportedly accounts for 5 to 6 percent of total CJF consumption in the U.S.

Full fuel cycle emissions (often called well-to-wheels or WTW emissions) -- and any GHG benefits that can be expected from using SAF blends -- are estimated using CARB's LCFS program methodology and CI data. As previously noted, the LCFS program assumes a baseline CI for CJF of 89.37 gCO2e/MJ. The CI for SAF used in the calculations for this study is determined using LCFS program quarterly data for credit generation, and volumes of SAF from Q2 2019 through Q1 2020. Table 9 summarizes these data and the implied average CI in each quarter. Note that the implied CI for Q2 2019 is 50.00 gCO2e/MJ, which is the temporary CI for Alternative Jet Fuel in the LCFS program and indicates that volumes claimed in Q2 2019 were produced under a temporary pathway rather than the actual, certified pathway. Consequently, data for Q2 2019 are not included in estimates of the volume weighted average CI for SAF of 36.06 gCO2e/MJ.

[112] GHG emissions data provided by BAAQMD staff for CY2019. Implied fuel consumption calculated by authors.
[113] 2300 feet is the approximate elevation at which atmospheric conditions change the dynamics of GHG impacts on warming, particularly when taking into account contrails.

Table 9. CARB LCFS program data for SAF

Quarter	**Q2 2019**	**Q3 2019**	**Q4 2019**	**Q1 2020**
Credits	3,600	4,579	2,924	2,082
Volume (gal)	723,542	693,621	445,027	284,190
Energy Density (MJ/gal)	126.37	126.37	126.37	126.37
Volume (MJ)	91,434,003	87,652,886	56,238,062	35,913,090
Base CI (gCO2e/MJ)	89.37	89.37	89.37	89.37
GHG Reductions (gCO2e/MJ)	39.37	52.24	51.99	57.97
Implied Avg CI of SAF (gCO2e/MJ)	50.00	37.13	37.38	31.40
Volume Weighted Avg CI gC02e/MJ (Q3 2019 – Q1 2020)				**36.06**

As noted, SFO staff report that approximately 1 billion gallons of CJF are loaded onto aircraft at the airport each year (pre-pandemic). The BAAQMD GHG inventory implies that approximately 139 million gallons of CJF for SFO-serving flights are consumed within the District boundaries (i.e., during LTO events), or approximately 14 percent of the total CJF volume loaded at SFO. This ratio is assumed to apply to the two other major airports in the region for purposes of estimating the total CJF volumes loaded at each airport.[114] As shown in Table 10, the combined fuel volumes loaded onto aircraft at the three major airports is approximately 1.4 billion gallons per year. CJF use results in full-fuel-cycle GHG emissions of 15.7 million metric tons per year.

Table 10. Estimated full fuel cycle GHG (CO2e) emissions and projected reduction potential

Airport	**Implied Fuel Consumption (gal/year)**	**Estimated Fuel Loaded (gal/year)**	**WTW GHG Emissions (MT/year) Baseline CJF**	**Projected Reductions (MT/year) Full adoption of SAF5**	**Projected Reductions (MT/year) Full adoption of SAF25**	**Projected Reductions (MT/year) Full adoption of SAF50**
SFO	138,650,209	1,000,000,000	11,293,687	336,827	1,684,134	3,368,268
OAK	34,767,451	250,756,572	2,831,966	84,462	422,308	844,615
SJC	19,596,156	141,335,207	1,596,196	47,605	238,027	476,055
Total	**193,013,816**	**1,392,091,779**	**15,721,849**	**468,894**	**2,344,469**	**4,688,938**

As previously described, current HEFA-pathway neat SAF reduces GHG emissions by approximately 60 percent compared to CJF. However, SAF is required to be blended with CJF at no more than 50 percent by volume, and much lower-level blends can be used to extend volume and/or improve affordability. Therefore, annual GHG reductions from SAF blends are dependent on the average fraction of CJF replaced by SAF. As shown in Table 10 and summarized in Table 11, GHG reductions from SAF blends at five percent to fifty percent would produce GHG reductions of approximately 0.47 to 4.7 million metric tons per year based on 2019 emissions estimates. The "Total" GHG reductions reported in Table 11 reflect emissions

[114] It is recognized that a larger percentage of flights operating out of SFO are international flights and that OAK and SJC host a larger percentage of domestic/regional flights. These differences could impact the ratio of fuel loaded versus fuel consumed within the BAAQMD, making the estimate of 14 percent for all airports a rough approximation only.

from all fuel loaded at the region's airports. The reductions are not constrained to only the reductions that occur within the BAAQMD boundaries. Emissions reductions within BAAQMD boundaries are calculated assuming that 14 percent of fuel loaded in the BAAQMD is consumed in the BAAQMD, as previously discussed. These differences in regional and total emissions highlight the additional GHG reductions that can be achieved by leveraging policies that support availability of SAF in the BAAQMD.

Table 11. Summary of GHG reduction potential from SAF using 2019 volumes (metric tons/year)

Blend	Total GHG Reductions (MT CO2e/year)	BAAQMD GHG Reductions (MT CO2e/year)
SAF5	468,894	65,012
SAF25	2,344,469	325,061
SAF50	4,688,938	650,122

7.2. Criteria and Hazardous Air Pollutants

SAF can produce significant reductions in CO, SOx, and PM emissions from jet aircraft, as discussed in Section 2.4 of this report. Such reductions increase with the percentage of SAF relative to CJF, as summarized in Table 12. While these reductions are significant on a percentage basis within the sector, an analysis of total mass emissions reductions based on the BAAQMD emissions inventory was conducted to place the emissions reductions in context to District-wide emissions.

Table 12. Emissions reduction factors for SAF blends (source: ACRP 02-80 study)

Blend	CO	SOx	PM10
SAF5	1%	4%	9%
SAF25	5%	19%	40%
SAF50	11%	37%	65%

Emissions inventory data (2011 calendar year) for commercial aviation in the counties hosting the three major commercial airports were extracted from BAAQMD's inventory and used to represent baseline emissions of criteria pollutants resulting from CJF combustion. These emissions rates are summarized in Table 13. The NOx emission rates are provided for context; as described, no NOx reduction benefit is assumed for SAF blends.

Table 13. Baseline criteria pollutant emission rates (CY 2011)

	2011 Base Inventory (tons/day)			
Airport	**NOx**	**CO**	**SOx**	**PM_{10}**
San Francisco International (SFO)	7.0	9.8	0.6	0.1
Oakland International (OAK)	1.8	3.6	0.2	0.0
San José International (SJC)	1.1	1.6	0.0	0.0
	9.9	**15.0**	**0.8**	**0.1**

Baseline emissions rates were then escalated to calendar year 2019 levels using the relative increase in direct GHG emissions for each airport, as reported by BAAQMD staff when compared to the 2011 baseline GHG emissions inventory. OAK and SJC emissions are estimated to have increased by 9 percent between 2011 and 2019; SFO increased an estimated 2 percent (Table 14).

Table 14. Projected criteria pollutant emissions rates (CY 2019)

	From GHG Inventory	2019 Projected Inventory (tons/day)			
Airport	**Implied Growth (2011-2019)**	**NOx**	**CO**	**Sox**	**PM_{10}**
San Francisco International (SFO)	2%	7.1	10.0	0.6	0.1
Oakland International (OAK)	9%	2.0	3.9	0.2	0.0
San José International (SJC)	9%	1.2	1.7	0.0	0.0
Totals	4%	10.3	15.7	0.8	0.1

Potential emissions reductions from SAF were determined by applying the emissions reduction factors from Table 12 to the emissions inventory data in Table 14 for blend levels of 5 percent, 25 percent, and 50 percent SAF. Table 15 summarizes these results and indicates that displacing all CJF with a SAF50 blend could provide reductions in CO emissions of 1.72 tons per day, SOx emissions of 0.31 tons per day, and PM10 emissions of 0.07 tons per day.

Table 15. Summary of criteria air pollutant reduction potential from SAF (CY2019 tons per day)

Blend	NOx	CO	SOx	PM10
SAF5	0.00	0.16	0.03	0.01
SAF25	0.00	0.78	0.16	0.04
SAF50	0.00	1.72	0.31	0.07

8. Cost, Price and Relative Value

The costs to produce SAF -- and the prices that end users pay for it (accounting for incentives) -- are key determinants for the pace at which SAF will be able to displace very large volumes of CJF in Bay Area commercial aviation operations. Purchasing fuel typically represents 20 to 30 percent of an airlines' total expenses (second only to labor costs). Consequently, paying significantly more for SAF will play a big factor in the financial position and stability of adopting airlines. Notably, one cost-related advantage of SAF is that CJF pricing can be very volatile, as it tracks crude oil pricing.[115]

8.1. Costs of Producing SAF as a Function of Product Yield

SAF costs more to produce than conventional petroleum-based jet fuel. This is generally the case with renewable transportation fuels that are produced on a relatively small scale. The actual incremental cost to produce SAF can vary as a function of many factors. These include feedstock type and location, capital and operational costs associated with the production process (e.g., the cost to purchase hydrogen for the HEFA process), the targeted relative "yields" of SAF and co-products, and how far the final product must be transported to reach end-use markets.

The International Coalition for Clean Transportation (ICCT) recently evaluated the costs of producing SAF for use in European aviation markets. ICCT estimated that the levelized cost to produce SAF (assuming a ~15% baseline yield for a HEFA process) is about $0.98 to $1.21 per liter ($3.71 to $4.58 per gallon). By comparison, CJF is produced at a cost of approximately $0.54 per liter ($2.03 per gallon). Based on the <u>low</u> case for SAF ($3.71 per gallon), it costs about 83 percent (1.8 X) more to produce SAF than CJF. ICCT attributes much of this to feedstock costs (tallow or other sources of triglycerides), which represents 50 to 75 percent of the total production cost. ICCT notes that the incremental cost of producing SAF may be lower for larger future facilities, due to economies of scale and/or technology improvements.[116]

Based on comments by various biofuel producers, the current incremental cost of making SAF is even higher than 1.8 X. In a 2018 interview, leading biofuels producer Neste indicated it pays "somewhere in the region of 3-4 [times] more" to produce SAF than fossil jet fuel. The actual multiplier varies largely as a function of volatile CJF pricing.[117] According to a May 2020 "Fact Sheet" prepared by the Air Transport Action Group, estimates for the incremental cost of producing SAF range from "2X for some waste-based sources" (e.g., the currently leading HEFA pathway), to "6-10X for synthetic fuels using carbon capture." Similar to the ICCT report, ATAG notes that the combination of new SAF-production facilities being built,

[115] Statista, "U.S. Airline Fuel Cost from 2004 to 2019," https://www.statista.com/statistics/197689/us-airline-fuel-cost-since-2004/.
[116] ICCT, "The costs of supporting alternative jet fuels in the European Union," 2019.
[117] Statement by Neste's Damian McLoughlin, reported during interview by Airport-Technology.com, "Renewable jet fuels : how to handle the heavy costs," August 21, 2018, https://www.airport-technology.com/features/renewable-jet-fuels-how-to-handle-the-heavy-costs/.

in tandem with major airlines now committing to large-volume offtake agreements with SAF producers -- "will help bring down the cost of SAF in the mid-to-long-term."[118]

As previously noted, biofuel refineries can be modified to produce a higher fraction of SAF in the co-product slate (up to about 50 percent). However, this entails greater incremental cost and may compromise the overall biofuel yield's market value, depending on the production process. The additional cost is attributed largely to reduced overall fuel production, as a fraction of the initially dominant co-product RD must be upgraded to SAF through additional refining that reduces yields by about 10 percent. ICCT estimates that producing SAF via the HEFA process at a 50 percent yield adds an additional $0.30 per gallon.[119] And, as previously noted according to one major SAF producer's comments, the overall yield of all co-products becomes less valuable.

These dynamics were alluded to by RD producer Renewable Energy Group, Inc. (REG) in comments to CARB about the need to treat SAF production differently than RD in the LCFS:

> *"The vast majority of renewable fuel producers capable of manufacturing (SAF) are currently producing renewable fuels for on-road transportation use. Due to historic incentives, these facilities were designed, built, and operated to produce on-road fuel rather than (SAF). While these facilities are capable of producing (SAF) with little modification to their process, generally the production of (SAF) leads to decreased yields and increased operating expenditures when compared to on-road renewable fuel production."*[120]

This cost / price disparity has reportedly resulted in SAF providers "struggling to find buyers in the industry" for SAF, "due to high production costs and limited supply."[121] Currently, airlines using SAF at SFO pay about $1.00 to $1.25 per gallon more for neat SAF compared to CJF[122] -- after taking into account government subsidies through the LCFS and RFS2 programs (see 8.2). Notably, this does not seem to diminish airline demand for SAF at SFO, at least in the current demonstration scale of deployment. They understand that, while SAF is a premium jet fuel that costs more, it delivers important hard-to-find in-sector GHG reductions that provide both societal and corporate benefits.

Still, fuel cost premiums have a big impact on airlines purchasing large volumes of jet fuel, so the higher price of SAF is a big barrier to scaled-up use. For example, Alaska Airlines consumes about 500 million gallons of CJF each year. According to company management, even the smallest incremental cost per

[118] Air Transport Acton Group, "Aviation's Energy Transition, FACT SHEET #5," May 2020, http://www.caafi.org/resources/pdf/FACT_SHEET_5_Aviations_Energy_Transition.pdf.

[119] International Council on Clean Transportation, "Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities," Briefing paper, January 2019, https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf.

[120] Renewable Energy Group, Inc., comments submitted to CARB regarding addition of AJF to the LCFS, May 2, 2017, https://ww3.arb.ca.gov/fuels/lcfs/workshops/05022017_reg.pdf

[121] Airport-Technology.com, "Renewable jet fuels : how to handle the heavy costs," August 21, 2018, https://www.airport-technology.com/features/renewable-jet-fuels-how-to-handle-the-heavy-costs/.

[122] Personal communication from Erin Cooke and John Galloway (Environmental Dept at SFO) to GNA, telephone interview, August 12, 2020.

gallon has "tremendous" negative impact on the airline's bottom line. To help lower future costs and prices, Alaska continues to search for alternative ways and feedstocks to produce SAF.[123]

SAF is especially expensive and cost-prohibitive for airlines operating outside of carbon markets like the low-carbon fuel programs in California and Oregon (if even available). This is similar to the case of ground transportation fleets outside these states trying to purchase RD. As to be expected, major airports in California – specifically SFO and LAX – are leading the way to demonstrate SAF blends in commercial aircraft, thanks to significant "market pull" that emerged when CARB modified its LCFS program to make alternative jet fuel a credit generator, effective in 2019. The federal Renewable Fuel Standard also helps buy down the costs of producing and purchasing SAF, albeit to a lesser degree. The following summarizes how California's LCFS program combines with the Federal RFS to help reduce SAF costs to end-user airlines.

8.2. Monetization of SAF Benefits by Key Government Programs

State Low Carbon Fuel Programs

California's LCFS and its counterpart, Oregon's "Clean Fuels Program," are the only two state programs that have (to date) monetized SAF's GHG-reduction benefits. Both programs have enabled alternative jet fuel to generate sellable credits when dispensed into aircraft within their state boundaries. SAF Producers pass some of these credit values on to their airline customers. This makes it possible for airlines servicing California and Oregon airports to purchase SAF at a lower cost, although not on price parity with CJF. Further information is provided below about how SAF is monetized under the California LCFS program. Oregon's Clean Fuels program uses a similar structure.

[123] Statement by Alaska Airlines executive, "Bridge to Biofuels: Renewable Biofuels and Biochemicals from Poplar Trees – Part 3 – Biojet Fuel, https://www.youtube.com/watch?v=pLye9duz1nU.

Effective in 2019, CARB added "alternative jet fuel" (AJF, used synonymously with SAF) as a credit-generating option in the LCFS. Figure 6 provides CARB's "benchmarks" for the CI values of fuels to be substituted for CJF under the LCFS, for years 2019 to 2030 (and beyond). To generate LCFS credits each year, an AJF's CI value must be below the corresponding benchmark. Overall, from 2019 to 2030 the CI benchmark curve declines by 10 percent.

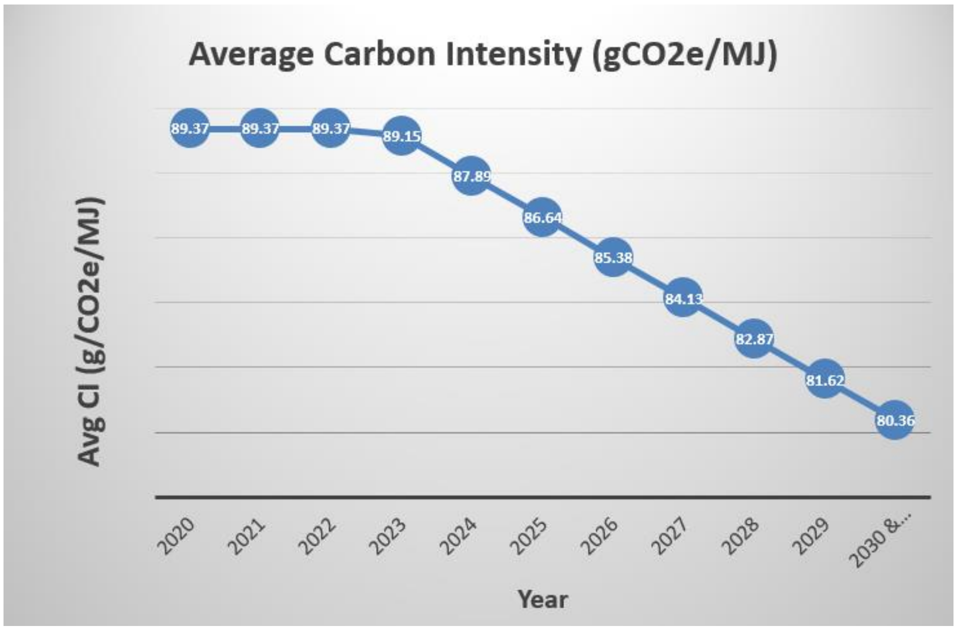

Figure 6. CARB's LCFS CI "benchmark" curve applicable to SAF credit generation

Upon this change, staff noted that SAF presents "major opportunity to generate LCFS credits." They estimated significant per-gallon values for SAF in the LCFS market as function of three feedstock types, all using a HEFA pathway. Table 16 provides CARB staff initial estimates[124] for the CI ratings and LCFS trading values of SAF made from animal tallow and two other feedstocks expected to become prominent for making SAF.

Table 16. CARB's assumptions for LCFS value of Alternative Jet Fuels by key feedstock

Feedstock	Assumed CI (gCO2e/MJ)	Reduction from 2020 Baseline (CI=89.37)	LCFS Value* ($/gallon)
Soybean	55.22	38%	$0.75
Tallow	37.61	58%	$1.14
Used Cooking Oil	22.40	75%	$1.47
Based on credit price of $190 / MT. (Prices currently range from about $188 to $210 / MT) *CARB assumes an energy density for AJFs of 126.37 MJ/gal* *CARB assumes an EER value of 1.0 for AJFs (i.e., same efficiency as conventional jet fuel)*			

[124] James Duffy, CARB, "Low Carbon Fuel Standard," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.

Notably, these were snapshots from early 2019; LCFS values are dynamic, depending on the value of LCFS credits, CI values of each pathway, and other factors. As further described below, the per-gallon LCFS credits for SAF can be significantly higher than shown in this table. However, the per-gallon LCFS value for SAF is not as high as RD used in ground transportation, even though they are currently co-produced using the same HEFA process and feedstocks. This important issue is discussed further in Section 8.3.

Federal Renewable Fuel Standard

At the federal level, EPA administers the Renewable Fuel Standard 2 program (RFS2), which also monetizes the societal benefits of renewable fuels, including SAF. Similar to California LCFS and Oregon Clean Fuels Program, jet fuel producers participate in RFS2 voluntarily – CJF producers are not subject to renewable "obligations." Producers (or importers) of "renewable jet fuel" (essentially SAF) can generate valuable "Renewable Identification Number" (RIN)[125] credits, provided their fuel meets applicable RFS2 definitions and EPA has approved a "D code" for it.

To date, EPA has approved multiple pathways that can be used to produce SAF and generate RINs. Notably, these pathways can also be used to produce RD and/or biodiesel for transportation use. Texmark-Neste's pathway (D-4 RIN), which EPA approved on September 23, 2019, appears to be the pathway for Neste's SAF now being provided to airlines at SFO. Under this pathway, Neste sells RD it produces in Finland (HEFA pathway) to Texmark Chemicals, Inc. Texmark fractionates this RD at its Texas facility, thereby producing SAF / RJF with entirely new D-code 4 RINs.[126]

As discussed below -- and similar to the case with LCFS credits -- under the current RFS structure the per-gallon value of HEFA-pathway SAF is worth about 6 percent less than RD used for ground transportation.

8.3. Current Market Value vs Renewable Diesel for Ground Transportation

Note: the discussion below provides an overview of key issues and implications associated with the relative market values of SAF versus RD. This topic has been extensively debated within aviation fuel stakeholders. For a comprehensive discussion that includes detailed perspectives from major biofuel producers – with CARB staff responses – see CARB's Final Statement of Reasons for the 2018 amendments to the LCFS that introduced alternative jet fuel into the program.[127]

Understanding the differential costs and values of SAF versus RD begins with the feedstock and refining biochemistry of these two co-products. The currently dominant HEFA production method co-produces a mixture of renewable long-chain paraffinic hydrocarbons in the boiling ranges of both jet and diesel fuel. RD is the dominant yield, with lighter chains like SAF being a subdominant coproduct. Based on limited

[125] RINs are tradeable commodities that represent gallons of renewable fuel produced and blended into U.S. gasoline and diesel fuels. One RIN is equivalent to one gallon of ethanol. Renewable fuels with more energy content per volumetric unit can generate more than 1.0 RIN per gallon. SAF is a D4 code RIN (defined to achieve least a 50 percent GHG reduction versus CJF) that generates 1.6 RINs per gallon.
[126] U.S. EPA, letter to Texmak Chemicals Inc., https://www.epa.gov/sites/production/files/2019-10/documents/texmark-chem-neste-us-deter-ltr-2019-09-23.pdf.
[127] CARB, https://ww3.arb.ca.gov/regact/2018/lcfs18/fsorlcfs.pdf.

public information, under current market conditions the SAF yield using a typical HEFA production pathway ranges from 10 to 15 percent of the total biofuel produced.[128] The refining process can be modified to increase SAF's relative yield, but there are tradeoffs with cost. Equally important, the total biofuel yield and/or its market value may be significantly reduced.

In addition to these production-related cost tradeoffs, a related disincentive to increasing the SAF yield is that a gallon of SAF has less value in today's market than a gallon of RD. Figure 7 compares the per-gallon market values of RD (left) and SAF (right) under current market dynamics, after taking into account combinable monies afforded under California's LCFS and Cap & Trade programs, plus the D4 RINs earned under the federal RFS2 program.

As can be seen from the stacked bar graph, SAF is currently worth roughly $0.42 per gallon (~8 percent) less than RD. This adds to the disadvantage that SAF is currently more expensive to produce than RD, due to additional production steps in the HEFA process. Finally, the renewable fuel produced in the jet fuel boiling range (i.e. upgradable to SAF) may be more valuable blending in with RD than it would be as SAF. The end result, according to an analysis by Stillwater Associates, is that "airlines would need to pay at least $0.42 more per gallon" for SAF compared to CJF "in order to pull the RD from the diesel pool into the jet fuel pool." Consequently, airlines that seek to reduce their carbon footprint using SAF blends "add about 25% to the cost of their fuel," which constitutes roughly 22 to 25 percent of each airline's operational expenses. Stillwater notes that under this current economic reality, "Any airline trying to

[128] International Council on Clean Transportation, "Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities," Briefing paper, January 2019, https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf.

reduce its carbon footprint by using (SAF) would, therefore, be at a considerable competitive cost disadvantage to another airline that does not use (SAF)." [129]

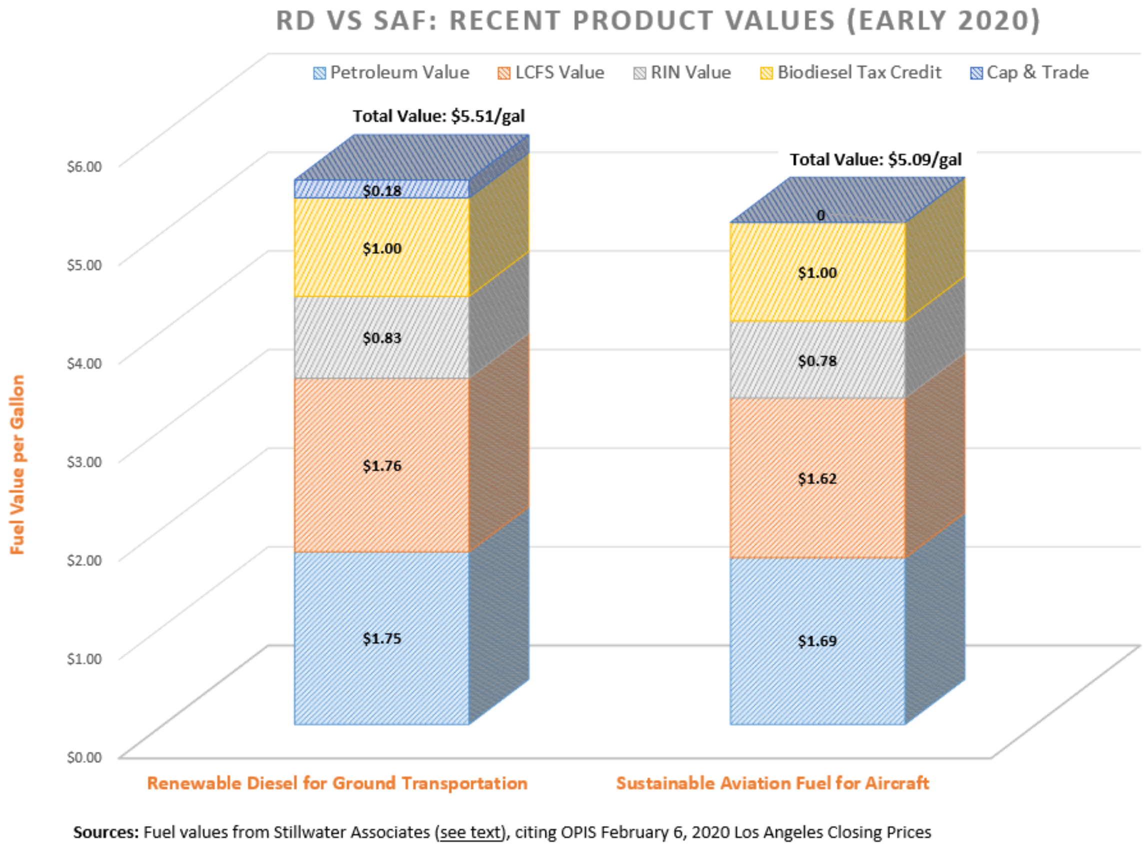

Figure 7. Recent Product Values for Renewable Diesel (left) vs SAF (right)

Stillwater Associates describes the economic dynamics of why SAF is less valuable, as follows:

". . . . RD is worth more than (SAF) because RD is assigned a higher energy density which is used to calculate RINs and LCFS credits per gallon of fuel. (RD generates 1.7 RINs per gallon and (SAF) earns 1.6 RINs per gallon. For calculating LCFS credit value, CARB assigns RD an energy density of 129.65 MJ/gal and (SAF) an energy density of 126.37 MJ/gal.) The cost to purchase allowances for California's Carbon Cap and Trade (C&T) Program is also much lower for RD than its petroleum-based diesel counterpart (ULSD), so RD has additional value relative to diesel in the market." [130]

Notably, when asked about this Stillwater Associates analysis, the two leading RD / SAF producers both confirmed that Stillwater's figures are "directionally correct" or "essentially accurate."

[129] Stillwater Associates, "Airlines want Renewable Jet Fuel, but Renewable Diesel is Stealing their Thunder," February 6, 2020, https://stillwaterassociates.com/airlines-want-renewable-jet-fuel-but-renewable-diesel-is-stealing-their-thunder/?cn-reloaded=1.
[130] Ibid.

The disadvantage regarding how SAF is treated under California's Cap and Trade Program is further described and quantified by a representative for the SAF Producers Group – with an update from SFO's Director of Sustainability – as follows:

> *Under California's Cap-and-Trade program, on-road diesel fuel triggers an allowance obligation when the fuel is sold or transferred over the rack. The obligated party incurs a cost per gallon of diesel fuel received over the rack that is based on the price of the Cap-and-Trade allowances that must be purchased and retired for that fuel. This cost is estimated and reported by a petroleum market service (OPIS), and is typically referred to as the Cap at the Rack Cost. For 2020, the Cap at the Rack Cost has been estimated by OPIS and other sources as in the range of $0.25 per gallon.*[131]

A related barrier is summarized by the SAF Producer Group:

> *SAF is also disadvantaged from a blending and logistics standpoint in that conventional jet simply flows through the system to airports whereas SAF must be trucked or railed to a terminal for blending and certification.*[132]

There are other related issues that significantly contribute to SAF's less-compelling economic proposition for biofuel producers. CJF is currently allowed to contain up to 3,000 ppm of sulfur, although 550 to 750 ppm is typical.[133] Today's ultra-low diesel fuel (ULSD) for ground transportation is capped at just 15 ppm. The FAA described this additional cost barrier in a 2009 SAF "feasibility report" as follows:

> *Under current U.S. and European regulations for automotive fuels, the exceptionally low sulfur and aromatic content of these fuels yields a higher price premium for ground applications. So long as the specification for jet fuel allows sulfur content of the order of 100 ppm or higher, it is unlikely that aviation uses of (ultra-low-sulfur) alternative fuels will be cost competitive with automotive applications.*[134]

Additionally, all renewable transportation fuels – including SAF and RD-- are disadvantaged by the current low market price of conventional (petroleum) fuels, with crude oil prices that hover around $40 per barrel in Q4 of 2020. Prices were as low as $20 per barrel in Q1 of 2020.[135]

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[131] Personal communication to GNA from Erin Cooke of SFO, citing an updated version of a letter submitted to CARB by the SAF Producers Group, September 2020.

[132] Letter to CARB from Graham Noyes (Noyes Law Corporation), representing the "SAF Producer Group," September 21, 2020, provided to GNA from a leading SAF producer.

[133] Atmospheric Chemistry and Physics (multiple authors), "Impacts of aviation fuel sulfur content on climate and human health," 2016, https://acp.copernicus.org/articles/16/10521/2016/acp-16-10521-2016.pdf.

[134] Federal Aviation Administration Technical Report: Near Term Feasiblity of Alternative Jet Fuels, James I. Hileman, MIT, David S. Ortiz, RAND, James T. Bartis, RAND Hsin Min Wong, MIT, Pearl E. Donohoo, MIT, Malcolm A. Weiss, MIT, and Ian A. Waitz, MIT; 2009, https://ascent.aero/documents/2020/01/near-term-feasibility-of-alternative-jet-fuels.pdf/.

[135] U.S. Energy Information Administration, https://www.eia.gov/outlooks/steo/report/prices.php.

9. Future Landscape: Opportunities and Barriers for Wider SAF Use

9.1. Estimated SAF Volumes Needed for Market Viability and to Meet GHG Goals

Various stakeholders have assessed the volume of SAF that will be needed over the near- to long-term to achieve a commercially stable market that can meet various state, national and international goals to reduce GHG emissions in the aviation sector. Citing various aviation industry sources and stakeholders, analysis performed by NREL in 2016 indicated that "a viable market for biofuels can be maintained when as little as 1% of world jet fuel supply is substituted by a biofuel . . . with aggregation of higher blending ratio for future years, such as 25% by 2020, 30% by 2030, and 50% by 2040." The NREL report estimated that biofuel (SAF) could meet 35 to 100 percent of global jet fuel demand by 2050.[136]

CAAFI has played a key role in bringing together stakeholders to assess the future supply of SAF for U.S. commercial aviation, specifically to meet goals set under CORSIA and other initiatives to reduce GHG emissions. For example, at its General Meeting in December 2018, CAAFI assembled an expert panel to discuss "Potential Future Scenarios for Aviation Biofuel." The focus of the panel was on 1) the possibility of producing 1 billion gallons of SAF "in the near term," and displacing "30% of the jet fuel market (6 billion gallons) with biofuels" by the 2030 or 2040 timeframes.

Key conclusions reached by various government and academic experts include the following (**emphasis added**):

- "**100% of 2050 jet fuel demand could be satisfied by domestically produced aviation biofuels**. But there may be decreasing marginal climate benefits of large fuel volumes." [137]
- "Satisfying 100% of US jet fuel demand **requires a 45% expansion in cultivated crop area**." [138]
- "**200 million to 1 billion gallons per year** of alternative jet fuel production **are possible by 2030 given multiple incentives and a favorable investment climate**"[139]
- "**Reaching a billion gallons of (SAF)** using only (HEFA and two other promising production pathways) **by 2030 will require concerted policy support and incentives**."[140]
- "Analysis suggests **6 billion gallons of aviation biofuel by 2030 (are) possible with aggressive assumptions**."[141]

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136 National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy16osti/66291.pdf.
137 Dr. Mark Staples, MIT, Long-term CO2 emissions reduction potential of aviation biofuels in the US," presentation at CAAFI General Meeting, December 5, 2018, http://www.caafi.org/resources/pdf/2.3_Future_Production.pdf.
138 Ibid.
139 Lewis, K., E. Newes, S. Peterson, M. Pearlson, E. Lawless, K. Brandt, D. Camenzind, et al. "U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons." Biofuels, Bioproducts and Biorefining, Accepted 2018.
140 Kristin C. Lewis, Ph.D., Department of Transportation Volpe National Transportation Systems Center, presentation at the CAAFI Biennial General Meeting, "U.S. Alternative Jet Fuel Deployment Scenario Analyses Identifying Key Drivers and Geospatial Patterns for the First Billion Gallons," December 2018, http://www.caafi.org/resources/pdf/2.3_Future_Production.pdf.
141 Newes, E., Jeongwoo H., and S. Peterson. "Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market." Golden, CO: National Renewable Energy Laboratory, 2017. http://www.nrel.gov/docs/fy17osti/67482.

- "**Construction/build out capabilities and development of the feedstock market are key bottlenecks** in the initial years." [142]
- "**Displacement of jet fuel by 30% with biofuels by 2030 is possible**, but several factors related to **policy design**—in the absence of high oil prices or policy uncertainty— contribute to the timing and magnitude of aviation biofuels production." [143]
- "Although the feedstock price and availability and energy intensity of the process are significant barriers, **biomass-derived jet fuel has the potential to replace a significant portion of conventional jet fuel required to meet commercial and military demand**."[144]

A 2019 SAF briefing report by ICCT presented a less optimistic outlook for SAF, implying likelihood that the aviation sector will get lower priority for biofuel feedstock compared to RD for ground transportation. ICCT projected the percentages of the world's low-carbon biomass "that could be supplied" to produce renewable transportation fuels and other bioenergy by 2050. ICCT concluded that – due to SAF's relatively unfavorable economics (described above) – the aviation sector will "likely" draw only about nine percent of the total available bioenergy, compared to roughly 40 percent for non-electric road transportation (even under an "aggressive vehicle electrification" scenario). ICCT summarized that "realistically" these market and supply dynamics for SAF make it unlikely that the aviation industry will "significantly decarbonize aviation fuel until well beyond 2050."[145] This assessment does not necessarily account for addition of new incentives for SAF use and production, as might be justified by its full suite of societal benefits. For example, one major SAF producer points out SAF benefits such as reduced emissions of black carbon and total ultra-fine particles in contrails[146] -- which, if fully valued / monetized, could significantly increase market pull.[147]

9.2. Primary Impediments to Rapid Growth and Adoption at Bay Area Airports

As described throughout this report – and corroborated by leading SAF advocate CAAFI[148] – three related issues are the primary impediments to rapid scale-up of SAF production for widescale use in U.S. commercial aviation (i.e., 1 to 6 billion gallons per year) are:

- Incremental production cost / higher price than CJF

[142] Newes, E., Jeongwoo H., and S. Peterson. "Potential Avenues for Significant Biofuels Penetration in the U.S. Aviation Market." Golden, CO: National Renewable Energy Laboratory, 2017. http://www.nrel.gov/docs/fy17osti/67482.

[143] Ibid.

[144] Wei-Cheng Wang, Ling Tao, Jennifer Markham, Yanan Zhang, Eric Tan, Liaw Batan, Ethan Warner, and Mary Biddy, National Renewable Energy Laboratory, "Review of Biojet Fuel Conversion Technologies," July 2016, https://www.nrel.gov/docs/fy16osti/66291.pdf.

[145] International Council for Clean Transportation, "Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities," January 2019, https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf.

[146] See for example 1) Nature.com, "Mitigating the contrail cirrus climate impact by reducing aircraft soot number emissions," October 2018, https://www.nature.com/articles/s41612-018-0046-4; and 2) ACS Publications, "Comparison of Particle Number Emissions from In-Flight Aircraft Fueled with Jet A1, JP-5 and an Alcohol-to-Jet Fuel Blend, https://pubs.acs.org/doi/abs/10.1021/acs.energyfuels.0c00260#.

[147] Personal communication to GNA from a major SAF producer, September 2020.

[148] Steve Csonka, Executive Director, Commercial Aviation Alternative Fuels Initiative, "Sustainable Aviation Fuel (SAF): Aviation needs SAF . . . SAF needs your technologies," key note speech, tcbiomass*plus*2019 conference, October 9, 2019, https://www.gti.energy/wp-content/uploads/2019/10/47-tcbiomass2019-Presentation-Steve-Csonka.pdf.

- Competition from renewable diesel for ground transportation
- Unfavorable policy environment to widely implement SAF blends as a GHG-reduction strategy

A fourth impediment to wide-scale use of SAF in commercial aviation is the current COVID-19 pandemic. This has dramatically reduced worldwide air travel and CJF consumption, including in the Bay Area, which is a major North American deployment site for SAF. Notably, this may not be a factor at current demonstration scale; many of the SAF offtake agreements summarized above were announced since breakout of the COVID-19 pandemic.

A fifth impediment is the potential for California to be "outcompeted" for limited available SAF supplies, because other nations (or even regions of the U.S.) now offer more favorable incentives and/or policies, or may offer them in the near-term future. While California currently has the big draw – its Low Carbon Fuel Standard -- other nations (such as those in the European Union) have already adopted policies that could "outpace" California as a market draw for SAF. This could make it increasingly difficult for airlines serving the Bay Area to procure large volumes of the fuel.

Further discussion is provided below for each of these four impediments, including actions that are being taken to address barriers and accelerate SAF adoption.

Incremental Production Cost / Higher Price Than CJF

As described in the previous section, the current higher cost to produce SAF (relative to CJF), in tandem with its low market value in the aviation sector (relative to RD's value for ground transportation), combine to present a formidable economic barrier to SAF becoming a major aviation fuel. This is the case even at California airports, where airlines can take advantage of low-carbon credits to reduce the price of neat SAF by more than $1 per gallon. As summarized in a 2016 report for the National Academy of Sciences, "commercial aviation is a highly competitive industry" that makes cost issues especially challenging.[149]

According to ICCT, in the currently dominant HEFA production process "approximately 65% of levelized HEFA costs are the feedstock . . . and these costs are unlikely to come down over time." Also, the HEFA process requires large volumes of hydrogen, which is the second-most-expensive cost when using this SAF production pathway. Moreover, hydrogen for the HEFA process is commonly made through steam methane reforming of pipeline natural gas; this process can be carbon intensive and lower the value of LCFS credits for SAF (i.e., it increases the SAF production pathway's CI value). ICCT notes that more-advanced production pathways of the future may hold the best promise for achieving significant cost

[149] National Academies of Sciences, Engineering, and Medicine 2016. "Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions." Washington, DC: The National Academies Press. https://doi.org/10.17226/23490.

reductions, but "the high and uncertain costs of first-of-a-kind plants for advanced technologies compared with HEFA are deterring investments." [150]

The Air Transport Action Group (ATAG) cites "growing policy progress" as being they key for significant SAF price reductions for end users. ATAG notes that the incremental cost of SAF is coming down due to the many emerging very large offtake purchase agreements, such as those United Airlines is executing:

> *"Global policy developments are making SAF a more important strategic consideration for aircraft operators and we have already seen some massive forward purchase agreements from airlines, with most able to negotiate SAF at only slightly higher cost than traditional jet fuel."*[151]

There also appears to be some uncertainty about how tightening environmental requirements that favor SAF use will affect future demand of SAF, and therefore its pricing. For example, FedEx has noted that CORSIA obligations to achieve offsets of aviation-related GHG emissions – which start in 2021 and can be reduced by SAF use – will cause prices to spike as respective settlement dates approach.[152] However, other stakeholders have noted that such a scenario is extremely unlikely, given the nature and limitations of CORSIA offsets.

Competition Between SAF for Aviation and RD for Ground Transportation

In the current situation of early commercial deployments, U.S. airlines have generally been able to procure sufficient supplies of SAF blends to launch new carbon-reduction programs and advance corporate sustainability goals. Although it appears that airlines currently purchase SAF as a premium fuel, it offers them a cost effective means to achieve valuable GHG reductions. Existing producers like Neste, World Energy -- and emerging producers like Fulcrum, Red Rock and others -- are building major new production capacity that will help reduce SAF costs.

Notwithstanding all this progress for SAF, it has been noted that scaling up SAF production to large volumes for widescale use in the aviation sector may be hindered by competition with RD's production and use as a ground transportation fuel. The emerging question pertains to how rising demand for SAF will impact already strong (and growing) use of RD for ground transportation uses, and vice versa. Because the same companies generally produce both types of biofuels – from the same feedstocks – it appears that important competition is emerging between these key end-use sectors to obtain as much RD or SAF as possible. The specific issue is that RD for ground transportation has key advantages, for both fuel production and end use.

[150] International Council for Clean Transportation, "Long-term aviation fuel decarbonization: Progress, roadblocks, and policy opportunities," January 2019, https://theicct.org/sites/default/files/publications/Alternative_fuel_aviation_briefing_20190109.pdf.
[151] Air Transport Action Group (ATAG), "Beginner's Guide to Sustainable Aviation Fuel," Edition 3, November 2017, https://aviationbenefits.org/media/166152/beginners-guide-to-saf_web.pdf.
[152] Allison Bird, FedEx, "Championing Sustainability in Air Freight," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.

The Atlantic Council recently evaluated "a menu of policy options for establishing a viable SAF sector in the United States." The report summarized why SAF does not yet compete on a level playing field with RD (and other on-road biofuels), as follows:

> *Currently, SAF is largely included as an add-on to existing renewable fuels policies that focus on addressing emissions from ground transportation. In this context, SAF is challenged to compete with other renewable fuels. This is partly due to its relatively recent emergence compared with other renewable fuels, the fact that it sells into a voluntary (rather than obligated) aviation fuel market, and that it receives fewer incentives.*[153]

In 2019 testimony to Congress, Neste's vice president used the "relative value" explanation to put "SAF versus RD competition" into the fuel producer's perspective:

> *"Unfortunately, the existing policy landscape does not adequately incentivize SAF deployment. In fact, there are both structural and policy disincentives to the production of SAF versus on-road renewable fuels. Policies like the Renewable Fuel Standard (RFS) were designed for ground transportation fuels, and while SAF qualifies under many of these policies, SAF generally generates fewer credits. For example, under the RFS, SAF receives 1.6 RINs per gallon while similar renewable diesel receives 1.7. And while states like California and Oregon have also sought to allow SAF to participate on an opt-in, credit-generating basis in low carbon fuel standards, SAF also generates fewer credits under these programs. Diesel historically commands a higher spot price than jet, further disincentivizing jet replacements as compared to diesel replacements. In sum, the significant opportunity costs for renewable fuel producers to produce SAF versus similar ground transportation fuel applications has been a headwind for the SAF industry."* [154]

Renewable Energy Group, Inc. (REG) – a major domestic producer of RD that seems likely to also enter the SAF market – noted the following to CARB in 2017:

> *"If producers are not equally incentivized to produce on road transportation fuel and (SAF), they will opt for the fuel which requires less operating expenses and inherently has greater credit generation potential. Furthermore, we believe that aircraft fuel emissions weigh more than on- road transportation fuel emissions (~2x) per a recent Biofuels Digest article and believe CARB should weigh the credit impact accordingly."*[155]

Reportedly, this has become a key concern for CARB, now that SAF has been added into the LCFS. Several interviewed stakeholders indicated that CARB is exploring ways to give greater prioritization for SAF, given the relatively few decarbonization options that exist for the aviation sector. CARB has convened high-level

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[153] Atlantic Council Global Energy Center, "Sustainable Aviation Fuel Policy in the United States: A Pragmatic Way Forward," by Fred Ghatala, April 2020, downloaded at https://www.atlanticcouncil.org/in-depth-research-reports/report/sustainable-aviation-fuel-policy-united-states/.
[154] Neste Corporation, Statement of Jeremy Baines, President Neste US, testimony to U.S. Congress, October 23, 2019, https://www.congress.gov/116/meeting/house/110124/witnesses/HHRG-116-IF18-Wstate-BainesJ-20191023.pdf.
[155] REG, comments submitted to CARB, May 2017, https://ww3.arb.ca.gov/fuels/lcfs/workshops/05022017_reg.pdf.

government-industry meetings to work through optimal ways that can ensure that both aviation and ground transportation markets get sufficient access to feedstocks and the low-carbon liquid fuels ultimately produced, to maximize GHG-reduction benefits.[156]

In mid-2020 interviews with several top biofuel producers, they readily recognized this disparity in value, but tended to downplay "competition" between RD and SAF. They indicate there is enough production capacity and resources for both fuels, and they intend to meet demand of their customers in both the aviation and ground transportation sectors. They cite production synergy between SAF and RD, and that they do not intend to "cannibalize" production of either fuel over the other. Moreover, many government and/or industrial studies exist that support these basic findings.[157]

They do acknowledge, however, that producers will choose to maximize the yield of one biofuel over the other depending on complex market dynamics. These entail many factors beyond cost and price, including their desire to establish and maintain strong long-term relationships with key customers in both sectors. They also note that "the relative urgency of reducing GHG emissions for the respective transportation sectors will come into play."[158] This factor seems to increasingly favor greater production yield for the SAF co-product.

Still, these dynamics are important factors in their current market decisions. For example, it appears to be the key reason why major existing and expected RD and SAF producers stress their "capacity" to produce SAF, rather than actual existing (or definitively planned) SAF production. This situation is fluid, and can change with improved SAF policies. As one of the major producers explained to GNA,

> *"We often note in our SAF policy advocacy that our announcements are related to capacity, and that ultimate SAF volumes will rely on eliminating the existing policy disincentives to SAF production vs. on-road production."*

As the world's largest producer of biomass-based biofuels (primarily RD, to date), Neste appears to be stepping up plans to commit emerging new production capacity to favor greater production of SAF (co-produce a higher relative yield). Neste is increasingly echoing aviation stakeholders by noting that there is greater need to use liquid renewable fuels for jets than ground vehicles, and demand is likely to last farther into the future for aviation. Noting that aviation-related GHG emissions "could triple by 2050," Neste U.S.'s president told Congress that

> *. . . .climate policy for aviation must be built around technologically feasible developments in the industry, and there is widespread consensus that while aircraft can continue to improve efficiency through use of advanced materials and more efficient engines, the vast majority of use cases (i.e.*

[156] Personal communications to GNA during interviews with representatives from the California Energy Commission and various SAF producers, mid-2020.
[157] Personal communication to GNA from Erin Cooke of SFO, September 2020.
[158] Based on a mix of personal communications to GNA from Neste, World Energy, and REG, August 2020.

medium- and long-haul and larger short-haul jets) will require liquid hydrocarbon fuels through at least 2050."[159]

The airline industry has taken notice of this competition between RD for ground use versus SAF for jets. For example, the National Air Transportation Association (representing more than 2,600 U.S. aviation-related businesses). In mid-2019, NATA's Chief Operating Officer publicly stated that the U.S. aviation industry seeks to become North America's dominant end user of renewable hydrocarbon diesel fuels (i.e., inclusive of both RD and RJF). Essentially, he stated that U.S. commercial and passenger airlines intend to outcompete ground transportation markets (goods movement trucking, in particular) to "soak up all available" renewable diesel fuels.[160] Notably, in the current policy environment and given the relative market values – plus the major drop off in air travel due to COVID-19 (see below) – market dynamics do not favor this happening.

At SFO, which is serving as a major North American testing grounds for SAF, officials consider this competition with RD to be a "primary barrier" for expanded SAF use in commercial aviation. They note that California's leadership in low-carbon fuels for ground transportation has been important and commendable, but the aviation sector has higher need for liquid fuels to decarbonize, and the "nascent" SAF industry is in a delicate stage that needs strong government support. They note it is time to "pivot" the competitive advantage towards SAF. Fortunately, there is promising movement, at various government levels, to get greater policy and monetary support (see below).[161]

Lack of Favorable Policies

The above two related problems – SAF's high incremental production cost and the potential for it to be "outcompeted" by RD (ground transportation) for favored production and use – have led SAF stakeholders to call for improved policies in the U.S. In effect, they argue that policy changes are needed to put greater value on rapidly decarbonizing the commercial aviation sector, because of the greater challenges and fewer options compared to ground transportation. In testimony to Congress, Neste further summarized this need for changes to SAF-related policies:

"Because of these significant structural and policy disincentives surrounding the production of SAF, the industry is unlikely to sufficiently scale and reach its full potential absent policy and price parity with ground transportation fuels. Given aviation's dearth of other options to decarbonize, the relative immaturity of the SAF industry, and the need to rapidly scale production, there is a

[159] Neste Corporation, Statement of Jeremy Baines, President, Neste US, to the House Energy and Commerce Committee, Subcommittee on the Environment and Climate Change Hearing on "Building a 100 Percent Clean Economy: Solutions for Planes, Trains and Everything Beyond Automobiles," October 23, 2019, https://docs.house.gov/meetings/IF/IF18/20191023/110124/HHRG-116-IF18-Wstate-BainesJ-20191023.pdf.

[160] Timothy Obitts, COO & General Counsel, National Air Transportation Association, "Green Aviation: Funding and Regulatory Drivers," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.

[161] Personal communication from Erin Cooke and John Galloway (Sustainability & Environmental Policy at SFO) to GNA, telephone interview, August 12, 2020.

compelling policy justification for additional, SAF-specific policies. Congress is uniquely positioned to develop these policies given its primacy over aviation."[162]

To expand SAF production and end use, Neste recommends that Congress adopt new polices that include "an economy wide price on carbon," improved support for "low-carbon liquid fuels," a long-term extension (20+ years) of the federal Renewable Fuel Standard, a higher RIN value for SAF, and more-favorable tax policies applicable to SAF. Some of these recommendations are now playing out at federal, state and local levels. For example, H.R. 6800: The Heroes Act is now under consideration by the House of Representatives. This bill includes COVID-19 relief payments for biofuel plants.[163] Additionally, the Moving Forward Act (H.R. 2) has significant grant and R&D provisions for SAF, although it lacks a long-term demand mechanism needed to scale the SAF industry (e.g., a tax credit).[164]

Airline industry supporter ATAG identifies a number of "positive policy options" that government agencies should pursue to "enable" wide-scale transition from CJF to SAF. These include[165]:

- Reduce commercial risk for SAF producers and users
- Ensure that aviation has access to the same alternative fuel policies as other transport modes
- Prioritize "aviation as a user of liquid alternative fuels" because "other transport modes have better options"
- Support research into / technology advancement for new SAF production processes and feedstocks
- Help alleviate costs and risks associated with constructing new production facilities
- Support ASTM's technical fuels approvals process
- Divert economic support from fossil jet fuel (CJF) towards SAF

As noted, SFO is taking a leading role in the Bay Area to identify and adopt new policies to help bring large SAF volumes to commercial aviation. This was codified first with SFO's 2017 adoption of an "Airport Policy on the Advancement of Sustainable Aviation Fuels." SFO's 2019 "feasibility" study on SAF identified a goal to obtain as much as 300 million neat gallons of SAF for its airline MOU partners, within about 10 years. The study prefaced the need for improved SAF policies by stating that "California's current policy environment favors the production of renewable diesel over SAF." Consequently, the SFO study identified the need for policy advocacy to correct "discrepancies" in the LCFS, i.e., the higher LCFS credit value afforded to RD compared to SAF. To that end, SFO has led a coalition of airlines, producers, NGOs and others in recommending higher ambitions for SAF through meetings with key California regulators and legislators, and is part of a coalition encouraging the same at the federal level in Washington, DC. Another key SFO focus that emerged was how to identify and implement various types of policies that support new

[162] Neste Corporation, Statement of Jeremy Baines, President Neste US, testimony to U.S. Congress, October 23, 2019, https://www.congress.gov/116/meeting/house/110124/witnesses/HHRG-116-IF18-Wstate-BainesJ-20191023.pdf.

[163] The HEROES Act (H.R. 6800) seeks a 45 cents per gallon payment for SAF and other qualified RFS-approved biofuels). However, it appears that RD will get the same subsidy, which would not necessarily improve SAF's ability to compete.

[164] See https://www.congress.gov/bill/116th-congress/house-bill/2/text.

[165] Air Transport Acton Group, "Aviation's Energy Transition, FACT SHEET #5," May 2020, http://www.caafi.org/resources/pdf/FACT_SHEET_5_Aviations_Energy_Transition.pdf.

funding mechanisms and sources.[166] SFO staff recently corroborated that improved or entirely new incentives for production and use will be important enablers to attain SFO's ambitious goals to deploy large SAF volumes over the next decade.

Other airports and their stakeholder airlines are taking similar actions. At Washington's SeaTac Airport, Alaska Airlines has joined with airport officials to identify "creative funding mechanisms" to address significant economic barriers associated with making SAF at scale. They note that developing new SAF production facilities can cost "hundreds of millions of dollars." [167] A study prepared by the Rocky Mountain Institute focused on SeaTac to further explore "innovative funding for SAF at U.S. airports." According to RMI, a variety of promising mechanisms are under development to make SAF more affordable; most of these involve fees and taxes on airlines and the general public when using aviation and peripheral services.[168]

COVID-19 Pandemic

The 2Out020 onslaught of the global COVID-19 pandemic has caused a major downturn in worldwide air travel. This has led to precipitous drops in the volume of CJF dispensed at airports in the U.S. and around the world. Even if the pandemic proves to be a temporary phenomenon, as long as it decreases air travel COVID-19 disincentivizes supply of / demand for low-carbon jet fuel. Thus, the pandemic could potentially deal a substantial blow to SAF progress at SFO, in its role as a major testing ground. While it is not possible to make meaningful estimates about how SAF growth in the Bay Area will ultimately be affected, the following discussion helps understand the directional impacts and challenges ahead.

Average CJF consumption in the U.S. for commercial aviation dropped from 4.3 million barrels per day in pre-pandemic 2020, down to just 1.0 million barrels per day by the start of Q2 2020 -- nearly an 80 percent reduction. Year-over-year drops were as high as 67 percent. The U.S. EIA notes that CJF consumption recovered somewhat during late spring and early summer of 2020, but it remains significantly reduced as of mid-summer 2020. In an August 2020 report about the impact of COVID-19 on air travel and energy consumption, EIA made the following distinction: "interior airports that cater primarily to domestic air travel have generally recovered faster than their typically coastal, more internationally oriented peers.[169]

[166] San Francisco International Airport, "Sustainable Aviation Fuel Feasibility Study," Final Report, September 2019, provided to GNA by SFO staff, July 2020. Additional inputs from this paragraph were communicated to GNA by Erin Cooke of SFO, September 2020.
[167] Statement by Alaska Airlines executive, "Bridge to Biofuels: Renewable Biofuels and Biochemicals from Poplar Trees – Part 3 – Biojet Fuel, https://www.youtube.com/watch?v=pLye9duz1nU.
[168] Craig Schiller, Rocky Mountain Institute, "Greening Aviation: Sustainability Takes Flight with Leading Airlines," Presentation at ACT Expo "Greening Aviation" session, April 26, 2019.
[169] U.S. Energy Information Administration, "COVID-19's impact on commercial jet fuel demand has been significant and uneven," August 7, 2020, https://www.eia.gov/todayinenergy/detail.php?id=44676.

In line with this point, California's three large "coastal, more internationally oriented" airports – SFO, LAX and San Diego -- have experienced prolonged, deep drops in commercial jet departures, which correlate directly with major reductions in dispensing of CJF at these airports. As shown in Figure 8, during the period of March 3 to April 21, 2020, jet aircraft departures declined by 67 percent at SFO, 56 percent at LAX, and 60 percent at San Diego. [170]

One official at LAX stated that the drop-off in flight departures and passenger throughput at major U.S. airports like LAX constitutes "the most steep and potentially sustained decline in air travel history." At SFO, it was noted that "United Airlines was hardest hit . . . in terms of raw decrease in flights," experiencing an overall departure decline of 87 percent."[171] At peak loss in April 2020, United – the largest airline serving SFO – reduced daily flights by six-fold, although this improved markedly by late summer. In

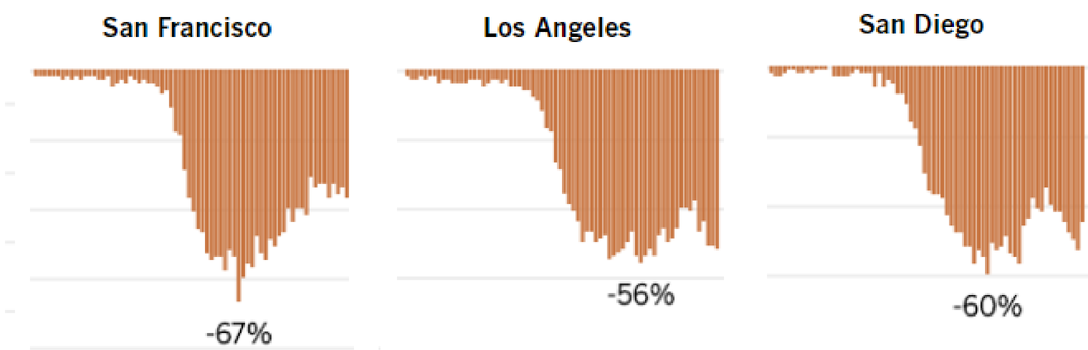

Figure 8 COVID-19-related reductions in commercial jet departures from March 3 to April 21, 2020

September 2020, United announced it will lay off more than 3,200 workers in the Bay Area, due to this pandemic-related collapse of air travel at SFO and other local airports.[172]

Commercial aviation industry association ATAG has acknowledged that COVID-19's impact on the world's aviation sector "is unprecedented in its severity" and scale. Effectively, ATAG noted that "it is much too early" to further define or quantify COVID-19's impact on longer-term GHG-reduction solutions like SAF under CORSIA.[173]

A spokesperson for the Low Carbon Fuels Coalition (representing most SAF producers) recently confirmed that the pandemic-caused downturn in commercial aviation "changes what the (SAF) growth curve looks

[170] Los Angeles Times, "California air travel plunged after the coronavirus. But by how much?", April 28, 2020, https://www.latimes.com/projects/california-coronavirus-travel-tracking-decline/.
[171] Ibid.
[172] SFGATE.com, "United to lay off 3,200 employees in the Bay Area, September 2, 2020, https://www.sfgate.com/travel/article/United-layoffs-SFO-15537360.php.
[173] ATAG, "Aviation Industry Welcomes Progress on CORSIA, Despite Global Emergency," press release, March 16, 2020, https://www.atag.org/component/news/?tmpl=pressrelease&view=pressrelease&id=119.

like, at least in the short term." But he emphasized that COVID-19 does not change the underlying fundamentals: people will continue to fly, and jets "will require liquid fuels for the foreseeable future." (Similar comments were recent made by the International Civil Aviation Organization, ICAO.) Emphasizing what has already been accomplished with SAF – multiple ASTM-approved production pathways for a drop-in CJF replacement fuel that is "truly sustainable" – the industry spokesman predicted that SAF will continue to generate "tremendous interest" with the commercial aviation sector. However, he implied there may be a temporary focal "shift" for SAF use towards the "business jet community" rather than "mainstream commercial aviation." He cited "more mobility" in this sector to regain pre-pandemic momentum of SAF deployments.[174] This appears to refer to private jet use operated by corporations, which may have less loss of jet travel demand and can better afford the price premium of SAF, especially in a period of relatively low demand. A good example of progress here is the recent announcements between Signature Flight Support and Neste for expanded SAF use by private aviation operators at SFO.[175]

Prior to the pandemic, the volume of CJF dispensed at SFO was expected to grow 20 to 40 percent over the next several years, reaching 1.2 to 1.4 billion gallons per year. Within about a decade, jet fuel use at SFO was expected to reach as high as 1.8 billion gallons per year. Pre-pandemic goals for neat SAF usage at SFO were set at 30 million gallons per year within 3 to 5 years (~2 percent of CJF use), and up to 300 million neat gallons per year within 5 to 10 years (~17 percent of CJF use).

Officials at SFO confirm that CJF usage at SFO is "way down" from this trajectory, due to COVID-19. As noted, United Airlines is the largest passenger airline at SFO -- and one of SFO's major SAF users. Notably, in this early phase of SAF adoption and usage, this does not appear to have reduced dispensing of SAF during the pandemic (e.g., at SFO). Of course, it remains to be determined how long COVID-19 will continue to dramatically reduce air travel at SFO (and other Bay Area airports). Given all these factors, it is not possible to predict how it will impact SFO's goal to obtain and dispense 300+ million gallons per year within about a decade.

<u>Outlook on Progress to Overcome SAF Impediments</u>

Notwithstanding these four related impediments and other market barriers for SAF, CAAFI notes that progress continues to accelerate. CAAFI's Executive Director notes that key collaborative efforts are being spearheaded by stakeholders that include "academia, national labs, entrepreneurs, big oil, fuel suppliers, pipeline companies, farmers and foresters, facilitators, aviation partners." Just prior to the pandemic

[174] Argus Media.com, "Q&A: LCFS key in post-COVID world," interview with Graham Noyes, Executive Director, Low Carbon Fuels Coalition, May 18, 2020, https://www.argusmedia.com/en/news/2106357-qa-lcfs-key-in-postcovid-world.

[175] See https://www.signatureflight.com/about/newsroom/details/2020/09/14/signature-flight-support-neste-and-netjets-establish-strategic-partnership-to-accelerate-the-adoption-of-sustainable-aviation-fuel-within-business-aviation

outbreak, he stated the following: "Given a policy framework that addresses the above, SAF is perhaps on the cusp of rapid expansion and replication."[176]

SAF producers intend to push forward on policy and technological fronts to help ensure both supply and demand for SAF continue to grow. They note that low-carbon SAF is a "must have" for commercial aviation to continue systematic decarbonization. SAF production has strong synergy with America's overall push for affordable, low-carbon biofuels across all energy sectors. Their message to stakeholder airports like SFO and agencies like BAAQMD is "SAF is here; stay the course and continue to lead."

[176] Steve Csonka, Executive Director, Commercial Aviation Alternative Fuels Initiative, "Sustainable Aviation Fuel (SAF): Aviation needs SAF . . . SAF needs your technologies," key note speech, tcbiomass*plus*2019 conference, October 9, 2019, https://www.gti.energy/wp-content/uploads/2019/10/47-tcbiomass2019-Presentation-Steve-Csonka.pdf.

10. Conclusions and Recommendations

10.1. Conclusions

Sustainable aviation fuel (SAF) is a drop-in replacement for conventional jet fuel (CJF) that can significantly reduce full-fuel-cycle GHG emissions from commercial aircraft. Neat SAF produced using the currently dominant “HEFA” process has a carbon intensity approximately 60 percent lower than baseline CJF, and future types of SAF will likely provide even greater GHG reduction benefits. SAF offers a cost-effective strategy to help decarbonize the world’s commercial aviation sector, which currently contributes roughly two percent of combustion-related GHG emissions. Importantly, aviation presents greater challenges to decarbonize compared to surface (ground and water) transportation modes. Globally, SAF is emerging as the leading approach to further reduce in-sector GHG (“CO2e”) emissions from commercial aviation.

Several million gallons of neat SAF are being used in the U.S. today (pre-COVID-19). The majority of this is being dispensed at two California airports -- Los Angeles International Airport (LAX) and San Francisco International Airport (SFO) -- which have become proving grounds for SAF use in North America. This is largely due to CARB’s addition of SAF as a credit generator under the landmark LCFS program, beginning in 2019.

As described in this report, the GHG-reduction benefits of SAF are compelling, and it can also help improve local ambient air quality in the Bay Area. However, SAF is a premium jet fuel that is not yet available and affordable for wide-scale use. It currently costs at least two times as much to produce SAF compared to CJF, using the leading HEFA pathway and assuming a typical SAF yield of less than 15 percent, with RD being the dominant co-product. While the SAF yield can be increased up to 50 percent, this entails greater incremental cost and appears to compromise the market value of the overall biofuel products. Once produced, an equally important market barrier is that a gallon of neat SAF’s current market value in California (the best-case scenario for SAF, due to the LCFS) is about eight percent lower than a gallon of RD, even though they are co-produced in the same HEFA process. Consequently, SAF producers are likely to continue gearing their biofuel production to maximize the yield of RD – the more valuable co-product – unless and until SAF becomes a more highly valued biofuel (monetarily, environmentally, or both).

While “offtake” agreements for SAF are confidential, it appears that this combination of higher cost / lower market value gets passed on to airlines that purchase SAF. Airlines using SAF at San Francisco International Airport (SFO) reportedly pay a premium of about $1.25 per gallon, under a best-case scenario that includes buydown of SAF costs using LCFS credits and RFS2 RIN values. Nonetheless, SAF has been in fairly strong demand in California -- specifically at SFO and LAX, the other North American test center for SAF. Roughly five million gallons of SAF blends were dispensed at these two airports in 2019 (just prior to the COVID-19 pandemic).

CAAFI and SAF producers indicate that at least 350 million gpy of neat SAF will be produced and available for dispensing at U.S. airports by the 2023 timeframe, with most of that likely to be dispended into aircraft serving SFO and LAX.

SAF Potential for Reducing GHG Emissions at Bay Area Airports

SFO in particular is a world leader in its commitments and actions to foster replacement of very large CJF volumes with SAF blends. The airport has been working with its airline partners for several years to test SAF blends and develop innovative ways to increase supply, while lowering costs. Under an MOU with airlines as well as SAF providers like Neste and World Energy, SFO has established the goal to procure and dispense enough neat SAF within three to five years to displace about two percent of its CJF use (30 million gallons per year), and 17 percent (300 million gallons per year) within about a decade. While this near-term goal may have been significantly set-back by the unprecedented COVID-19 pandemic, it is too soon to know the impact on meeting the longer term goal (a decade out).

Oakland International Airport (OAK) is the other Bay Area airport that has made progress to pilot test the benefits of SAF blends in commercial aviation. At least six million gallons per year of neat (100 percent) SAF have been committed to FedEx and Southwest Airlines for dispensing out of the OAK fuel farm facility. There appears to be significant synergy between SFO, OAK and SJC to share delivery and storage logistics for large-scale SAF usage in the Bay Area, as SFO has invited both airports to join its MOU and interdisciplinary Stakeholder Working Group (SWG) that meets each quarter to deliver work defined within its own Feasibility Study.

Over the longer term (about a decade), pre-pandemic estimates indicate that one to six billion gallons of neat SAF may be available for the U.S. commercial aviation sector. This will be supplied by a combination of key current SAF producers (primarily World Energy and Neste) as well as newcomers to SAF production such as Fulcrum BioEnergy, Red Rock Biofuels, Phillips 66 and others. The vast majority of this appears likely to be targeted for consumption in California, due to monetary incentives offered under the LCFS. A significant portion – perhaps half or more – may be used in the Bay Area at SFO and OAK, with potential synergy for use at SJC.

A high-level estimate was performed to roughly calculate the full-fuel-cycle GHG reductions that could be realized by widely using SAF blends at the three largest Bay Area airports. The assumptions were that pre-pandemic demand will return for jet fuel at SFO, OAK and SJC; and that 100 percent of the flights at all three airports will use SAF blends instead of neat CJF. A range of blends – SAF5, SAF25, and SAF50 – were evaluated. It is estimated that GHG reductions from SAF blends would range from 0.47 million metric tons per year (SAF5) up to 4.7 million metric tons per year (SAF50), based on 2019 emissions estimates. Notably, these combined GHG reductions reflect emissions from all fuel loaded at these three Bay Area airports, i.e., they are not constrained to reductions that would occur within BAAQMD boundaries.

A similar analysis was performed to estimate criteria pollutant emission reductions that could be realized within BAAQMD boundaries under the same SAF blend deployment scenarios. For the best-case scenario, it is estimated that displacing all CJF use at the three major airports with a SAF50 blend could provide reductions in CO emissions of 2.27 tons per day, SOx emissions of 0.39 tons per day, and PM10 emissions of 0.28 tons per day.

A number of challenges and barriers exist that currently hinder SAF producers from providing commercial aviation operations at SFO and other California airports with the large volumes they ultimately seek. The three key (related) impediments under current dynamics are 1) higher cost/price of SAF relative to CJF; 2) reduced value of SAF on a per-gallon basis compared to its more-dominant co-product RD (which disfavors gearing the production process for a higher SAF yield versus RD); and 3) federal and state policies that generally favor using limited biofuel resources to decarbonize surface transportation more than the aviation sector.

A fourth impediment has been the global COVID-19 pandemic, which has dramatically decreased aircraft departures at large coastal airports (nearly 70 percent at SFO at its peak), thereby greatly reducing demand for CJF and lessoning the need for airlines to continue switching to SAF blends.

A fifth impediment is the potential for California to be “outcompeted” for limited available SAF supplies, because other nations (or even regions of the U.S.) now offer – or may offer in the near future -- more favorable incentives and/or policies, which could make it increasingly difficult for airlines serving the Bay Area to procure large volumes of the fuel.

10.2. Recommendations

The following provides actions that BAAQMD may wish to explore and implement – in conjunction with various stakeholders – to address barriers currently impeding wider-scale use of SAF at Bay area airports and achieve GHG-reduction objectives for the commercial aviation sector.

- Engage with CARB and other relevant state or federal agencies about how to 1) improve the relative value of SAF through changes in the monetization metrics of key programs (LCFS, Cap and Trade, RFS2, etc.), and 2) generally modify California’s GHG-reduction policies to more favorably treat SAF production and/or end use.

- Further evaluate the pros and cons of channeling more types of support (policy, incentive funding, permitting requirements, etc.) towards SAF as the leading available strategy to further decarbonize the Bay Area’s aviation sector. This may or may not entail reducing emphasis on RD as a strategy to decarbonize ground transportation, which has growing near-term access to deploying electric drivetrain technology (battery-electric and hydrogen fuel cell architectures) as the key decarbonization strategy.

- Consider exploring new pilot program incentives for SAF production and end use, based on air qualify benefits associated with reducing criteria pollutants and air toxics in DAC / EJ areas near Bay Area airports.

- Consider creative methods to incentive larger-scale production and use of SAF, such as fast-track permitting and/or CEQA approval for new biofuel production facilities or conversion of conventional refineries to biorefineries.

SAF Potential for Reducing GHG Emissions at Bay Area Airports

- Commission a study (e.g., using the UC system) that corroborates and further quantifies SAF's effects on criteria and toxic air pollutants from commercial aircraft, which can help ensure that grant funding achieves its intended use (i.e., to reduce surplus, quantifiable emissions.

- Establish (or join existing) regular working groups with SFO and other major Bay Area Airports (OAK, SJC) to monitor SAF-related progress, developments and status of key impediments (including Covid-19 impacts).

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