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Sustainable Aviation Fuel: Opportunities and Challenges for San Diego

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Opportunities and Challenges for San Diego

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Disclaimer

The author of this report is solely responsible for the content thereof; this report does not necessarily reflect the views or endorsement of the individuals or organizations mentioned above.

Abstract

Sustainable aviation fuel is the primary tool through which the aviation sector can reduce greenhouse gas emissions in the next few decades. Its ability to penetrate the jet fuel market is currently constrained by high prices, policy barriers and supply challenges. A federal tax credit is politically viable and has the potential to drastically increase sustainable aviation fuel production in the United States. As more sustainable aviation fuel becomes available over the next 5 years, San Diego International Airport has the opportunity to become an early adopter of this fuel due to favorable California policies and proximity to fuel suppliers. Airport engagement with airlines and fuel suppliers could help promote San Diego as a welcome destination and partner in sustainable aviation fuel use.

Keywords

Aviation, emissions, sustainable aviation fuel, climate change, decarbonization, biofuel, alternative fuels

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List of Acronyms

ATAG	Air Transportation Action Group
AtJ	Alcohol-to-Jet
CAAFI	Commercial Aviation Alternative Fuels Initiative
CI	Carbon Intensity
CJF	Conventional Jet Fuel
CO_2	Carbon Dioxide
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FT-SPK	Fischer-Tropsch Synthetic Paraffinic Kerosene
GHG	Greenhouse Gas
HEFA	Hydrogenated Esters and Fatty Acids
IAG	International Airlines Group
IATA	International Air Transportation Association
ICAO	International Civil Aviation Organization
LAX	Los Angeles International Airport
LCFS	Low Carbon Fuel Standard
MMT	Million Metric Tonnes
MSW	Municipal Solid Waste
PM	Particulate Matter
PtL	Power-to-liquid
RIN	Renewable Identification Number
RD	Renewable Diesel
SAF	Sustainable Aviation Fuel
SAN	San Diego International Airport
SFO	San Francisco International Airport
TAMT	Tenth Avenue Marine Terminal

Introduction & Background

As the world continues to recognize the growing threat of climate change, nations have begun taking action to reduce greenhouse gas emissions. Over the last decade, California, like much of Europe, has made progress primarily through carbon emission reductions in the electric grid, leaving transportation as the next major hurdle.[i,ii] The transportation sector in California makes up 40% of state emissions.[ii] On-road vehicles represent the bulk of these emissions and have been the focus of most policy discussions. However, vehicle efficiency improvements and electrification have created a path for emissions reductions in this sub-sector that is expected to experience a decrease in fuel consumption even under the U.S. Energy Information Administration's (EIA) more conservative reference case.[1,iii] In contrast, the airline industry is projected to see significant growth in demand – and emissions – without comparable decarbonization options. Airlines and airports have recognized the need for emissions reductions, along with the threat of national and international regulation, and have begun making sustainability commitments with a focus on reaching net zero.[2] Unfortunately, many of these commitments rely on the purchase of carbon offsets due to the fossil fuel-centric nature of air travel. However, with the appropriate policy support, sustainable aviation fuel offers an opportunity for a meaningful reduction in aviation emissions over the next few decades.

Emission Contributions

In the United States, aircraft emissions make up 2.7 - 5% of total CO_2 emissions.[3,iv,v] As this range indicates, fuel consumption and emissions data from the aviation industry is nuanced

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[1] The EIA's Annual Energy Outlook 2021 Reference case creates energy use projections based off existing laws and regulations. The analysis was performed during a pro-business, anti-regulation administration and reflects minimal federal commitments to reducing transportation emissions.

[2] "Net zero" refers to minimizing GHG emissions and offsetting any remaining emissions so that a business's operations have no net GHG emissions. This is different than "zero carbon" or "carbon zero" which is when there are no carbon emissions from a business operation. The distinction is important as net zero goals are often criticized for an overreliance on the purchase of carbon offsets without meaningful effort to reduce emissions.

[3] The Aviation and Climate Change report from the Congressional Research Service stated that aviation emissions were 5% of US emissions in 2018. This data included international flights departing from the US and emissions from military aviation. The 2.7% estimate come from the Environmental Protection Agency's 2019 Greenhouse Gas Emission and Sink Inventory, which includes military and non-military flights. This discrepancy is expected to be due to attribution for international flights, however the EPA's reported total for transportation bunker fuels is lower than would be expected to account for the 2% difference between these reports.

and can benefit from improved reporting and standardization. Reporting on a country's aviation emissions often excludes international flights and varies on whether it includes military operations, private flights or cargo travel in addition to commercial passenger travel. This is further complicated by how traditional emissions inventories differ from lifecycle analysis. In the case of transportation fuels, carbon emissions during production can vary greatly and therefore heavily influence the carbon intensity of a fuel – a measure of emissions over a fuel's full lifecycle.[vi] In calculating lifecycle emissions, the Environmental Protection Agency (EPA) includes emissions during feedstock production and transportation, fuel production and distribution, and fuel consumption.[vii] In comparison, emissions inventories tend to only look at 'tailpipe' emissions – the emissions that occur during the consumption of a fuel. Lastly, projections of aviation fuel consumption are complex and require accurate models of market demand and understanding a dozen different factors that affect fuel consumption during operations, half of which rely on government action and the uncertainty that comes with it. Due to the above factors, this report provides data from numerous aviation markets in multiple formats in order to provide a more robust picture of the current and future state of aviation emissions.

While aviation emissions from all sources only make up 5% of US emissions today, this proportion is expected to increase as other sectors continue to decarbonize while aviation net emissions steadily increase. Historically, net CO_2 emissions from aviation have increased by 2.2% per year, however more recently emissions have increased at a rate of 5% per year.[4,viii] This is due to the combination of explosive growth in travel demand combined with incrementally smaller gains in fuel efficiency.[viii] Over the years airlines have continued to reduce fuel consumption through aircraft design, weight reductions and efficiencies in on-ground and in-flight operations. However, travel demand has continuously outpaced these efficiency improvements, with annual jet fuel consumption expected to increase by 50% or more by 2050.[ix,x] The International Civil Aviation Organization (ICAO) estimates that by 2050 net emissions from international aviation will increase to over 600 million metric tons (MMT)

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[4] Lee et al. calculated the average growth rate per year from 1970 to 2012 to be 2.2% per year, compared to 5% per year from 2013 to 2018.

per year, three times more than their 2015 levels, taking into account fleet turnover that leads to fuel efficiency improvements.[5,xi]

Decarbonization Challenges and Opportunities

The on-road transportation sector is being decarbonized through a multi-pronged approach that includes operational efficiencies, alternatives to the automobile and vehicle electrification. However, only some of these tools are available in the aviation industry. Operational efficiencies are being achieved through modernization, spearheaded by the Federal Aviation Administration's NextGen program. This program is helping to reduce fuel consumption and emissions through tools such as continuous descent operations and minimizing taxi time. Urban areas have worked on reducing reliance on personal vehicles by enabling greater pedestrian activity, biking and access to mass transit. This focus on providing alternatives is only slightly transferable to the aviation industry which provides expedient travel over long distances – including over bodies of water. In places like Europe, high-speed rail and short distances between major metropolitan areas provide the public with greater choice when travelling. However, in the United States there is not a high-speed rail system that can act as an alternative to air travel. Lastly, electrification – and alternative fuels - are the promising deep decarbonization method for on-road transportation. Ideally the airline industry could follow that path and shift to cleaner technologies such as electric or hydrogen-powered aircraft, however there are significant technological and logistical challenges to that transition.

The primarily technological restraint is the issue of weight. For electric airplanes, the energy density of a battery is significantly lower than that of jet fuel, making batteries an ineffective replacement due to the weight they would add to an aircraft.[6,xii] Many companies are working on electric aircraft, however the technology currently only supports 4-8 seat, short-haul, passenger aircraft.[x] In the near term, this does not lend itself to meaningful decarbonization as only 7% of industry emissions are from regional transport – which uses

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[5] This takes into account efficiency gains from fleet turnover, but not other technology or operating improvements.

[6] While jet fuel has an energy density approximately 50 times better than current battery technology, it is an inefficient propulsion system. This allows batteries to be slightly more competitive, however their power output is still less than 10% of that of jet fuel per kg.

planes that typically have 20 to 130 seats.[xiii,xiv] In summary, batteries technology requires significant increases in energy density in order to support even a small portion of air operations.

Hydrogen faces a similar weight challenge. Liquid hydrogen is more energy dense than jet fuel, however its storage requirements add weight that put it at a disadvantage to jet fuel.[xv] While this weight difference is still notable, it is currently more competitive than electric aircraft for commercial passenger operations. However, hydrogen has additional challenges in the form of infrastructure requirements for fuel delivery and aircraft refueling. There is some potential for natural gas pipelines to be converted to transport hydrogen, however there is still costly and time-consuming investment needed to get hydrogen infrastructure to a comparable level as that of the nation's jet fuel infrastructure. Lastly, hydrogen burns cleaner and has substantial benefits for local air pollution, yet there is still need for it to be produced in a sustainable manner. Today, 98% of hydrogen is produced from fossil fuels and this would need to shift to more sustainable and cost competitive methods to meaningfully impact emissions.[xvi]

Another factor to consider is the time it takes for new technologies to penetrate the fleet. Where on-road vehicles have lifespans in the 10-to-15-year range, aircraft have a lifespan between 25 and 35 years.[xvii,xviii,xix] Even if electric and hydrogen aircraft technology were commercially available and cost competitive today, it would still take decades for these aircraft to make up over half of the fleet. The use of hydrogen and electric planes is a great long term – 50+ year – solution to airline emissions, however a different approach is needed to reduce emissions over the next few decades.

Commitments to Sustainable Aviation

In the last decade, there has been a significant growth of awareness of climate change and the perception of it as a major threat to society.[xx] This has led to a greater demand from the public for government action on climate change, along with a growing consumer expectation of corporate environmental responsibility. Companies are responding by incorporating social responsibility into their business activities, and polls have shown that corporations acknowledge these actions improve financial performance through both brand reputation and by attracting talented employees.[xxi] In the airline industry, a combination of flight shaming and a climate conscious public has led to a change in demand for air travel in

Europe. This is most notable in Sweden where train travel increased by 11% in 2019 while air travel dropped 4%.[xxii]

This societal change has led to commitments by the aviation industry. The International Airlines Group (IAG) members and other international airlines such as Qantas committed to reaching net zero emissions by 2050.[xxiii,xxiv] In the United States, Delta committed to being carbon neutral and Airlines for America, an industry trade organization, also committed to net-zero emissions by 2050.[xxv,xxvi] Additionally, the International Air Transport Association (IATA), ATAG and other industry groups have committed to reducing emissions to 50% of their 2005 levels by 2050.[xxvii] Governments and intergovernmental organizations have also begun to make commitments. Under the Paris agreement, the nationally determined contributions included commitments for states to reduce emissions from domestic flights. ICAO, as the United Nation's agency for regulating international aviation, established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) in 2016 to address emissions from international flights. The pilot phase of CORSIA begins this year, with the goal of offsetting any growth in international aviation emissions after 2020, essentially capping international aviation emission levels in 2020.[7,xxviii]

While the industry is taking action to advance technology and policy to meet these commitments, they currently heavily rely on the use of carbon offsets. Even in 2050, carbon offsets are expected to make up 50% of the 'reductions' in aviation emissions.[xxvii] Delta, whose net zero commitment began in March of 2020, purchased 13 MMT of carbon offsets for 2020, which is less than one third of their pre-pandemic annual emissions.[xxix] Many entities have also committed to fuel efficiency improvements of 1.5 – 2% per year, however the expected demand for air travel will outpace these advancements.[xxx] Many of these commitments, notably CORSIA, have been criticized as being technology following as opposed to technology forcing.[xxxi]

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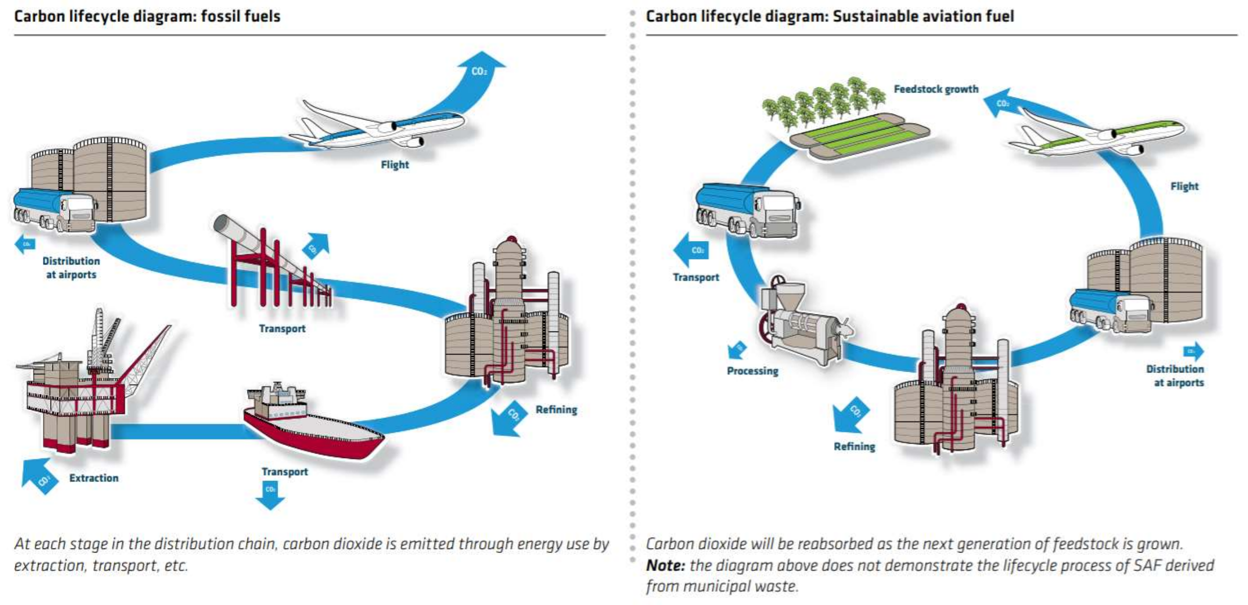
[7] ICAO has since adjusted CORSIA's framework to account for the unexpected emissions levels in 2020 due to the COVID-19 pandemic. More information on these modifications can be found here: https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-and-Covid-19.aspx

Sustainable Aviation Fuel

Conventional – or traditional – jet fuel (CJF) is fossil-fuel based kerosene that is used in aircraft around the globe. Sustainable aviation fuel (SAF) is a broad term that incorporates a wide range of alternative – non-fossil fuel based – fuels.[8] While SAF includes biofuels, it is also broader in that these fuels can be sourced from non-biological feedstocks.[9,xxx] In addition to being alternative, these fuels also have to be sustainable. To that end, SAF must have lower carbon emissions than CJF on a full lifecycle basis. Where CJF takes carbon from sinks and releases it into the atmosphere, SAF feedstocks take carbon from other parts of the biosphere, resulting in up to 80% reduction in CO_2 emissions on a lifecycle basis.[xxx] This is important as there is not a noteworthy reduction in exhaust CO_2 emissions from the combustion of SAF. However, there is still a significant difference over the fuel lifecycle as the production process can have negative emissions. Figure 1 shows these lifecycle differences.


Carbon lifecycle diagram: fossil fuels

At each stage in the distribution chain, carbon dioxide is emitted through energy use by extraction, transport, etc.

Carbon lifecycle diagram: Sustainable aviation fuel

Carbon dioxide will be reabsorbed as the next generation of feedstock is grown.
Note: *the diagram above does not demonstrate the lifecycle process of SAF derived from municipal waste.*

Figure 1: Diagram of Carbon Lifecycle from CJF and SAF [xxx]

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[8] SAF is the industry standard term that more accurately reflects the group of fuels needed to mitigate aviation greenhouse gas emissions. However, some older, less common, and overlapping terms are: aviation biofuels or biojet, renewable jet fuel and sustainable alternative fuels.

[9] Power-to-liquid is an example of a non-biological feedstock. This technology uses renewable energy and carbon capture systems to produce liquid fuels.

The last aspect of the sustainable part of SAF is the need to have minimal impact on ecological systems. The aviation industry has been focused on ensuring that feedstocks minimize the indirect land use change that has plagued the early generations of biofuel use.[xxxii,xxx,xxviii] Many entities use independent reviewers to validate fuel sustainability, however skepticism is expected and welcome to ensure SAF efforts are meeting climate change needs.[10]

Emission Reductions and Other Benefits

SAF is touted to be able to reduce emissions by up to 80%, however there is a broad range of lifecycle emissions reductions – influenced by feedstock and pathway - which can result in reductions anywhere from 10% to 80%.[11] World Energy, one of the largest global producers of SAF, creates a tallow-based product using the hydrogenated esters and fatty acids (HEFA) pathway that achieves 52% - 73% lifecycle emissions reductions compared to CJF.[xxxiii] This is for a gallon of *neat* SAF. One important aspect of SAF is that it is a drop-in fuel. Once blended, SAF is certified to the same ASTM standards as CJF and can therefore be used in all existing aircraft and supply infrastructures. Neat SAF is the sustainable fuel product prior to blending. Depending on the feedstock and pathway, neat SAF can be blended up to a 50/50 ratio with CJF, after which it is certified as Jet A.[12] Thorough analysis of current and future feedstocks and pathways can be found in the Department of Energy's Sustainable Aviation Fuel: Review of Technical Pathways report.

While the *exhaust* CO_2 emissions from SAF are comparable to CJF, SAF also benefits from having negligent sulfur and aromatic content, a lower freezing point and higher thermal stability.[xxxiv] The lack of sulfur and aromatics would radically reduce particulate matter from the aviation industry and improve local air quality and public health.[xxxiv] The reduced aromatics and higher thermal stability also has the potential to reduce maintenance costs by 5%.[xxxiv] These benefits also have the potential to improve over time as engines are designed with SAF in mind.

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[10] CORSIA has eligibility criteria such as requiring feedstock biomass to not be made from land converted from woodlands, wetlands or peat lands after 2008. This requirement is a good start, however indirect land use change may occur if feedstock production displaces other agriculture use onto lands converted after 2008. Source: ICAO CORSIA Sustainability Criteria for CORSIA Eligible Fuels

[11] Anything less than 10% of emissions reductions is broadly considered to not be SAF. This is the minimum set by CORSIA's eligibility criteria; however, this is a much lower offset than the industry is aiming for at large.

[12] Many pathways, including the most common HEFA pathway, allow blending to 50%.

Current and Future State

SAF has been in use in the United States and around the world for over 5 years, however it is still only being produced and consumed in nominal amounts. In the United States, it is primarily used at San Francisco International Airport (SFO) and Los Angeles International Airport (LAX).[xxxiii] As supply increases, other airports near production sites will begin to utilize the fuel, however California will likely see the greatest usage as state policies make SAF more cost competitive. Globally, there were 66 million gallons of SAF produced in 2019, which is around what the United States consumes on a busy summer day.[x,xxxv] Over the next four years, production of SAF is expected to increase 16-fold, with the potential for even more production dependent on how it shares capacity with other renewable fuel products.[x] However, production will need to scale at an exponential rate in order to supplant the billions of gallons of CJF used by the industry. Aviation decarbonization plans rely heavily on substituting CJF with SAF. ATAG identifies SAF as the “single largest component” of aviation’s 2050 climate goals where it is expected to make up 26% of the reductions.[13,xxvii] ICAO’s 2016 report estimates that SAF will offset 1,000 MT of CO_2, or approximately one third of the total sector emissions.[xxxvi]

The majority of neat SAF is currently produced using the HEFA process which can provide 50% to 80% emission reductions.[14] However, other technologies such as alcohol-to-jet (AtJ) and power-to-liquid (PtL) can result in net negative emissions with carbon capture during production.[15,xxxiii,x] There are differing opinions on whether sufficient feedstock is available to provide truly sustainable alternative fuels. The Commercial Aviation Alternative Fuels Initiative (CAAFI) predicts that while sufficient SAF supply will be available, there will be significantly less climate and environmental benefits to that supply if it is used to fuel the entire industry in 2050. Conversely, the Clean Skies report from the World Economic Forum expects the commercialization of PtL to permit the disuse of less sustainable feedstocks.[xxxvii,x]

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[13] 50% of emissions reductions are expected to be accomplished via carbon offsets, making SAF the largest contributor to actual reductions from the sector.

[14] While neat SAF can provide those emissions reductions, the HEFA mixing limit is currently 50%. Therefore, once neat SAF is blended with CJF, the resulting jet fuel can have 25% to 40% reductions over CJF.

[15] Alcohol-to-Jet, also known as Alcohol-to-Fuel, converts alcohol (ex. ethanol) to an alternative fuel blendstock.

Challenges to adoption

SAF supply and production capacity is currently insufficient to meaningfully offset carbon emissions from aviation. This lack of supply stems from the price premium of SAF compared to CJF and the feedstock and production competition from the renewable diesel market. This is further complicated by the lack of infrastructure to support this new fuel type, primarily driven by the blending requirement.

Transportation and Blending

Once neat SAF is blended with CJF and certified to ASTM standards, it is eligible for transport within the refined petroleum pipeline infrastructure that supplies all major airports in the United States. The current maximum blending ratio is 50%, which is restricted by the lack of aromatics in the fuel. While this is beneficial from an engine maintenance and air pollution perspective, it can cause O-rings in older aircraft engines to not swell sufficiently.[16,xxxiv] Until these engines phaseout, blend limitations will likely remain in place, however Rolls Royce is already testing its next generation engines on 100% SAF to demonstrate feasibility and environmental performance of the unblended product.[xxxviii] While the blending requirement exists, transportation becomes more complex and costly, further hindering SAF's ability to scale. Even without a blending requirement, current and future SAF production facilities located near feedstock sources may not be located on an existing pipeline. Logistically, neat SAF and CJF need to be transported to a blending site, then additional testing and certification occur after blending, and finally the finished product can be transported to a terminal or the airport itself. In practical terms, this means that the ideal blending site for SAF would have the following characteristics:

- Storage tanks for Jet-A that the blended SAF can be stored in.
- Connection to a refined petroleum pipeline that already services airports.[17]
- Existing infrastructure and expertise in fuel blending.

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[16] This occurs in engines that have previously been exposed to fuel with a high level of aromatics. The nitrile O-rings may not swell sufficiently, which is why blended SAF requires a minimum amount of aromatics.

17 Refined petroleum product pipelines in the United States carry products ranging from premium gasoline to jet and diesel fuel. The higher quantity of a single product going through a pipeline before switching to the next product helps to decrease costs by avoid transmix and intermix. Costs will increase if the pipeline servicing the blending site does not already transport Jet-A unless the biorefinery is expected to produce large quantities of SAF.

- Existing equipment and expertise to perform fuel certification.
- Located in close proximity to a SAF refinery.

The World Energy plant in Paramount, CA is the only significant supplier of SAF in the United States. The company has been able to more easily satisfy the logistical requirements through their proximity to CJF suppliers and an offtake airport. The Paramount refinery is located in Los Angeles County, less than 20 miles from LAX and multiple oil refineries in Wilmington. This allows them easy access to CJF for blending and close proximity to multiple terminals that store Jet-A. For World Energy's current operations, CJF is trucked in, SAF is blended on-site, and much of the final product is transported via truck to LAX.[xxxix] Truck transportation of these products is undesirable as it adversely affects local air pollution, public health, road congestion and maintenance. Using trucks is also a substantially more carbon intense method of transport; Strogen and Horvath estimate that emissions per ton-kilometer is 10 times higher when oil products are transported via truck instead of by pipeline.[18,xl] However, the short distances and small quantities involved with World Energy's SAF transport make this the most economically and logistically feasible option.

Price

The most price competitive SAF is approximately two to four times more expensive than CJF and fuel makes up 20% - 30% of airline operation costs.[xli,xxxiv] Assuming the more conservative estimates of SAF costing twice that of conventional Jet A, it is understandable that airlines cannot voluntarily take a 25% increase in their operating costs and remain competitive in the industry. Part of the challenge is to reduce the cost of quality feedstocks. Generally speaking, cheap, low-quality feedstocks have a higher production cost. HEFA is a more expensive production process than AtJ, however the ethanol and syngas feedstocks used in AtJ are much more expensive than the oil and tallow used in HEFA.[xlii] In addition, many SAF pathways are in the early stage of technological development. A report by the World Economic Forum on SAF, in collaboration with McKinsey & Company, shows how the industry expects production costs

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[18] Strogen and Horvath's analysis looked at lifecycle emissions and compared them on a per ton-kilometer basis. The paper also shows how infrastructure and fuel production account for the bulk of emissions of pipe transportation, whereas tailpipe emissions are the largest component from truck transportation.

to decrease for different pathways over the next 30 years. The forecasted cost reductions vary greatly by the maturity of the technology; see Figure 2 for these estimates.

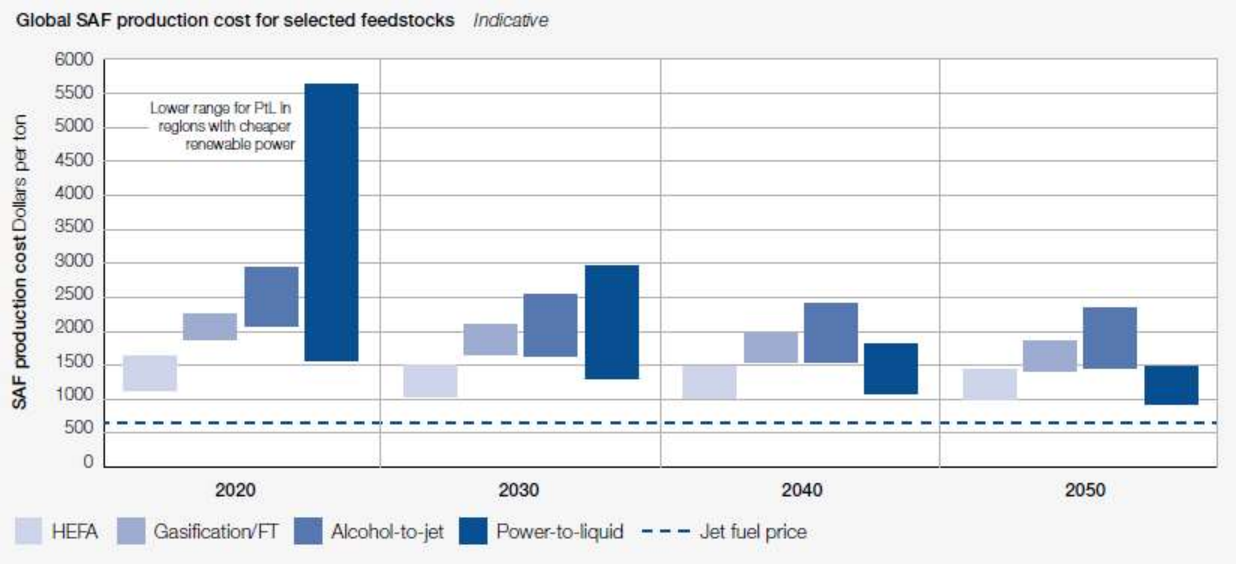

Figure 2: Cost Projections for SAF Feedstocks Based on Expert Interviews Conducted by McKinsey & Company[x]

With appropriate policy mechanisms, SAF will benefit from economies of scale. As demand for SAF increases, producers will be able to reduce costs through more cost-effective transportation and specialized equipment and labor. For World Energy, it is sufficient to truck fuels to their destination at the current production quantity, despite the adverse environmental effects. However, as demand increases, pipeline transportation becomes more economical. At high enough quantities, World Energy may be able to outsource blending to a local terminal. This would remove the need to receive CJF at the facility and allow for the piping of neat SAF to the terminal.[19]

Renewable Diesel

Renewable diesel (RD) and SAF can be produced using some of the same feedstocks and pathways, yet in 2018 only 2 million gallons of SAF were produced compared to 300 million gallons of renewable diesel.[xxxiv] This is caused by multiple factors that make renewable diesel a more appealing product for biofuel producers. Numerous government policies result in the relative price of SAF being meaningfully higher than that of RD when compared to their fossil-

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[19] World Energy's Paramount facility has private pipelines that enable non-standard products, including neat SAF, to be sent to nearby terminals.[xxxix]

fuel based counterparts. Despite RD and SAF having equivalent carbon intensities, RD receives more credits under California's Low Carbon Fuel Standard (LCFS) and the federal Renewable Fuel Standard (RFS).[xliii,xliv] Diesel is also included in California's Cap and Trade program, creating three policy price incentives for RD in that state. Some of these policies will be discussed in greater detail in the next section. In addition to the policy incentives for RD, SAF is also slightly more expensive to produce.[xlv] Lastly, the price of diesel has historically been higher than that of jet fuel and the EIA projects this to continue over the next few decades.[xlvi] The higher production costs of SAF, lower cost of CJF and pro-RD policies create a market environment that heavily incentivizes RD production over SAF production.

Transparency in Reporting

Without regulations requiring the use of low carbon fuels, airlines' motivation for purchasing a more expensive fuel is to reduce carbon emissions and market those environmental efforts. Due to the wide range of carbon reduction benefits that SAF can offer, reporting on SAF usage needs to be detailed and standardized. A gallon of blended SAF (Jet-A) can have anywhere from 1% to 50% neat SAF in it. Neat SAF can also have lifecycle emissions anywhere from 10% to 80% lower than CJF. Therefore, if a company were to advertise use of SAF in gallons, it could represent a carbon reduction from 5% to 80% depending on the mixing ratio, lifecycle emission reductions and whether it is reported in neat or blended gallons. For this reason, the industry could benefit from established reporting standards.

United Airlines is transparent and provides the percent of lifecycle emissions reduction, the mixing ratio, and the total carbon emissions offset each year from SAF usage on their website. However, United Airlines' SAF usage is also quantified by the statement, "United will purchase up to [15 million gallons]", which does not identify the exact amount purchased thus far.[20] American Airlines is also fairly transparent in that they provide the number of gallons they agreed to purchase, the timeline and the precise GHG reductions the fuel offers.[21] In

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[20] Details on United Airlines' use of sustainable aviation fuel can be found in their corporate responsibility report and sustainable fuel source website.

[21] American Airlines' SAF commitments can be found on these websites: https://www.aa.com/i18n/customer-service/about-us/sustainability.jsp, https://www.aa.com/content/images/customer-service/about-us/corporate-governance/aag-esg-report-2019-2020.pdf

comparison, other companies advertise SAF usage and do not provide specifics on either the number of gallons purchased or the equivalent carbon offset. For example, JetBlue's marketing of SAF does not mention a quantity and instead only highlights that the fuel is made from "100 percent renewable and sustainably sourced waste and residue" with "up to 80 percent smaller carbon footprint compared to fossil jet fuel".[22] This can be misleading to the climate conscious consumer and can discourage airlines from making robust commitments to SAF if the additional efforts are not anticipated to be recognized by consumers.

Standard reporting is needed in order for consumers to accurately understand the voluntary carbon reduction efforts by airlines. Companies should provide the amount of carbon emissions avoided through the use of SAF. This is specific and provides an easy means for directly comparing SAF emission reductions to other methods and airlines. The downside to this approach is that metric tons of CO_2 does not convey magnitude well to all consumers. An alternative approach would be for the company to state avoided CO_2 emissions in terms of equivalent gallons of CJF. This provides a metric that is both specific and consumable. The mixing ratio and percent reduction of GHG emissions compared to CJF are relevant data points, however it is harder to do a side-by-side comparison of the environmental benefits. These can be included as ancillary information in addition to the total emissions avoided.

While this section focused on the importance of quantifying SAF benefits, it is also recommended that organizations qualitatively discuss the sustainability of the feedstock for their fuels. This can help to assuage concerns about direct and indirect land use change and other unsustainable practices. United Airlines does this well by highlighting feedstock and production processes of the SAF purchased from different biorefineries.[20]

Policy Options and Motivations

As highlighted above, the price difference between CJF and SAF is significant, with neat SAF costing at least twice as much per gallon. This is the largest barrier to SAF adoption as there is a substantial economic disincentive to voluntary purchases of large volumes of SAF. In addition to the underlying feedstock and production costs, the price of SAF is influenced by more costly

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[22] JetBlue's marking on SAF usage were found at these sites: https://www.jetblue.com/sustainability/climate-leadership, http://blueir.investproductions.com/investor-relations/press-releases/2020/08-13-2020-152953291

transportation requirements, feedstock competition with renewable diesel and competing government policies. Further public policies are needed in order for the United States to scale SAF production and capitalize on its decarbonization potential. This section will discuss current policies that promote and hinder SAF adoption in California, along with policies currently being proposed.

Current Policies

One of the primary drivers of SAF production and consumption is California's Low Carbon Fuel Standard (LCFS). The LCFS is a market-based regulation designed to decrease emissions from the transportation sector. It requires transportation fuels to meet a lifecycle carbon intensity (CI) benchmark that decreases over time.[23] Fuels generate a credit or a deficit based off whether their CI is higher or lower than the fossil fuel-based benchmark. This flexible framework economically incentivizes alternative fuels that minimize both lifecycle emissions and production costs. The aviation sector is unique in that CJF is exempt from the LCFS while SAF was eligible for credit generation starting in 2019. This allows airlines to purchase SAF at lower prices without a corresponding increase in overall jet fuel costs. This resulted in the aviation-related program amendments receiving broad support from the private sector.[xlv]

	Average CI (gCO_2e/MJ)	
Year	**CJF**	**Diesel**
2019	89.37	94.17
2020	89.37	92.92
2021	89.37	91.66
2022	89.37	90.41
2023	**89.15**	**89.15**
2024	87.89	87.89
2025	86.64	86.64
2026	85.38	85.38
2027	84.13	84.13
2028	82.87	82.87
2029	81.62	81.62
2030	80.36	80.36

Table 1: Carbon Intensity Benchmarks

This policy makes California one of the primary markets for SAF in the United States.[24] It also is expected to be a significant driver of the growing SAF production capacity over the next few years. While RD and SAF have the same CI, they do not currently receive the same credit under the

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[23] Carbon intensity is the amount of carbon emitted per unit of energy. In calculating carbon intensity, the LCFS looks at emissions from the full lifecycle of the fuel.

[24] Oregon has a similar low carbon fuel standard that contributes to the state being another top consumer of biofuels in the United States. More information can be found on the Clean Fuels Program website.

LCFS due to the benchmarks set for the fossil counterparts.[25] However, from 2023 onward the benchmarks for diesel and CJF will be equal.[xliii] This will allow for SAF and RD to receive equivalent credits under LCFS, encouraging additional capacity for SAF by correcting one of the policy disparities between the two fuels.

Federally, the Renewable Fuels Standard (RFS) also promotes SAF usage. Neat SAF generates 1.6 renewable identification numbers (RINs) per gallon.[xliv] With the range of RIN prices over the last 5 years, this has provided a credit from $.64 to $1.76 per gallon of neat SAF.[xlvii] However, the RFS also provides fewer credits for SAF than RD, which receives 1.7 RINs per gallon - 6% higher than SAF.[xliv] Together, the LCFS and RFS are the primary policies in that drive the SAF market in California, however the nuance within the policies also hinder SAF adoption by providing greater fiscal support to SAF's feedstock competitor, RD.

Other policies that compete with those that promote SAF are California's Cap and Trade and federal fossil fuel subsidies. Similar to the LCFS, California's Cap and Trade program applies to diesel and excludes jet fuel.[xlviii] In March of 2018, the Oil Price Information Service (OPIS) market report found that CARB diesel had a $0.15 per gallon premium over renewable products.[26,xlv] This is another example of RD's policy premium in California. Federally, entrenched fossil fuel subsidies undermine the price incentives of renewable fuel policies.[27] In the United States, fossil fuels are directly subsidized at an estimated $20 billion per year – 80% of which is for oil and natural gas.[xlix] While fossil fuel subsidy reform is recognized as a global issue in the fight against climate change, organized pro-oil lobbying has prevented meaningful change in the United States.

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[25] RD and SAF have a wide range of CIs based on feedstock, refinery processes and individual batches. However, they are coproduced, so the RD and SAF that come out of a particular batch of biofuel have the same CI and are therefore directly comparable under the LCFS.

[26] OPIS provides detailed market data on petroleum products. This includes analysis on the cost of CARB policies "at-the-rack". See McKinsey Energy Insights for further information on rack prices.

[27] Fossil fuel subsidies work against emission reduction goals and policies across economic sectors. However, these subsidies can be seen as a complement to renewable energy and fuel policies in an effort to increase energy independence.

Proposed Policies

There are currently multiple bills in Congress designed to increase SAF production and usage in the United States.[28] The Sustainable Aviation Fuel Act (H.R. 741) was introduced by Representative Brownley in February of this year. This bill would benefit the adoption of SAF by:[l]

- Creating a grant program for the express purpose of expanding SAF infrastructure.
- Amending the Clean Air Act; mandating the EPA create a low carbon fuel standard for the aviation industry.
- Requiring the Department of Defense to purchase SAF for at least 10% of its fuel needs.
- Providing a tax credit of $1.50-$1.75 per gallon of neat SAF.

This is a comprehensive bill that invests in infrastructure, legislates demand through federal spending, subsidizes the cost of SAF and sets national goals for the reduction of emissions from the aviation industry. Only fuels with greater than 50% carbon reductions are eligible for the tax credit and the value of the credit increases as CI decreases.[l] In addition, the inclusion of a federal aviation low carbon fuel standard is beneficial in that it not only provides monetary benefits to airlines using SAF, but it also imposes a financial penalty on the use of high carbon fuels. This industry-wide increase in fuel cost is expected to be passed on to consumers through an increase in ticket price which has the potential to reduce emissions through a reduction in air travel demand for short haul flights where alternative modes of transportation are an option.

The fuel standard is expected to receive the greatest pushback from the industry as it will directly add to operating costs. During previous hearings on the potential for aviation emission regulations, members of the airline industry have repeatedly stated that regulations are not needed to address emissions. The private sector accurately describes their great track record on improving fuel efficiency, highlighting that operating costs from fuel provide sufficient economic incentive for airlines to take steps to reduce fuel consumption, and therefore GHG emissions.[xxxi] While emissions reductions have historically aligned with reducing fuel

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[28] A third bill, H.R. 1542, creates a renewable fuel grant program that sustainable aviation fuel investments are eligible for. However, the bill is primarily targeted toward ethanol production and solely sponsored by representatives from corn belt states.

consumption efforts, that does not apply to the adoption of SAF which increase fuel costs while decreasing emissions.

The airline industry was also decimated by COVID-19 pandemic, leaving the sector with massive amounts of debt. The current financial stress on airlines will reduce the political will to pass a policy that increases airline costs. However, McKinsey estimates ticket prices will increase as supply lags travel demand.[li] This surplus in demand may create an opportunity for additional fuel costs to be added to ticket prices without adversely affecting ticket sales. Additionally, a 2008 study by IATA found that a nationwide increase in ticket price is fairly inelastic, with shorter flights demonstrating a higher elasticity than medium and long-haul flights.[lii] This further supports the likelihood that an increase in ticket prices across all airlines due to rising fuel prices will have minimal impact on travel demand.

The second bill on SAF was introduced by Representative Schneider on May 20th. The Sustainable Skies Act (H.R. 3440) proposes a tax credit very similar to Brownley's bill.[liii] This tax credit is also present in the American Jobs Plan – President Biden's signature clean infrastructure plan.[liv] The credit provisions in these bills are likely to receive greater support from the airline industry than H.R. 741 as it provides a SAF subsidy while not imposing any costs through a low carbon fuel standard. Conversely, these tax credits are less likely to receive support from fiscal conservatives as they are expected to reduce annual revenue from $.3 billion in 2022 to $1.7 billion in 2027.[liv] Proponents of emissions reduction in aviation and alternative fuel producers are more likely to favor Brownley's more comprehensive bill as it sets national goals and invests directly in supply infrastructure, however the individual tax credit is more politically viable.

San Diego International Airport

The paper thus far has discussed the challenges of decarbonizing the aviation sector and the crucial role that sustainable aviation fuel plays on the path to deep decarbonization. Despite the challenges SAF currently faces, it is the author's view that both necessity and the industry reliance on SAF in emissions planning will result in the fuel being readily available and distributed through standard supply chains within 20 years. This section of the paper will discuss potential opportunities to bring SAF to the San Diego International Airport (SAN) in the near term in alignment with SAN's leadership in sustainability. SAN is owned and operated by the San Diego County Regional Airport Authority (Airport Authority). Although the Airport Authority is not directly involved in the purchase, transportation or storage of jet fuel, the public agency has adopted a formal Carbon Neutrality Plan, which includes a strategy to partner with airlines to help facilitate their future use of SAF at SAN. The section will cover potential suppliers, infrastructure constraints and fuel acquisition challenges.

Potential Suppliers

SAF is an emerging technological solution to aviation decarbonization and as such there are very few companies currently producing the product. As industry and policy shifts forecast a rise in demand, additional biorefineries are being constructed. The producers found to be most likely to be able to supply SAN in the near-term are World Energy, Neste, Fulcrum BioEnergy and Red Rock Biofuels.

	Current SAF	Future - All Fuels	Future - SAF	Location
World Energy	5+	350	150	Paramount, CA
Neste	30	-	500	Multiple
Fulcrum	-	11	-	Reno, NV
Red Rock	-	16	-	Lakeview, OR

Table 2: Annual production capacity of SAF producers in million gallons

World Energy, formerly AltAir, is the largest producer of SAF in the United States and one of the two major producers globally. They have been producing SAF at a biorefinery in Paramount, California for 5 years and regularly supply fuel to LAX and other airports. Approximately 45 million gallons of alternative fuels are produced at the Paramount site, with the bulk of capacity going towards the production of renewable diesel.[lv,xxxiii] Precise production values of SAF are not available, however the plant is currently capable of producing at least 5 million gallons of SAF a year.[29] The Paramount facility is currently undergoing a major conversion project that will increase total production capacity to 350 million gallons, with approximately 150 million gallons of SAF capacity.[xxxix,xxxiii] It is important to note that World Energy may choose not to

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[29] Precise production values are not advertised. This is likely influenced by market dynamics shifting demand between Paramount's RD and SAF products. Given United Airlines offtake agreement of up to 15 million gallons over three years, 5 million gallons per year is the expected minimum production capacity of the plant. Actual capacity for SAF production could be much higher, given the additional offtake agreements and the volume of total biofuels produced there.

produce that much SAF based on the policy, market dynamics and offtake agreements for a given year. Much of the current production of SAF is spoken for via offtake agreements with United Airlines, Amazon Air and others; however, there may be some volume available for purchase and use at SAN.[xxxix] The additional production capacity post-conversion may present additional offtake opportunities as well.

Neste is the other major producer of SAF in the world with a capacity of over 30 million gallons.[lvi] The company is currently supplying SAF to SFO for use by multiple passenger and cargo airlines.[lvii,lvi] Expansion projects in the Netherlands and Singapore are expected to increase Neste's total production capacity of SAF to approximately 165 million gallons in 2023.[lviii] While demand in Europe may retain the production from the Netherlands and Finland, SAN could be a potential destination of the increased production in Singapore.

Construction is underway for two new SAF production facilities in the western United States. Fulcrum BioEnergy is building the Sierra BioFuels Plant near Reno, Nevada. Total production capacity at this facility is relatively small at 11 million gallons per year.[lix] Unlike World Energy and Neste who primarily use the HEFA process, this plant will be using the Ficher-Tropsch (FT-SPK) pathway with municipal solid waste (MSW) as a feedstock.[lx] The Nevada plant will produce a synthetic crude for processing at a Marathon refinery near San Francisco.[lxi] Production from the Nevada facility is less likely to reach SAN given the relatively small capacity and refiner's proximity to SFO – one of the leading consumers of SAF. Fulcrum BioEnergy planned to create multiple other refineries near large MSW sites, including Los Angeles.[lxii] However, the current status of these proposed facilities is unclear.

Lastly, construction has begun at the Red Rock Biofuels facility in Southern Oregon. This plant will process woody biomass waste from the lumber industry using the FT-SPK process.[lxiii] The plant is expected to enter service in 2022 and have a total production capacity of 16 million gallons per year.[lxiii] This is another less likely source for SAF for SAN given the existence of a low carbon fuel standard in Oregon and the limited production capacity of the plant.

Supply Logistics

The primary logistical challenges to using SAF at SAN are the availability of a blending site and integration with the existing supply infrastructure. To identify opportunities, this section will discuss potential blending sites, starting upstream and moving down to SAN.

Watson Station

The Watson Station Terminal is located in Long Beach, California near several refineries that supply SAN with jet fuel. A terminal is a facility that stores and distributes petroleum products. As such, they often have the infrastructure in place to perform blending operations.[30] Watson Station is also located less than 10 miles southwest of the Paramount facility, presenting two opportunities. First, blended SAF can be transported to this terminal. Alternatively, neat SAF could be transported to this terminal, where it could be blended and certified as Jet-A. Both of these would be ideal supply solutions as it would rely primarily on transporting SAF via pipeline, which is a cheaper, low-carbon transport method than trucking or rail.

Kinder Morgan, which owns and operates this terminal, could not be reached for an interview. This has left the author with multiple outstanding questions that influence the feasibility of SAF entering the supply chain at this point:

Does Watson Station have the capacity available for SAF blending? Terminals have long term leases with customers and often operate at full capacity.[lxiv] For Watson Station to perform the blending, infrastructure would need to become available for World Energy to lease. Alternatively, World Energy could partner with a fossil fuel company to scale SAF supply and leverage that company's leased infrastructure.[31]

Is Watson Station connected to the Paramount facility via pipeline? World Energy described their Paramount facility as being pipeline connected "in all directions", however an explicit list of connected terminals was not obtained. If Watson Terminal is one of those destinations, World Energy may be able to pipe neat SAF or blended SAF to that terminal to join the existing supply route. As discussed earlier, the Paramount facility has private pipelines that enables World Energy to transport non-standard products. In the interstate multi-product

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[30] An example of a common blending operation performed by terminals is creating ethanol gasoline blends.

[31] Many biofuel producers have partnered with fossil fuel companies in order to facilitate blending and supply logistics.

refined petroleum product pipelines, SAF can only be transferred after blending and certification.

Is a separate storage tank needed for blended SAF? While the blended fuel is ASTM certified jet fuel, terminal storage is often leased out to individual companies. It is suspected that a separate storage tank is needed for each company's product. If blended SAF can go into a tank with other Jet-A fuels, then there is less likely to be storage capacity restraints at the terminal that would prevent World Energy or other producers from entering the supply line here. If it is stored with Jet-A from other refineries, that would also imply the purchase of SAF for use at SAN may come from a mixed tank that distributes to other airports as well.

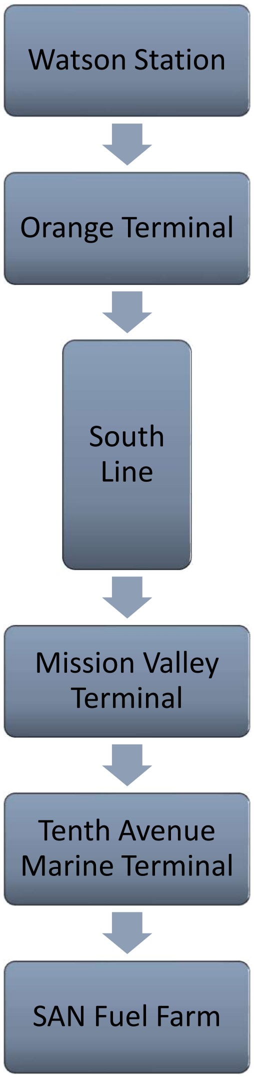
Can Watson Station – or another nearby terminal – receive refined petroleum products from the Port of Los Angeles? The Port of Los Angeles receives over 50 million barrels of petroleum products a year, including jet fuel.[lxv] This could be an import site for SAF from Neste's production facility in Singapore. Given the quantity of liquid bulk imported through Los Angeles, it is highly likely that SAF can be offloaded at the port and travel via pipeline to Watson Station, or another terminal that can connect with SAN.

Orange Terminal

Orange Terminal is 20 miles southeast of the Paramount plant and is the second stop for jet fuel on its way south to SAN. It has similar operations and considerations to that of Watson Station. Orange Terminal would be a good entry point into the supply line if it has blending capacity available. Ideally, World Energy would be able to pipe neat SAF directly there, however trucking would be cost effective – if not as environmentally effective – at this distance. Another consideration is the quantity of SAF that would need to be blended at Orange Terminal in order for leasing to be appropriate. This location is far enough east that the blended product may only service San Diego County airports. This would require a larger offtake agreement to be fiscally feasible. Alternatively, it may be more economical to transfer lower quantities of blended SAF to this site as long as it can be stored with other Jet-A on the property.

Mission Valley Terminal

Mission Valley Terminal is the main road-fuel distribution station in the San Diego area. This is a less likely blending site and has similar considerations to the aforementioned terminals. This location would be best if an SAF production facility is built in San Diego area – potentially



one that uses MSW as a feedstock. Otherwise, neat SAF would need to travel to this site via high-carbon, high-cost trucking. It is also less likely that this distribution site is set up for truck offloading, potentially requiring additional infrastructure investments.

Tenth Avenue Marine Terminal

The Tenth Avenue Marine Terminal (TAMT) has three storage tanks designated for jet fuel with a total capacity of 5 million gallons.[32,lxvi] These tanks receive fuel from the Los Angeles area through the south line and complement the jet fuel storage at the airport. TAMT is located at the Port of San Diego which is railway-connected. However, TAMT is only capable of filling the jet fuel storage tanks from the pipeline and trucks.[lxvii]

If TAMT were to gain the ability to offload jet fuel from tank railcars or oil tankers, this would enable SAN to more easily receive blended SAF from a broader range of suppliers, in particular Neste's Singapore plant.[33] An infrastructure project that expands TAMT's fuel capabilities in this way also provides resiliency benefits. The South Line is the only pipeline that supplies jet fuel to the San Diego area. If it were unavailable, fuel would need to be trucked to SAN and fuel tankering operations may be necessary.[34,lxvi] Additional infrastructure for offloading fuel into the TAMT tanks would not only enable SAF imports from other sources, it would also significantly improve the resiliency of the airport's fuel supply.

Airport Fuel Farm

The airport fuel farm is supplied via a pipeline from TAMT and currently has two, one-million-gallon fuel tanks.[lxvi] This provides the airport with 3 days of fuel on-site during the peak flying season.[lxviii] SAN is currently expanding the fuel farm by adding three additional tanks,

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[32] Fuel tanks do not operate at full capacity. For that reason, the total storage at TAMT may be slightly lower than the 5 million gallons mentioned above.

[33] TAMT is currently able to offload some fuels from non-pipeline and truck sources. However, this capability does not extend to jet fuel.

[34] Fuel tankering is the practice of inbound flights carrying enough fuel for the original flight in addition to follow-on route. This reduces the need to fuel up at an airport. However, it results in greater fuel burn and emission due to the additional weight from the surplus fuel on the inbound flight.

bringing total usable capacity up to 4.6 million gallons.[lxviii] This is a necessary upgrade as the existing storage capacity is insufficient to reliably handle upstream supply interruptions.

It is not recommended for the fuel farm to be used as a blending site. The airport has neither the blending infrastructure, nor the equipment and expertise necessary to certify the Jet-A post-blending. It is also not recommended for SAN to pursue additional operations and infrastructure requirements given the limited space on the property and the likelihood that it would become obsolete as SAF begins to scale. The airport fuel farm could receive blended SAF directly via truck. However, trucking fuel adds to local congestion and air pollution, making this counterproductive to SAN's environmental mission. This would however be an appropriate supply method if a small-scale biorefinery was built in San Diego County.

Conclusion

Aviation is a growing percentage of global emissions and a difficult sector to decarbonize. The sector has continually demonstrated an ability to reduce emissions on a service level basis, with recent data showing a 3% increase in fuel efficiency from 2016-2018 per revenue passenger mile.[lxix] However over that same time period, there was a 7% increase in fuel consumption as demand continued to outpace these efforts. Deep decarbonization through radical aircraft and propulsion transformation is stymied by significant technological challenges, infrastructure constraints and long aircraft lifespans. Sustainable aviation fuel provides a crucial near and mid-term solution that allows the sector to begin decoupling emissions from growth.

While the industry and consumers are beginning to address emissions through the purchase of SAF, more drastic action is needed to scale SAF and meaningfully reduce aviation emissions over the next decade. The proposed Sustainable Aviation Fuel Act offers a robust set of policies for increasing the use of SAF; however, an industry-favored tax credit is more politically viable and will still stimulate production. San Diego International Airport has a few opportunities to obtain SAF for its operations. Small quantities may be available for purchase now, however the airport may wish to wait to bring SAF to San Diego until there is sufficient capacity to justify more environmentally friendly transportation. The likelihood of SAN obtaining a supply in the next few years will be heavily influenced by whether TAMT's fuel infrastructure can support offloading from railcars and oil tankers and if World Energy’s growing SAF production enables the company to begin utilizing oil terminal and pipelines for product delivery. SAN will need to actively engage airlines, infrastructure owners, and terminal operators in order to ensure SAF adoption in San Diego ahead of the industry at large.

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