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Clean TAKEOFF

Policy Solutions to Promote Sustainable Aviation in California

OCTOBER 2022
Policy Report

CLIMATE & ENERGY
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ABOUT THIS REPORT

This report is the result of an expert stakeholder convening held by UC Berkeley's Center for Law, Energy & the Environment (CLEE) in January 2022 to develop sustainable aviation fuel policies in California. CLEE thanks the ClimateWorks Foundation and Transportation Program Manager Lina Fedirko for their generous support and guidance in this initiative. CLEE also thanks Amy Malaki, former Associate Director at ClimateWorks, for her significant leadership in this initiative.

AUTHORS

Ethan N. Elkind
DIRECTOR - CLIMATE PROGRAM
CENTER FOR LAW, ENERGY & THE ENVIRONMENT

Katie Segal
RESEARCH FELLOW - CLIMATE & OCEANS
CENTER FOR LAW, ENERGY & THE ENVIRONMENT

Ted Lamm
SENIOR RESEARCH FELLOW - CLIMATE
CENTER FOR LAW, ENERGY & THE ENVIRONMENT

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ABOUT THE CENTER FOR LAW, ENERGY & THE ENVIRONMENT

The Center for Law, Energy & the Environment (CLEE) channels the expertise and creativity of the Berkeley Law community into pragmatic policy solutions to environmental and energy challenges. CLEE works with government, business, and the nonprofit sector to help solve urgent problems requiring innovative, often interdisciplinary approaches. Drawing on the combined expertise of faculty, staff, and students across the University of California, Berkeley, CLEE strives to translate empirical findings into smart public policy solutions to better environmental and energy governance systems.

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Dan Adler
INFRASTRUCTURE AND ECONOMIC DEVELOPMENT BANK

Theresa Chen
BARCLAYS

Erin Cooke
SAN FRANCISCO INTERNATIONAL AIRPORT

Bahram Fazeli
COMMUNITIES FOR A BETTER ENVIRONMENT

John Holler
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Adam Klauber
WORLD ENERGY

Jonathan Lewis
CLEAN AIR TASK FORCE

Amy Malaki
SKYNRG

Alex Menotti
LANZAJET

Patty Monahan
CALIFORNIA ENERGY COMMISSION

Andrew Murphy
TRANSPORT & ENVIRONMENT

Colin Murphy
UC DAVIS

Graham Noyes
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This report and its recommendations are solely a product of UC Berkeley School of Law and do not necessarily reflect the views of all individual convening participants, reviewers, or the ClimateWorks Foundation.

I. EXECUTIVE SUMMARY AND INTRODUCTION

Airplane travel is essential for mobility, economic development, and quality of life. Yet the sector emits approximately 915 million metric tons of carbon dioxide (CO_2) each year, accounting for 2.1 percent of global carbon dioxide (CO_2) emissions.[1] Non-CO_2 emissions raise the total impact further, accounting for approximately two-thirds of aviation's overall climate impact. Lowering the emissions intensity of aviation will be a critical, if challenging, piece of the transition to a sustainable advanced economy.

Aviation's future contribution to global emissions will depend on the popularity of air travel, trends in the shipping of goods, and the industry's ability to adopt lower-emission aircraft and fuels alongside other decarbonization measures. To achieve carbon neutrality by mid-century and avert the worst impacts of climate change, policy makers and industry will need to reduce aviation emissions.

Due to the singular technical challenges of aviation, aircraft decarbonization technologies are not yet as common as similar technologies in other major emitting sectors like transportation and electricity. Until these technologies (such as electrification, hydrogen fuels, and improved airframe design, among others) are accessible and mature, sustainable aviation fuel, largely derived from low-carbon biofuels, represents the most promising decarbonization option. This report focuses on bolstering low-carbon biofuels for aviation, while also encouraging longer-term solutions including non-biogenic fuels, hydrogen, and electric-powered planes, as part of the broader sustainable aviation movement.

California is uniquely suited to be a global leader in sustainable aviation. The state has ambitious goals to decarbonize its economy by 2045, including programs (like the Low Carbon Fuel Standard) that leaders can tailor to include sustainable aviation fuel. The state also hosts 12 international airports and numerous in-state flights, presenting opportunities for regulatory and incentive programs.

Yet California lacks a comprehensive plan to decarbonize aviation, missing an opportunity to promote sustainable aviation globally at a critical moment. This gap is despite Governor Gavin Newsom's July 2022 call for a 20 percent clean fuels target for the aviation sector, along with modifications to the state's transit fuel program (the Low Carbon Fuel Standard) that could facilitate the transition to clean fuel production.[2] To address this challenge, the Center for Law, Energy and the Environment (CLEE) at UC Berkeley School of Law convened experts from the aviation sector, sustainable aviation fuel industry, academia, advocacy groups, airports, and state government to identify barriers and recommend solutions.

While the group did not agree on all the recommendations in this report, many of the solutions here received widespread support from participants. Notably, airline industry participants in particular objected to recommendations that involve state-based mandates for sustainable aviation fuel, which they argued are preempted by federal law. While a thorough discussion of federal preemption on aviation preemption is beyond the scope of this report, policymakers would need to craft any solution discussed in this report in a manner that would withstand legal challenges to state authority.

Ultimately, the group envisioned a strategy for decarbonizing aviation in California that would:

- Support net greenhouse gas emission reductions from the aviation sector by emphasizing in-sector reductions rather than offsets.
- Maximize air quality and economic co-benefits in communities near airports and production facilities.
- Incentivize lower-carbon liquid fuels and advance new electric and hydrogen technologies for shorter regional and in-state flights.
- Maintain affordable, equitable access to air travel for consumers by ensuring financial sustainability and equitable distribution of cost burdens (including by non-residents of California).
- Provide all airlines with access to sustainable aviation fuel supplies.
- Engage the agricultural community to promote appropriate and sustainable production practices.
- Foster clean energy jobs regionally and locally.
- Build in-state sustainable aviation fuel use and production capacity while catalyzing the national market and federal policy goals.

The state will need to assess the potential risk that federal preemption could restrict California's ability to regulate the aviation sector. While a comprehensive legal analysis on this point is beyond the scope of the report, state policymakers will need to ensure that policy can withstand court challenges to their authority, as well as work with federal leaders to resolve any conflicts. For additional discussion of preemption, see Section IV.

The participants then identified three priority barriers to realizing the vision, along with recommended solutions to overcome each one. The list below represents a high-level summary of recommendations. For a full analysis of each recommendation, see Section IV.

A. BARRIER #1: LACK OF POLICY SIGNALS TO ENCOURAGE INVESTMENT AND OVERCOME HIGH CAPITAL COSTS TO AVIATION DECARBONIZATION EFFORTS

To address this barrier, the Governor's office, state legislature, and the California Air Resources Board could:

- Develop a comprehensive statewide commitment and long-term plan to decarbonize in-state aviation fuels while working with national and international leaders on broader decarbonization goals, where consistent with federal law.
- Tax or levy a carbon fee on conventional aviation fuel and use the proceeds to fund research and development, where permitted by federal law.
- Develop permit-streamlining pathways for priority sustainable aviation fuel infrastructure, such as through the Governor's Office of Business and Economic Development (GO-Biz).
- Incentivize private investments by facilitating offtake agreements, contracts-for-differences, low-interest loans, and commercial partnerships for state aviation investments or travel, including through the California Treasurer's Office.

The California Air Resources Board could:

- Regulate conventional aviation fuels under California's Low Carbon Fuel Standard and promote that approach nationally and internationally, where permitted by federal law.
- Coordinate with the U.S. Environmental Protection Agency to regulate more strictly the criteria pollutants from burning conventional fuels in the sector.

Airport leaders could:

- In collaboration with airlines, develop plans to invest in infrastructure and other supportive tools to encourage sustainable aviation fuel deployment.

BARRIER #2: LACK OF SUSTAINABILITY AND AVAILABILITY OF FUEL SUPPLIES AND CERTAINTY OF TECHNOLOGIES

To address this barrier, state and industry leaders could:

- Develop a comprehensive sustainable aviation fuel feedstock sustainability framework.
- Accelerate research into low-emission flight technologies and free up low-carbon biofuel supplies through investment in electrified road transportation.

The California Air Resources Board and California Energy Commission could:

- Develop a strategy to reduce and mitigate risks from induced land use change from biogenic sustainable aviation fuel feedstock production.
- Assess life cycle emissions and environmental impacts of potential sustainable aviation fuel technologies to balance strategies.

BARRIER #3: INADEQUATE POLITICAL SUPPORT AND LACK OF POLICYMAKER AND CONSUMER EDUCATION

To address this barrier, the Governor's Office and the California Air Resources Board could:

- Develop a state playbook to guide sustainable aviation fuel deployment.[3]
- Direct state agencies to address equity concerns and advance equitable outcomes through a sustainable aviation fuel policy.

Sustainable aviation fuel producers and industry leaders could:

- Advance educational and promotional efforts to raise awareness of sustainable aviation fuel and pathways for adoption.


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II. OVERVIEW: SUSTAINABLE AVIATION FUEL AND CLIMATE CHANGE POLICY

Sustainable aviation fuel is rapidly developing and gaining support in a range of initiatives, but key technology, policy, and sustainability questions remain.

A. IMPORTANCE OF REDUCING AVIATION EMISSIONS GIVEN RISING DEMAND

Aviation accounted for 2.1 percent of global carbon dioxide (CO_2) emissions in 2019.[4] Although the COVID-19 pandemic stunted the sector's growth and operations, customers are returning to air travel and passenger volumes have begun to recover to pre-pandemic levels.[5] Aviation's contribution to global emissions by mid-century depends, in part, on the portion of conventional jet fuel replaced with alternative fuel sources, along with other measures to decrease emissions. An International Civil Aviation Organization (ICAO) analysis estimated that without an influx of alternative fuels, aviation fuel consumption could increase nearly threefold by 2050, resulting in increased carbon emissions; however, technology improvements and jet fuel replacements could reduce emissions substantially by 2050, in concert with other demand-side measures.[6] The extent to which industry, government, and researchers can advance alternative fuel options will determine the extent of emissions reduction in the coming decades. Reducing these emissions will be a critical component to the global effort to achieve greenhouse gas reductions and carbon neutrality by mid-century, if not sooner, in order to avert the worst impacts of climate change.[7]

Aviation-induced contrails and changes to high-altitude atmospheric chemistry can affect the exchange of energy between Earth and space, meaning the sector's total contribution to climate change may be greater than predicted by its greenhouse gas emissions alone.[8] When accounting for this radiative forcing, aviation's total contribution to climate change is more significant. As analysts expect the demand for air transport to grow, these emissions could worsen in the coming years.[9]

Several existing roadmaps and policy reports describe a path towards zero-emissions for the aviation sector.[10] This report offers a California-focused approach and outlines specific actions that California state leaders can take to encourage aviation emission reductions by increasing uptake of sustainable aviation fuel.

B. SUSTAINABLE AVIATION FUEL AS A VIABLE EMISSION REDUCTION OPTION

Sustainable aviation fuel is a low-carbon alternative to traditional jet kerosene and could represent a fast and viable approach to reducing aviation emissions in the near to medium term. Sustainable aviation fuel can be derived from a variety of biogenic, renewable feedstocks (the source from which the fuel is produced) including used cooking oil, energy crops, and municipal and other waste materials.[12]

Non-biogenic sources are also available, such as hydrogen or waste gases. Electric aircraft may become viable, especially for shorter flights, and therefore may play an important role in reducing emissions from intra-state flights. See Part D of this section for a more detailed overview of hydrogen and electric aviation pathways.

- Waste fats, oils, and greases (FOGs) consist of plant, animal, and other types of fats or greases, including waste products with no residual value and byproducts or residues that have little value but may experience some market demand. The supply of these materials is small compared to total demand.
- Energy Crops are crops grown exclusively for energy production instead of consumption due to their high lipid oil content. Growing these crops requires arable land, which can raise land use challenges. Several different categories of energy crops can contribute to sustainable aviation fuel production, including:
    - Cover crops, such as castor seed or carinata
    - Cellulosic energy crops, such as switchgrass and Miscanthus
    - Conventional oilseed crops, such as soybean, canola, or palm
- Municipal Solid Waste is the biogenic portion of household and business waste which may include food scraps and product packaging and clothing derived from biogenic sources (fuel providers can utilize non-biogenic waste for some fuels as well, but the practice is not common at this point).

Aviation activities generate not only carbon dioxide emissions, but also non-CO_2 emissions of fine and ultra-fine particulate matter, NO_x, SO_x, and water vapor, all of which have climate change impacts and some of which have air quality impacts. Aircraft contrails (cooled exhaust formed under certain conditions) can also increase the heat trapped in the lower atmosphere. When taken into account, non-CO_2 effects are estimated to be responsible for two-thirds of aviation's overall climate impact.[11] Greater policy emphasis on reducing these non-CO_2 emissions could help to improve public health and climate change outcomes. More research is needed to determine the full impact of non-CO_2 emissions.

- Other Waste Materials, which include a variety of excess wood, agricultural, and/or forestry waste residues with the most common source being agricultural residues. The residues are first processed into synthetic fuel and jet fuel thereafter.
- Algae is a promising source for large-scale production of sustainable aviation fuel. Challenges surrounding commercialization have limited algae's potential, and further research and development are needed to widen its application and adoption.
- Electrofuels (e-fuels) can be synthesized by using electricity to split hydrogen from water, as well as carbon from carbon dioxide. These can then be synthesized into finished fuels; if the electricity used for the process is renewable then the resulting fuels can be extremely low-carbon, and even carbon neutral if the carbon dioxide is sourced from direct air capture. This process is extremely energy-intensive at present.

A variety of production processes and technologies exist for producing sustainable aviation fuel, but they typically fall into two main categories: hydrotreating and synthesis.

- Hydrotreating uses a lipid, such as vegetable oil or waste oil, as its feedstock, and runs the lipid through a process similar to one that occurs in conventional petroleum refining. The output is typically a mixture of sustainable aviation fuel, renewable diesel, and renewable gasses like propane.
- Synthesis pathways take a variety of feedstocks, such as cellulosic biomass, and break these feedstocks down into smaller component molecules, and then re-assemble them into larger molecules like those in sustainable aviation fuel. Synthesis pathways can use a variety of thermal, chemical, or biological techniques to produce their fuel, such as Fischer-Tropsch synthesis, hydrolysis and fermentation, gasification, or pyrolysis.
- Often, a fuel production pathway may combine elements of both pathways, such as using pyrolysis to produce a crude "bio-oil" that is then hydrotreated and upgraded at a refinery.

The first sustainable aviation fuel pathway was approved by the American Society for Testing Materials (ASTM) in 2009; at present, international regulators have approved seven technical pathway processes and two co-processing pathways.[15] Where sustainable aviation fuel is compatible with existing aircraft and fueling infrastructure, large-scale amendments and aircraft or airport remodeling are not needed. However, currently sustainable aviation fuel must be blended with fossil jet fuel, and blends can only contain up to 50 percent sustainable aviation fuel, though this percentage is expected to increase in the future. Regulators first

DEFINING SUSTAINABLE AVIATION FUEL

The International Civil Aviation Organization (ICAO) defines "alternative fuel" as "any fuel that has the potential to generate lower carbon emissions than conventional kerosene on a life cycle basis."[13] Previously exclusively known as "biofuels," the term was later adjusted with the development of new technologies to incorporate fuels originating from non-biological sources. The broader term "sustainable aviation fuel" is now widely used by the industry to highlight the sustainable quality of these fuels, although the precise characteristics and climate benefit varies greatly depending on the fuel feedstocks and production pathway.[14] Many definitions require that sustainable aviation fuel act as a drop-in fuel capable of using the same distribution infrastructure and engines as conventional fuels. Many of the recommendations in this report could apply to multiple alternative fuel pathways for aviation, including hydrogen and electric-powered flights along with other non-biogenic and biogenic feedstock sources, although much of the report is focused on biogenic sustainable aviation fuel.

certified commercial aircrafts using sustainable aviation fuel in 2011, and since then over 400,000 flights have utilized the mixed fuel approach.[16]

Sustainable aviation fuel has the potential to reduce direct aviation carbon emissions significantly, although the exact greenhouse gas savings for a given sustainable aviation fuel may vary significantly based on its feedstock and conversion process. Sustainable aviation fuel's indirect and non-CO_2 emissions also contribute to warming. [17] However, comparative studies analyzing sustainable aviation fuel and other alternatives remain limited. Sustainable aviation fuel also generates fewer sulfur dioxide and particulate matter emissions than fossil fuels.[18] In addition, because sustainable aviation fuel can be produced across a range of different feedstocks around the world, it may reduce airlines' exposure to fluctuating fuel prices.

A critical barrier to the widespread adoption of sustainable aviation fuel is achieving commercialization at a competitive cost and in a low-carbon manner. Sustainable aviation fuel is currently two to five times the price of conventional jet fuel, a cost premium most airlines are unable or unwilling to pay.[19] To address these challenges and increase the level of sustainable aviation fuel production, the Biden Administration established in 2021 the Sustainable Aviation Fuel Grand Challenge, a multi-agency package of policy and investment actions intended to reduce aviation emissions 20 percent and produce 3 billion gallons of sustainable aviation fuel by 2030.[20]

Additionally, the Inflation Reduction Act of 2022 establishes a tax credit for "any sale or use of a qualified mixture [of sustainable aviation fuel]."[21] The credit amount is tied to the emissions reduction of the fuel. Qualified mixtures include those that are produced, used, or sold by a U.S. taxpayer and those that are used in an aircraft fueled in the U.S. The Act also allocates roughly $300 million towards a competitive grant program for research, development, and deployment "projects in the United States that produce, transport, blend or store sustainable aviation fuel, or develop, demonstrate, or apply low-emission aviation technologies."[22] Advancements in technology, along with increased production capacity, are expected to drive down costs.

The International Air Transport Association (IATA), which represents nearly 300 airlines, claims the industry can surpass its goal of around 5 percent sustainable aviation fuel consumption by 2030 if production rises and costs fall.[23] Other sources estimate that sustainable aviation fuel can perhaps only cover 2 percent of total fuel demand by 2025.[24]

C. INITIATIVES AND COALITIONS

Regulatory and voluntary initiatives have begun to respond to the challenge of reducing aviation emissions. In the United States, the federal Sustainable Aviation Fuel Grand Challenge and the sustainable aviation fuel provisions in the Inflation Reduction Act, as described in Section B, are examples of ambitious actions designed to promote fuel uptake and reduce costs.

Recent European Union initiatives offer valuable examples for promoting sustainable aviation fuel, including through the Renewable Energy Directive and Emissions Trading System. The European Union is considering revisions to the Emissions Trading System's treatment of aviation emissions through the "Fit for 55" proposal, which aims to cut emissions 55 percent by 2030. This package also introduces the ReFuelEU Aviation initiative, which proposes measures to increase sustainable aviation fuel supply and demand, in part by requiring fuel suppliers to provide more sustainable aviation fuel to airports over time; the proposed sustainable aviation fuel mandate is 2.5% of EU aviation fuel supply in 2025, increasing to 5% in 2030, with a sub-mandate for e-fuels, which are synthetic fuels produced using electricity.[25] The Emissions Trading System accounts for aviation emissions and requires that airlines track and report emissions from operations in Europe and use allowances to cover those emissions.[26] Proposed revisions would expand aviation allowance auctions, among other amendments.[27]

The International Civil Aviation Organization (ICAO) is a United Nations specialized agency that "develops policies and standards, undertakes compliance audits, performs studies and analyses, provides assistance and builds aviation capacity..."[28] ICAO designed the Global Framework for Aviation Alternative Fuels, sustainable aviation fuel stocktaking process, and sustainable aviation fuel feasibility studies to accelerate the global implementation of alternative fuels for aviation.[29] ICAO also oversees the Carbon Offsetting & Reduction Scheme for International Aviation, which is a global market-based scheme designed to offset aviation CO_2 emissions and meet ICAO's goal of carbon-neutral growth from 2020 onwards through standardized offsetting requirements.[30] This program credits the use of sustainable aviation fuel for international aviation but does not obligate or incentivize use of the fuel. ICAO is preparing to adopt a goal of achieving net-zero carbon emissions by 2050. A final decision is expected later in 2022.[31]

To facilitate the transition to a net-zero aviation sector, several groups have set targets to reduce emissions and boost fuel supply. In 2021, Airlines for America (A4A) "pledged to work with government leaders and other stakeholders to make 3 billion gallons of cost-competitive sustainable aviation fuel available to U.S. aircraft operators in 2030."[32] Additionally, Airlines for America has established a goal of achieving net-zero carbon emissions by 2050. The International Air Transport Association (IATA) initially set a target of reducing net aviation carbon dioxide (CO_2) emissions 50 percent by 2050, relative to 2005 levels. But in late 2021 it announced a more ambitious target of achieving net zero emissions by 2050, though it relies on large quantities of zero-carbon sustainable aviation fuel without a clear production plan.[33] In addition, nearly 20 percent of the greenhouse gas cuts from this pledge come from carbon capture and storage and offsets, as opposed to direct emission reductions from aviation fuel.[34]

Past aviation emission reduction targets have proven difficult to achieve. An International Council on Clean Transportation (ICCT) analysis showed that while airlines increased fuel efficiency between 2009 and 2019, "only two out of the seven airlines [evaluated by the ICCT analysis] achieved the target of an average 1.5% per year improvement in fuel efficiency over the decade [2009 to 2019]."[35] The feasibility of emission reduction goals will depend on scaling operations, alternative fuels, technology innovations, and economic instruments to enable the sector to achieve and exceed future targets.

International efforts to increase sustainable aviation fuel transparency and production have rapidly expanded in recent years. Various initiatives and coalitions have formed with the recognition that sustainable aviation fuel must be developed and deployed in an environmentally sustainable yet economically feasible manner. Some prominent groups and initiatives (both regulatory and voluntary) include:

- The Commercial Aviation Alternative Fuels Initiative, which is a coalition of airlines, engine and aircraft manufacturers, energy producers, researchers, and government agencies that promotes the development of alternative jet fuel technologies through fuel certification and qualification, research and development, and business deployment.[36]
- The Sustainable Aviation Buyers Alliance (SABA), which is establishing a rigorous sustainable aviation fuel certificate system to drive sustainable aviation fuel investment opportunities for businesses, organizations, and individuals. In addition, SABA offers education and policy support relevant to aviation emissions accounting and the sustainable aviation fuel policy landscape.[37]
- The Business Aviation Coalition for Sustainable Aviation Fuel, which was created to increase the understanding of the availability and safety of sustainable aviation fuel and "advance the proliferation of alternative jet fuels at all logical touchpoints."[38]

Rising fuel demand and growing fleet numbers have prompted many of these and other initiatives and coalitions to cultivate working partnerships and collaborations. Three key barriers remain for the entire renewable jet fuel market: producing alternative fuels at acceptable costs, developing a supply of sustainable feedstock large enough to meet the needs of the aviation sector, and overcoming current operational and technical inefficiencies. The coalitions described above are taking certain measures to address these challenges.

D. CALIFORNIA INITIATIVES AND OPPORTUNITY TO BOOST SUSTAINABLE AVIATION FUEL

California has been an early leader on sustainable aviation fuel deployment. Currently, the state has two of the five airports worldwide (San Francisco and Los Angeles) with regular sustainable aviation fuel supply (the other three airports are Stockholm, Bergen, and Oslo).[39]

California is well positioned to advance the sustainable aviation fuel market, given the state's ambitious and robust climate policies and relatively high aviation emissions. A 2021 inventory of statewide aviation emissions estimates that California's aviation sector generated approximately 34 million metric tons of CO_2 emissions in 2018.[40] To disaggregate emissions by route segment, this report draws upon modeling developed by the International Council on

Clean Transportation's Global Aviation Carbon Assessment (GACA) model; that model uses a purchased dataset from OAG Aviation Worldwide Limited in conjunction with data from ICAO, individual airline reporting, and the Piano aircraft emissions modeling software to estimate emissions by route.[41] Of that total, approximately 2 million metric tons came from intra-state passenger civil aviation, the highest total in the country (total US-wide intra-state emissions are approximately 6 million metric tons CO_2 equivalent or CO_2e). Figure 1 below illustrates the contribution of intra-state aviation to California's total aviation emissions, with intra-state flights broken out by flight distance up to 1,000 miles in the blue bars. The remaining state-wide aviation emissions from inter-state and international flights total approximately 32 million metric tons CO_2e, as shown in the brown bars. Electric planes could potentially play a role in reducing shorter-distance flights. These figures do not include general (i.e., non-commercial) aviation, which is a small contributor to overall emissions.[42]

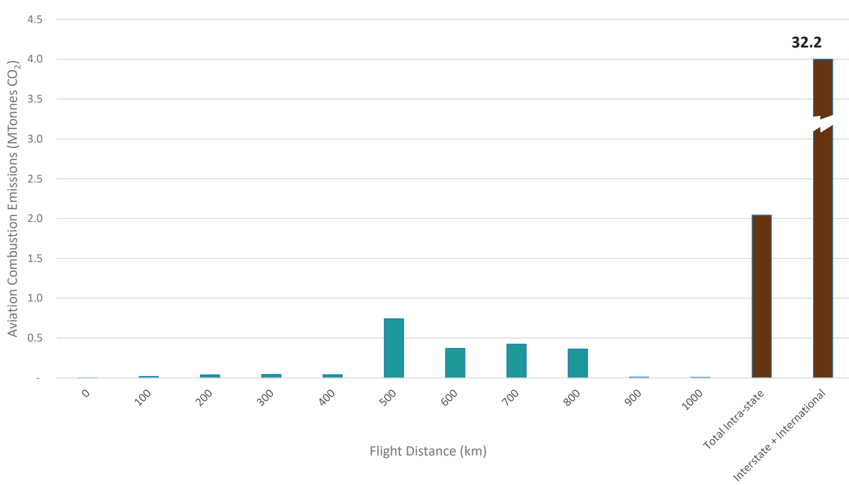

Figure 1: Breakdown of intra-state California aviation sector emissions, split out by distance, vs. California inter-state and international aviation emissions. The potential coverage of zero-emission plane routes for intra-state is illustrated by the green (electric) and orange (hydrogen) arrows. Analysis and graph produced by ICCT.[43]

Of the 2 million metric tons of intra-state CO_2e emissions, the bulk of these emissions are attributable to flights with distances of approximately 500 to 800 kilometers. To assess the share of short-haul, intra-state flights that could theoretically be displaced with zero-emission planes in the long-term, ICCT contributors to this report compared these distances to the estimated ranges for emerging zero-emission plane technologies that could be available by 2035. For electric aviation, the researchers compared these routes to the proposed 19-seat Heart Aerospace ES-19, which is intended to have a range of 400 kilometers and a certification date of 2026.[44] They also compared these distances to the estimated evolutionary advances in hydrogen aircraft designs, based on a regional turboprop ATR-72 with 70 passengers, which would be feasible to enter service by 2035 and could operate on routes up to 1,400 kilometers in length.[45] The researchers concluded that by 2035, approximately

6 percent of intra-state emissions could be eliminated through all-electric planes on routes of 400 kilometers or less.

The top 10 airports for short-haul flights in California, defined as all those with ranges of less than 1,500 kilometers, together accounted for approximately 500,000 annual departures in 2018, as shown below in Figure 2. The International Council on Clean Transportation noted that this ranking resembles an assessment of the overall traffic at California airports and does not reflect those smaller airports where short-haul general aviation (rather than commercial) flights may comprise a greater share of overall travel. Due to the volume and frequency of short-haul flights at these airports, they may be suitable candidates to pilot zero-emission airplanes and fueling infrastructure.

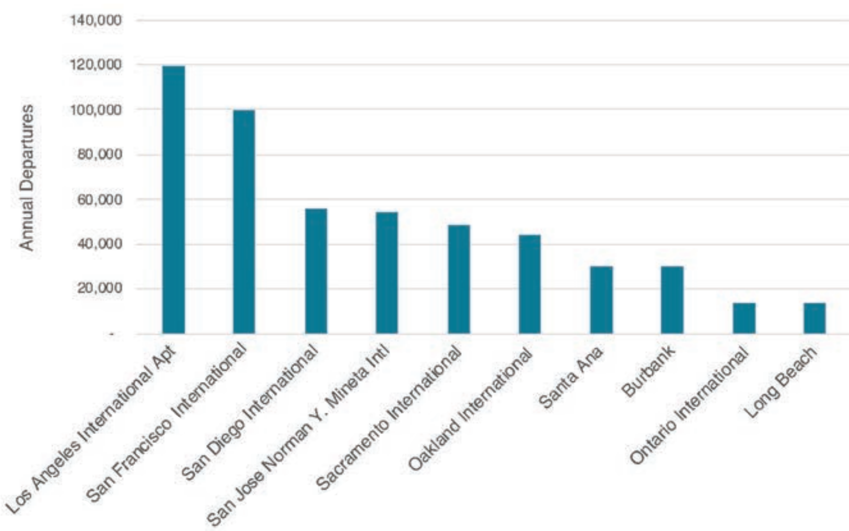

Figure 2: Distribution of annual departures (number of passengers per airport) for short-haul (<1,500km) flights at top 10 California airports, 2018. Analysis and graph produced by ICCT.[46]

Californians currently burn about five billion gallons of fuel for transportation per year, with roughly ten percent (500 million gallons) of that amount burned in intrastate flights (fuel for which the California Air Resources Board might have clearer authority to regulate under federal law). By contrast, there are only about 4.5 million gallons of sustainable aviation fuel in the current California supply.[47]

E. CALIFORNIA'S LOW CARBON FUEL STANDARD

The Low Carbon Fuel Standard (LCFS) is one of the most powerful policy tools that California leaders have to boost sustainable aviation fuel and other climate-beneficial aviation fuel options.[48] The policy aims to reduce the carbon intensity of California's transportation fuel pool by at least 20 percent by 2030.[49] By setting a declining carbon intensity target, CARB leaders seek to reduce California's dependence on petroleum in the transportation sector and incentivize the wider adoption of low-carbon and renewable alternatives. Fuel producers and refiners that supply low carbon fuels below the annual carbon intensity benchmark receive credits, which consequently allow them to participate in private transactional trades to help meet regulatory requirements. By contrast, fuels unable to meet the carbon intensity benchmark generate deficits. The carbon intensity standards, administered by the board, measure the greenhouse gas emissions associated with the production, distribution, and consumption of fuel based on a complete life cycle analysis.

The Air Resources Board amended the Low Carbon Fuel Standard to include aviation fuels in 2018, specifically to include alternative jet fuel as an "opt-in" pathway within the program.[50] The California Low Carbon Fuel Standard regulation exempts conventional jet fuel, aviation gasoline, and alternative fuels that are not biomass-based or supplied in California with "an aggregated quantity of less than 420 million MJ/year."[51] With the 2018 update, conventional fossil jet fuel still does not generate deficits for obligated parties such as oil importers and refiners; however, alternative jet fuel is eligible to generate Low Carbon Fuel Standard credits based on their life cycle carbon intensity and proportionally to their greenhouse gas emission reduction, as assessed by the CA-GREET model.[52] Credit holders can use them to offset deficits generated by gasoline and diesel within the program.

To implement the opt-in sustainable aviation fuel provisions, California Air Resources Board leaders developed a parallel benchmark for fossil jet fuel, to which they compare alternative jet fuel. Starting out at 89.37 gCO_2e per megajoule of fuel (a lower initial carbon intensity than either diesel or jet fuel but similar to the CORSIA benchmark[53]), the benchmark declines toward 2030 and converges with the diesel benchmark in 2023.[54] Alternative jet fuel generates credits based on its carbon intensity compared to the jet benchmark; thus, they generate fewer credits than an equivalent quantity of diesel-substitute until 2023, at which point the greenhouse gas reductions from the two fuel pools are equivalent, assuming an identical carbon intensity score, as illustrated below in Figure 3.

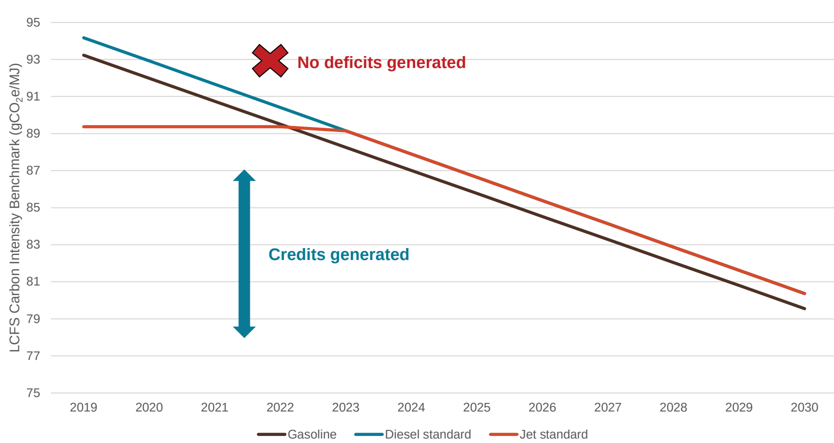

Figure 3. Comparison of benchmark carbon intensities for gasoline, diesel, and jet fuels in the California Low Carbon Fuel Standard, 2019-2030. Analysis and graph produced by ICCT.

The Low Carbon Fuel Standard can send a critical value signal to alternative fuel producers. In addition to incentives for alternative jet fuels, the Low Carbon Fuel Standard can also create value for zero-emission aviation. Over the last two years, Low Carbon Fuel Standard credits have traded for between <$100 and $200 per metric ton of CO_2e, although the price has been below $100 for much of 2022.[55] The value of the Low Carbon Fuel Standard is also directly proportional to the carbon reductions attributable to a given fuel: a fuel that offers 80 percent greenhouse gas savings will generate greater value than a fuel that generates only 20 percent greenhouse gas savings relative to the fossil fuel baseline. For example, at a Low Carbon Fuel Standard credit price of $150 per metric ton, jet fuel produced from waste oils such as that produced by World Energy in California (certified to provide approximately an 80 percent greenhouse gas reduction relative to conventional fossil jet fuel), would receive approximately $1.25 in policy value per jet-equivalent gallon.[56] This revenue ultimately comes from the producers of high-carbon fuels, who must acquire Low Carbon Fuel Standard credits, and ultimately pass the cost on to consumers.

Given aggressive policies and programs like the Low Carbon Fuel Standard to decarbonize its economy, coupled with its relatively high in-state aviation emissions and existing low-carbon fueling infrastructure, California is well positioned to take a leading role for the nation in promoting low- and zero-carbon aviation.

EQUITY AND THE LOW CARBON FUEL STANDARD

At present, gasoline is the primary high-carbon fuel in the Low Carbon Fuel Standard market, meaning that revenue in this market predominantly flows from gasoline consumers to low-carbon fuel producers. Given that gasoline is purchased for car travel by consumers across the full range of incomes, while sustainable aviation fuel for air travel is disproportionately consumed by more affluent people, the opt-in status of sustainable aviation fuel could exacerbate environmental and economic inequity.


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III. VISION FOR BOOSTING SUSTAINABLE AVIATION FUEL IN CALIFORNIA

Participants at CLEE's January 2022 convening described a vision for sustainable aviation fuel policy in California that leverages the state's climate leadership and its major airports to drive the broader market for lower-carbon flight options through both near-term and long-term scalable actions.

This policy landscape would:

- Support net greenhouse gas emission reductions from the aviation sector, emphasizing in-sector reductions rather than offsets.
- Maximize air quality and economic co-benefits in communities near airports and production facilities.
- Incentivize lower-carbon liquid fuels and advance new electric and hydrogen technologies for shorter regional and in-state flights.
- Maintain affordable, equitable access to air travel for consumers by ensuring financial sustainability and equitable distribution of cost burdens (including by non-residents of California).
- Provide all airlines with access to in-state fuel supplies.
- Engage the agricultural community to promote appropriate and sustainable cover crop production practices.
- Foster clean energy jobs regionally and locally.
- Build in-state fuel production and use while catalyzing the national market and federal policy goals.

This vision would coexist with broader state and national transportation decarbonization goals, including mode shifts where appropriate and available, while ensuring that greater use of sustainable aviation fuel addresses, rather than exacerbates, equity-based concerns regarding access to and impacts of air travel.

IV. BARRIERS AND PRIORITY POLICY SOLUTIONS

Participants identified the barriers to achieving this vision and suggested the policy solutions best positioned to overcome those barriers. This section details the top barriers and high-priority solutions.

BARRIER #1: LACK OF POLICY SIGNALS TO ENCOURAGE INVESTMENT AND OVERCOME HIGH CAPITAL COSTS

The capital cost of producing and deploying sustainable aviation fuel is currently more expensive than producing conventional fuel, which does not have to account for externalities associated with the pollution and has benefitted from decades of investment, market development and policy engagement. As a result, the aviation sector lacks the investment needed to deploy and use sustainable fuel widely. Participants attributed this dynamic in part to the lack of comprehensive state policy to encourage investment. For example, key policies like the Low Carbon Fuel Standard and cap-and-trade program do not mandate sustainable aviation fuel due to industry opposition and concerns regarding federal preemption, or even impose a cost on more pollution-intensive conventional fuels. At the same time, state policies that encourage sustainable fuel instead direct investment to ground-based transportation rather than aviation fuel. California lacks long-term goals on sustainable aviation fuel and a strategy to achieve them. Some participants attributed the gap to fears over federal preemption of state aviation policies, while others cited opposition to binding requirements that would encourage private sector investment. Others noted that the unclear viability of various technologies—including both sustainable aviation fuel and electric and fuel cell aircraft—discouraged policymakers and industry leaders from taking more robust and decisive action. Participants also mentioned the challenge of permitting and funding the necessary infrastructure to deliver these fuels, such as pipelines and fueling stations.

Solution: The Governor's office, state legislature, and the California Air Resources Board could develop a comprehensive statewide commitment and long-term plan to decarbonize in-state aviation fuels while working with national and international leaders on broader decarbonization goals, where consistent with federal law.

Participants recommended that state leaders develop a comprehensive plan for increasing both near- and long-term uptake of sustainable aviation fuel, along with hard targets and pathways to achieve them, to support its overall scoping plan to decarbonize the California economy. This plan should strike a balance between maximizing near-term greenhouse gas reductions through already commercialized fuels and ensuring that the sector as a whole has a pathway to zero (or near-zero) emissions by mid-century. First, the state may need to expand its definition of sustainable aviation fuel and what qualifies for incentives under it, from the near-term blends of low-carbon biofuels in conventional petroleum to long-term options such as battery electrics, hydrogen, and other emerging technologies. The state could then set volumetric targets, or perhaps a greenhouse gas reduction or low-carbon fuels target, for incorporating sustainable aviation fuel into California's broader policy plan, consistent with federal law. This plan must consider the sustainability of feedstock and associated production systems, including indirect or market-mediated effects, to avoid excessively incentivizing fuels that will have only a limited period of value as a decarbonization measure.

As part of this strategy, the state will need to assess the potential risk that federal preemption could restrict California's ability to regulate the aviation sector. Industry participants argued that Section 233 of the federal Clean Air Act holds that the United States Environmental Protection Agency (EPA) has exclusive authority to regulate emissions from aircraft engines and that the Federal Aviation Act gives the Federal Aviation Administration (FAA) exclusive authority to regulate aircraft safety and pricing.[57] As a result, they contended that federal law and regulations are likely to preempt many options for state regulation regarding aircraft or fuel requirements, thus limiting California's options to require sustainable aviation fuel use within the state. Other participants argued that federal preemption is less clear, particularly with respect to regulation of fuel inputs rather than vehicle performance—noting that the Low Carbon Fuel Standard, which accomplishes the former, has largely avoided preemption-based challenges. Others felt that California may have more latitude to regulate wholly in-state flights. While a comprehensive legal analysis on this point is beyond the scope of the report, state policymakers will need to ensure that any policy can withstand court challenges to their authority, while working with federal leaders to resolve any conflicts.

Solution: The California legislature or the California Air Resources Board could tax or levy a carbon fee on conventional aviation fuel and use the proceeds to fund research and development, where permitted by federal law.

The state already funds research and development of low-carbon biofuels, which could be used for aviation. However, the state faces limits on what funds could be available for more specific aviation fuel research and development. Fees on passenger vehicles and trucks fund current California Energy Commission programs and support clean transportation program funds. The Energy Commission also hosts a separate gas research and development program funded by a surcharge. The program is focused on renewable gas, including hydrogen. Because aviation is not subject to these fees, the Energy Commission and other state agency program administrators cannot directly invest in aviation projects because aviation fuels do not generate revenue from fees. State regulators therefore lack a legally required nexus for using the proceeds on aviation-specific applications. The legislature could remedy the gap by levying a fee or tax on polluting aviation fuels.

Alternatively, the California Air Resources Board could implement carbon pricing on conventional aviation fuels such as through the state's cap-and-trade program or other structure, consistent with federal law. Finally, the state could dedicate a portion of funding from its current 2022 budget surplus to support zero-emission aviation technology deployment. The governor's current proposed budget recommends $100 million for emerging zero-emission vehicle technology, and air travel could potentially fit within this budget category.

Solution: The California Air Resources Board could regulate conventional aviation fuel under California's Low Carbon Fuel Standard and promote that approach nationally and internationally, where permitted by federal law.

The International Council on Clean Transportation found that as a technology-neutral performance standard, the Low Carbon Fuel Standard does not provide any preferential crediting or benefits to alternative jet fuel producers. Deploying sustainable aviation fuel does not reduce the carbon policy obligation in the same way that alternative on-road fuels remove the impact of California's cap-and-trade program. Though the bulk of present-day alternative jet fuel production is typically generated as a co-product of renewable diesel, it is typically more expensive and inefficient to optimize a biorefinery to generate a greater share of alternative jet fuel output in place of diesel.[58] However, the Low Carbon Fuel Standard can provide greater value for the jet co-product of a biorefinery and therefore benefit the commercial viability of the biorefinery as a whole, thus supporting the drop-in biofuel industry more broadly.

In addition to creating incentives for alternative jet fuel, the Low Carbon Fuel Standard can also create value for zero-emission aviation. Currently, the low carbon fuel standard generates substantial value for electric vehicles and electric vehicle chargers, facilitating electric vehicle rebates over $1,000 per vehicle and encouraging the deployment of direct current fast-charging infrastructure.[59] Electric vehicle charging infrastructure and fleet operators can generate Low Carbon Fuel Standard credits for each unit of electricity supplied to vehicles, receiving additional credits based on vehicle efficiency and the use of renewable electricity.[60] Similarly, green hydrogen producers can generate over $3 per kilogram of hydrogen supplied, which also benefits from a multiplier for vehicle efficiency. The use of electricity and hydrogen in the aviation sector could also tap into these incentives, generating revenue to facilitate the installation of fueling infrastructure and transition to zero-emission airplanes. Some zero-emission airplane designs may also be able to demonstrate efficiency benefits compared to conventional designs, thus qualifying for multipliers for the electricity or hydrogen supplied to the aviation sector. Zero-emission aviation may also reduce the impact of warming contrail formation; these effects could be incorporated into the sustainable aviation fuel pathways under a future Low Carbon Fuel Standard, though more research is needed to fully understand and quantify them. Further analysis is necessary to evaluate the energy economy ratio for hydrogen and electric-drive airframe designs for Low Carbon Fuel Standard crediting, similar to the work the California Air Resources Board has already done on passenger vehicles and heavy-duty vehicles.

Convening participants noted that as an opt-in pathway, the Low Carbon Fuel Standard does not create a market for alternative jet fuel on its own and does not assure alternative jet fuel producers of the offtake of their fuel. They found that the opt-in pathway makes these fuels less competitive than renewable diesel, because conventional fuels do not lead to deficit generation. An additional point of current weakness in the Low Carbon Fuel Standard is the political and market uncertainty associated with the program and Low Carbon Fuel Standard credit prices. For example, the Low Carbon Fuel Standard credit market faced instability in the mid-2010s due to political headwinds and depressed credit prices; similarly, credit prices have declined by nearly 50 percent from their 2020 peak since 2021 due to a variety of market factors.[61] The uncertainty associated with future Low Carbon Fuel Standard credit prices can stifle investment in biorefineries with high upfront costs and long commercialization timelines, particularly for advanced low-carbon biofuels and alternative jet fuel with uncertain demand and market prices.[62]

Furthermore, participants believed the opt-in approach creates an economic equity issue because on-road gasoline consumers would be effectively subsidizing air travelers. In the Low Carbon Fuel Standard, consumers of high-carbon fuel, primarily on-road gasoline consumers, would pay higher fuel prices reflecting the deficits such fuels generate. The revenue from those higher prices is transferred to sellers of Low Carbon Fuel Standard credits, such as those generated by sustainable aviation fuel. This approach could ultimately result in an annual subsidy from drivers to air travelers, placing a greater cost burden on drivers not necessarily offset by the benefits from reduced pollution. Some participants estimated that this subsidy could reach into the tens or hundreds of millions of dollars annually. Although reductions in aviation emissions benefit everyone, especially communities living near airports, some participants wanted policymakers to avoid placing the full cost burden on drivers, especially lower-income drivers who may not be participating in air travel (i.e., it would be better to have air travelers shoulder some or all of the cost).

To address the challenge, some convening participants recommended incorporating in-state aviation fuel into the Low Carbon Fuel Standard program, similar to petroleum gas or diesel in on-road vehicles, with a carbon intensity target and credit price, consistent with federal law. However, because few lower-carbon intensity options are available, they noted that the Low Carbon Fuel Standard market may become imbalanced if aviation is linked with the rest of the transportation sector.

Alternatively, the state could promulgate regulation to establish a Low Carbon Fuel Standard exclusively for aviation, consistent with federal law. This would position conventional aviation fuel as a deficit generator, like conventional road fuels, and could potentially address the discrepancy in incentives between road and aviation biofuels. An aviation-specific standard would have a separate target and credit market, with limited trading across gasoline, diesel, and other road fuels. An aviation-specific standard also could potentially address the equity concerns of including aviation fuel in the on-road Low Carbon Fuel Standard, as well as the revenue challenges and long-term incentives needed for deployment of sustainable aviation fuel. Some participants felt that under either model, California could demonstrate a model policy for aviation fuel standards that other states could adopt. However, other participants representing the airline industry disagreed, arguing that states are potentially preempted by federal law from incorporating aviation fuel as a deficit-generator under the Low Carbon Fuel Standard and that California should focus on providing incentives to encourage production of lower-cost sustainable aviation fuel.

Others cited the European Union policy of placing a cap on use of feedstocks, like lipids (fats, oils, and greases) that can have a high risk of emission-driving land use change, along with a sub-target for developing advanced sustainable aviation fuel pathways with grants for using in-state feedstocks.[a] Some participants recommended a more restrictive carbon intensity reduction schedule to counter the recent decreases in credit prices, as CARB may be considering for 2030 according to their recent draft Scoping Plan.

Solution: The California Air Resources Board could coordinate with the U.S. Environmental Protection Agency to more strictly regulate the criteria pollutants from burning conventional fuels in the sector.

Burning jet fuel results in emissions of pollutants that degrade air quality and harm public health, including nitrogen oxides and sulfur oxides (such as sulfur dioxide, a toxic gas). The federal Clean Air Act already authorizes state regulation of these conventional pollutants through the National Ambient Air Quality Standards, which cover six common air pollutants: carbon monoxide, lead, ground-level ozone, nitrogen oxides, particulate matter, and sulfur dioxide.[63] Each state then develops a state implementation plan (SIP) to reduce these pollutants. The California Air Resources Board could assume a leadership role in regulating these criteria pollutants from in-state sources by increasing the stringency of future SIPs for nitrogen oxides and sulfur dioxide. The legislature could support this move by authorizing additional funding for research and SIP development.

Aviation also results in emissions of ultra-fine particles less than 100 nanometers in diameter.[64] However, these particles are not included in the National Ambient Air Quality Standards. California could advocate for inclusion of an ultra-fine

a Although waste fats, oils, and greases currently incur no land use change adjustment under the Low Carbon Fuel Standard or similar policies, the increased demand that would occur if this material is incentivized would result in land use change impact. Additionally, non-waste lipids present a higher risk of land use change impacts.

particle pollution standard in future federal regulation. The state could also examine the potential for establishing other environmental attribute markets aside from the current carbon market under cap and trade, such as a program to regulate and trade emissions credits for oxides of both nitrogen and sulfur. The public would receive additional potential benefits from reducing sulfur and NOx emissions, as these pollutants impact climate at high altitudes. However, experts are uncertain about the most appropriate legal pathway for doing so.[65]

Solution: Legislative and agency leaders, including the Governor's Office of Business and Economic Development (GO-Biz), could develop permit-streamlining pathways for priority sustainable aviation fuel infrastructure.

Delays and complexity associated with obtaining permits can increase costs and make sustainable aviation fuel infrastructure too expensive to deploy. Some participants noted it can take three to five years to receive permits. California could foster innovation and expedite commercialization in this sector by adopting permit-streamlining practices from other states and reducing this time frame to at least two years or less. For example, the state could establish a customized, clear pathway to navigate and streamline permitting that incorporates pre-application meetings, as demonstrated by the Nevada Economic Development Incentive Application.[66] State leaders could also foster interagency partnerships to coordinate agency reviews and set joint-agency working groups. The Oregon Regional Solutions Team/Centers serves as an example, with the Governor's Office brokering, guiding, and assisting across Department of State Lands, Historical Preservation, Environmental Quality, and Municipal Government Partners.[67] Another model could be the Climate Solutions Sustainable Advanced Fuels Program, a collaborative effort created by The Boeing Company, Alaska Airlines, Portland International Airport, and others to develop sustainable and economically viable aviation biofuels in the Northwest. The initiative consists of low-carbon biofuel producers, nonprofit advocacy organizations, research institutions, government agencies, agricultural producers, and other entities.[68] Ultimately, California could prioritize and expedite review of permit applications for sustainable aviation fuel production facilities, including navigation of construction permits across issues like air quality and wetlands, and provide a clear timeframe for review of all permits and environmental review.

Solution: Legislative leaders and the California Treasurer's Office could incentivize private investments by facilitating offtake agreements, contracts-for-differences, low-interest loans, and commercial partnerships for state aviation investments or travel.

Rather than directly investing in sustainable aviation fuel, the state could encourage more private investment by reducing the risk for investors. California policy makers could leverage the value provided to alternative jet fuel producers by the Low Carbon Fuel Standard through complementary aviation specific policies and incentives and simultaneously mitigate uncertainty by guaranteeing a market for alternative jet fuel. Specifically, through the Treasurer's Office or Infrastructure Bank, the state could offer low-interest loans for sustainable aviation fuel projects. As project developers repay the loans, the state could then re-capitalize the fund. In addition, the state could develop commercial partnerships with airlines that purchase sustainable aviation fuel credits for any state fleet purchases or Department of General Services-approved business travel.

State leaders could also offer a "contract-for-differences" structure modeled after an approach adopted in the United Kingdom. Similar to an offtake agreement (an agreement for a given quantity of fuel at a set price regardless of market fluctuations), a contract-for-difference ensures future price stability for emerging fuel producers and can mitigate uncertainty. The United Kingdom debuted the concept to incentivize renewable electricity production. In this context, a contract-for-difference approach "locks in" a future fuel market value floor agreed upon between the government and sustainable aviation fuel producer for a set period of time, paying the difference between the *de facto* market value and the floor whenever instability drops the market value below the contractual price floor, as shown in Figure 4. In California, the contract-for-difference can incorporate prevailing Low Carbon Fuel Standard credit prices and renewable identification numbers prices and only pay out when those credit prices drop. This policy can reduce uncertainty for alternative jet fuel producers and is cost-effective, as it only pays out when the value of other policies such as the Low Carbon Fuel Standard decline.[69] Furthermore, the contract-for-difference price floor can be established by a reverse auction, awarding contracts to the fuel producers who offer the most competitive bids. The state could employ this model for different technologies to encourage ultra-low carbon fuel projects.

Ultimately, these policies could better leverage both Low Carbon Fuel Standard credits and renewable identification numbers (RINs) generated through the federal renewable fuel standard, which can drive the overall policy value of jet fuel even higher; the value of a D4 renewable identification number has ranged from $0.5 to $2 per ethanol-equivalent gallon (or approximately $0.75 to $3 per gallon of jet fuel).[70]

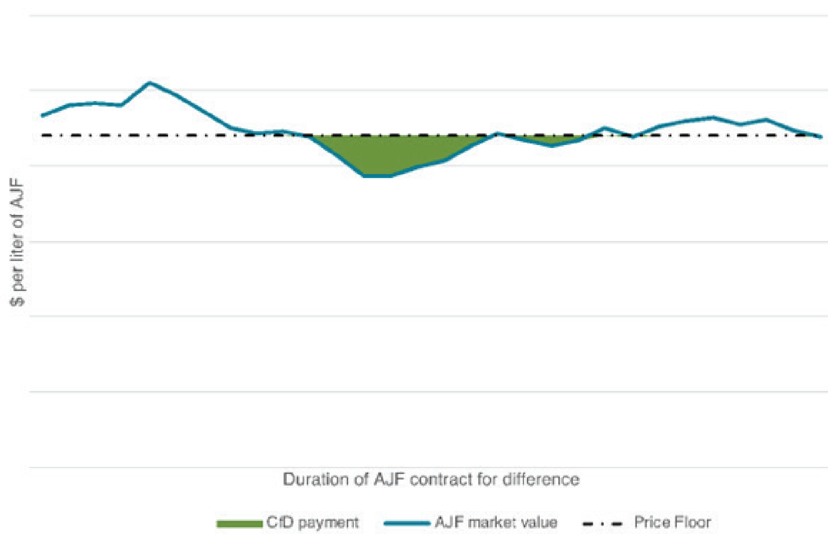

Figure 4: Illustration of a potential contract for difference pay structure for alternative jet fuel production. Analysis and graph produced by ICCT.

Figure 5 below illustrates the market value of a gallon of jet fuel with an 80 percent greenhouse gas savings relative to fossil jet, considering policy incentives, relative to a gallon of renewable diesel with the same carbon intensity. In both cases, the fuels have a wholesale market value of the alternative fuels is substantially higher than that of their fossil fuel counterparts due to the value of policy credits. In both cases, at 2022 credit values, the fuels' total market value is more than twice that of conventional fossil fuel; the diesel-substitute has an estimated value higher than the alternative jet fuel due to the higher underlying value of diesel as well as the higher 2022 greenhouse gas benchmark for diesel in the Low Carbon Fuel Standard.[b] Furthermore, this does not take into account the additional value that renewable diesel has due to the carbon pricing under the California Cap-and-Trade system, which penalizes fossil diesel but not fossil jet; at allowance prices ranging from $20 to $30 per tonne CO_2e over the last year, this could add up to approximately $0.30 of perceived value per gallon of renewable diesel. California policies that promote offtake agreements, contracts-for-differences, low-interest loans, and commercial partnerships could therefore take advantage of these existing state and federal incentives.

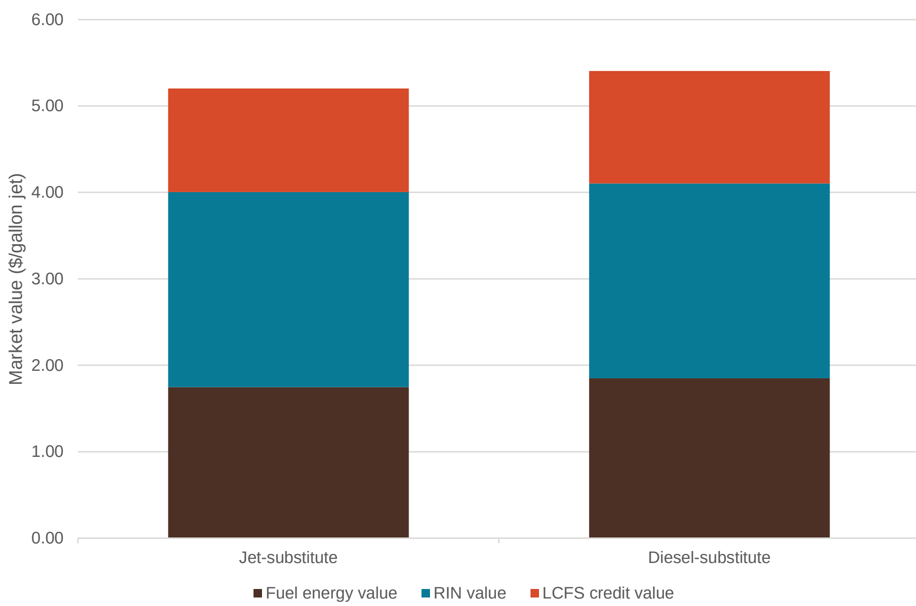

Figure 5: Market value for jet-substitutes and diesel substitutes in California. Based on average 2022 RIN and Low Carbon Fuel Standard credit values, and five-year average of wholesale refiner price for fossil kerosene & low-sulfur diesel.[90] Analysis and graph produced by ICCT.

b The biodiesel blender tax credit expired in 2017 and was renewed in 2020 to apply retroactively through 2022. If included, this adds an additional $1 per gallon to the market value of diesel-substitutes.

BARRIER #2: SUSTAINABILITY AND AVAILABILITY OF FUEL SUPPLIES AND CERTAINTY OF TECHNOLOGIES

Beyond the need for incentives and policy signals to drive sustainable aviation fuel investment, participants highlighted two related challenges for sustainable aviation fuel supplies: total adequacy of feedstock supply compared to the level of consumption needed to meet emission reduction targets; and confidence in the sustainability of those feedstocks as demand increases and new products emerge. While estimates vary, according to a 2020 World Economic Forum analysis, fewer than 200,000 metric tons of sustainable aviation fuel were produced worldwide in 2019, accounting for less than 0.1 percent of total commercial airline fuel demand.[71] Industry estimates for sustainable aviation fuel production in 2021 were around 25 million gallons.[72] Approximately 4.5 million gallons are currently in supply in California. In 2019, the U.S. consumed approximately 18.5 billion gallons of jet fuel.[73] Even scaling sustainable aviation fuel production to meet current project commitments via the existing resource base (over 1 billion total gallons) could account for as little as one percent of anticipated global fuel demand, which could double by 2030.[74] While total biomass production in the United States could potentially meet national sustainable aviation fuel demand in a high-uptake future scenario, much of this biomass is committed to road fuel and other uses, and producing the feedstock in a sustainable manner (domestically and abroad) presents a significant challenge. Scaling up non-biomass fuel options could help to mitigate this challenge.

Many sustainable aviation fuel feedstocks—including some of the most common vegetable oil-based feedstocks—are associated with induced land use change impacts (i.e., displacement of forest and pasture lands, crop substitution, and increased production intensity) that generate significant life-cycle emissions, in some cases matching those of fuel production and consumption.[75] These impacts can occur both domestically and internationally. Land use changes can also cause significant local ecosystem, water quality, and other impacts in addition to increasing total emissions. Ramping up production while ensuring that fuels are legitimately sustainable will require a range of policies and strategies.

Solution: State and industry leaders could develop a comprehensive sustainable aviation fuel feedstock sustainability framework.

Participants noted that while some sustainable aviation fuel sustainability certification processes exist, the California sustainable aviation fuel market lacks a sufficiently comprehensive, rigorous, and transparent framework for certifying the integrity and origins of sustainable aviation fuel feedstocks. Existing frameworks include ICAO's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Sustainability Criteria for CORSIA Eligible Fuels, which includes clear emissions and carbon stock requirements (requiring a minimum 10 percent life cycle greenhouse emission reduction compared to jet fuel) and a set of principles for ecosystem, human rights, land use, and other impacts[76]; and the California Air Resources Board's life-cycle greenhouse gas analysis for opt-in sustainable aviation fuel under the Low Carbon Fuel Standard, which accounts for climate impacts but not others.[77] Participants emphasized the need for a complete feedstock certification process—including life-cycle greenhouse gas emission analysis as well other environmental, social, and economic impacts (including but not limited to induced land use change impacts)—to build confidence that products are high integrity, sustainable substitutes for traditional jet fuel. Such a process would also help ensure that growth in sustainable aviation fuel production does not sacrifice broad sustainability as new technologies and feedstocks are developed.

To develop such a process, leaders at the California Air Resources Board, California Energy Commission, and the California Department of Food and Agriculture, together with sustainable aviation fuel and airline industry leaders, could collaborate on a state certification framework that combines the emissions analysis of the Low Carbon Fuel Standard with a detailed analysis of non-emissions impacts (including those covered by the CORSIA criteria). Since many of these criteria fall outside the Air Resources Board's AB 32/SB 32 emission reduction mandate and the current Low Carbon Fuel Standard program, new legislation might be required to enforce the framework via legislation. Alternatively, the state could rely on third-party sustainability certification schemes like the International Sustainability & Carbon Certification (ISCC) and the Roundtable on Sustainable Biomaterials (RSB), which could devise a certification process that meets the requirements of both the Low Carbon Fuel Standard and CORSIA. Producers would therefore have an incentive to certify to get credited under both programs.

Solution: The California Air Resources Board and California Energy Commission could develop a strategy to reduce and mitigate risks from induced land use change from biogenic sustainable aviation fuel feedstock production.

Induced land use change includes both direct land use change (i.e., the immediate conversion of forest or pasture to cropland) and indirect land use change (i.e., changes in land management resulting from economic effects, such as a change in crop preference due to a policy- or market-induced price shift, often abbreviated as ILUC).[78] The greenhouse gas emission impacts of ILUC are variable, uncertain, and challenging to quantify; for example, the CORSIA life-cycle analysis ILUC values for eligible fuels range from approximately -54 to 39 of CO_2 equivalent per megajoule depending on the feedstock, and some studies show an even higher range, in some cases up to 150 CO_2e/MJ for the highest land use impact lipid-based sources such as some palm oils.[79]

Cellulosic biomass and certain energy crops that actively sequester carbon and do not displace other land uses, algae-based feedstocks, and non-biofuel alternatives can generate minimal indirect land use change impacts, but these fuels are mostly far from large-scale commercial production. In addition, the models used to estimate these impacts (such as the Global Biosphere Management Model or GloBIOM) may require adjustment to account for the market and agricultural conditions of a significant increase in feedstock production.

Although the majority of current sustainable aviation fuel in the United States derives from waste oils, developers have the potential to secure long-term fuel supply from crop-based sources. As a result, policy instruments to limit and account for emissions from land use change will be vital to efforts to scale up production. At present, most of the waste oil sources in the U.S. and Europe are already being utilized for biofuel feedstock; future growth in hydrotreated sustainable aviation fuel will almost certainly come from crop-based feedstocks. Additionally, if fuel demand outpaces supply in the coming decades, it may prove difficult for feedstocks to supply enough fuel to reach aviation decarbonization goals. Therefore, deployment of non-biogenic fuel sources, such as hydrogen or electric batteries, will be crucial to ensuring a diversified, sufficient supply. California state agencies should encourage development and deployment of non-biogenic fuel sources as part of the overarching strategy to address land use change impacts while ensuring that demand does not overshoot supply.

To assess, account for, and mitigate indirect land use change impacts and ensure that growth in sustainable aviation fuel production does not drive unsustainable land use practices, the Air Resources Board and/or Energy Commission could:

- Conduct and fund further research on these impacts (including life-cycle greenhouse gas emissions and non-greenhouse gas impacts to local ecosystems and populations) of sustainable aviation fuel development, with a focus on lipid-based fuels and feedstocks.
- Craft the comprehensive feedstock sustainability framework described above to prioritize indirect land use change criteria, potentially including an eligibility screen for feedstocks (or source jurisdictions) that pose the highest indirect land use change risk and/or a carbon intensity threshold more stringent than CORSIA's (which requires eligible sustainable aviation fuel to be at least 10 percent lower emitting than traditional jet fuel) as a safeguard.
- Establish quantity caps on high-ILUC-risk lipid-based biofuels in California, accounting for availability of waste and non-biofuel feedstocks (potentially via phased-in or delayed implementation to avoid negative impacts on investment), while accounting for the possibility that demand may greatly outpace supply.
- Institute a small (i.e., 1 cent per gallon) surcharge on lipid-based fuels to fund land conservation efforts that can help offset the indirect land use change impacts of sustainable aviation fuel development. Such a measure might require legislative authorization and, given likely international scope of the investments, would ultimately be better suited to a consensus international actor, but state-level action could provide a valuable first step.

Solution: State leaders could accelerate research into hydrogen fuel cell, synthetic or e-fuels, and battery electric flight technologies to free up low-carbon biofuel supplies for aviation through increased investment in electrified road transportation or regional rapid transportation options.

While hydrogen fuel cell and battery electric flight technologies are still nascent and the latter may only be viable for a subset of short-haul flights, these technologies could help ensure that the limited supply of sustainable aviation fuel is used for the highest priority flights—those most difficult to transition to electric or fuel cell technologies—and that increased feedstock production does not present indirect land use change or other indirect-effect risk. Similarly, since the vast majority of low-carbon biofuels currently consumed in California and nationwide are used in on-road vehicles, any increase in road transportation electrification (which is far more feasible than flight electrification, at least in the near term) will free low-carbon biofuel feedstocks for use in sustainable aviation fuel applications without increasing total demand for feedstocks.

To maximize the availability of feedstocks for sustainable aviation fuel and of the fuel for necessary long-haul flights, state legislators could consider measures such as increasing electric vehicle purchase incentives, deploying more charging infrastructure, investing in regional transportation options (such as rapid rail or bus service), and setting a fossil fuel vehicle phaseout date. Additionally, the California Air Resources Board could (with legislative support) provide more funding for electric and hydrogen flight research and development, as well as expand the Low Carbon Fuel Standard to include zero-emission airplanes. The Advanced Clean Cars II regulation, which was approved by the California Air Resources Board in August 2022, increases the stringency of California's zero-emission vehicle ambitions by establishing that all new car and light truck sales will be zero-emission vehicles by 2035.[80]

Solution: The Governor's Office and the California Air Resources Board could assess life cycle emissions and environmental impacts of potential sustainable aviation fuel technologies to balance strategies.

The Governor's Office and the California Air Resources Board could allocate resources towards assessment of sustainable aviation fuel's relative life cycle climate and environmental impacts, including both quantitative and qualitative analyses. Doing so would ensure that stakeholders and state leaders are using the same assumptions and inputs and would improve transparency in decision making. Additionally, ensuring high-quality information about the relative environmental impacts of sustainable aviation fuel technologies, including a no-action pathway (i.e., not adopting sustainable aviation fuel within a given timeframe), would help to illuminate the most appropriate policy approach, especially given the tradeoffs inherent in adopting any new technology.

However, measuring aviation emissions is more difficult than measuring ground transportation emissions. Not only are aviation emissions more challenging to identify based on the location of the pollution, but it is also harder to pinpoint local air quality impacts attributable to aviation. State-funded research could alleviate these types of information gaps around criteria pollutants and other air quality impacts from aviation.[81] Understanding aviation's effect on air quality can help guide policy that is responsive to the needs of workers and communities affected most by aviation-related pollution, given that sustainable aviation fuel adoption can generate air quality improvements that benefit those workers and communities.[82]

The Governor's Office could emphasize a state goal of achieving zero-emission aviation rather than promoting a specific fuel type, which can engender controversy. Specifically, some environmental justice and equity organizations have voiced significant concerns about biofuels due to the potential for negative health impacts. Non-biofuel pathways (such as electric or fuel cell planes) are under development but are not yet commercially feasible. State agencies and stakeholders will need to assess the balance between: 1) advancing biofuels for sustainable aviation fuel use, acknowledging concerns around air pollution from biofuel production but reducing aviation-induced air pollution in and around airports and throughout the airshed; and 2) delaying the alternative aviation fuel transition until electric or fuel cell technologies are viable, thus prolonging negative air pollution impacts from traditional fuels but avoiding negative impacts around biofuel production. Policymakers should strike a balance between these two pathways and search for opportunities for complementary or synergistic strategies. For example, adopting cleaner fuels would reduce health risks for the thousands of airfield workers at California's major airports. Additionally, most flights cover too great a distance for electric planes, so advancing electric or hydrogen use for short-haul flights while supporting sustainable aviation fuel for longer flights may allow the greatest emission reductions in the short term.

Additionally, state leaders will need to quantify a full spectrum of sustainable aviation fuel co-benefits to help identify where benefits outweigh costs. Analyzing co-benefits also will help decision makers and stakeholders understand potential consequences, both positive and negative, of accelerating sustainable aviation fuel deployment. Co-benefits of sustainable aviation fuel deployment include air quality improvements and associated public health benefits, job and economic opportunities, and workplace safety improvement for airfield workers.

BARRIER #3: INADEQUATE POLITICAL SUPPORT AND LACK OF POLICYMAKER AND CONSUMER EDUCATION

Participants emphasized the need for more robust political action and clear signals to guide market development. Additionally, participants identified inadequate sustainable aviation fuel awareness and education as a barrier to achieving the policy and technology changes necessary to catalyze greater sustainable aviation fuel adoption. In 2021, the Biden Administration established sustainable aviation fuel production goals and aviation emissions reduction goals, along with loan guarantees and other federal funding measures. This federal direction on aviation emissions and sustainable aviation fuel development and deployment can catalyze action in California and can provide a basis for stronger political support.

Any policies or programs developed to tackle aviation emissions or encourage sustainable aviation fuel uptake should incorporate equity and environmental justice considerations. State and local leaders will need to meaningfully engage with affected communities at every stage. They will need to commit to a life cycle assessment of fuels' emissions and environmental impact to help clarify where potential negative impacts exist and inform mitigation or avoidance options. Additionally, public engagement and informational efforts are critical to building understanding and political momentum.

Solution: The California Air Resources Board could develop a state playbook to guide sustainable aviation fuel deployment.

As California considers action on aviation emissions, a comprehensive roadmap would facilitate coordination across government and stakeholder groups and would provide clarity to regulated entities. This need is even more pressing given Governor Newsom's July 2022 request that the Air Resources Board set a 20 percent clean fuels target for the aviation sector.[83] The legislature has passed such a plan; Assembly Bill 1322 (Rivas) would require the California Air Resources Board to "develop a plan, consistent with federal law, to reduce aviation greenhouse gas emissions and help the state reach its goal of net-zero greenhouse gas emissions by 2045").[84] However, Governor Newsom vetoed the bill in September 2022. If a similar policy were enacted in a future legislative session, implementation would require close coordination and additional research to create a guiding strategy to drive sustainable aviation fuel deployment in California.

To remedy this need, the California Air Resources Board—perhaps in partnership with research institutions, industry experts, and other stakeholders—could develop a strategic plan for sustainable aviation fuel deployment. This state playbook could define an approximate timeline for sustainable aviation fuel adoption, introduce adoption targets, and integrate sustainable aviation fuel deployment into existing state transportation and alternative fuel plans. Sustainable aviation fuel roadmaps created by other entities, such as the International Air Transport Association, could serve as guides for development of an in-state plan.[85]

Any targets state leaders adopt in the roadmap should align with and advance the Biden Administration's national goal of reducing aviation emissions 20 percent by 2030 while increasing sustainable aviation fuel production to 3 billion gallons per year by the same deadline (the state's goal would reflect California's proportionate contribution to this national goal). Furthermore, federal funding could become available to support California through this initiative.[86] The U.S. Department of Energy recently announced up to $3 billion loan guarantees to catalyze sustainable aviation fuel projects.[87] State leaders could integrate these and other funding opportunities into a California-specific roadmap charting a path for sustainable aviation fuel deployment.

A definitive roadmap for action would enable California to adopt a leadership role, demonstrating the potential for subnational sustainable aviation fuel action and perhaps emboldening other states to pursue similar policies and initiatives. The roadmap could incorporate a coordinated permitting pathway and broadened eligibility criteria, identify funding opportunities, and assess innovative incentives or other policy levers, which could then be advanced by the state legislature. The roadmap could also synchronize actions and roles across various state agencies and relevant industry players.

Solution: The Governor's Office should direct state agencies to address equity concerns and advance equitable outcomes through any sustainable aviation fuel policy.

Policies to promote sustainable aviation fuel adoption could exacerbate equity challenges if not carefully designed to avoid inequitable impacts. Well-designed sustainable aviation fuel policy could generate substantial equity gains by reducing local air pollution, creating jobs, and improving public health outcomes. The Governor's Office can work to ensure that policy maximizes positive equity outcomes and minimizes negative outcomes by issuing guidance directing state agencies to prioritize equity in any sustainable aviation fuel-related policy or program.

Sustainable aviation fuel adoption can drive overall emissions reduction from airports while reducing criteria air pollutants and other local air pollutants (including aromatics and particulates), thus improving air quality around airports and throughout the airshed. Air quality improvements are especially critical for residents near airports, where environmental justice and public health considerations tend to be the most substantial.[88]

Solution: Sustainable aviation fuel producers and industry leaders could advance educational and promotional efforts to raise awareness of sustainable aviation fuel and pathways for adoption.

Participants described a lack of sustainable aviation fuel awareness among the public and policymakers alike and urged additional education and outreach to improve understanding of sustainable aviation fuel opportunities and benefits. Specifically, participants identified a lack of awareness regarding what sustainable aviation fuel is, where it is available, how airports can source it, its environmental impacts compared to conventional fuel, and its potential uses.

Sustainable aviation fuel use is otherwise not visible to air passengers in the same way that electric vehicle technology is to drivers and passengers. Travelers may take a sustainable aviation-fueled flight without knowing it, and therefore are less likely to demand sustainable aviation fuel investment or to urge airlines to commit to its usage. On-road transportation benefits from its visibility—electric vehicles, for example, are common on California roads and drivers and passengers actively interact with the technology. Electric vehicles benefit from increased funding and policy attention, partially as a result of consumers' increased interactions with and understanding of the technology. For example, some rideshare platforms offer customers the option to select an electric vehicle.[89] With similar focus and investment, sustainable aviation fuel could gain market traction and contribute to greater emissions reductions.

Sustainable aviation fuel producers and industry leaders could invest more resources into public outreach, workshops, or training sessions, with special attention on briefing policymakers on existing options and the need for additional funding and market development. Additionally, airports and policy leaders could develop a series of pilot projects aimed at expanding fueling and charging infrastructure at California's airports. Airports in California, such as LAX and SFO, are not able to purchase aviation fuels directly. However, these facilities (as well as other entities) could fund deployment of related infrastructure (either on-airport or offsite, in ways that are consistent with existing requirements about airport revenue spending) that supports the co-benefits of greater uptake of sustainable aviation fuel.

V. CONCLUSION

With its ambitious climate policy and programs, existing uptake of low-carbon biofuels, and significant volume of in-state flights, California is well positioned in both the short and long term to help advance sustainable aviation fuel and decarbonize the sector. In the near term, the state has immediate opportunities to act on existing state policies and goals and federal investment in sustainable aviation fuel. In the long term, California can be a national leader on sustainable aviation policy and fuel deployment. However, until the state develops detailed plans for how to achieve sustainability in this sector, industry will be less likely to invest in these solutions, while the public will be left without a framework to monitor and demand progress.

While the long-term technology solutions to fully decarbonize aviation may still be uncertain, the state has a successful track record of pioneering zero-emission on-road transportation, by first reducing the carbon content of fuel and mandating and subsidizing battery electric vehicles. That same policy approach, and indeed many of the same tools, such as the Low Carbon Fuel Standard, could apply to the aviation sector, helping support and inform global efforts to decarbonize this critical sector of the economy.

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390 Simon Hall
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