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MTI MINETA TRANSPORTATION INSTITUTE

Recognizing the Potential to Reduce GHG Emissions Through Air Transportation Electrification

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CSUTC California State University Transportation Consortium

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16. Abstract

California is aggressively moving forward with efforts to deploy zero-emission transportation technology to fight climate change, especially the Greenhouse Gas (GHG) emissions from the high-impact transportation sector. However, to date, the investments California has made with Cap-and-Trade funding have focused on ground transportation and some marine sources and not the aircraft at the over 140 airports in the state. Through a California-focused comprehensive GHG emissions analysis, this research project seeks to determine how RAM using electric/hybrid electric aircraft can provide new high-speed transportation for high-priority passenger and cargo movement within Fresno County and connections to coastal urban centers. Using VISION, a model developed by the Argonne National Laboratory Transportation Systems Assessment Group, the research team identified and compared the emission per mile and emission per passenger mile between different modes of transportation using traditional petroleum fuel and other sustainable alternatives at an individual level and within the context of the transportation sector, by comparing different modes of transportation. With this estimation on hand, it becomes more viable for the state of California and other states, as well as the federal government, to establish guidelines and goals for transportation policies and investments.

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Executive Summary

In the context of many federal and state policies being placed with the goal of reducing carbon emissions, the transportation sector is a significant concern due to its large carbon footprint. This study presents a California-focused comprehensive GHG emissions analysis, at an individual level and within the context of the transportation sector, by comparing different modes of transportation.

According to the United States Environmental Protection Agency (EPA), a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year, depending on a vehicle's fuel, fuel economy, and the number of miles driven per year. According to the 2016 Federal Highway Administration Highway Statistics database, the average gasoline vehicle has a fuel economy of about 22.0 miles per gallon and drives around 11,500 miles per year (EPA 2022).

Also, according to EPA's Motor Vehicle Emission Simulator (MOVES), every gallon of gasoline burned releases about 8,887 grams of CO_2, and there are one million grams per metric ton. Therefore, for 2016, the average vehicle over a year of driving had tailpipe CO_2 emissions of about 4.6 metric tons (California Air Resources Board, 2021).

In order to find out the 2017 GHG Emissions per Vehicle, this study has used the California Greenhouse Gas Emissions for 2000 to 2019, Trends of Emissions, and Other Indicators by the California Air Resources Board.

Powered flight has made travel by air for humans a reality for nearly 120 years and, as the technology has improved, increasingly more people have been using air transport in place of land transportation. However, powered flight requires significant energy, and the fact that this energy comes from fossil fuels is what has caused aviation to contribute to an ever-increasing amount of greenhouse gases accumulating in the Earth's atmosphere.

This project has evaluated the GHG emissions for relatively small aircraft currently used in the San Joaquin Valley that provide air charter services for flights from Fresno to the Bay Area and Los Angeles region. The numbers found are significant. Fortunately, zero-emission electric propulsion for this class of aircraft is now becoming a reality with the advent of aircraft such as the Eviation Alice and electric propulsion conversions for Cessna 208 Caravans.

1. Introduction

California is aggressively moving forward with efforts to deploy zero-emission transportation technology to fight climate change. However, to date, the investments California has made with cap-and-trade funding has focused on ground transportation and some marine sources. These sources are major contributors to climate change but do not represent the entirety of transportation modes in California.

One mode of transport where California lags in recognizing the potential to reduce GHG emissions through electrification is air transport. As the rapidly emerging development and deployment of zero-emission aircraft, those powered by battery/hybrid electric motors, is revealed to the public and begins to enter service, state and local governments around the country should begin to evaluate the potential of this technology to improve connectivity, reduce GHG emissions, and generate new economic activity.

Regional Air Mobility (RAM), when operating with advanced electric, provides communities the opportunity to receive the benefits of using their local airport infrastructure to provide a conduit for new opportunities in their region. As this new generation of aircraft enters the market, they provide a cost-effective solution to connect communities that have been underserved by the current aviation service, while also providing needed relief to capacity-constrained aviation hubs and regional highways.

There are over 140 public-use airports in California; 32 of them in the San Joaquin Valley. Many of these airports are in close proximity to the growing population and commerce centers, particularly in the San Joaquin Valley, but they are underutilized. The development of advanced electric aircraft is opening the door to using these airports for both passenger and freight movement through significantly reduced operation costs associated with electric propulsion.

Strategic investment in the supporting infrastructure to facilitate the operations of these new aircraft in conjunction with zero-emission ground vehicles could transform these existing airport assets into multi-modal, zero-emission transportation hubs for the communities they are located in, bringing enhanced mobility and increased economic activity to many communities currently isolated due to limited ground transportation connections.

2. Project Objective and Motivation

Advances in electric aircraft development are providing opportunities for new Regional Air Mobility (RAM) services that can enhance the connectivity of regions by using underutilized existing airport infrastructure and integrating the use of electrified ground transportation. This research project seeks to determine how RAM using electric aircraft can provide new high-speed transportation for high-priority passenger and cargo movement within Fresno County and to coastal urban centers.

This study covers a range of topics to help clarify the environmental benefits in terms of GHG emissions for RAM operations. It should not be construed as the final, defining source of all knowledge when it comes to possibilities and the best ways forward as they relate to RAM initiatives. Rather, this study intends to start a conversation with the communities that will participate in an evolving RAM deployment process.

The focus of this study is an inquiry into what is needed in terms of RAM development to effectively implement RAM for high-priority cargo and passengers.

2.1 Objective

Maximize opportunities for California's cap-and-trade program to reduce the impact of GHG emissions and transportation on climate change by comparing GHG emissions from both ground and air modes of transportation. This includes the evaluation of new advances in air mobility being developed using electric propulsion for aircraft.

2.2 Motivation

With over 450 companies across the world investing billions of dollars in the development and certification of advanced electric aircraft, California is missing a critical opportunity to incorporate these aircraft into the fight against climate change by investing in the development of supporting infrastructure at public-use airports across the state concurrent with infrastructure for zero-emission ground vehicles. Since the infrastructure to support electric aircraft is very similar to what is needed to support zero-emission ground vehicles, the strategic investment in multi-modal support infrastructure could transform hundreds of under-utilized airports in California into zero-emission multi-modal transportation hubs that would improve connectivity, reduce emissions, and foster innovation for fast-growing regions such as the San Joaquin Valley.

3. Methodology

According to the Environmental Protection Agency (EPA)'s Inventory of U.S. Greenhouse Gas Emissions and Sinks, the transportation sector generates the largest share of GHG emissions, which primarily come from burning fossil fuels for cars, trucks, ships, trains, and planes. In the context of many federal and state policies having the goal of reducing carbon emissions, the transportation sector is, as has been made clear by the EPA's findings, a significant concern due to its large carbon footprint. This study presents a California-focused comprehensive GHG emissions analysis, at an individual level and within the context of the transportation sector, by comparing different modes of transportation.

The main objective is to identify and compare the emissions per mile and per passenger mile between different modes of transportation using traditional petroleum fuel and other sustainable alternatives. Once an estimation is on hand, it becomes more viable for California and other states, as well as the federal government, to establish guidelines and goals for transportation policies and investment.

4. Literature Review

4.1 Greenhouse Gas Emissions from the Transportation Sector

This section reviews relevant prior work on GHG emissions for the transportation sector. According to 2021's annual statewide GHG emission inventory by the California Air Resources Board (CARB), the transportation sector accounted for 41% of total emissions in 2019. Also, according to the same report, heavy-duty vehicles, such as trucks and buses, accounted for a quarter of these emissions. GHG emissions in the transportation sector come mainly from burning fossil fuels such as diesel and gasoline. Ground transportation contributes significantly to global GHG emissions, with carbon dioxide being the main culprit according to the EPA, making it a reference standard by which GHG emissions are measured.

4.2 Forecasting GHG Emissions

Various calculation methods are available for quantifying the GHG emissions associated with different types of public transit services. These methods are arranged into two major categories: (a) registry-and inventory-based calculators, and (b) life-cycle analysis calculators. Regardless of the significant progress shown in the techniques covered by this research, it has been concluded that no single calculator contains all information necessary for transit agencies to address a fully comprehensive lifecycle-based analysis of emissions produced by vehicles in general (Weigel et al., 2010). Although the most suitable method used for CO_2 estimation approaches the volume of fuel used, the assessment of the GHG emissions CH_4 and N_2O is better represented by vehicle miles traveled (VMT).

It's widely known that carbon dioxide emissions are the primary contributor to global warming. To avoid the harmful effects of emissions on climate change, developing actions to reduce emissions is necessary. Because this is a responsibility shared between regions, countries, and individuals, there are various ways in which emissions can be compared, such as annual emissions by country, emissions per person, and historical contributions. Depending on the perspective of the metric, different approaches and assumptions can be taken in the analyses, and this contributes to affirming that there is not a fully comprehensive method that addresses all factors contributing to emissions and their prospective impacts (Ritchie et al., 2020).

5. Assessment of Emission, Power, and Performance for Representative Zero-Emission Aircraft

5.1 Net Zero Emissions Pathway

According to the U.S. Department of Transportation in the Bureau of Transportation Statistics, the volume of passengers and cargo is set to rise in the coming decades. In the past, energy reduction programs have been insufficient to counterbalance such activity growth.

A range of operational, technical, and behavioral solutions will be required to cut exhaust emissions from 2025 onwards, to reduce them to just over 780 $MtCO_2$ by 2030 and around 470 $MtCO_2$ by 2040 in line with the International Energy Agency's (IEA) Net Zero Emissions pathway. Near- to medium-term priorities should include implementing fiscal and regulatory measures to promote efficiency, managing the investment risks for scaling up sustainable fuels, and developing alternatives to jet kerosene, such as battery-electric and hydrogen-powered aircraft (IEA, 2022).

5.2 Emission Analysis of Regional Electric Aircraft

Electric aircraft can provide a 49% to 88% reduction in CO_2 emissions relative to fossil-fueled reference aircraft (Mukhopadhaya and Graver, 2022). This includes the carbon intensity of the battery production process, which can account for up 80% of GHG emissions from the operation of electric aircraft. Decarbonization of the electric grid and batteries with higher specific energy reduces the carbon intensity of electric aircraft.

Electric aircraft can be 2.1 to 3.2 times more energy efficient during the cruising stage (Mukhopadhaya and Graver, 2022). Electric motors convert electricity into propulsive force more efficiently than combusting fossil fuels in an aircraft engine. This difference is pronounced in commuter aircraft that are typically powered by piston engines rather than the turbines that power turboprop aircraft. It is still more pronounced regarding aircraft powered by e-fuels such as e-methane, e-kerosene, and e-methanol which are likely fuel sources in a deeply decarbonized future. In that case, electric aircraft could use 4.5–6.9 times less energy than those running on e-fuels (Mukhopadhaya and Graver, 2022).

5.3 Sustainable Air Mobility Using eVTOLs

Electric Vertical Take-Off and Landing vehicles (eVTOL) offer fast, predictable transportation and could have a niche role in sustainable mobility (Kasliwal et al., 2019). In principle, eVTOL can travel the shortest distance between two points, and their relatively modest sizes would enable near-point-to-point service. Conversely, road networks are much less direct. This benefit of eVTOL aerial systems could favor energy and travel-time performance, particularly in locations with congestion.

High eVTOL cruise speeds could reduce travel time further. Significant time savings and associated productivity gains could be a major factor in consumer adoption of eVTOL transportation (Kasliwal et al., 2019). When comparing fully loaded eVTOLs (three passengers) with ground-based cars with an average occupancy of 1.54, eVTOL GHG emissions per passenger-kilometer are 52% lower than Internal Combustion Engine Vehicles (ICEVs), and 6% lower than Battery electric Vehicles (BEVs) (Kasliwal et al., 2019).

5.4 eVTOL Aircraft Operations

The estimated range for eVTOL is 150–200 nautical miles (nm), and the majority will operate shorter distances initially due to their use in larger urban areas, such as Los Angeles and the San Francisco Bay Area, to overcome ground transportation congestion. The passenger capacity for most of these aircraft is planned to be limited to five (5) passengers or less. eVTOL operations will be limited by the availability of high-power fast-charging infrastructure both at their points of departure and their destinations. Demand for fast transport to overcome both urban congestion and poor ground transport infrastructure in rural areas will likely be the first application for eVTOL. These early aircraft will likely enter service doing emergency medical transport to replace helicopters in rural settings and providing high-priority passenger and freight movement in dense urban settings, replacing all modes of ground transport for these missions.

Initially, eVTOL missions are likely to have one-way travel distances of 50–60 nm to allow for trips to be completed without recharging since charging infrastructure is limited. This trip distance works well for eVTOL since they will have lower GHG emissions for such trips than electric ground vehicles (Kasliwal et al., 2019).

As battery and fuel cell technology improves, it is estimated that eVTOLs will get up to the 200 to 300 nm range. However, they stop becoming a preferred aircraft type for ranges above 200 nm, similar to flights using helicopters today. This is because in those applications the trip can be done faster with an eCTOL (electric conventional take-off and landing) aircraft such as the Eviation Alice.

For trips above 200 nm, it is likely that a mix of eVTOL and eCTOL aircraft will be used. The eCTOL will operate from small general aviation airports near both the departure and destination locations, and an eVTOL will provide first- and last-mile transport of the people or cargo to those airports for transfer to faster eCTOL aircraft. This type of joint operation of aircraft to fulfill a high-priority mission is common in both military and civilian applications. The application of eCTOLs above 200 nm makes sense for high-priority operations, such as medical transport or organ transport, due to their higher cruise speed, while the first- and last-mile transport for these missions would best fit the eVTOL aircraft. This scenario takes advantage of the strengths of both types of electric aircraft while avoiding ground transportation delays.

5.5 Electric Aircraft Certification and Manufacturing

Developers of advanced eVTOL aircraft are partnering with well-established aircraft manufacturers, such as the partnership between Eve Air Mobility and Embraer to develop a holistic urban air mobility (UAM) ecosystem with plans to launch in 2026. The goal of such partnerships is to both assist with certification and manufacturing capacity (Forrest, 2022).

In terms of manufacturing, Eve lists a non-binding backlog of 2,060 eVTOL orders from 22 customers, valued at over $6 billion USD, for its four-passenger piloted eVTOL. This includes orders from SkyWest Airlines, Republic Airways, and Kenya Airways (Forrest, 2022). The plan is for the aircraft to be first certified with the National Civil Aviation Agency of Brazil (ANAC), and then the Federal Aviation Administration (FAA) may allow for a fast-track approval in the U.S. (Forrest, 2022). Certification with the European Union Aviation Safety Agency (EASA), and other major certification authorities, is also underway (Forrest, 2022).

5.6 Advanced Air Mobility Infrastructure and Financials

The greatest challenge for advanced air mobility (AAM) could be putting in place the infrastructure required for the system to become operational. Potential roadblocks include the need to raise large amounts of capital for AAM infrastructure, the complexity of integrating autonomous flight into the national airspace system, and the costs associated with delivering sufficient electric power to the stations. But what is not disputed is the tremendous financial impact AAM could have on states and local communities (Huber, 2022).

A study done in Ohio by Crown Consulting estimated a cost of $10 to $30 billion to build out the AAM infrastructure in the 38 largest American urban markets. It also estimated that this could add $11.4 billion to the state of Ohio’s gross domestic product (GDP) by 2045, create more than 15,000 jobs, and raise $2.5 billion in tax revenue, with a high percentage of those numbers coming from cargo and emergency services operations (Huber, 2022). However, investment funds from AAM are unlikely to be provided by the public sector yet. The FAA has not recognized the need to fund electric-aircraft-supporting infrastructure at airports yet, and this could be a task being left to state governments to reduce more localized GHG emissions and criteria pollutant emissions since electric aircraft range is limited to short haul regional flights (FAA, 2022).

According to the Congressional research report, federal action to significantly reduce GHG emissions from aircraft is not going to happen any time soon, so that leaves it to states such as California to take action to promote the deployment of electric aircraft to reduce local GHG emissions and criteria pollutants (Congressional Research Service, 2022).

6. Comparative Operational GHG Emission Analysis with Zero-Emission Aircraft

When analyzing the potential for electric aircraft to replace some ground transportation options, one must look at the distances traveled in different scenarios and then select the aircraft best suited to fulfill the mission. For this section, we examine the GHG emissions of conventional fuel versus electric aircraft for high-speed transport for high-priority passengers and freight.

6.1 EVOTL vs. ECTOL Aircraft Operations

The Eviation Alice has a cruising speed of 200 to 250 knots, while the eVTOL has a cruising speed of 110–120 knots at maximum range cruise. Initially, speed values for eVTOL will be in the 90–100 knot range because battery technology is still limited in capacity and pilots will want to conserve power for the critical take-off and landing phases of each flight where power demand is the highest due to sole reliance on the electric motors to provide lift for the aircraft in vertical flight.

Conventional takeoff and landing aircraft currently have a speed advantage over rotary wing VTOL aircraft, and this trend will continue with eVTOL designs. The added drag created by the vertical flight rotors makes any eVTOL slower than a similarly sized eCTOL design. For shorter trips, such as Fresno to Merced, which is 47 nautical miles, the speed advantage is not that significant because an eCTOL aircraft spends time climbing and descending at slower than maximum cruise speed while the eVTOL can go to cruise speed faster.

An airplane that will do 200 knots versus an airplane that does 100 knots does not have a big time advantage for short-distance flights. However, when the range starts getting further, for example from Fresno to Sacramento which are 133 nautical miles apart, the speed difference begins to pay off in terms of time savings. The charts displayed in Figures 3 and 5 show the difference in time for both trips using a 200-knot (shown in Figure 1) vs. a 100-knot aircraft (shown in Figure 2). The comparisons listed in Table 1 show the time difference between flying a Cessna 172 (100 kt cruise speed) and a Beechcraft King Air C-90 (200 kt cruise speed aircraft). Course plots and navigation logs are shown in Figures 4 and 6 for the flights from Fresno Chandler Executive Airport (KFCH) to Sacramento Executive Airport (KSAC) to highlight the differences in flight profiles and show that changes to cruising altitude do not significantly impact the time difference between the two aircraft. The shorter distance flight comparisons are not shown because the time savings are not significant.

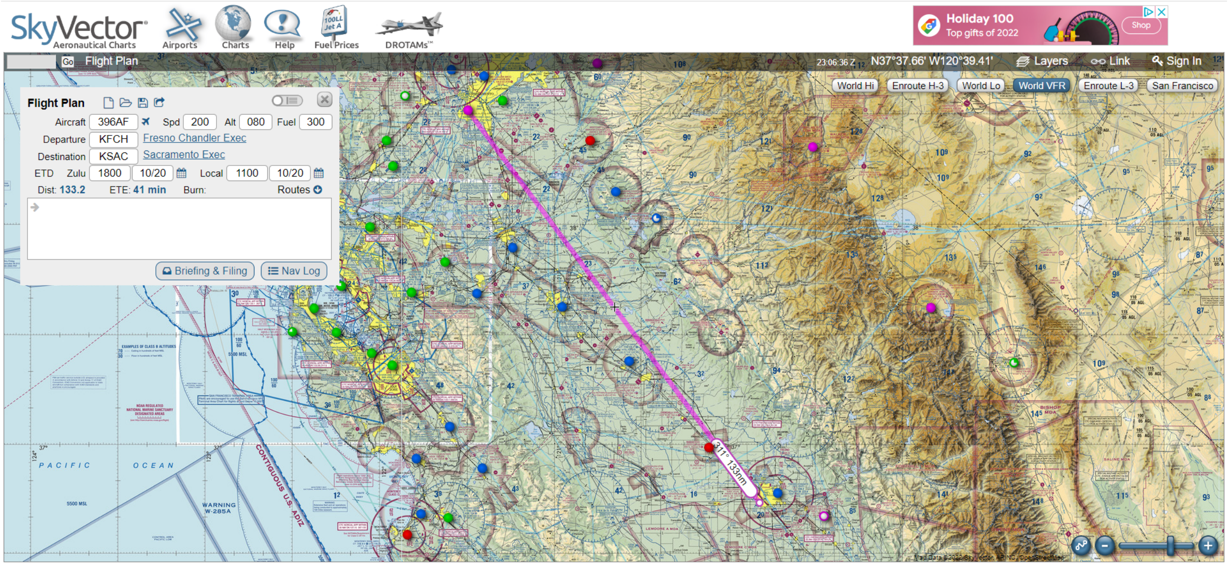
Figure 1. KFCH to KSAC 100 kt Aircraft (Cessna 172)

Figure 2. KFCH to KSAC 200 kt Aircraft (Beechcraft King Air C-90)

Table 1. Flight Distance and Speed Comparison

Departure Airport	Destination Airport	Distance (nm)	Aircraft Airspeed (kts)	Time to Complete (minutes)
KFCH (Fresno)	KMCE (Merced)	47	100	30
KFCH (Fresno)	KMCE (Merced)	47	200	17
KFCH (Fresno)	KSAC (Sacramento)	133	100	88
KFCH (Fresno)	KSAC (Sacramento)	133	200	45

Figure 3. KFCH to KSAC in 200 kt Aircraft



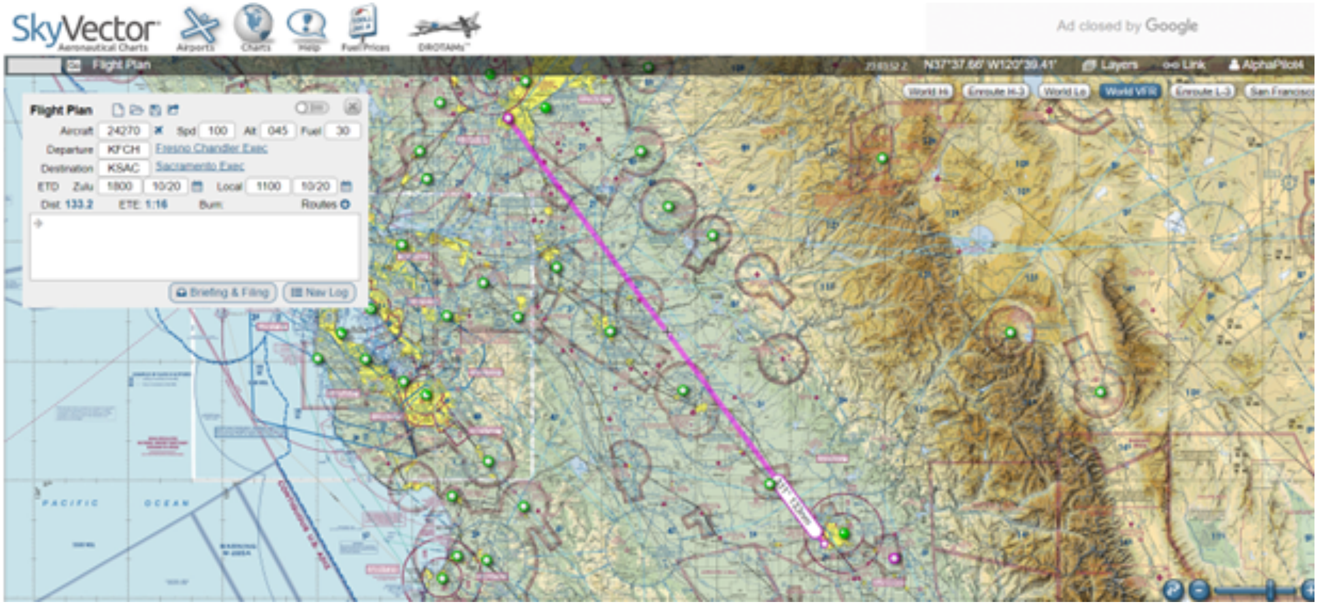
Flight Plan

Aircraft 396AF Spd 200 Alt 080 Fuel 300
Departure KFCH Fresno Chandler Exec
Destination KSAC Sacramento Exec
ETD Zulu 1800 10/20 Local 1100 10/20
Dist: 133.2 ETE: 41 min Burn: Routes

Figure 4. KFCH to KSAC Navigation Log in 200 kt Aircraft

Waypoint	Route Altitude	wDir Temp (dev)	wSpd	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO	ATE ATO	Fuel EFR	Fuel AFR
KFCH N 36°43.93' W 119°49.22'													
	-D-> ↗	159° 12°C (-3°)	11	130	324° -1°	322° -12°	310°	141	15.5	6.1 6.1		0.0 300	
TOC N 36°56.41' W 120°00.63'													
	-D-> 8000	215° -3°C (-2°)	23	200	324° -6°	317° -12°	305°	206	90.5	26 33		0.0 300	
TOD N 38°09.00' W 121°08.64'													
	-D-> ↘	224° -3°C (-2°)	44	200	323° -13°	310° -12°	298°	202	27.3	8.0 41		0.0 300	
KSAC N 38°30.77' W 121°29.60'													

Figure 5. KFCH to KSAC in 100 kt Aircraft



Flight Plan

Aircraft 24270 Spd 100 Alt 045 Fuel 30
Departure KFCH Fresno Chandler Exec
Destination KSAC Sacramento Exec
ETD Zulu 1800 10/20 Local 1100 10/20
Dist 133.2 ETE 1:16 Burn: Routes

Figure 6. KFCH to KSAC Navigation Log in 100 kt Aircraft

Waypoint	Route	wDir	wSpd	TAS	Track	TH	MH	GS	Dist	ETE	ATE	Fuel	Fuel
	Altitude	Temp (dev)			WCA	Var				ETO	ATO	EFR	AFR
KFCH N 36°43.93' W 119°49.22'	-D→	304°	2	64	324°	323°	311°	63	7.3	6.5		0.0	
	↗	7°C (-8°)			-1°	-12°				6.5		30.0	
TOC N 36°49.85' W 119°54.63'	-D→	148°	8	100	324°	323°	311°	108	120.2	1h05		0.0	
	4500	2°C (-5°)			-0°	-12°				1h12		30.0	
TOD N 38°26.24' W 121°25.21'	-D→	131°	8	99	323°	324°	311°	107	5.7	3.7		0.0	
	↘	2°C (-5°)			+1°	-12°				1h16		30.0	
KSAC N 38°30.77' W 121°29.60'													

6.2 Simulation Scenario from the Central Valley to the San Francisco Bay Area

For the scenario focused on the Bay Area, we analyze a trip from Fresno to catch a long-distance international flight out of San Francisco International Airport (SFO). For this simulation, we focus on the Fresno Chandler Executive Airport to the city of San Carlos, which has the closest small airport to San Francisco's international airport terminal. The assumption is that passengers would board ground transport at San Carlos Airport to go the final few miles to SFO. They would use a Beechcraft King Air C-90 to make the trip from Fresno Chandler Executive Airport to San Carlos Airport and then use the same aircraft to make the return flight once they return from their long-distance trip.

The Beechcraft King Air C-90 burns 100 gallons of Jet A fuel per hour of flight cruising at 220 kts. The carbon intensity of Jet A is reported by the Energy Information Agency as 21.5 lbs of carbon per gallon of fuel consumed (IEA, 2022). The Beechcraft King Air C-90 is a 5-passenger, twin-turbo prop engine aircraft capable of cruising at up to 220 knots at a maximum altitude of 30,000 ft with a normal range of 840 nm and a crew of two. The aircraft is powered by two Pratt and Whitney model PT-6A-21 turbine engines rated at 500 shp each. The Eviation Alice is being built to carry up to 9 passengers, but will likely operate with 5 or 6. The two aircraft have a similar performance, but the Alice will not have to fly at high altitudes to be efficient, whereas the Beechcraft King Air must fly at altitudes above 10,000 ft for maximum efficiency.

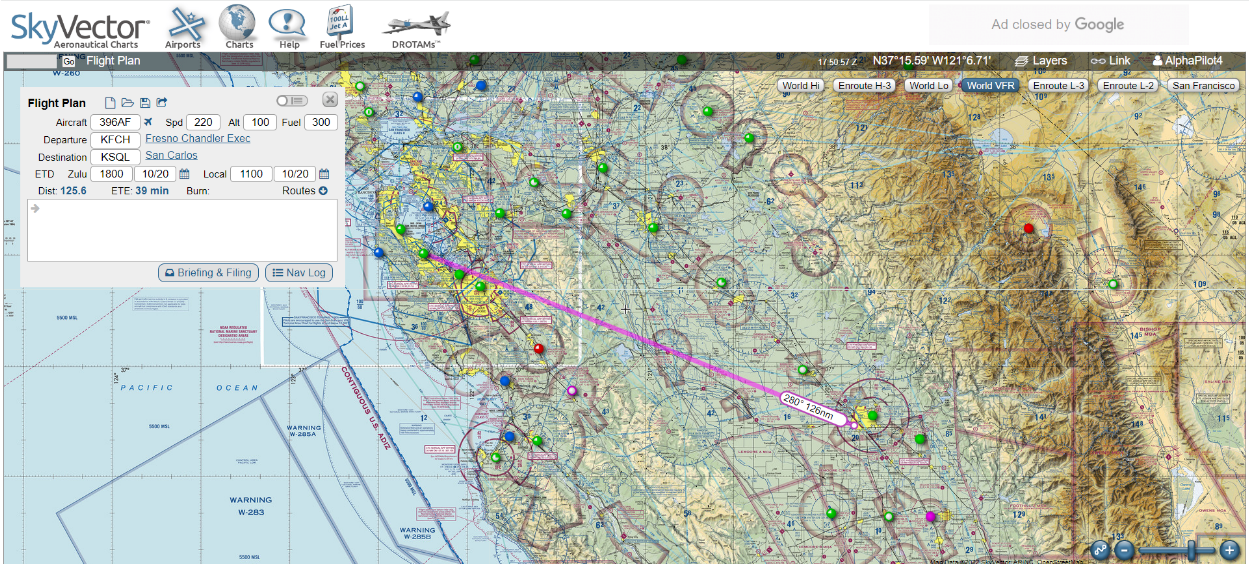
For a single round trip flight from Fresno Chandler Executive Airport to San Carlos Airport in the Bay Area, the GHG analysis is shown in Table 2 for a Beechcraft King Air C-90.

Table 2. FCH to SQL Round Trip GHG Emissions

Hours of Flight one way	GHG emissions (lbs) one way	GHG emissions (lbs) RT	GHG Emissions (Metric tons) RT
0.61	1,312	2,623	1.19

Total round trip distance for this scenario is 251.2 nm. This is doable with the Eviation Alice with a recharge at San Carlos. The Alice currently has a published VFR range on a single charge of 250 nm (Eviation, 2022). The course plot for this flight is shown in Figure 7.

Figure 7. KFCH to KSQL in Beechcraft King Air C-90



Flight Plan
Aircraft 396AF Spd 220 Alt 100 Fuel 300
Departure KFCH Fresno Chandler Exec
Destination KSQL San Carlos
ETD Zulu 1800 10/20 Local 1100 10/20
Dist: 125.6 ETE: 39 min Burn:
17:50:57 Z N37°15.59' W121°6.71'

6.3 Simulation Scenario from the Central Valley to Los Angeles

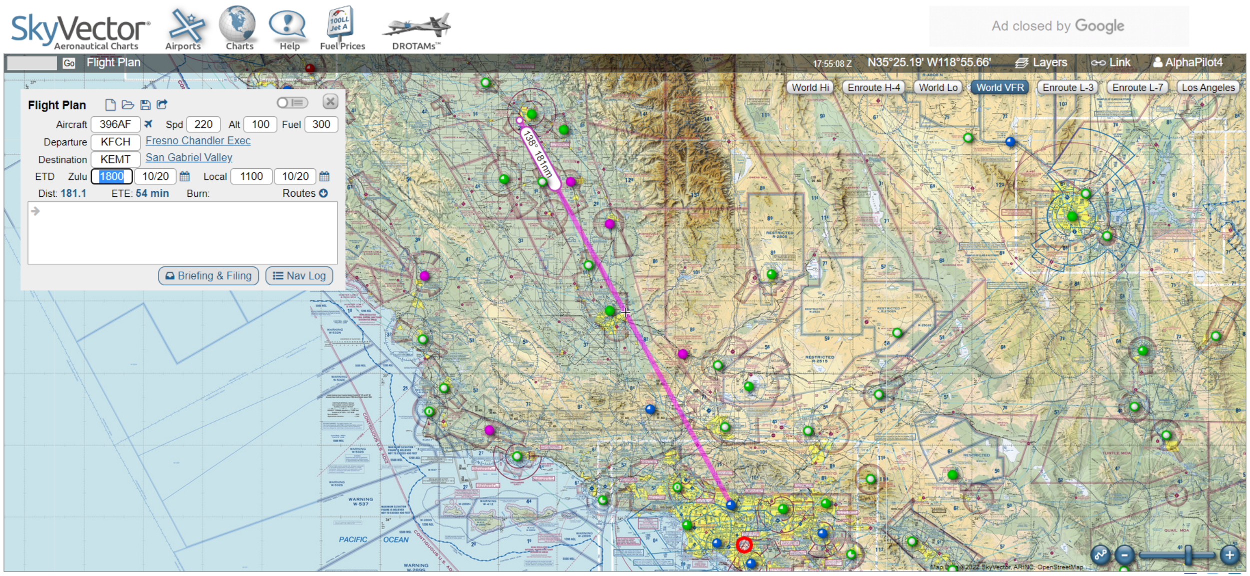
For the simulation focused on the Los Angeles basin, the flight is from Fresno Chandler Executive Airport to El Monte Airport. El Monte is a good location because it's on the east side of the LA Basin and near Pasadena, where there are many businesses that offer potential destinations for clients from Fresno. For a single round trip from Fresno Chandler Executive Airport to El Monte Airport near Pasadena in the LA Basin, the GHG analysis is shown in Table 3 for a Beechcraft King Air C-90.

Table 3. FCH to EMT Roundtrip GHG Emissions

Hours of Flight one way	GHG emissions (lbs) one way	GHG emissions (lbs) RT	GHG Emissions (Metric tons) RT
0.86	1,849	3,698	1.68

The total round-trip distance for this scenario is 362 nm. This is doable with the Eviation Alice with a recharge at El Monte. The Alice currently has a published VFR range on a single charge of 250 nm (Eviation, 2022). The course plot for this flight is shown in Figure 8.

Figure 8. KFCH to KEMT in Beechcraft King Air C-90



Flight Plan

Aircraft 396AF Spd 220 Alt 100 Fuel 300

Departure KFCH Fresno Chandler Exec

Destination KEMT San Gabriel Valley

ETD Zulu 1800 10/20 Local 1100 10/20

Dist: 181.1 ETE: 54 min Burn:

Both scenarios when flown using an Eviation Alice would result in zero direct GHG emissions and zero total GHG emissions if the electricity for the aircraft was produced from renewable energy. Table 4 describes airtime versus ground time from Fresno Chandler Airport to the selected destinations. Table 5 shows a trip cost comparison for the Beechcraft King Air C-90 versus the Eviation Alice Electric.

Table 4. Airtime vs Ground Time from Fresno Chandler Airport to Selected Destinations

Destination Airport	Distance	Time by Air (at 220 kt airspeed)	Time by Ground	Time Savings
Redding Municipal	254.5 nm	1.4 hrs	5.1 hrs	3.7 hrs
Palo Alto	118.5 nm	0.7 hrs	2.8 hrs	2.1 hrs
Henderson, NV	231.6 nm	1.3 hrs	6.1 hrs	4.8 hrs
Fullerton	193.7 nm	1.2 hrs	4.9 hrs	3.7 hrs
Sacramento Executive	133.2 nm	0.8 hrs	2.7 hrs	1.9 hrs
Reno, NV	165.9 nm	0.9 hrs	4.8 hrs	3.9 hrs
Lake Tahoe Airport	129.8 nm	0.7 hrs	4.4 hrs	3.7 hrs

Table 5. Cost Comparison Calculations for Beech King Air C-90 to Eviation Alice Electric

Trip Length	440		
Passenger Load	5		
Operating Costs	King Air Turbine	Eviation Alice Electric	Electric Difference
Trip time (hrs)	1.95	2.00	-0.05
Over-all cost per trip	$2,510	$1,004	$1,506
Fuel cost for trip	$351	$109	$242
Cost per passenger	$502	$201	$301

7. GHG Emission Analysis for Ground Transportation

7.1 Carbon Emission Impacts of Vehicle Technologies and Alternative Fuels

Regarding biofuels and other possible solutions to reduce GHG emissions, a 2011 study published in the *Energy for Sustainable Development* journal (Andress et al., 2011) compared potential GHG reduction strategies, ranging from hybrid electric vehicles (HEV) to fuel cell electric vehicles (FCEV) and biofuels. To compare the different options, the study quantified the increasing engine efficiency and transitioning to low-carbon fuels for each method separately, measuring the extent to which the reductions could be achieved.

The analysis method used by the study involved VISION, a model developed by the Argonne National Laboratory Transportation Systems Assessment Group, which provides estimates of the potential energy use; oil use; carbon emission impacts of vehicle technologies, light and heavy; and alternative fuels through the year 2050. The model was then calibrated using the 2010 Annual Energy Outlook published by the U.S. Energy Information Administration, which presented a projection and analysis of U.S. energy supply, demand, and prices through 2035. Among the inputs used in the model were the annual shares of new vehicle sales by vehicle type and the fuel economy of each vehicle type. This allowed for the model to track vehicular turnover internally to calculate aggregate fuel consumption.

After obtaining the output produced from VISION, the data was then input into TRANCE, another model which was originally based on California's Low Carbon Fuel Standard (LCFS), which calculates lifecycle GHG emissions and carbon intensity statistics for transportation fuels. After performing the analysis, the study found out that some combination of coal gasification with carbon capture and sequestration and/or nuclear energy would likely be necessary to promote carbon intensities for hydrogen and electricity reductions. Biofuels, in contrast, would not be able to allow major reductions in carbon emission reductions by themselves due to supply constraints. However, combining such alternate fuels with other solutions could potentially achieve greater results.

7.2 Greenhouse Gas Emissions Per Vehicle

According to the United States Environmental Protection Agency (EPA), a typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year, depending on a vehicle's fuel, fuel economy, and the number of miles driven per year. According to the 2016 Federal Highway Administration Highway Statistics database, the average gasoline vehicle has a fuel economy of about 22.0 miles per gallon and drives around 11,500 miles per year (EPA 2022).

Also, according to EPA's Motor Vehicle Emission Simulator (MOVES), every gallon of gasoline burned creates about 8,887 grams of CO_2, and there are one million grams per metric ton.

Therefore, for 2016, the average vehicle over a year of driving had tailpipe CO_2 emissions of about 4.6 metric tons (California Air Resources Board, 2021).

In order to find out the 2017 GHG Emissions per Vehicle, the study has used the California Greenhouse Gas Emissions for 2000 to 2019, Trends of Emissions and Other Indicators by the California Air Resources Board.

7.3 GHG Emissions in California

The annual statewide GHG emission inventory is an important tool in tracking the progress of California's climate programs towards achieving statewide GHG emissions goals (Croci et al., 2013). Using the California Air Resources Board Greenhouse Gas Emissions for 2000 to 2019, Trends of Emissions and Other Indicators, the study has found the following GHG Emissions for the transportation modes selected in this study; the total emissions per passenger cars, buses, and rail are described in Tables 6, 7, and 8, respectively.

Table 6. CO2 Equivalent for Passenger Cars

On-Road: Light-duty Vehicles: Passenger Cars	
Million Tonnes (Tg) of CO_2 Equivalent	**59.23**

Type of emission	**GHG**	**2017**
Passenger Cars–Biodiesel	CH_4	3.31E-06
Passenger Cars–Biodiesel	N_2O	9.83E-04
Passenger Cars–Distillate	CH_4	5.10E-05
Passenger Cars–Distillate	CO_2	3.24E-01
Passenger Cars–Distillate	N_2O	1.51E-02
Passenger Cars–Ethanol	CH_4	7.68E-03
Passenger Cars–Ethanol	N_2O	6.73E-02
Passenger Cars–Gasoline	CH_4	7.02E-02
Passenger Cars–Gasoline	CO_2	5.81E+01
Passenger Cars–Gasoline	N_2O	6.15E-01
Passenger Cars—Renewable Diesel	CH_4	6.53E-06
Passenger Cars—Renewable Diesel	N_2O	1.94E-03

Table 7. CO_2 Equivalent for Buses

On-Road: Light-duty Vehicles: Buses	
Million Tonnes (Tg) of CO_2 Equivalent	**1.38**

Type of emission	**GHG**	**2017**
Buses–Biodiesel	CH_4	2.80E-05
Buses–Biodiesel	N_2O	2.10E-03
Buses–Distillate	CH_4	4.32E-04
Buses–Distillate	CO_2	6.93E-01
Buses–Distillate	N_2O	3.24E-02
Buses–Ethanol	CH_4	4.37E-05
Buses–Ethanol	N_2O	5.35E-04
Buses–Gasoline	CH_4	3.99E-04
Buses–Gasoline	CO_2	6.42E-01
Buses–Gasoline	N_2O	4.90E-03
Buses—Renewable Diesel	CH_4	5.53E-05
Buses—Renewable Diesel	N_2O	4.15E-03

Table 8. CO_2 Equivalent for Rail

Rail	
Million Tonnes (Tg) of CO_2 Equivalent	**1.83**

Type of emission	**GHG**	**2017**
Rail–Distillate	CH_4	1.85E-03
Rail–Distillate	CO_2	1.82E+00
Rail–Distillate	N_2O	4.41E-03

7.4 Carbon Emission Impacts of Vehicle Technologies and Alternative Fuels

In regard to biofuels and other possible solutions to reduce GHG emissions, a 2011 study published in *Energy for Sustainable Development*, compared potential GHG reduction strategies, ranging from hybrid electric vehicles (HEV) to fuel cell electric vehicles (FCEV) and biofuels. To compare the different options, the study quantified the increasing engine efficiency and transitioning to low-carbon fuels for each method separately, measuring the extent to which the reductions could be achieved (4).

Once the totals of GHG emissions per mode in 2017 were encountered, as shown in Tables 9, 10, and 11, it was possible to calculate the total emissions per vehicle type by dividing the GHG emissions per mode by the total number of vehicle types operating in California in 2017, which was extracted from the Bureau of Transportation Statistics' State Motor Vehicle Registrations for 2017.

Table 9. CO_2 Total GHGs Emissions Per Mode

Total GHGs Emissions Per Mode–2017
Million Tonnes (Tg) of CO_2 Equivalent

Trip Mode	**CA**
Cars, SUVs, Pickup Trucks, RVs	59.23
Bus	1.38
Rail	1.83

Table 10. CO_2 Total Number of Vehicles Operating in 2017

Total Number of Vehicles Operating in 2017

	Cars, SUVs, Pickup Truck, RVs	**Buses**	**Rail**
California	14,860,967	99,917	62,050

Table 11. CO_2 Metric Ton Per Vehicle Type in 2017

CO_2 Metric Ton Per Vehicle Type–2017
Million Tonnes (Tg) of CO_2 Equivalent

Vehicle Type	**CA**
Cars, SUVs, Pickup Trucks, RVs	4.0
Bus	13.8
Rail	29.5

The next step consisted in finding out the total emissions per person commuting in different transportation modes. This was possible by dividing the total emissions per vehicle type in 2017 by the average occupancy of each category. Table 12 shows the results that a person using a car in California contributed an average of 2.3 metric tons of CO_2 in 2017, while a person commuting by bus in the same year contributed an average of 1.3 metric tons of CO_2. Lastly, a person utilizing rail contributed an average of 0.9 metric tons of CO_2 in 2017.

Table 12. Average Vehicle Occupancy in 2017

Annual Metric Ton of CO_2 Equivalent Per Person by Mode in California

Trip Mode	CA
Cars, SUVs, Pickup Trucks, RVs	2.3
Bus	1.3
Rail	0.9

The average passenger vehicle emits about 411 grams of CO_2 per mile. In this case, the comparison would be 943 grams per passenger mile versus 411 grams per passenger mile of CO_2.

8. Conclusion

Since antiquity, humans have recognized, as they watched birds fly overhead, that flight allows for travel over distances without concern for physical barriers and thus provides time savings that ground transport cannot equal. Even the Bible references human flight in the Book of Isaiah Chapter 40, verse 31. “But they that wait upon the Lord shall renew their strength; they shall mount up on wings like eagles…” (NKJV). Since time is the one commodity in life that can’t be retrieved when lost, the ability to fly has been a goal for mankind for millennia!

Powered flight has made travel by air for humans a reality for nearly 120 years and, as the technology has improved, increasingly more people have been using air transport in place of land transportation. However, powered flight requires significant energy, and the fact that this energy comes from fossil fuels has caused aviation to contribute to an ever-increasing amount of greenhouse gases accumulating in the Earth’s atmosphere.

This project has evaluated the GHG emissions for relatively small aircraft currently used in the San Joaquin Valley to provide air charter services for flights from Fresno to the Bay Area and the Los Angeles Basin. The numbers found favor energy and travel-time performance. Fortunately, zero-emission electric propulsion for this class of aircraft is now becoming a reality with the advent of aircraft such as the Eviation Alice and electric propulsion conversions for Cessna 208 Caravans.

It is anticipated that by 2030 zero-emission electric aircraft will supplant existing turbine- and piston-powered aircraft in air charter and flight training operations, driven by lower operation costs and lower noise for communities where these aircraft operate. The lower operation costs for electric propulsion aircraft will make them more competitive with ground modes for larger numbers of people. Further, the time savings for flying versus ground transport will open many new opportunities for smaller communities in California to have greater connectivity with larger urban centers, thereby improving the economies of these communities.

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Dr. Roa is currently an Assistant Professor at California State University (CSU), Fresno. Before joining California State University Fresno in 2018, he was an Instructor at Virginia Polytechnic Institute and State University, where he completed his Master's degree (2008) and doctoral degree (2018) in civil engineering. The aim of Dr. Roa's research is to contribute to air transportation sustainability. This includes researching renewable energy supplies to support the aviation industry's transition to fully electric systems, as well as evaluating required modifications and additions to airport infrastructure in order to accommodate new technologies. Dr. Roa also has interests in regional mobility, urban mobility, and reducing air transportation environmental impact. Dr. Roa's current teaching at CSU, Fresno includes undergraduate and graduate courses in Transportation Planning and Design; Airport Planning and Design; and DataScience, Simulation, and Modeling. He has contributed to STEM outreach activities since 2012.

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Mr. Oldham is a native of Fresno and President/CEO of New Vision Aviation, Inc. A general aviation pilot since 1974, Mr. Oldham is the project lead for the Sustainable Aviation Project that has deployed four Pipistrel Alpha Electro aircraft in Fresno County and developed the first network of electric aircraft charging infrastructure in the United States. Mr. Oldham has over 220 hours of flight experience in the Alpha Electro aircraft making him one of the most experienced pilots in electric aircraft flight operations in the United States. New Vision Aviation is a non-profit devoted to providing education and training in aviation for residents in the San Joaquin Valley with a primary emphasis on youth from disadvantaged communities in the region. New Vision Aviation's tag line is "Elevating People Through Aviation."

Marina Lima, MSc

Marina Lima has a Master's degree in Civil Engineering from CSU, Fresno. She earned her Bachelor's degree from the University of Brasilia, her hometown, and moved to Fresno, CA in 2019 to work in a local civil engineering company. Ever since, she has gained experience in transportation engineering, being involved in drafting and designing many local commercial and residential projects with AutoCad Civil 3D. Marina's particular interest in air transportation comes from her lifelong passion for travelling all over the world. While working on her undergraduate thesis on transportation, her interest in the subject grew more, and she saw in CSU, Fresno the opportunity to delve even further in this topic. Marina recently joined JMA Civil as a Senior Project Engineer.

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