NASA/CR–20250001574

Assessing The Electrification of Aviation's Impact on the Airport and Airway Trust Fund

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February 2025

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Prepared for NASA Langley Research Center
under Contract/Task 100090040025WA942

February 2025

Available from:

NASA STI Program / Mail Stop
050 NASA Langley Research
Center Hampton, VA 23681-2199

ABSTRACT

The electrification of aviation presents significant challenges to the Airport and Airway Trust Fund and the broader aviation ecosystem, particularly for small and rural airports. As aircraft transition to electric power, the Airport and Airway Trust Fund will lose crucial income from fuel taxes, impacting funding for smaller airports. This shift may lead to diminished operational viability and negative effects on local economies for small, rural, underrepresented, and economically disadvantaged airports. The Federal Aviation Administration anticipates Advanced Air Mobility services to begin between 2025-2027, with gradual growth expected from 2030. To ensure successful transition and scalability of Advanced Air Mobility, stakeholders must determine how an electrified aviation system will participate in the Airport and Airway Trust Fund and mitigate lost revenue throughout the evolution to electrification. Electrified aviation when converted to Aviation Gas equivalent U.S. gallons represents a loss of approximately 64% annual Aviation Gasoline equivalent gallons, fuel sales, and Airport and Airway Trust Fund excise tax for both LOW and BASE case forecasts. Key challenges include developing a taxation and fee structure for Advanced Aircraft Mobility participation, addressing energy demands for various Advanced Air Mobility aircraft types and missions, and mitigating the economic impact of losing legacy fueling enterprises at airports. To maintain a robust and inclusive air transportation system, policymakers must prioritize the unique challenges of small, rural, and economically disadvantaged airports while implementing the new electrification paradigm. Collaboration between government, industry, and academia, similar to the NASA-led Advanced Air Mobility working group, will be crucial in addressing these significant issues and advancing this nascent technology.

I. INTRODUCTION

The electrification of aviation poses significant challenges to the Airport and Airway Trust Fund (AATF). The AATF maintains FAA operations and aviation infrastructure investments and is primarily funded through a variety of aviation-related excise taxes to include taxes levied on fuel sales. As aircraft transition from traditional fuel to electric power, the AATF will lose a crucial source of revenue from fuel tax. This shift will have far-reaching consequences, particularly for small, rural, underrepresented, and economically disadvantaged airports. These airports are likely to face severe impacts including reduced AATF funding over time, stagnation and eventual loss of fuel flowage fees, and negative effects on local economies. Further, due to limited financial resources and prioritization of essential safety-related infrastructure improvements (e.g., pavement maintenance) small and rural airports will struggle to participate in electrified aviation initiatives (e.g., regional air mobility or RAM) [1,2]. These fiscal constraints may prevent such facilities from fully integrating into an electrified aviation system, potentially limiting their communities' access to the national economy. Last, for RAM to scale effectively, it requires a network of similarly equipped airports to ensure operational alignment, particularly in terms of "fuel" availability. The accessibility and growth of RAM depend on a comprehensive network of airports capable of supporting electric aircraft.

II. BACKGROUND

On December 10, 2019, a significant milestone in aviation history was achieved when a Vancouver-based Harbour Air DHC-2 de Havilland Beaver seaplane, retrofitted with a 750 horsepower (560 kW) magni500 electric propulsion system, successfully completed the world's first all-electric commercial aircraft flight [3]. This groundbreaking event heralded the dawn of the "electric age" in aviation, showcasing the potential for environmentally friendly and cost-effective commercial air travel. Since this historic flight, the electric aviation sector has experienced remarkable growth and diversification. Significant advancements have been made in technology, performance, and the variety of aircraft types. Current trends suggest that by 2030, we can anticipate:

1. A wider range of electric aircraft types.
2. Substantial technological improvements.
3. Expanded infrastructure to support electric aviation.
4. Significant market growth [4].

These developments are expected to contribute to a more interconnected world, offering faster, cleaner, and more accessible transportation options [5]. The evolution of electric aviation promises to revolutionize air travel, potentially reducing carbon emissions and operating costs while improving overall efficiency and accessibility.

III. THE FUTURE OF GENERAL AVIATION PROPULSION

The transition to electric aviation is expected to be gradual, with electric aircraft initially operating alongside traditional, hydrocarbon fueled aircraft. As technology advances, electricity and hydrogen are poised to increasingly replace legacy aviation fuels such as Aviation Gasoline (AvGas) and jet fuel in general aviation. Though there is not yet a widespread industry consensus on electricity completely supplanting AvGas as the primary fuel source, electric aircraft are likely to play a growing role in this sector, particularly for shorter flights and specific applications. In the near future, a hybrid approach combining electric and traditional propulsion systems is more probable for commercial aviation. This transition will likely unfold in stages, with electric aircraft initially being adopted for short-distance flights and specialized uses, followed by the emergence of hybrid systems that offer the benefits of both electric and traditional propulsion. The aviation industry is actively working towards this future, guided by initiatives like the Climate Action Plan and NASA's Sustainable Flight National Partnership (SFNP). These programs aim to accelerate the development and integration of sustainable aviation technologies, including electric and hybrid propulsion systems. One key project under the SFNP is the Electrified Propulsion Flight Demonstrator (EPFD), which focuses on developing and testing hybrid electric propulsion systems for single-aisle commercial aircraft [6]. This project demonstrates the industry's commitment to bridging the gap between current technology and fully electric commercial aviation. Several Original Equipment Manufacturers (OEMs) and startups are at the forefront of this transition:

1. Ampaire: Developing hybrid-electric aircraft for regional flights, with successful test flights of their EEL technology demonstrator [7].
2. Electra: Working on hybrid-electric short takeoff and landing (eSTOL) aircraft for regional air mobility [8].
3. Regent: Focusing on all-electric "seagliders" for coastal transportation [9].
4. Joby Aviation: Developing all-electric vertical takeoff and landing (eVTOL) aircraft for urban air mobility [10].
5. Archer Aviation: Creating both battery-powered eVTOL aircraft for civilian use and exploring hybrid propulsion systems for military applications [11].

These companies are paving the way for a more sustainable aviation future, with hybrid and electric aircraft expected to play a significant role in reducing the industry's carbon footprint. As battery technology improves and infrastructure adapts, we can anticipate a gradual shift towards more electric propulsion in aviation, starting with shorter routes and specialized applications before expanding to larger aircraft and longer distances [12].

As technology improves, fully electric and hydrogen-powered aircraft may become more prevalent for longer distances. We also have new transportation paradigms, such as UAM [13] and RAM [14] that will actually seek to increase aviation in sectors that traditionally have not been major contributors to aviation emissions due to the low demand that exists in these sectors today. The pace of this transition will depend on technological advancements, infrastructure development, and regulatory frameworks.

IV. LEGISLATIVE/REGULATORY ENVIRONMENT

The March 2023 White House National Aeronautics Science and Technology Priorities document established the mandate for electrification of aviation in the United States. This mandate is predicated in part on the 2021 US Aviation Climate Action Plan. The document outlines the United States Government's strategic priorities to expand U.S. leadership, enable U.S. government-wide collaboration, and support public-private partnerships to ensure continued success in aeronautics. Stated goals of the U.S. government's aeronautics strategic priorities include *"transition its legacy systems and modernize and adapt regulatory and operational structures."* Also, *"...promote connectivity through supporting the development of AAM"* and *"...enable more connections to less utilized airports and underserved communities"* [15]. Further, The U.S. Government is committed to achieving sustainable aviation to reduce and eventually eliminate the greenhouse gas emissions from aviation by implementing the U.S. 2021 Aviation Climate Action Plan (ACAP). Specifically, ACAP advocates for *"Electrification and potentially hydrogen as solutions for short-haul aviation"*, and *"International initiatives such as the airplane CO2 standard and the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)"* [16].

A. Airport Improvement Program

The Airport Improvement Program (AIP) provides the connective tissue between national priorities and airports by way of grants in aid administered by the Federal Aviation Administration (FAA). However, the FAA faces a challenge in distributing AIP funds due to demand exceeding availability. To address this, the FAA prioritizes fund allocation based on current national priorities and objectives in aviation. Airports seeking AIP grants must adhere to specific obligations set by the program. To be considered for funding, projects must focus on enhancing airport safety, capacity, security, and environmental concerns. For a project to receive AIP funding, it must meet several key criteria to include justification based on civil aeronautical demand, compliance with Federal environmental requirements, and adherence to Federal procurement standards [17]. The AIP handbook provides guidance on how to identify, design, and implement electrical infrastructure projects but is silent on electric infrastructure associated with Advanced Air Mobility (AAM) and the electrification of the National Airspace System (NAS). To address potential funding gaps, adaptation of AIP criteria to determine eligibility for electric aviation infrastructure projects may be required.

B. FAA Reauthorization

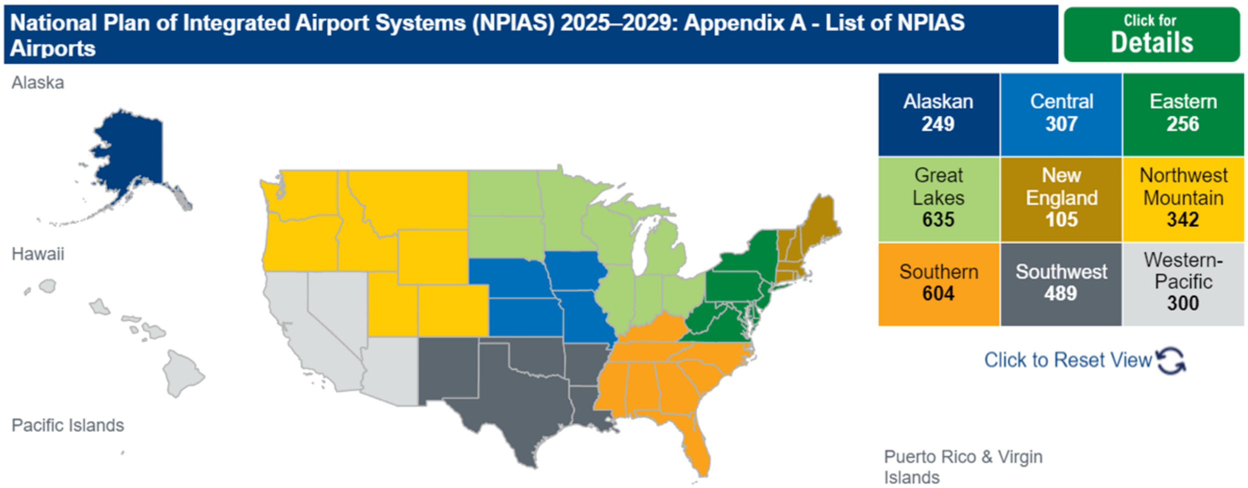
On May 16, 2024, the FAA Reauthorization Act of 2024 (H.R. 3935) was signed into law. The law reauthorizes the FAA and aviation infrastructure and safety programs for five years [18]. Provisions affecting electrified aviation or rather, AAM are enumerated in Table 1. According to the FAA Reauthorization Act of 2024, AAM is defined as *"A transportation system that transports people and property by air between two points in the NAS using aircraft with advanced technologies, including electric aircraft or electric vertical takeoff and landing aircraft, in both controlled and uncontrolled airspace."*

FAA Reauthorization Act of 2024 - Provisions Affecting AAM	
Title II – FAA Oversight and Organization	
Sec. 201 – Future of NextGen	Specifies that any functions related to AAM will be transferred to the Office of Advanced Aviation Technology and Innovation (as established by Sec. 801).
Sec. 202 – Airspace Innovation Office	Establishes Airspace Innovation Office within FAA to develop a plan for the continuous modernization of the National Airspace System.
Title VI – Modernizing Airport Systems	
Sec. 639 – Study on Autonomous and Electric-Power Track Systems	Requires a study to develop a standard for autonomous and electric-powered track systems that are located underneath the pavement at an airport and allow a transport category aircraft to taxi without the use of the main engines of the aircraft.
Title VIII, Subtitle B (Advanced Air Mobility)	
Sec. 824 – Advanced Air Mobility Working Group Amendments	Amends the AAM Coordination and Leadership Act to mandate that the Act's National Strategy include recommendations for expertise and data sharing on critical items, such as long-term electrification requirements and city needs for deploying AAM.
Title IX, Research and Development and Innovative Aviation Technologies	
Sec. 910 – Electric Propulsion Aircraft Operations Study	Directs GAO to study the safe and scalable operation and integration of electric aircraft into the national airspace system.

Table 1 FAA Reauthorization Act 2024 - Provisions Affecting AAM.

Alignment between National Priorities, AIP, and FAA Reauthorization enables the advancement of the electrification of aviation. However, given current fiscal limitations of AIP and those limitations previously highlighted for small, rural, and economically disadvantaged airports, it seems likely that without additional financial levers, many identified airports will be unable to fully participate in the electrified marketplace. AIP is the primary mechanism the FAA uses to administer grants-in-aid to airports within the National Plan of Integrated Airports System (NPIAS). The AIP provides grants to public agencies and, in some cases, private entities for the planning and development of public-use airports included in the NPIAS.

Eligibility for AIP funding is limited to airports that are part of the NPIAS including publicly owned airports, privately owned but designated by the FAA as reliever airports, and privately owned airports with scheduled commercial service and at least 2,500 annual enplanements [19]. The FAA uses the NPIAS and the Airports Capital Improvement Plan (ACIP) to prioritize and distribute AIP funds based on current national priorities and objectives. According to the Department of Transportation (DOT), the program provides more than $3.35 billion annually to over 3,300 eligible airports within the NPIAS. Figure 1 provides a more detailed overview of U.S. aviation facilities, emphasizing NPIAS categories of airports. Vertiport and its various forms (e.g., vertistop, vertihub) is a type of airport specifically designed for vertical takeoff and landing (VTOL) aircraft. These have yet to be accounted for within the U.S.



	Airport Role					Hub Size				
Region	National	Regional	Local	Basic	Unclassif..	Large Hub	Medium ..	Small Hub	Nonhub	Grand Total
Alaskan		1	56	155	14		1	1	21	249
Central	7	34	137	96	11		3	4	15	307
Eastern	13	68	81	28	24	7	2	8	25	256
Great Lakes	22	104	302	124	21	4	4	6	48	635
New England	3	24	37	15	8	1	1	5	11	105
Northwest Mountain	8	43	141	85	10	3	2	7	43	342
Southern	26	159	215	98	30	7	8	23	38	604
Southwest	23	94	172	106	49	3	5	9	28	489
Western-Pacific	20	59	80	71	23	6	7	11	23	300
Grand Total	122	586	1,221	778	190	31	33	74	252	3,287

Source: FAA National Plan of Integrated Airports System 2025 – 2029 [45]

Fig. 1 2024 NPIAS Airport Categorization.

V. AIRPORT AND AIRWAY TRUST FUND

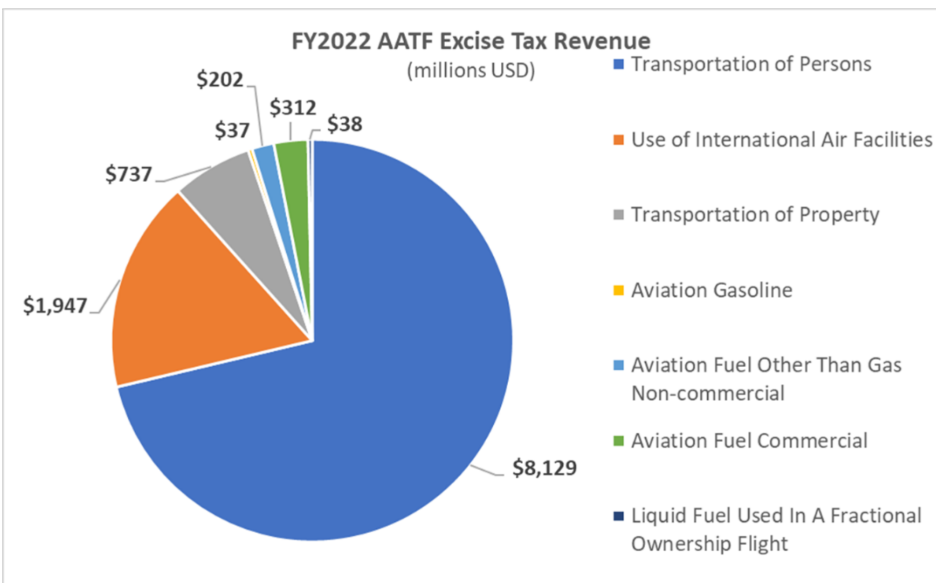
The Airport and Airway Trust Fund (AATF) was established in 1970 [20] as a dedicated source of funding for the U.S. aviation system, separate from the General Fund. According to the Government Accounting Office, the U.S. General Fund accounts for all financial resources of the federal government that are not required to be accounted for in other specific funds. It serves as the primary operating fund for the government, handling most of its day-to-day financial transactions. The AATF finances FAA investments in the airport and airway system, including construction and safety improvements at airports, technological upgrades to air traffic control, FAA operations (e.g., providing air traffic control services, overseeing commercial space launches), and conducting safety inspections. Further, the AATF ensures that revenues from aviation-related excise taxes on passengers, cargo, and fuel will be used specifically for aviation programs rather than general government spending. Through the collection of various aviation-specific taxes and fees, the AATF creates a stable and predictable funding mechanism for long-term aviation infrastructure projects and improvements and aligns the costs of maintaining and improving the aviation system with the users who benefit from it [21]. Table 2 delineates the tax and fee structure of the AATF as of 2024.

2024 AATF Tax or Fee	Rate
Passenger ticket tax (on domestic ticket purchases and frequent flyer awards)	7.50%
Flight segment tax (domestic, indexed annually to Consumer Price Index)	$5.00
Cargo waybill tax (based on the cost of domestic cargo or mail transportation)	6.25%
Frequent flyer tax (value of FF miles purchased by entities e.g., airlines, business rewards programs)	7.50%
General aviation gasoline	19.3 cents/gallon
General aviation jet fuel (kerosene)	21.8 cents/gallon
Commercial jet fuel (kerosene)	4.3 cents/gallon
International departures/arrivals tax (indexed annually to Consumer Price Index)	$22.20
Prorated Alaska/Hawaii to/from mainland United States	$11.10
Fractional ownership surtax on general aviation jet fuel	14.1 cents/gallon

Source: FAA Reauthorization Act 2024

Table 2 AATF Tax and Fee Rates.

As of 2022, the AATF collected approximately $11.4 billion in tax and fee revenue. Figure 2 provides a delineation of the source and amount of revenues collected [21]. For purposes of this study,

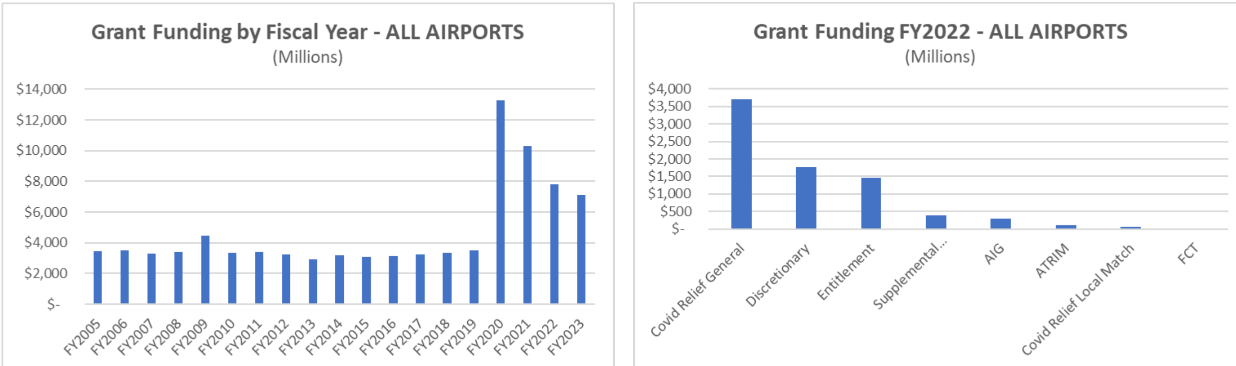


Source: FAA 2023 AATF Fact Sheet [21]

Fig. 2 AATF FY2022 Excise Tax Revenues.

focus is given to three of the seven listed revenue categories: aviation gasoline, aviation fuel other than gas non-commercial, e.g., Jet Fuel, and liquid fuel used in a fractional ownership flight. These three categories cumulatively represent approximately $277 million of the $11,402 million total tax revenues, representing approximately 2.43% of cumulative AATF revenue for fiscal year 2022. For ease of illustration, these revenues are assumed to be primarily generated at non-hub and general aviation airports. Further analysis is required encompassing all airport category types for contributions across the three identified revenue categories.

AATF grants-in-aid across all airports for fiscal years 2005 through 2023 are depicted in Figure 3. Emphasis is given to fiscal year 2022 and as illustrated, of the total $7.8 billion awarded across all categories of airports, approximately $3.7 billion originated from outside the AATF, presumably the General Fund, making the total grants-in-aid awarded originating from the AATF approximately $4.1 billion.

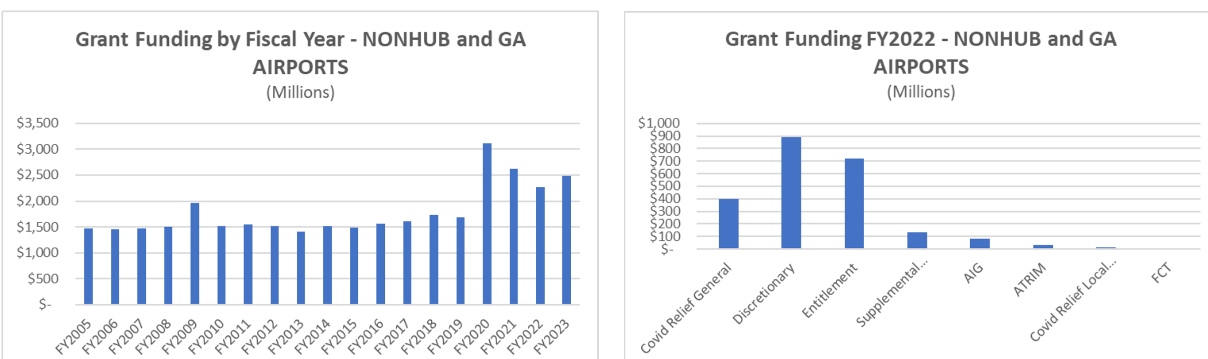


Source: FAA AIP Tableau Dashboard [46]

Fig. 3 AATF FY2005 – 2023 Grants-in-Aid for All Airports.

AATF reported revenues collected for fiscal year 2022 (approximately $11.4B) are not aligned with reported disbursements to airports for the same year (approximately $7.8B). The difference is assumed to flow to FAA operations and facilities (approximately $3.6B). For this analysis, the reported disbursement to airports amount will be used hence forth.

Figure 4 depicts grants-in-aid awarded for non-hub and general aviation airports for fiscal years 2005 through 2023. Approximately $2.3 billion were distributed in fiscal year 2022 of which, approximately $397 million was from the General Fund labeled Covid Relief General. The AATF distributed $1.87 billion from its actual revenues, which represented approximately 45% of the total AATF distributions for the fiscal year, excluding any COVID-19 relief funds.



Source: FAA AIP Tableau Dashboard [46]

Fig. 4 AATF FY2005 – 2023 Grants-in-Aid for Non-Hub and General Aviation Airports.

A historical review of non-hub and general aviation airports total grants-in-aid as a percentage of the AATF for fiscal years 2019 and 2018 (pre-Covid) was conducted to assesses the consistency of the cumulative average annual distribution from the AATF to non-hub and general aviation airports. Fiscal year 2019, at approximately 49%, showed a slight decline from fiscal year 2018, at approximately 50%, both years besting 2022 by approximately 4% and 5% respectively. Figure 5 illustrates the identified

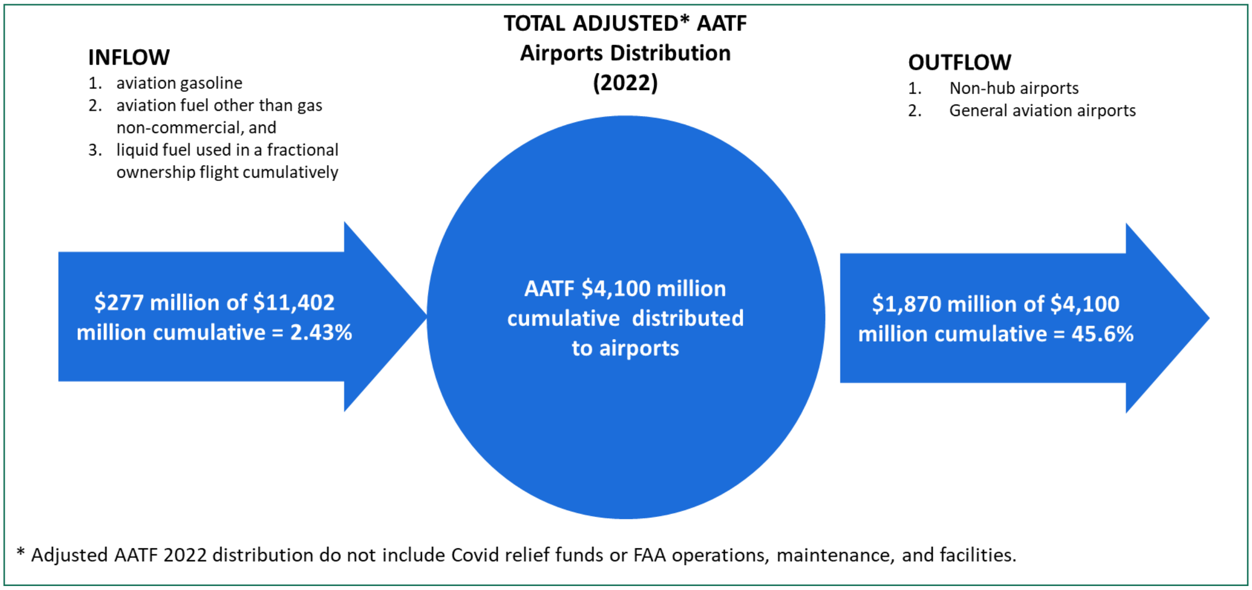


Fig. 5 AATF FY2022 Inflow/Outflow.

excise tax revenue inflow as a percentage of the total AATF tax and fee inflow. At approximately 2.4% of cumulative inflow to the AATF, the awarded grants-in-aid to identified NPIAS airport categories seem disproportionately large. The intent of this review is to show non-hub and general aviation airport dependency on the AATF relative to these category airports contribution to the fund. It is important to note that non-hubs and general aviation airports account for 6% of NPIAS airports i.e., nonprimary national, regional, local, basic, and unclassified airports account for 89% of total NPIAS airports [22]. The remaining 5% are large-, medium-, and small-hub category airports numbering 30, 35, and 80 respectively, where the majority of excise tax revenue is generated via transportation of persons, use of international air facilities, and transportation of property. As depicted in Figure 2, $10,813 million was generated by these categories accounting for approximately 95% of revenue to the AATF. The remaining 5% AATF revenue generated by fuel sales, while relevant to the AATF and subsequently in the underwriting of the NAS, holds importance beyond the AATF.

The sale of AvGas and Jet A fuel at general aviation and non-hub airports has far-reaching economic implications that extend well beyond tax revenue, impacting various levels of the economy and supporting critical infrastructure and industries. According to the FAA, for Calander Year 2011, the aviation fuel industry supported numerous jobs across the supply chain, from refineries to airports supporting 1.2 million jobs and $247 billion in U.S. economic impact per year [23]. Airports that sell aviation fuel attract aircraft, leading to increased economic activity in surrounding communities. Fuel sales are a crucial revenue source for many airports, especially smaller general aviation facilities. This income helps maintain and improve airport infrastructure. According to a 2011 FAA study on the economic impact of civil aviation on the U.S. economy, a robust network of fuel-selling airports supports the entire U.S. air transportation system, enhancing mobility and connectivity across the country [24].

For fiscal year 2022, excise tax revenue for aviation gasoline, aviation fuel other than gas non-commercial, and liquid fuel used in a fractional ownership flight amounted to approximately $277 million in tax revenue to the AATF (see Figure 2). Table 3 illustrates the amount of each fuel expressed in gallons relative to the imposed tax and calculated value and based in part on a 2019 GAO report on average price of aviation fuels at selected NPIAS airports with and without air traffic control towers [25].

AATF Category	2022 AATF Tax Revenue		Total Gal.	Fuel Type	Avg. $/gal.	Total Point Of Sale Value
	Tax/gal.	Total Tax				
Aviation Gasoline	$ 0.193	$ 37,000,000	191,709,845	100 LL	$ 5.56	$ 1,065,906,736
Aviation Fuel Other than Gas Non-commercial	$ 0.218	$ 202,000,000	926,605,505	Jet A	$ 5.26	$ 4,873,944,954
Liquid Fuel Used In a Fractional Ownership Flight	$ 0.141	$ 38,000,000	269,503,546	Jet A	$ 5.26	$ 1,417,588,652
	TOTAL	**$ 277,000,000**	**1,387,818,895**			**$ 7,357,440,342**

Table 3 2022 Excise Tax Expressed in Gallons.

As Table 3 shows, in Calander Year 2022, aviation fuel sales totaling approximately $7.4 billion contributed $277 million to the AATF. This funding supports the NPIAS and the NAS. Airports generate significant economic benefits for their local areas. However, the precise impact varies considerably based on factors such as location, airport size, and activity levels. It is important to note that there are no universally accepted economic multipliers for quantifying the direct, indirect, and induced impacts of airport operations on local economies [27].

The economic impact of reduced aviation fuel sales extends far beyond the immediate loss of revenue to the airport and the AATF. It affects airport operations, local employment, regional economic activity, and long-term airport development plans. The interconnected nature of aviation economics means that a decrease in fuel sales can have ripple effects throughout the airport ecosystem and the broader local economy. The long-term effects of aviation electrification on hydrocarbon fuel demand remain uncertain, but as electric aircraft adoption increases, traditional aviation fuel demand is expected to decline. This shift could potentially impact:

- Airport Operations: Diminished fuel sales may result in reduced revenue for airports.
- Local Municipalities: A decrease in airport-related economic activity could lead to lower local tax revenues and reduced employment opportunities.
- Regional Economies: Reduced airport activity might affect broader economic development and regional connectivity.

A. Revenue Replacement Potential

The transition from hydrocarbon fuels to electricity in aviation will impact revenue streams. However, airports and surrounding communities have opportunities to adapt and potentially replace fuel sale revenue with electricity-related income. This transition presents both challenges and opportunities. Airports can generate revenue from providing electricity for charging electric aircraft, similar to how they currently profit from fuel sales. This revenue generation can take several forms including the following examples:

- Hourly Rates for Electricity Usage - Airports can charge electric aircraft operators an hourly rate for electricity usage, measured by software integrated into the charging system. This is analogous to how airports currently charge for fuel based on volume. For example, just as an airport might charge $5 per gallon of jet fuel, they could charge $20 per hour of charging time for electric aircraft.
- Flowage Fees for Electricity Provision - Similar to fuel flowage fees currently imposed on fuel sales, airports can implement flowage fees for electricity provision. For instance, if a fuel flowage fee is $0.154 per gallon of Jet-A fuel, an equivalent electricity flowage fee could be $0.05 per kilowatt-hour of electricity provided to electric aircraft.
- Fixed Fees for Tenants Operating Electric Aircraft - Airports may establish fixed fees for tenants that operate and service electric aircraft, helping to offset the costs of providing charging infrastructure. This is comparable to how some airports currently charge landing fees or have lease agreements with airlines and fixed-base operators (FBOs) that include fuel-related charges. For example, an airport might charge a monthly fixed fee of $500 for tenants operating electric aircraft, in addition to their regular lease payments.

Airports may charge for the use and maintenance of charging infrastructure, offsetting installation and upkeep costs. Further, the longer charging times for electric aircraft may create opportunities for increased revenue from restaurants, shops, and parking near charging stations. By implementing these revenue generation methods, airports can adapt their business models to accommodate the growing electric aircraft market while maintaining a steady income stream, similar to their current fuel-based revenue systems.

B. Challenges and Considerations

Some states may have regulations limiting the resale of electricity, requiring airports to work closely with utility providers and regulators. Also, significant upfront costs will be needed to install charging infrastructure and upgrade power systems. Efforts by NASA and NREL are underway to determine current and forecast peak power demand [1]. However, the transition period may see a temporary decrease in revenue as fuel sales decline before electric charging can fully compensate. The shift to electric infrastructure could create new jobs in installation, maintenance, and related services. However, many of these jobs may be considered temporary and fulfilled by regional power utilities. While increased passenger dwell time during charging could lead to more spending in airport facilities and nearby businesses, initial capital expenditures may be excessive for many small, rural, and economically disadvantaged airports.

Although replacing fuel sale revenue with electricity sales revenue presents challenges, it is possible with proper planning, investment, and adaptation. The transition offers opportunities for new revenue streams and economic growth but requires proactive collaboration across various stakeholders in the airport ecosystem.

VI. Advanced Air Mobility and Electrification

In September 2017, NASA initiated a market study for a new aviation segment, now known as Advanced Air Mobility (AAM). This category encompasses piloted electric vertical takeoff and landing (eVTOL) vehicles, aircraft with evolving remote-piloted or automated control capabilities, RAM aircraft, and Small Unmanned Aircraft Systems (sUAS). NASA defines AAM as *"A safe and efficient system for air passenger and cargo transportation, including small package delivery and other urban drone services, utilizing a combination of onboard/ground-piloted and increasingly autonomous operations"* [28]. Two subsets of AAM are Urban Air Mobility (UAM) and Regional Air Mobility (RAM). UAM focuses specifically on transportation systems operating at lower altitudes and services within urban and suburban areas for both passenger and cargo transport. UAM aircraft are expected to incorporate electric propulsion systems and vertical takeoff and landing capabilities with the aim of enhancing operational efficiency in urban environments. The vision for UAM involves a gradual transition from piloted aircraft to increasingly automated systems, improving transportation options in densely populated areas. RAM expands the concept of UAM to cover larger geographical areas, including connections between cities, towns, and rural locations [29]. RAM focuses on transportation systems operating at medium altitudes, typically serving routes between 50 to 500 miles for both passenger and cargo transport [2]. RAM aircraft are expected to utilize a mix of electric and hybrid-electric propulsion systems, with some incorporating vertical or short takeoff and landing capabilities to serve a wider range of destinations [30]. These aircraft aim to enhance regional connectivity and reduce travel times between urban centers and outlying areas. The vision for RAM involves developing a network of smaller airports and vertiports to create a more distributed air transportation system, gradually transitioning from traditional regional aircraft to more efficient and environmentally friendly options [31]. This evolution is expected to improve transportation options for underserved communities and provide faster alternatives to ground transportation for intercity travel.

A. FAA AAM Forecast

In its most recent forecast, the FAA states, *"It is likely that AAM services will become a reality in the US by 2025-2027 and will become incrementally available in urban and suburban areas followed by an* *accelerated growth trajectories targeted to reach farther and distant travel destinations and routes over time"* [27]. The 2024–2044 timeframe provides an estimate of a base-case scenario (likely; or potential risk adjusted) and lower-range scenario for departure forecasts for the hypothetical years of one through six after these aircraft enter service. Utilizing the FAA AAM forecast, Table 4 attempts to address the amount of electricity expressed in kilowatt hours (kWh) required of AAM over the FAA's six-year planning horizon. FAA forecast both departures and passengers thereby providing the foundation of the analysis. Determination of average trip distance was inferred largely from UAM aircraft mission targets.

B. Urban Air Mobility – Trip Distance

UAM is expected to focus on medium to long-distance commutes within urban and suburban areas suggesting that AAM, which includes regional travel, would likely cover longer distances on average [32]. For UAM, typical flight distances are expected to be between a few miles to a few dozen miles [33]. As AAM encompasses a broader range of operations, including regional travel, it is reasonable to assume that AAM trips could extend beyond this range. UAM is more beneficial for longer ground travel times, with average travel time reductions of 30-40% in the US and 40-50% in China for major metropolitan areas [32]. Further, current data on general travel patterns in the U.S. shows the average one-way commute time in the US is 27.6 minutes [34], 59.4% of vehicle trips are less than six miles [35], and only 2% of all trips are greater than 50 miles [36]. Given these points, an estimate of AAM trips might typically range from around 20-50 miles for urban and suburban connections, with regional AAM potentially extending to 100-500 miles.

C. Electric Passenger Mile

Depending on the specific aircraft design, flight profile (vertical vs. horizontal flight phases), and passenger load, an eVTOL aircraft is estimated to consume between 0.26-1.30 kWh per nautical mile [37, 38]. The higher end of this range typically includes the energy-intensive vertical takeoff and landing phases, while the lower end represents more efficient cruise flight. Alternatively, a small electric non-eVTOL aircraft, the Eviation Alice, a 9-passenger aircraft, has a battery with a capacity of 500 kWh. It can fly about 250 nautical miles on a full charge translating to approximately 2 kWh/nm. Note that the technical specifications for the Eviation Alice are subject to change as the concept aircraft progresses through development. This translates to approximately 1.88 kWh per mile or approximately 0.21 kWh per electric passenger mile (EPM) [39]. Given the uncertainty surrounding the mix of AAM flight (e.g., UAM, RAM) referenced in the FAA forecast, the lower end (0.3 kWh per nautical mile) of the range was selected for this study. For context, 0.3 kWh would provide roughly 1 – 1.6 miles (approximately 0.869 – 1.4 nm) of driving range for an electric ground vehicle, depending on the vehicle's efficiency. This estimate is based on the average energy consumption of electric ground vehicles, which is around 0.20 kWh/mi according to the EV Database cheat-sheet [40]. Further study of the various AAM aircraft types is required to determine the actual energy requirement per EPM and electric cargo mile (ECM) by aircraft type. Table 4 expands on the FAA 2024 – 2044 Aerospace Forecast for AAM vehicles. Multiplying mission-based average trip miles by annual AAM passenger forecast (low, high) by an estimated energy cost (e.g., 0.3 kWh) yields total annual AAM energy requirements (*Avg. Trip Miles x Ann. Pax. (Low) x kWh*).

AAM Forecast	YEAR 1			YEAR 2			YEAR 3		
	ANN. PAX	AVG. TRIP MILES	TOTAL ANN. ENERGY REQUIREMENT (KWh)	ANN. PAX	AVG. TRIP MILES	TOTAL ANN. ENERGY REQUIREMENT (KWh)	ANN. PAX	AVG. TRIP MILES	TOTAL ANN. ENERGY REQUIREMENT (KWh)
ANNUAL pax - low	413,742	20	2,482,452	692,491	20	4,154,946	1,159,042	35	12,169,941
ANNUAL pax - base	886,590	75	19,948,275	1,483,910	75	33,387,975	2,483,661	100	74,509,830
ANNUAL departures - low	206,871			346,246			579,521		
ANNUAL departures - base	295,530			494,637			827,887		
	YEAR 4			YEAR 5			YEAR 6		
	ANN. PAX	AVG. TRIP MILES	TOTAL ANN. ENERGY REQUIREMENT (KWh)	ANN. PAX	AVG. TRIP MILES	TOTAL ANN. ENERGY REQUIREMENT (KWh)	ANN. PAX	AVG. TRIP MILES	TOTAL ANN. ENERGY REQUIREMENT (KWh)
ANNUAL pax - low	1,939,920	35	20,369,160	3,246,898	50	48,703,470	5,434,422	50	81,516,330
ANNUAL pax - base	4,156,972	100	124,709,160	6,957,638	110	229,602,054	11,645,190	110	384,291,270
ANNUAL departures - low	969,960			1,623,449			2,717,211		
ANNUAL departures - base	1,385,657			2,319,213			3,881,730		

Table 4 AAM Forecast Energy Requirement.

The fuel consumption of a 4-passenger hydrocarbon-fueled aircraft varies based on the specific model and its efficiency. Some 4-seat aircraft consume approximately 10.4 to 15 gallons of fuel per hour. Assuming an average speed of 120 mph, this translates to 1.73 to 2.5 gal. AvGas for a 20-mile flight. At the lower range, 1.73 gallons of AvGas equals approximately 63.32 kWh (1-gallon of AvGas equals 36.6 kWh). This example illustrates that the notional electric vehicle uses approximately 38% of the energy of an equivalent hydrocarbon-fueled aircraft. The electric aircraft is approximately 62% more efficient or approximately 2.64 times more efficient in this example.

Electric aircraft can be 2.1 to 3.2 times more energy efficient during cruise compared to their fossil-fueled counterparts. This is because electric motors convert electricity into propulsive force more efficiently than combusting fossil fuels in an aircraft engine. The efficiency difference is even more pronounced in commuter aircraft typically powered by piston engines rather than turbines. When compared to aircraft running on e-fuels (sustainable alternatives to fossil fuels), electric aircraft could be 4.5 to 6.9 times more energy efficient [41].

The greenhouse gas (GHG) emissions associated with electric aircraft operation come from electricity generation and battery replacement. Even in conservative scenarios, electric aircraft could provide a 49% to 57% reduction in carbon intensity per revenue passenger kilometer (RPK) compared to fossil-fueled aircraft. This assumes batteries achieve an energy density of 300 Wh/kg in 2030 and 500 Wh/kg in 2050. In the best-case scenario, where batteries are charged using renewable energy, the reduction in carbon intensity is estimated to be 82% to 88% [41].

A life cycle assessment of a two-seater electric aircraft showed that it can have up to 60% less climate impact than an equivalent fossil-fueled aircraft. However, there is a trade-off regarding mineral resource scarcity, which is about 50% higher even in the most favorable scenario, mainly due to rare metals in the batteries. The environmental benefits of electric aircraft increase over time. After approximately 1,000 flight hours, the electric aircraft surpasses the fossil fuel aircraft in terms of reduced climate impact, assuming green energy is used for charging [42].

While hydrocarbon jet fuel is more efficient at storing energy than batteries, electrical motors can be more efficient at converting potential energy to propulsive energy. A jet engine can expect an overall efficiency of roughly 33%, whereas a battery-powered motor can achieve 73% efficiency, meaning that electrically powered aircraft may be 2.2 times more efficient [43].

These findings support the initial calculation of electric aircraft being about 2.64 times as efficient as hydrocarbon aircraft. The efficiency gains of electric aircraft are significant and represent a promising avenue for reducing energy consumption and environmental impact in aviation, particularly for short-range flights.

D. Hydrocarbon Fuel Equivalent

For context, it is important to translate the forecast AAM total annual energy requirement into legacy fuel equivalent to begin to assess the implications electrified aviation will have to the AATF, airports, and adjacent communities. Building from Table 4, Table 5 provides the equivalent annual hydrocarbon-based fuel necessary to power AAM as forecast by the FAA e.g., LOW Forecast, BASE Forecast. The efficiency factor of 2.64 is applied to both LOW and BASE forecasts to illustrate the amount of AvGas an equivalent hydrocarbon-fueled aircraft would require for the same flight.

AvGas Equivelent U.S. Gallons

	YEAR 1	**YEAR 2**	**YEAR 3**
	AVGAS Equivalent (gal.)	**AVGAS Equivalent (gal.)**	**AVGAS Equivalent (gal.)**
LOW Forecast	67,827	113,523	332,512
BASE Forecast	545,035	912,240	2,035,788
Efficiency Factor LOW	179,062	299,701	877,832
Efficiency Factor BASE	1,438,892	2,408,313	5,374,480

	YEAR 4	**YEAR 5**	**YEAR 6**
	AVGAS Equivalent (gal.)	**AVGAS Equivalent (gal.)**	**AVGAS Equivalent (gal.)**
LOW Forecast	556,534	1,330,696	2,227,222
BASE Forecast	3,407,354	6,273,280	10,499,761
Efficiency Factor LOW	1,469,251	3,513,037	5,879,866
Efficiency Factor BASE	8,995,415	16,561,460	27,719,370

36.6 kWh to 1 gallon AvGas	**36.60**
Efficiency Factor	**2.64**

Table 5 AAM AvGas Equivalent (U.S. Gallons).

E. Fuel Sales

As discussed, fuel sales remain a crucial component of small airport operations and their overall economic impact on local communities. General aviation pilots are known for being price-conscious and often shop around for the best fuel prices at different airports within a region. This means that smaller airports must be competitive with their fuel pricing to attract and retain customers. Airports compete fiercely for fuel sales and customers, which can drive down already thin profit margins [44]. Loss of fuel service may result in decreased traffic and lost revenue from fuel sales and other services. This diminishes the economic viability of the airport and may negatively impact surrounding municipalities in both economic impact (e.g., difficulty attracting business) and provision of services (e.g., flight training, emergency services). For most small airports, fuel sales are a critical component of their business model and overall viability. Building from Table 5 and applying an average cost of USD $5.26 gallon, Table 6 illustrates the value of FAA forecast AAM equivalent hydrocarbon fuel sales. The anticipated loss of fuel sales over time stemming from national aviation priorities shifting to the electrification of aviation, requires airports to somehow replace this revenue stream with something as equally lucrative as well as equally beneficial to the market in which hydrocarbon fuel sales support. Participation in the national economy requires airports to provide the fuel of the new economy i.e., electricity. The means by which economic benefit and margin is assessed is worthy of additional study.

Equivalent Fuel Sale at Airport U.S. Dollars

	YEAR 1	YEAR 2	YEAR 3
	USD	USD	USD
LOW Forecast	$ 356,768	$ 597,132	$ 1,749,013
BASE Forecast	$ 2,866,883	$ 4,798,381	$ 10,708,243
Efficiency Factor LOW	$ 941,867	$ 1,576,427	$ 4,617,395
Efficiency Factor BASE	$ 7,568,572	$ 12,667,726	$ 28,269,762

	YEAR 4	YEAR 5	YEAR 6
	USD	USD	USD
LOW Forecast	$ 2,927,371	$ 6,999,460	$ 11,715,188
BASE Forecast	$ 17,922,683	$ 32,997,454	$ 55,228,745
Efficiency Factor LOW	$ 7,728,260	$ 18,478,576	$ 30,928,097
Efficiency Factor BASE	$ 47,315,882	$ 87,113,278	$ 145,803,888

Avg. $$/gal. across all categories **5.26 USD**

Table 6 AAM Equivalent Fuel Sales (USD).

F. AATF Excise Tax

At scale, the loss of excise tax from hydrocarbon-based fuels emanating from general aviation to the AATF would have meaningful negative implications for the FAA, the NAS, the NPIAS as well as municipalities, states, and the nation. Fuel excise taxes arising from general aviation (see Figure 2) account for approximately 5 percent of receipts to the AATF not including those derived from the aviation fuel commercial category. Replacement of the use of hydrocarbon-based fuels for electricity comes at a financial cost. Consideration of new excise tax categories aligned with electrified aviation are necessary for the nation to continue to pace the changing aviation environment. Table 7 provides insight on multiple fronts. First, the kWh to fuel gallon equivalent schema may not be the best framework from which to build new taxation verticals to the AATF. As illustrated, at $0.193 per gallon excise tax (general aviation gasoline) on AAM gasoline equivalent fuel sales revenue to the AATF would not be representative of the envisioned requirement, that is to replace general aviation fuel (AvGas and Jet A) excise tax with an equal and equitable mechanism that allows for the revitalization and growth of the new burgeoning system. As illustrated in Table 7, application of the 2.64 Efficiency Factor against EPM would be instrumental in achieving excise-tax parity with hydrocarbon-based fuel sales; however, given the new infrastructure requirements in support of an electrified NAS, this may fall short toward the revitalization and equipage of the NAS for electrified aviation.

Equivalent Excise Tax to AATF

	YEAR 1	YEAR 2	YEAR 3
	USD	USD	USD
LOW Forecast	$ 13,091	$ 21,910	$ 64,175
BASE Forecast	$ 105,192	$ 176,062	$ 392,907
Efficiency Factor LOW	$ 34,559	$ 57,842	$ 169,422
Efficiency Factor BASE	$ 277,706	$ 464,804	$ 1,037,275

	YEAR 4	YEAR 5	YEAR 6
	USD	USD	USD
LOW Forecast	$ 107,411	$ 256,824	$ 429,854
BASE Forecast	$ 657,619	$ 1,210,743	$ 2,026,454
Efficiency Factor LOW	$ 283,565	$ 678,016	$ 1,134,814
Efficiency Factor BASE	$ 1,736,115	$ 3,196,362	$ 5,349,838

General Aviation Gasoline **0.193 $/gal**

Table 7 AAM Equivalent Excise Tax to AATF.

VII. Summary

The electrification of aviation presents significant challenges to the AATF and the broader aviation ecosystem, particularly for small and rural airports. To ensure the successful transition to electrified aviation and scalability of AAM, stakeholders must determine how an electrified aviation system will participate in the AATF as well as understand and mitigate lost revenue throughout the systems evolution to electrification to include other forms of fuel yet to be introduced into the system (e.g., liquid hydrogen). For national aviation priorities to be achieved, policymakers must give special consideration to small, rural, underrepresented, and economically disadvantaged airports. Addressing the unique challenges associated with these airports all the while ushering in the new electrification paradigm will be crucial for maintaining and evolving a robust and inclusive air transportation system that can fully contribute to the growth and prosperity of the nation.

As aircraft transition to electric power, the AATF will lose a crucial source of income from fuel taxes. This shift will have far-reaching consequences, especially for smaller airports. Small, rural, underrepresented, and economically disadvantaged airports are likely to face severe impacts, including diminished AATF funding over time, stagnation and eventual loss of fuel flowage fees leading to the loss of operational viability and negative effects on local economies. Due to financial constraints, these airports will struggle to participate in electrified aviation initiatives like RAM and prioritize essential safety-related infrastructure improvements over electrification projects. Fiscal limitations may prevent smaller facilities from fully integrating into an electrified aviation system, potentially restricting their communities' access to the national economy. For RAM to scale effectively, it needs a network of similarly equipped airports to ensure operational alignment, particularly in terms of "fuel" availability. The accessibility and expansion of RAM depend on a comprehensive network of airports capable of supporting electric aircraft. The inability of small and rural airports to participate in this network could hinder the overall growth and effectiveness of RAM networks.

The FAA believes that AAM will likely enter into service in the 2025-2027 timeframe. It must be noted that AAM as used by FAA for this forecast primarily focuses on UAM or eVTOL aircraft and does not consider RAM aircraft. Starting from limited services to initial launch cities, services will be experimental, slow, and likely not gain a gradual trajectory of growth until 2030. This analysis attempts to identify the connection points of the framework required to ultimately determine an AAM taxation and fee structure that allows for AAM to participate in the system. Potential future directions include additional study and economic analysis. This study touches upon many of the topical areas requiring additional analysis to include energy demand per person per mile of various representative AAM aircraft of all types and fulfilling varying missions for both passenger and cargo. Also, addressing the business activity and economic impact of the loss of the legacy fueling enterprise at identified airports will be essential to these airports' survival. Development of turnkey airport business franchises centered around the production, storage, and transmission of clean, renewable energy will not only enable identified airports continued participation within the system but will additionally incentivize the transition of these airports to electrified aviation. Last, AAM greatly benefited from the collaboration between government, industry, and academia. The vehicle of which was the NASA led AAM working groups. These working groups proved instrumental in the understanding and advancement of this nascent technology. Leveraging the working group process to address this significant issue will be met with enthusiasm from industry, especially those currently grappling with these issues.

Acknowledgments

This work was funded by the Airports as Energy Nodes Activity (Ænodes) of the Convergent Aeronautics Solutions Project of the Transformational Aeronautics Concepts Program within NASA's Aeronautics Research Mission Directorate. The author which to thank NASA for their financial and technical support of this effort. In addition, the author wishes to thank Nicholas K. Borer and Nathaniel J. Blaesser, NASA Langley Research Center, Scott Cary, Department of Energy National Research Energy Laboratories and David Ulane, Colorado Department of Transportation Aeronautics Division.

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