Colorado Alternatively Powered Aircraft Airport Infrastructure Study

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National Renewable Energy Laboratory

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Strategic Partnership Project Report
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List of Acronyms

ABQ	Albuquerque International Sunport
AIP	Airport Improvement Project
ATB	Annual Technology Baseline
BAU	business-as-usual; refers to electric utility costs and consumption results in which additional on-site solar photovoltaics or electric storage capacity are not considered
BESS	battery energy storage system
BJC	Rocky Mountain Metropolitan Airport
CDOT	Colorado Department of Transportation
CO_2	carbon dioxide
COS	Colorado Springs Airport
DCFC	direct current fast charging
DEN	Denver International Airport
DER	distributed energy resources
DOE	U.S. Department of Energy
DRO	Durango-La Plata County Airport
EVSE	electric vehicle service equipment
eVTOL	electric vertical take-off and landing
FAA	Federal Aviation Administration
GJT	Grand Junction Regional Airport
IRR	internal rate of return
ITC	investment tax credit
kW	kilowatt
kWh	kilowatt-hour
LPEA	La Plata Electric Association
MACRS	Modified Accelerated Cost Recovery System
MW	megawatt
MWh	megawatt-hour
NASEM	National Academies of Sciences, Engineering, and Medicine
NREL	National Renewable Energy Laboratory
PEV	primary electric voltage
PNM	Public Service of New Mexico
PV	photovoltaic
RAM	regional air mobility
SAF	Drop in liquid hydrocarbon jet fuel
SOC	state of charge
SPP	simple payback period
VALE	Voluntary Airport Low Emissions Program
WSDOT	Washington State Department of Transportation

Executive Summary

The aviation sector is experiencing rapid investment and innovation in the modernization and electrification of aircraft, which offers potential new opportunities for local and regional airports. The purpose of this study, conducted by the National Renewable Energy Laboratory (NREL) on behalf of the Colorado Department of Transportation's (CDOT's) Division of Aeronautics, was to assess the likely infrastructure requirements for local and regional airports related to the Colorado aviation market to support electrified fixed-wing aircraft. In the study discussed in this report, researchers identified the current state of advanced aircraft development and the industry, as well as challenges that aircraft manufacturers face in electrifying aircraft. Based on the current state of industry, follow-on analysis reviews the necessary infrastructure required to enable modern modes of aerial mobility.

Potential benefits of electrified aircraft for owners, operators, and surrounding communities include lower life cycle costs, shorter runway takeoff requirements, and less noise and local pollutants. Additionally, the energy assets and infrastructure required for electric aircraft operations could potentially allow airports to serve as energy resilience hubs during outage events. Even without new electricity demand from electric aircraft charging, energy generation and storage assets can help lower energy bills, increase resilience during outages if designed to do so, and potentially create a new revenue stream if net metering or similar export agreements are available with the local utility.

Some of the challenges related to electrifying aircraft operations include limitations on the range of travel distance and passenger/cargo capacity. These limitations arise from the current state of energy storage systems (e.g., batteries), which become too heavy for aircraft operations as energy capacity increases. Advancing energy storage technologies is key to unlocking the full potential of aircraft electrification and fuel diversification in the aviation industry. Other considerations include possible impacts to flight operations due to long charge durations and the associated increase in peak energy demand. As a result, it is essential to partner with the local utility provider to understand the impacts of increased load under existing rate structures, and if there are beneficial alternative rate structures.

Another option for electrifying aircraft is utilizing hydrogen as an energy carrier. Adopting hydrogen aircraft will help modernize aviation while unlocking more service options—from commuter and regional to short-haul and medium-haul flights (Airport Transport Action Group Board of Directors 2021). Hydrogen can be used to power turbine engines, which are expected to operate at similar efficiencies as existing turbines. Hydrogen fuel cells, on the other hand, can generate electricity for electric motors at typically higher efficiencies, with water as their only byproduct. Currently, the trade-off is between increased system weight, from larger batteries and more passenger capacity, and maximum speeds which are limited by the increased system weight. The desired method of storing fuel on aircraft is cryogenic hydrogen. Airbus believes hydrogen to be one of the most promising technologies to decarbonize the aviation industry and is important to achieving their goal of bringing a low-carbon commercial aircraft to market (Airbus 2025). In early 2025, Airbus adjusted their time frame for entry to service from 2035 to 2040 or beyond because the development of the hydrogen ecosystem took longer than anticipated; a test of a complete hydrogen propulsion system, including engines, storage, and distribution systems is planned for 2027 and will provide further clarity on the potential entry to service date for Airbus' ZEROe hydrogen aircraft Furthermore, Boeing states that fuel-cell-powered aircraft could enter the market in 2040 and beyond, assuming an abundance of renewable energy and a widespread hydrogen economy (Boeing 2024). The Federal Aviation Administration (FAA) Reauthorization Act of 2024 helped develop a research strategy for the safe entry of hydrogen into the aviation system, concurrently with early adopters working through FAA certification. Due to the anticipated service entry of 2040 and beyond, hydrogen technologies were not specifically studied in this report. FAA research is ongoing in this area and may further inform the industry on this topic.

The advancement of the industry prompted the Colorado Department of Transportation to request an analysis to determine likely infrastructure requirements needed at airports within the state of Colorado. Using various modeling tools and analytical approaches, the NREL research team simulated electrified regional air mobility (RAM) passenger service loads along with simulated flight school charging loads to answer the following questions related to electrifying RAM air travel and flight school operations in Colorado and some airports serviced in neighboring states:

- How many fully electric flight school trainers, RAM, and hybrid RAM aircraft could potentially use local and regional airports in the near future?
- How many electric vehicle supply equipment chargers would be required at local and regional airports to service the forecasted demand of electric aircraft?
- What challenges exist with charging infrastructure, such as instances in which aircraft are not able to fully recharge due to slow recharging rates?
- What on-site power generation technologies can allow for economically meeting future electric aircraft electricity demands?
- What are the potential benefits to the local and regional airports from on-site power generation and storage?

To forecast potential flights, data was used that was developed by the Georgia Institute of Technology (Georgia Tech) and the National Aeronautics and Space Administration (NASA). The data characterize RAM passenger service demand between numerous local, regional, and large commercial airports across Colorado, New Mexico, Wyoming, and Utah. Flight school demand was forecast by NREL using tail numbers to track flight school aircraft and simulate flight school operations based on real flight data. Knowing the possible number of arrivals and departures of electrified aircraft on a daily basis, and how rapidly the aircraft need to recharge to remain on schedule, NREL's Electric Vehicle Infrastructure-Energy Estimation and Site Optimization[1] (EVI-EnSite) tool was used to estimate the number of electric vehicle supply equipment chargers needed to recharge aircraft without interrupting flight schedules. Electrified aircraft properties were modeled based on the electrified 9-, 19-, and 48-passenger regional aircraft models presented in the Georgia Tech study (Justin, Payan, and Mavris 2022).

Electrified flight training aircraft loads were also included in the analysis, not just those from RAM passenger service aircraft. Electric flight trainers are already being certified around the world. The Pipistrel Velis Electro, for example, can operate in the United States and has received

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[1] https://www.nrel.gov/transportation/evi-ensite.html

certification from the European Union Aviation Safety Agency, the Civil Aviation Authority in the United Kingdom, and four other countries including Mexico, Norway, and Switzerland (Pipistrel 2025). Other companies like Diamond Aircraft claim to be close to certifying their eDA40 two-seat all electric flight trainer (Diamond Aircraft 2025). Known aircraft tail numbers for flight training aircraft were used to develop synthetic electrical demand curves based on real flight paths collected by FlightAware.[2] These electrified aircraft flight training load profiles were added to the RAM passenger service loads to produce a total electrical load for the airports included in the analysis.

To begin evaluating charging scenarios, different rates or "speeds" of charging were considered for electric aircraft. Table ES-1 describes how quickly batteries of any size would be recharged from zero to full charge using electric vehicle charging equipment. For this study, 1C, 2C, and 4C charging rates (C rating) were used for our charging scenarios. Higher charging rates require larger power demands and increase battery degradation, as such, charging rates over 4C were not considered for this effort.

Table ES-1. C Rating and Time to Fully Charge a Battery

C Rating	Service Times
1C	60 minutes
2C	30 minutes
4C	15 minutes
5C	12 minutes
10C	6 minutes

Information from Power Sonic (2021) and adapted by NREL

Note: this study only considers the 1C, 2C, and 4C charging cases

The EVI-EnSite analysis found that at the lowest recharge rate (1C), several aircraft couldn't fully recharge before departure, with fewer instances at the mid-rate (2C). At the highest recharge rate (4C), all aircraft were able to maintain their departure times.

Figure ES-1 provides an example of the charging demand for Grand Junction Regional Airport (GJT) across a single day of modeled RAM electrical charging loads.

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[2] https://www.flightaware.com/

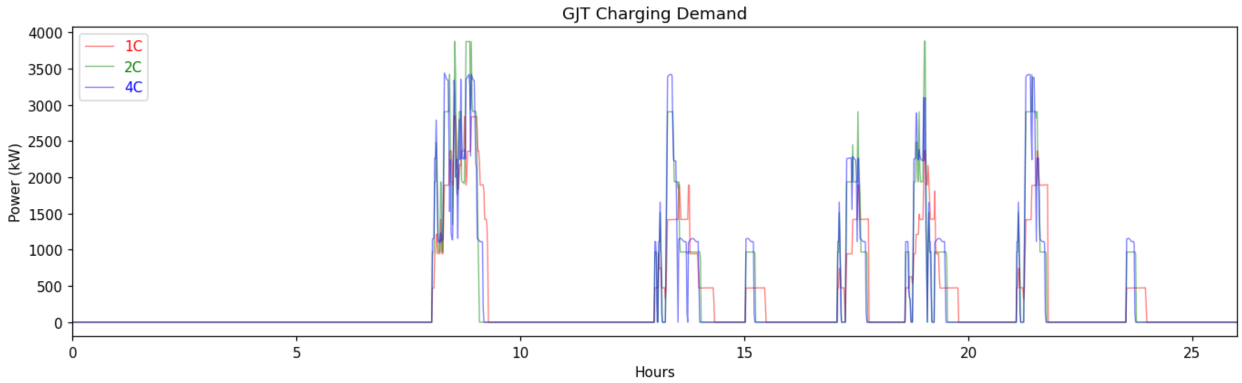

Figure ES-1. 24-hour simulated aircraft charging demand at GJT.

Note: Total kilowatt-hour daily consumption for charging aircraft: 7,449 kilowatt-hours

1C scenario: 2,845-kilowatt (kW) peak demand; 6 chargers; 35-minute maximum charge duration; 10 aircraft out of 53 not fully charged before scheduled departure, minimum battery state of charge: 77%

2C scenario: 3,881-kW peak demand; 5 chargers; 17-minute maximum charge duration; all aircraft fully charged before scheduled departure

4C scenario: 3,441-kW peak demand; 3 chargers; 14.5-minute maximum charge duration; all aircraft fully charged before scheduled departure.

In Figure ES-1, the resulting peaks show that the 1C charging scenario has lower peaks, with longer-duration charging, whereas the 2C and 4C charging scenarios have higher peaks, with shorter-duration charging. There are also instances in which the 4C charging scenario has lower electrical load peaks because the rapid charging reduces the number of aircraft that are charging in parallel, ultimately reducing the peak electrical load on the airport.

Energy demands identified in this analysis would require servicing from existing electrical providers or a self-developed energy generation asset. To efficiently serve the electrical loads for the airport and potentially future aircraft, airports can consider developing on-site power generation systems to supplement utility-provided generation. The Renewable Energy Integration and Optimization Platform[3] (REopt®) is an NREL tool used worldwide to identify potential cost/resilient optimal energy systems and compare on-site power generation options with traditional utility-provided services. Using local energy rates, the tool identifies cost-optimal solutions for servicing known loads. Potential benefits to on-site generation and storage could include additional revenue from electricity generation for airports, improved power quality in the community, improved operational resilience, and sharing infrastructure upgrade costs between near-term revenue generation assets and future forecasted needs.

Table ES-2 summarizes an optimal sizing of solar photovoltaic (PV) and battery energy storage systems (BESS) for Rocky Mountain Metropolitan Airport (BJC) using the electric aircraft loads modeled in EVI-EnSite. Solar and energy storage technologies were chosen based on the current

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[3] https://reopt.nrel.gov/tool

economics of the systems (i.e., cost per kilowatt delivered), and typical compatibility with nearby airport facilities.

Table ES-2. BJC PV BESS System Sizes and Economics

C-Rate	PV [kilowatt, direct current]	BESS [megawatt-hour/megawatt]	Net Present Value [$M]	Annual Payment to Developer [$k]	SPP/ Internal Rate of Return [Years/ %]	Capital Costs After Incentives [$million]	Annual Demand Charge Savings [$k]	Annual Energy Charge Savings [$k]
Direct Ownership								
1C	1,191	0/0	0.13	0	11/7%	1.53	4	72
2C	1,195	0/0	0.19	0	11/8%	1.54	10	64
4C	1,198	0/0	0.17	0	11/8%	1.54	8	62
Third-Party Ownership								
1C	1,191	0/0	0.15	150		1.11	4	72
2C	1,195	0/0	0.22	150		1.12	10	64
4C	1,198	0/0	0.20	151		1.12	8	62

Table ES-2 describes the different charging rates considered (1C, 2C, and 4C), the size of the cost-optimal PV system and BESS system, and related economic estimations. For the BJC example, the analysis suggests that installing PV systems that are roughly 1.1 MW direct current would help economically charge electric aircraft as opposed to using more electricity from their local utility. For BJC, BESS are not suggested based on the utility rate structure expected from the utility. The rate structure does not include high enough demand charges, which could incentivize the need for batteries to offset power demand from utility during peak hours, also known as “peak shaving”. We note that using the on-site generation during utility outages may not be reliable, due to weather and time of day, without some sort of BESS. More information on these analysis results is in Section 3.3.1., along with results from other airports.

The questions of which distributed energy resource (DER) technologies to use and how much on-site generation and storage is optimal can be considered with and without aircraft charging loads. Although the detailed analysis includes aircraft charging loads, energy generation and storage assets can potentially provide a revenue stream and reduced energy costs even without those loads being present. The business-as-usual (BAU) scenario looks only at existing airport loads to use as a baseline comparison.

Increases in electricity consumption were reviewed from electrified RAM and flight school aircraft and their impacts on energy flows in the regions adjacent to the studied airports. NREL’s Engage™ model, a capacity expansion tool used to model energy systems and determine cost-optimal system configuration and operation was used to assess distribution-level impacts of the added electricity demand from forecasted loads. Each airport’s energy generation and consumption, assuming airports integrate distributed energy resources, were aggregated up to the full study focus area: Colorado, the northern parts of New Mexico, southern parts of Wyoming, and eastern parts of Utah. Figure ES-2 presents the projected dispatch and consumption of electricity related to electrified aircraft across the region. A representative 3-day period of electric aircraft charging from December 6, 2030, to December 8, 2030, was chosen for one scenario with a modeled build-out of all local and regional airports included in this study. The build-out includes cost-optimal PV and BESS systems, in addition to upgrading interconnections to local electric utilities where necessary. For the initial estimation, the La Plata Primary Service Rate tariff was used in this scenario for the full study area. For this relatively conservative charging scenario, the region saw a modeled increase in peak demand each day of more than 20 MW. More information and results on this, and other scenarios, can be found in Section 3.2.

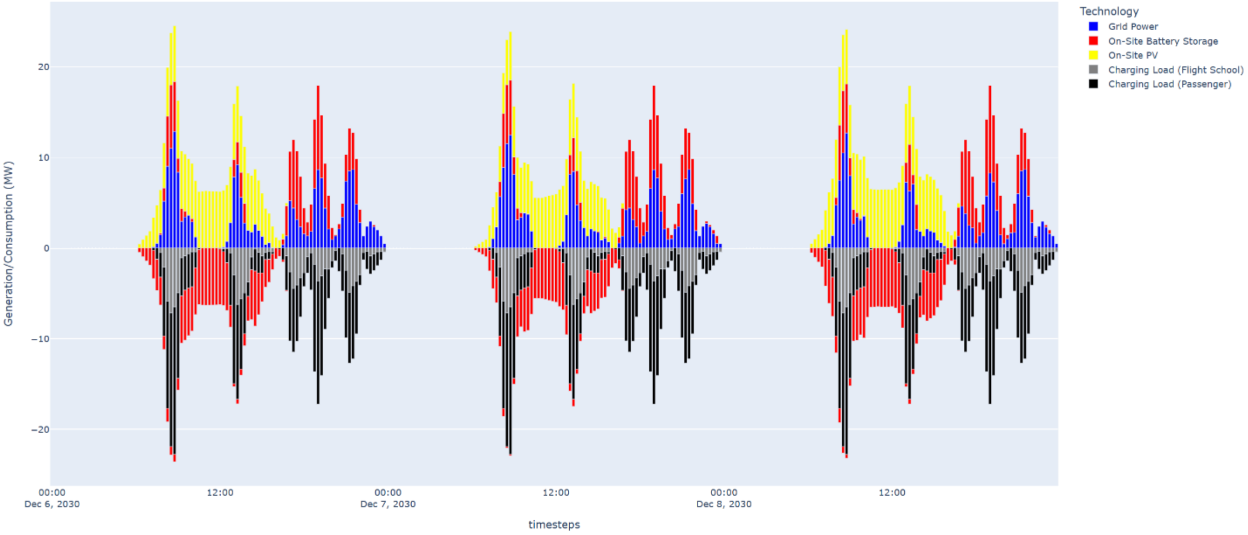

Figure ES-2. All airports 1C charging rate with the La Plata PSR tariff

Assuming existing loads are properly accommodated with existing systems, the analysis focuses on the new forecasted aircraft loads. The blue bars indicate grid power serving load, yellow bars are on-site PV systems serving load, grey bars are flight school aircraft recharging at the airports, black bars are electrified RAM passenger aircraft recharging, and red bars indicate on-site battery energy storage either discharging (when positive) or recharging (when negative). The figure shows that during the three day period in December, a solar PV system will often recharge BESS during periods that aircraft are not charging, but when aircraft begin requiring electricity draws for recharging, a combination of grid power, batteries, and PV can serve the loads. The day-to-day solar resource variability will affect how much electricity can be serviced using distributed energy resources and additional electricity demand will be serviced by the local electric utility and BESS when available. Using Engage, multiple scenarios were run to explore the regional impacts related to utility tariff structures, charging strategies, distribution system congestion, and flight school demand. More information and additional analysis for each airport is available in Section 3.2.

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1 Introduction

1.1 Study Purpose

The purpose of this study, conducted by the National Renewable Energy Laboratory (NREL) on behalf of the Colorado Department of Transportation's (CDOT's) Division of Aeronautics, was to assess the likely infrastructure requirements for local and regional airports to support electrified, fixed-wing regional air mobility (RAM) aircraft. Prior to airports investing in the necessary infrastructure to support electrified operations, they must understand the potential capital and operating costs required. This report seeks to provide key insights for the CDOT Division of Aeronautics and local and regional airports so that they can begin planning, working more closely with their utilities regarding potential electrification of aircraft operations, and investing in the necessary infrastructure to enable electrified RAM aircraft to use airports in Colorado. Additionally, NREL aims to inform the local and regional airports of the modeled economic costs and benefits of implementing distributed energy resources in their business-as-usual (BAU) scenario without added aircraft charging loads.

RAM is an emerging mode of transportation that has the potential to revolutionize how people travel. It refers to shorter-distance flights, typically under 300 miles, that use smaller aircraft for commuters, and regional airlines that typically operate aircraft with 9, 19, or 50 seats (Justin, Payan, and Mavris 2021). RAM offers many potential benefits over traditional spoke-and-hub[4] transportation systems by providing greater accessibility to rural and other underserved communities, utilizing existing airports, providing shorter travel times compared to land transportation, lowering operational costs for airlines, offering more flexibility for scheduling and routing, and creating fewer environmental impacts through reduced greenhouse gas emissions and sound pollution (Justin, Payan, and Mavris, 2022).

RAM is in the early stages of development, as evidenced by recent announcements of companies like Electra and Eviation revealing their electric and hybrid-electric short take-off and landing regional aircraft. Electra (2024) reports preorders of their Ultra Short electric aircraft exceeding 2,000 orders. Similarly, Eviation (2024) announced an order for 20 of their Alice aircraft by UrbanLink, an advanced air mobility company out of South Florida. However, in early 2025, the company announced a significant reduction in force.

The introduction of new aircraft that use electric, hydrogen, or hybrid-electric engines represents an opportunity for the aviation industry but also presents new challenges for the regional and local airports that might serve them. To support electrified RAM aircraft, airports will need to invest or enable investment in new electrical infrastructure, potentially including new distribution lines to connect to the local electrical grid, charging stations for electric aircraft, and on-site power generation technologies to offset new electrical demand. Such technologies can include hydrogen fueling and storage, or traditional solar photovoltaic (PV) systems and battery energy storage systems (BESS). New operating procedures will also need to be adopted to safely

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[4] A spoke-and-hub transportation system relies on centralized transportation hubs with shorter distance connections, or "spokes," to reach less centralized regions.

and efficiently manage new high-energy electrical charging and battery storage technologies onboard the aircraft. Within the airport boundaries, power generation would require additional construction costs and ongoing maintenance costs, regardless of the power generation technology. Outside of an airport's boundaries, electric utilities that serve the airports may require grid infrastructure upgrades and the installation of new equipment to handle higher peak electrical loads during an airport's busiest charging times.

Successfully integrating energy technologies will require implementing new energy management approaches and leveraging new technologies. With a menu of different options available for local and regional airports to determine how to best provide the services needed for the next generation of electric aircraft to operate, airports must look to minimize costs and maximize efficiency. For many airports, the optimal solution could be a combination of increased utility electrical supply, on-site power generation and storage, and service contracts with original equipment manufacturers for the ongoing maintenance and operation of these assets.

The BAU scenarios explored in this study are used in comparison with scenarios which demonstrate the potential benefits airports receive when investing in distributed energy resources (DERs), such as solar PV systems and BESS, regardless of future electrified aircraft loads.

Colorado represents a unique and dynamic environment for developing the RAM market. The state is home to Denver International Airport, which was ranked as the sixth busiest airport in the world and third busiest for passenger traffic in 2023 (O'Clair 2024). In total, there are 76 airports across Colorado, ranging from small local and regional airports to larger commercial hubs. Fifty-two airports are listed as publicly owned, 14 as public commercial service, and 10 as privately owned and open to the public (CDOT Division of Aeronautics n.d.). Local and regional airports were included in this study (41 in total) ranging across the eastern Front Range of Colorado, the mountainous central region, and the western slope. Additionally, airports in Wyoming, Utah, and New Mexico were included to better understand inter-state air transportation opportunities.

Multiple modeling tools and analytic methods were used to develop this study. RAM flight forecasts were provided by Georgia Institute of Technology (GA Tech) researchers, aircraft details provided by National Aeronautics and Space Administration (NASA) researchers. An overview of the flow of data is described in Figure 1; descriptions of the various methodologies are included in sections 1.1.1, 1.1.2, and 1.1.3.

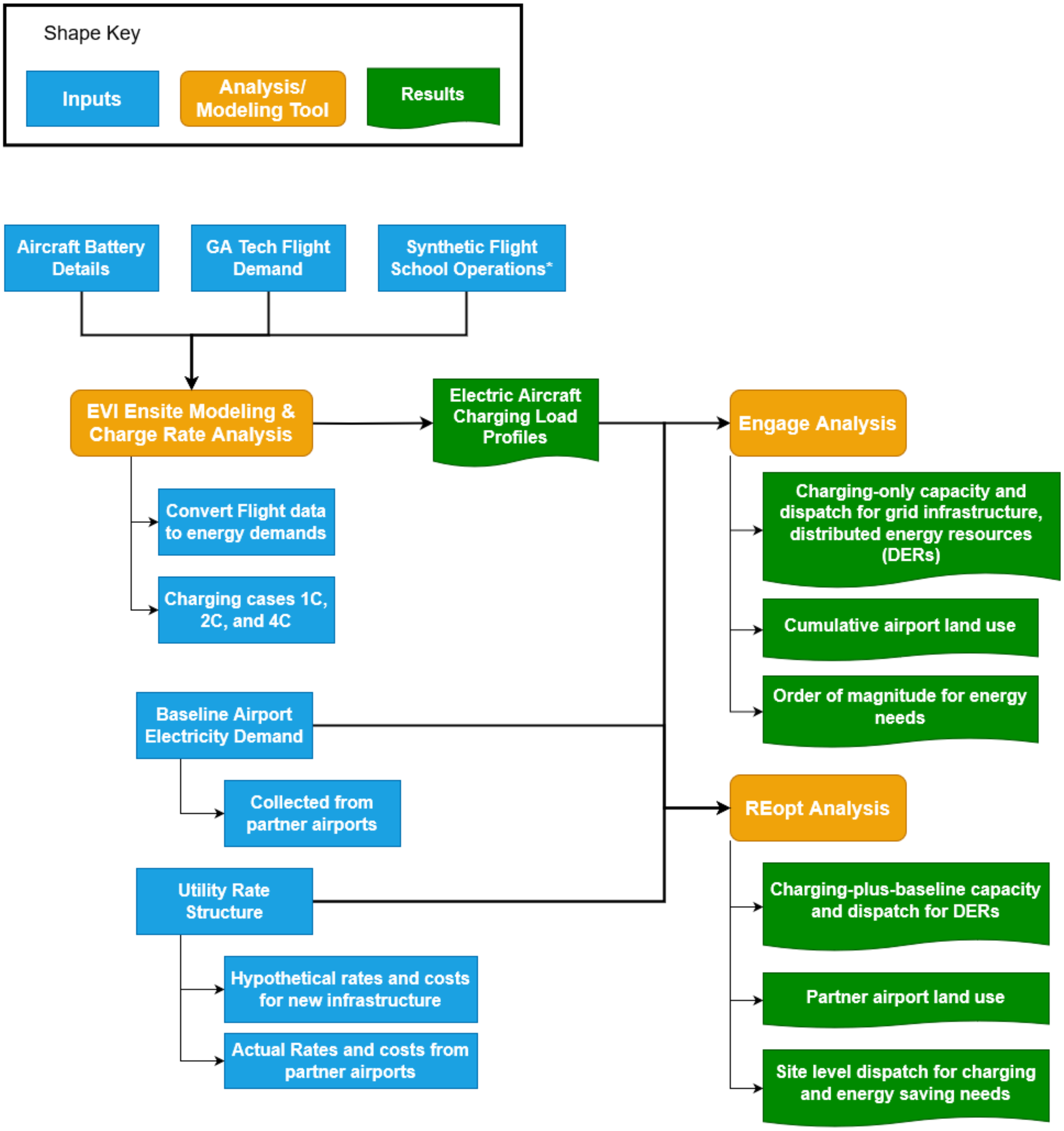

Figure 1. Modeling and analysis flow. ***Figure adapted from (Cox et al. 2023).***

* Synthetic flight school operations were generated by sampling real flight data from FlightAware and scaling to the appropriate fleet size.

1.1.1 Electric Vehicle Infrastructure – Energy Estimation and Site Optimization Tool

NREL's Electric Vehicle Infrastructure − Energy Estimation and Site Optimization[5] (EVI-EnSite) tool allows users to investigate light-, medium-, and heavy-duty electric vehicle (EV) charging at different charging station configurations. EVI-EnSite was used in this study to simulate the charging operations necessary at airports for electrified RAM flights.

1.1.2 Engage

We used NREL's Engage™ capacity expansion model to evaluate regional energy implications for this study. The publicly available web application evaluated cost-optimal capacities of on-site solar PV and lithium-ion battery energy storage systems and the power delivery capacity to the electric vehicle service equipment (EVSE) systems. Engage assumes a new primary voltage electric utility service to serve direct current (DC) fast charging (FC) of future electrified RAM aircraft. The capacity of the new utility infrastructure to the airport for DCFC is based on the available capacity of supporting distribution system assets upstream of the utility service interconnection point.

1.1.3 REopt

We used NREL's Renewable Energy Integration and Optimization platform (REopt®) to identify potential on-site DER technologies, to serve electricity for both existing loads and future electrified RAM aircraft. REopt seeks to identify optimal sizes for energy assets. Current economic conditions favor solar PV and lithium-ion battery energy storage systems.

REopt and Engage complement each other, providing unique insights on regional versus site-specific needs. Results between the two models differ slightly.

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[5] https://www.nrel.gov/transportation/evi-ensite.html

2 Overview of Sustainable Regional Aviation in Colorado

2.1 Introduction

This section summarizes existing literature on the technical features and applications of alternatively powered fixed-wing and electric vertical takeoff and landing (eVTOL) aircraft for regional air mobility services. In highlighting the latest developments and challenges for electric and hybrid aircraft adoption, this report also describes existing infrastructural needs for the state of Colorado's airport system to support electrification and fuel diversification in the context of flight training, and general and regional aviation. Furthermore, a series of case studies are presented to aid discussions around the efficacy of alternatively powered aircraft in different settings.

2.2 Benefits, Challenges, and Risks with Electric Aircraft

Electric aircraft have the potential to benefit owners, operators, and surrounding communities in several ways. Greatest among these potential benefits are lower life cycle costs, noise reduction, the ability for electric aircraft to take-off from existing smaller airfields, and reduced local emissions as the industry transitions away from leaded aviation gasoline (Coenen et al. 2022; Washington State Department of Transportation [WSDOT] 2020; Cox et al. 2023; National Academies of Sciences, Engineering, and Medicine [NASEM] 2022). In certain applications, including short-haul service, electric power is likely more energy efficient than jet engines powered by fossil fuels (NASEM 2022). In the future, airports that host electric aircraft could also serve as both regional mobility and energy resilience hubs—providing more point-to-point transport connections between communities—while improving the security and reliability of the power supply to those communities (NASEM 2022; Roa and Oldham 2022).

There are challenges and risks to address, however, before electric aviation can become mainstream. Challenges include travel range concerns for the aircraft, lower capacity for passengers and cargo, payload issues, and the potentially disruptive impact of long charge durations on airline travel schedules (Cox et al. 2023; NASEM 2022). Coenen et al. (2022) rank technical risk as "moderate" for fixed-wing electric aircraft, which includes the technological and design challenges inherent to current efforts for electrifying air travel. Other moderate risk categories include Federal Aviation Administration (FAA) certification and aircraft operations. Infrastructural needs and sociocultural factors present only low risk to fixed-wing electric aircraft deployment (Coenen et al. 2022). Several of these risk categories are elaborated in the following sections.

2.3 Technological Needs

The future of sustainable regional aviation through aircraft electrification and fuel diversification will be governed, in part, by progress made in energy storage systems, particularly the development and continual improvement of batteries with high mass and volumetric energy density. Electric Power Systems released multiple battery packs for both eVTOL and electric trainer aircraft. The EPiC 1.0 and EPiC 2.0 battery packs are available for both eVTOL thin-haul aircraft, as well as Hybrid eVTOL military flights with durations of 60 and 90 minutes (Electric Power Systems 2025). Modern aviation-grade batteries store less than 1/50th of the energy present in jet fuel or aviation gasoline for a given weight because the gravimetric energy density of current battery chemistries is substantially less than that of jet fuel (Roa and Oldham 2022; Justin, Payan, and Mavris 2022). In terms of reaching underserved communities at the regional level, current battery technologies have been demonstrated to be feasible for this shorter range. Furthermore, according to Cox et al. (2023), more research is necessary to better estimate aircraft battery life with frequent fast charging and cycling multiple times daily in high-use commercial aircraft applications.

Throughout the aviation industry, energy density and effective cycle life are employed to gauge aircraft battery capabilities. Optimizing both energy density and effective cycle lives to yield lightweight and robust batteries requires certain trade-offs between payload and range, particularly for light-cargo and commuter passenger aircraft. Because of a battery's significant contribution to an aircraft's weight, maximizing its energy density will alleviate some of the current challenges to full electrification (NASEM 2022). Considering a battery's effective cycle life, improvements that increase the number of discharge and recharge cycles can reduce the need for battery replacements over the aircraft's lifetime. Such improvements will lower maintenance costs even further and reduce barriers to entry for electric and hybrid aircraft. Another approach to improving the effective cycle life of batteries has been demonstrated by the automobile industry in its development of buffering techniques that prevent full discharge of the battery, enabling thousands of charge cycles before it degrades (NASEM 2022). By applying these strategies to aviation, electric aircraft manufacturers can make electrification more economically feasible.

Fuel cell technologies provide another potentially viable option for alternative powering of aircraft. The U.S. Department of Energy describes how a fuel cell produces electricity using the chemical energy provided by different types of fuel, including hydrogen and feedstocks[6]. Fuel cell advancements make regional deployment of a wider range of alternatively powered aircraft possible. Examination of current fuel cell technologies indicates proton-exchange membrane fuel cells as being the most suitable to support all-electric aircraft, whereas solid oxide fuel cells are better suited for aircraft that have a hybrid configuration of propulsion systems with turbomachines. Though solid oxide fuel cells can operate under higher temperatures, proton-exchange membrane fuel cells are advantageous with their ability to satisfy varying power requirements needed for different phases of a flight mission (Massaro et al. 2023). Given their light weight, high power density, responsiveness to load changes, and ability to work as a range extender for hybridizing battery-based powertrains, recent literature supports these types of fuel cells as being the most promising for aviation use (Massaro et al. 2023; Inacio et al. 2022).

A key challenge for alternatively powered aircraft is ensuring their safety and reliability. Thermal management of battery and power generation is critical to limiting accelerated battery degradation and the risk of thermal runaway, which can lead to combustion, toxic emissions, and high-voltage short-circuiting (NASEM 2022; Bærheim et al. 2022). Although embedding aircraft battery and power generation systems with cooling systems to increase service life and decrease degradation is one possible preventive measure, it can add weight, thereby reducing range and payload capacity. Other supporting efforts include updating aircraft rescue and firefighting

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[6] For more information regarding hydrogen fuel cells, visit https://www.energy.gov/eere/fuelcells/fuel-cells.

requirements, learning from existing standards established for other industries, and relevant battery deployments already in service in aviation. Fully established guidance for long-term adoption is currently under development by the FAA. At the time of this writing, existing recommendations offer important considerations for dealing with incidents involving electric power and new energy storage systems, storing batteries, and responding to hydrogen-related events (National Fire Protection Association 2023).

In addition to addressing incidents based on alternative fuels, Torres (2014) emphasizes the need for training and response strategies for incidents involving electric vehicles on-site. Hydrogen-electric vehicles require more specific standards due to the invisible and buoyant nature of the molecule, its low ignition threshold, and its explosiveness at higher concentrations. Requirements for personal protective equipment and thermal imaging technology, however, will likely remain similar to those associated with other fuels (Nixon 2022).

With the efficiency and cost stability of electricity, relative to jet fuel, electrified aircraft platforms have commercial utility. Therefore, to enable widespread use of electric aircraft, the following areas need attention: improvements in specific energy and weight of electrical energy storage systems, increases in specific and rated power produced by electric motors, aviation-compatible packaging of electric machines, strategic approaches to thermal management, and integration impact assessments (NASEM 2022). Addressing these priorities will help expedite the aviation industry's transition to aircraft electrification.

Unlike battery-electric and fuel cell systems for electric and hybrid aircraft that have a limited range, SAF can be used for varying flight ranges. SAF is "drop-in" liquid hydrocarbon jet fuel produced from renewable or waste resources that is compatible with existing aircraft and engines (U.S. Department of Energy et al. 2022). Per the International Civil Aviation Organization, SAF use will need to comprise more than 30% of jet fuel consumption by 2040 to meet current industrywide commitments for greenhouse gas reductions (Holladay et al. 2020). Current goals by private industry to reduce emissions while meeting expected passenger growth are expected to make SAF a critical alternative fuel for modernizing the aviation industry. With aviation fuel use projected to reach 230 billion gallons worldwide by 2050, more carbon-neutral forms of SAF are needed to increase SAF use while reducing greenhouse gas emissions by 50% before 2050 (Holladay et al. 2020). Primarily derived from biomass sources, SAF has been produced through nine certified pathways with eight more conversion processes currently under evaluation. The eight potential pathways include synthesized aromatic kerosene, integrated hydropyrolysis and hydroconversion, and pyrolysis of nonrecyclable plastics (International Civil Aviation Organization 2023).

Limited opportunities for SAF production can be attributed to difficulties with cost, effort, permitting, financing, feedstock acquisition, and bringing production plants online to deliver economically viable SAF (Csonka, Lewis, and Rumizen 2022). The International Air Transport Association (2023) suggests SAF diversification can be achieved by scaling up feedstock conversion technologies and already-certified SAF pathways (such as alcohol-to-jet and Fischer-Tropsch processes) and accelerating research and development of SAF production pathways still under development. As SAF technologies improve and policies that expedite SAF diversification are implemented, more fuels resulting from mature conversion processes will allow for more SAF to be brought to market.

2.4 Electrical Infrastructure Needs

Assuming demand for electrified aircraft continues to grow, funding and deploying the supporting infrastructure for electric aviation represents one of the largest short-term barriers for airports. Electric aircraft trigger three main airport infrastructural needs: 1) charging infrastructure and charging strategies, 2) broader electrical infrastructure, both on-site and grid-level, to support charging and meet increased demand, and 3) hydrogen infrastructure for aircraft with fuel cells (NASEM 2022). To help airports address these needs, NREL is looking at various charging infrastructure options and their overall impact on the grid via modeling software such as Engage. Each of these infrastructural needs is discussed in more detail below.

2.4.1 Charging Infrastructure

Cox et al. (2023) state that to optimize the integration of electric aircraft, smaller airports should identify and deploy the most appropriate charging infrastructure simultaneously with these aircraft. As with electric vehicles today, there will be a range of electric aircraft charging speeds and requirements for different applications (Cox et al. 2023). Projected charging requirements for CDOT's interest areas of general aviation, flight training, and regional air mobility are evaluated in this analysis along with the potential for energy generation independent of potential charging needs.

2.4.1.1 Charging Requirements

The development of charging requirements for different electric aircraft applications is still an evolving research area that builds on related research for other ground and marine vehicle types. NASEM (2022) introduces an infrastructure development market assessment that estimates anticipated fleet size, number of chargers required, charger capacity, and charger cost for five use cases (e.g., turboprop airliner, commuter aircraft, light air cargo, flight training, and general aviation). There are limits to these projections, which should be viewed as a starting point for discussions around charging requirements for different types of electric aircraft. Additionally, charging requirements discussed throughout this study do not include the charging of electric ground support equipment vehicles. The focus of this study is on aircraft charging demand; charging requirements for electric ground support equipment vehicles are currently being investigated under separate research programs at NREL and, together with this report, will help to inform airport operators of the complete energy demand associated with airport modernization. Table 1 provides an overview of NASEM's estimated charging needs for flight training, general aviation, and regional air mobility. Electric aircraft to replace existing turboprop airliners (for regional air mobility) present the most significant challenge in terms of technological and infrastructural readiness, whereas capacity requirements for flight training and general aviation fall within the capabilities of current charging technologies.

Table 1. Estimated Charging Requirements by Aircraft Type

Aircraft Type	Required Charging Capacity	Number of Chargers Required	Assumed Charging Time	Notes
Flight Training	75 kilowatts (kW)	One per two aircraft	1 hour	Charging capabilities under 1 hour will likely be needed to support operational pace requirements
General Aviation (Private Operators)	100 kW	One per 10 aircraft	1 hour	Relatively low traffic/operational urgency means general aviation aircraft can charge at low power for a long time
Regional Air Mobility (Turboprop Airliner)	1,300 kW	Three chargers per four aircraft	30 minutes	Rapid aircraft turnaround times necessitate small charging windows, high-power charging capacity needs

Source: Table by NREL, data from NASEM (2022)

Although flight training requires the lowest-average charging capacity in Table 1, NASEM argued that privately operated general aviation aircraft will be the lightest infrastructural lift for airports in the short term. This projection is because NASEM expects electrified flight training will require more chargers per aircraft than general aviation, as well as fast-charging capabilities (under 1 hour) for future electric training fleets to meet the high operational pace requirements of pilot training schools. As the proportion of electric training aircraft grows, training schools will require greater charging capacity to support the highest utilization of aircraft during typical operations.

Across all three of the aircraft types in Table 1, NASEM estimates a baseline charger cost of $464 per kilowatt (kW). Note that this baseline charger cost may generally apply to kilowatt-scale charging infrastructure and not necessarily to higher-capacity chargers. Baseline charger costs used in this study are discussed in section 3.3.4 (Bennett et al. 2022; Cox et al. 2023).

This study takes a different approach to estimating charging requirements for regional air mobility. Charging load profiles were derived from the NASA-provided flight schedules and per-flight energy consumption from electric flight demand that used Georgia Tech calculations and simulations. NREL derived electric aircraft charging profiles using its EVI-EnSite. Three charging cases were investigated that correspond to charge rates of 1C, 2C, and 4C, which allows recharging a battery from zero to 100% state of charge (SOC) in 1 hour, 30 minutes, and 15 minutes, respectively.

2.4.1.2 Charging Strategies

There are two main strategies for charging electric aircraft: plug in and battery swapping. Plug-in charging entails plugging aircraft directly into either fixed or mobile charging stations on the ground, whereas battery swapping involves replacing a depleted aircraft battery with a fully charged one (Cox et al. 2023). Previous studies assumed battery swapping to be the most technically feasible short-term strategy for infrastructural readiness (Cox et al. 2023; NASEM 2022; WSDOT 2020). Plug-in systems are likely most effective in the long term; however, given the FAA’s public statements considering battery swapping a major repair or aircraft alteration

(Cox et al. 2023), this strategy is likely not operationally feasible. The research team is currently unaware of any known aircraft manufacturers that are currently seeking FAA aircraft/power plant certification with swappable batteries. Assuming swapping continues to be classified as a major repair rather than a typical ground handling operation, requiring licensed mechanics to conduct the battery swap instead of ground support crews, added scheduling and financial challenges will be realized, which could significantly limit interest in this approach for electrified aircraft (NASEM 2022). Batteries are also a large part of electrification of flight costs, so the need for battery swapping infrastructure and duplicate battery capacity will likely make battery swapping much more costly than battery charging. As high-speed charging technology advances, recharging will likely be more cost-effective from an infrastructure perspective than battery swapping.

2.4.1.3 Electrical Infrastructure

Introducing electric aircraft will inevitably increase demand for electricity at airports. Cox et al. (2023) estimate that introducing electric aircraft, using the same forecast methodology from Georgia Tech, would increase annual electricity consumption at Colorado Springs Airport (COS) by approximately four times—with peak on-site demand increasing by a multiple of more than 10. Although there are limits to the underlying model used in their study, these projections provide a good baseline for smaller airports on what to expect in terms of increased on-site electricity demand. On-site power generation in addition to new interconnections with utilities is likely required for local and regional airports to support these new electrified aircraft loads, depending on their specific circumstances.

Even in an ideal scenario wherein airports collaborate with their energy providers, the electric grid may not have the capacity to sustain high power draws in more remote locations (Justin et al. 2020) without supplemental DER assets. Lack of current grid capacity is one reason local and regional airports should explore enhancing their on-site power capacity via independent power generation. On-site power generation can provide opportunities to leverage microgrid technologies as well (NASEM 2022). Cox et al. (2023) recommend some level of on-site electric infrastructure or distributed energy resources to serve electric aircraft at all 163 airports considered in their study.

2.4.1.4 Hydrogen Infrastructure

Adopting hydrogen aircraft could help modernize aviation while unlocking more service options—from commuter and regional to short-haul and, at the most, medium-haul flights (Airport Transport Action Group Board of Directors 2021). Hydrogen can be used to power turbine engines, which are expected to operate at similar efficiencies as existing turbines. Hydrogen fuel cells, on the other hand, can generate electricity at potentially higher efficiencies, with water as their only byproduct. Currently, the trade-off is increased system weight and maximum speeds. Boeing states that fuel-cell-powered aircraft could enter the market in 2040 and beyond, assuming an abundance of renewable energy and a widespread hydrogen economy (Boeing 2024). The desired method of storing fuel on the aircraft is cryogenic hydrogen. It has a poor packaged energy density and requires four times the volume of jet fuel for the same amount of energy, and must be cooled to -253 ° Celsius; however, it decreases the volume of storage on an aircraft and high pressures associated with gaseous hydrogen. Significant energy is required to cool and maintain the temperature of cryogenic hydrogen, and active research is collecting and using “boil off” gaseous hydrogen that occurs as tanks warm and during fueling events.

Airbus believes hydrogen to be one of the most promising technologies to advance the worldwide aviation industry and is an important technology pathway to achieve their goal of bringing a low-carbon commercial aircraft to market (Airbus 2025). In early 2025, Airbus adjusted their time frame for entry to service due to slower development than anticipated for the hydrogen ecosystem. Given the interest in hydrogen as a viable aviation fuel source, addressing the challenges related to hydrogen production, transport, storage, and on-site fueling require attention, on the part of airports, to ensure their safe and responsible use as it relates to electricity demands and other infrastructure needs. Additional considerations include the need for new safety protocols, training, and quality assurance standards to ensure all participants in the refueling infrastructure and operations space are protected.

There are multiple approaches to hydrogen storage, with various trade-offs (Massaro et al. 2023). Liquid and cryo-compressed hydrogen are considered the most viable methods for on-aircraft storage. At the time of this writing, there is a growing consensus favoring liquid over compressed hydrogen (Massaro et al. 2023) for on-aircraft use.

An alternative to storing pure hydrogen is by accessing it through a more stable material compound. If material compounds are used to store and access hydrogen, then these storage alternatives comprising borohydride metals, liquid organic hydrogen carriers, or ammonia are better suited than metal hydrides or metal organic frameworks. While materials-based storage methods are still maturing, they have high potential and are expected to improve considerably in the near term. Metal-based hydrides and ammonium-based hydrogen storage solutions are expected to become lighter and subsequently more feasible for aircraft use.

Potential benefits of these methods include simpler handling and fewer new technologies to develop; however, they may also come with trade-offs of higher weight, less efficient processes, and so on. Considering optimal liquid hydrogen storage, allocation, and propulsion use, Gao et al. (2022) suggest that lightweight liquid hydrogen tanks be developed, tested, and manufactured in tandem with safe onboard fuel distribution systems, hydrogen combustion components with low nitrous oxide emissions and longer lifespans, and high-power-density fuel cells. Currently, hydrogen is more expensive than traditional kerosene fuels, in part due to the lack of existing production, delivery, and storage infrastructure. Associated infrastructure capital costs result in integrated hydrogen-based energy systems that are more expensive than typical energy infrastructure solutions; however, the long-term economic and environmental benefits could justify the initial upfront investments (Xiang et al. 2021). Should hydrogen become more prevalent, storage and access methods will need to be included in site electrical requirement evaluations as well, along with factors such as location and method of pure hydrogen processing, methods for compression/liquefaction, or alternative chemical storage conversion methods to useable hydrogen.

2.4.2 Operational Needs

Beyond the technological and infrastructural requirements associated with electric aircraft, airports must also enhance their operational processes to ensure the optimal use of these aircraft (Justin et al. 2022).

Operational needs stemming from the electrification of aviation include:

- Alternate training for ground support crews. This will likely be the most immediate operational need due to the new skillset and safety requirements associated with recharging electric batteries and refueling hydrogen tanks (NASEM 2022).
- Updated procedures for assigning fleets and scheduling flights
- Preparation for declining petroleum fuel tax and flowage fee revenues
- Consideration of emergency backup power
- More widespread firefighting response preparations for larger battery systems.

Efficient operations will be essential in optimizing the use of electric and hybrid-electric aircraft. Justin, Payan, and Mavris (2022) point to fleet assignment, flight scheduling, and passenger and aircraft routing as key parts of flight operations. The authors introduce an optimization model to help maximize operating profits, minimize emissions, and identify the best fleet composition to meet passenger demand. By introducing environmental considerations early on, Justin, Payan, and Mavris suggest that regional air mobility operators of electric and hybrid-electric aircraft could potentially reduce their local emissions footprint, more than the reduction from vehicle improvements alone (albeit with an associated profit penalty of 10% and 20%, respectively). Note these numbers represent just one estimate, and they will likely change based on the findings of Cox et al. (2023) that on-site renewable energy generation and stationary storage could prove more cost-effective than grid power in providing most of the energy for electric aircraft charging.

Electrification of aircraft and airports also introduces the need for federal, state and local entities to consider declining petroleum fuel tax and flowage fee revenues and potential power outages (NASEM 2022). Potential operational strategies for addressing reductions in fuel taxes and airport fuel flowage fees could include adjusting existing fees or creating new charges for electric aircraft operations (e.g., battery recharges, landing fees, ramp parking; WSDOT 2020). Electric aircraft also require operators to determine how to respond to a long-term power outage, whether natural (e.g., extreme weather event) or human (e.g., cyberattack) in origin. The transition to all-electric operations should also prompt discussions on how to ensure a reliable power supply during emergency events (NASEM 2022). A recently published study commissioned by NASA (Walsh 2025) begins to evaluate the economic implications on aviation with a shift in policy and provides a significant addition to this analysis.

2.4.3 Potential Funding Opportunities

2.4.3.1 Federal Funding Opportunities

Table 2 provides a brief overview of potential federal funding opportunities for airport infrastructure projects related to electric aviation as of early 2025. It is important to note that electric aircraft projects are not currently eligible for all the grants listed in the table—making electric aircraft charging infrastructure projects eligible for some funding (especially under the FAA's Airport Improvement Project [AIP] and Voluntary Airport Low Emissions Program [VALE]) but would require a change of policy at the federal level. U.S. Department of Transportation (DOT) programs are not specific to aviation; however, could apply to relevant infrastructure. (NASEM 2022).

Table 2. 2Potential Federal Funding Opportunities for Electric Aircraft Infrastructure

Funding Source	Description
Federal Aviation Administration's (FAA's) **Airport Improvement Program (AIP)**	Funding for AIP is allocated annually from the Airport and Airway Trust Fund, which is funded by aviation excise taxes (on passenger tickets, cargo fare, fuel sales, and so on). Small, reliever, and general aviation airports could likely expect 90%–95% coverage from AIP for eligible aircraft charging infrastructure costs. Medium and large hub airports could expect closer to 75%–80% coverage.
FAA's Airport Zero Emissions Vehicle and Infrastructure Pilot Program	This program is intended to help improve airport air quality and support the implementation of zero-emission vehicles at airports. Airports eligible for AIP grants can use this program to purchase zero-emission vehicles and any corresponding required infrastructure.
FAA's Continuous Lower Energy, Emissions and Noise (CLEEN) Program	Implemented in 5-year phases, this program funds industry partners to create aircraft and engines with less noise, fewer emissions, and improved fuel efficiency. Partners do need to match or exceed FAA funds to receive funding from CLEEN.
FAA's Passenger Facility Charge	The passenger facility charge allows commercial airports to tax passengers up to $4.50 per flight segment for projects that enhance safety, security, capacity, noise reduction, or air carrier competition. Electric aircraft charging infrastructure is potentially eligible as well.
FAA's Voluntary Airport Low Emissions (VALE) Program	VALE was established primarily to help improve air quality at commercial airports, but estimated electric aircraft infrastructure costs are within its historical funding capabilities. Specifically, 75% to 90% of eligible charging installation costs could be reimbursable under VALE.
USDOT Better Utilizing Investments to Leverage Development (BUILD) Grant Programs	BUILD grant program provides grants for surface transportation infrastructure projects with significant local or regional impact.
USDOT Infrastructure for Rebuilding America (INFRA) Grants Program	INFRA grants program awards competitive grants for multimodal freight and highway projects of national or regional significance to improve the safety, efficiency, and reliability of the movement of freight and people in and across rural and urban areas.
USDOT Transportation Infrastructure Finance and Innovation Act (TIFIA)	TIFIA program provides Federal credit assistance in the form of direct loans, loan guarantees, and standby lines of credit to finance surface transportation projects of national and regional significance
Joint Office of Energy and Transportation (DOE/DOT) Charging and Fueling Infrastructure Program	This initiative funds the strategic deployment of publicly accessible electric vehicle charging and alternative fueling infrastructure. The program is not specifically intended for airports, although they should still meet the eligibility criteria for discretionary funds. Federal agencies take on 80% of project costs under a cost-sharing agreement.

Funding Source	Description
Joint Office of Energy and Transportation (U.S. Department of Energy/DOT) Ride and Drive Electric Program	This program aims to provide administrative and technical support for assessing electric vehicle service equipment planning, capacity building, and evaluation of performance and reliability of charging stations. Airports could potentially quality and benefit from having planning models identified, developed, and tested that complement or integrate operations of electric vehicle charging.

Source: Table by NREL, content from NASEM (2022), Joint Office of Energy and Transportation (n.d.)

2.4.3.2 State Funding Opportunities

Table 3 provides a brief overview of potential State of Colorado funds for airport infrastructure projects related to electric aviation. State funds typically cover the nonfederal portions of FAA-supported projects, and the management of these funds varies from state to state (NASEM 2022). Green revolving funds (GRF) are included in this section because Colorado has experience operating the state revolving funds for drinking water and water pollution control (Colorado Water Resources and Power Development Authority n.d.). Revolving funds typically represent a financing partnership between states and the U.S. federal government.

Table 3. 3Potential State Funding Opportunities for Electric Aircraft Infrastructure

Funding Source	Description
Colorado Department of Transportation's (DOT's) **Discretionary Aviation Grant Program**	This program funnels 35% of aviation fuel tax revenues to serve maintenance, capital equipment, and developmental needs at Colorado's 74 public-use airports.
CDOT's **Office of Innovative Mobility Grants**	This program provides grants to private, public, nonprofit, and local agencies to fund innovative mobility and electrification solutions in the state of Colorado.
CDOT's State Infrastructure Bank Loan Program	This program helps fund transportation facilities via a low-interest revolving loan program.
Colorado Energy Office's Clean Air Program Grants	Eligible grant applications include airline operations, local governments, and public-private partnerships. Project types that may become eligible for Clean Air Program grants include transportation projects, projects that produce or use SAF, and projects that produce or use clean hydrogen.
Colorado Office of Economic Development & International Trade's Advanced Industries Accelerator Program	In this program, advanced industries companies that support aerospace are eligible to apply for four types of grants: proof of concept, early-stage capital and retention, collaborative infrastructure, and export-related.
Green Revolving Funds (GRFs)	GRFs are internal investment vehicles that: 1) aim to reduce resource use or carbon emissions, and 2) revolve by using generated savings to repay the initial loan or investment. Hartsfield–Jackson Atlanta International Airport became the first U.S. airport to adopt a GRF in 2016, and there are also collective GRF models (like Virginia Airports Revolving Fund) to assist smaller airports that

Funding Source	Description
	may lack the resources to invest in and maintain an airport-level GRF on their own.

Sources: Table by NREL, content from NASEM (2022, 2019)

2.4.4 Potential Aircraft of Interest

There were at least 100 electric aircraft designs under development worldwide in 2022 (NASEM 2022). Projects for aircraft of different use cases at the regional level vary in focus—from novel design and adaptation of existing airframes (in the case of pilot training) to retrofitting and developing electric and hybrid-electric variants of existing aircraft in service. Examples of manufacturers working on next-generation aircraft include:

- Pipistrel's fully electric Alpha Electro trainer (a Textron company)
- Bye Aerospace's two- and four-seat variants of the eFlyer
- Eviation's Alice
- ZeroAvia's Q400/Dash 8-400 hybrids (NASEM 2022; Cox et al. 2023; Bærheim et al. 2022)
- Heart Aerospace's ES-30 Hybrid electric.

It is expected that consolidation will occur as the market matures.

Several recent case studies have helped evaluate the performance and feasibility of alternatively powered aircraft with potential for full service. According to Roa and Oldham (2022), an early electric propulsion demonstration project in California showed that a two-seat training aircraft's energy and annual inspection costs were lower by 85% and 50%, respectively, compared to a traditional piston engine variant of the same aircraft. Another analysis involving a plug-in hybrid version of a six-seater aircraft similarly demonstrated that energy costs were lower by 50% compared to the standard model at the same flight distance and trip time. A separate cost comparison between the standard utility Beechcraft King Air C-90 aircraft and the all-electric Eviation Alice showed that the Alice only incurred half of the overall cost per trip, a third of the fuel cost, and less than half of the cost per passenger compared to King Air (Roa and Oldham 2022).

The results of a Norwegian study comparing Eviation's Alice to a retrofitted De Havilland Canada Dash 8-100 showed that the purposely built, all-electric aircraft could fulfill regional flights and cover more range than a retrofitted version that would require complex modifications to meet the same range (Bærheim et al. 2022). Although all-electric aircraft with modern batteries can be viable because of their lower structural weight and higher lift to drag ratio, retrofitting traditional aircraft with batteries and electric motors requires less time to take to market. Battery limitations were most glaring from the Norwegian review, reinforcing our prior discussion emphasizing the importance of improvements in battery technology to fully integrate electric aircraft.

Prospects for other potential aircraft compatible with regional air mobility include retrofitting existing aircraft made possible with hydrogen-based hybrid-electric propulsion systems, like a traditional 72-600 from ATR. Heart Aerospace has announced orders from United Airlines and Air Canada for 30-seat planes with a range of 200 kilometers (124 miles) on batteries alone with an electric aircraft version or double the amount with their SAF-fueled hybrid-electric model (The Economist 2023).

To support electric aircraft as they come online, charging will be another important consideration for service providers and manufacturers. Clay Lacy Aviation, a fixed-base operator service company, recently announced an agreement to provide charging for Eviation's upcoming nine-passenger Alice aircraft (Cox et al. 2023) and similar relationships continue to develop through other manufacturer and fixed-base operator initiatives. The company states an estimated flight range of 815 kilometers (506 miles) with a charge time of 30 minutes or less, as of 2023. For aircraft under development that are nearing certification and deployment, having the operational infrastructure in place will help commercialize next-generation aircraft within the short-haul aviation sector and allow regional operators to scale-up their fleets.

2.4.5 Conclusion

In summary, research and development of alternatively powered aircraft is quickly maturing for different use cases. Energy requirements depend on flight demand, charging operations, charging infrastructure, and utility rate structures, resulting in great potential for optimizing charging schedules and flight operations to minimize peak energy demand. Airport systems in Colorado should consider preparing to operate and manage regional aircraft in a way that accounts for the technical, infrastructural, and operational needs required to support their entrance into service. Colorado's high altitude and weather may present additional challenges for procuring new aircraft, although some of the manufacturers may be suitable for that environment. Given Colorado's central location and existing airport infrastructure, the potential for regional air mobility driven by next-generation aircraft remains significant, and opportunities exist to prepare for potential future demand without the risk of oversizing assets.

3 Methodology

3.1 Electrified Flight Charging Demand

For this project, the potential amount of added electricity demand from RAM passenger service and flight schools at regional airports in and around Colorado was quantified. Electricity demand from electrified flights for each airport can vary and depends on the type and number of chargers installed, electricity demand of the individual aircraft, and the frequency and time of day of the charging events to service electrified RAM passenger and flight training aircraft. The number of EVSE chargers needed to service these aircraft depends on the demand for charging by electrified flights each day and the required charging speeds. A maximum power rating of 3 MW was set as the default to ensure all fast-charging operations would have sufficient power at each charger. This approach adopts the emerging megawatt charging standard as the baseline and reduces variables in evaluating upstream (behind the charger) electrical needs. NREL used different methods to estimate passenger travel electrical charging demand and flight school electrical charging demand. The resulting electrical loads were combined when evaluating airport-specific and regional opportunities for serving these charging demand loads.

Georgia Tech provided NREL with simulated flight schedules that aimed to capture the regional air mobility demand in various regions. The researchers used a national travel survey to identify potential regional air mobility routes based on existing travel patterns and several economic factors (Cox et al. 2023). This travel replacement method was then employed to generate a flight schedule for regional air mobility in the Colorado region. The methodology is outlined in more detail by Georgia Tech in a published report (Justin, Payan, and Mavris 2022).

NREL worked with partner airports within the study focus region and reported the fleet sizes of their various flight schools. Not all airports discussed in this report provided flight school information. Where needed, the research team developed modeled flight school aircraft operational patterns based on the available training fleet information received from airports and their associated flight schools.

Rocky Mountain Metropolitan (BJC) and Northern Colorado Regional airports provided NREL with the tail numbers of specific aircraft at the McAir and Aims Community College flight schools. These numbers allowed us to obtain flight records for those aircraft from FlightAware, which hosts public flight information across the country. The flight records obtained from FlightAware provided the operations for 17 total flight school single-engine aircraft operating between October 5, 2023, and October 15, 2023. The 17 aircraft did not encompass the entirety of the flight school's fleet operations but were instead used as a sample from which full fleet operations could be scaled up. The sample represents typical flight operations for these aircraft for the given dates in October. Future studies could incorporate larger samples across several months to better represent flight school operations that could vary throughout the year.

To model flight school operations for a typical week in October, the reported fleet size of the flight school being modeled was input, and the software model randomly selected the tail numbers from the available aircraft flight pattern sample data. The model then used randomly selected tail numbers to generate weekday and weekend flight schedules for each day of the week and aggregated them to provide 1 weeks' worth of flight school operations. This information provided the research team with a feasible flight school pattern for analysis purposes.

Next, an analysis was conducted to determine the number of chargers necessary at each airport based on the arrival and departure times, as well as the aircraft type, for each flight passing through the airport in a single day. The methods applied to calculate energy demand varied between passenger flight aircraft and flight-school aircraft.

3.1.1 Electrified Aircraft Specifications

Although a variety of electrified aircraft exist, none are currently capable of providing the passenger travel simulated in the flight schedules developed by Georgia Tech and used in this study. Assumptions about the aircraft battery cell chemistry and voltages were made based on existing specifications for similarly sized aircraft batteries produced by Electric Power Systems, Inc., a leader in certifiable electric power systems for high-reliability applications. The simulated passenger flight schedules include 9-, 19-, and 30-passenger aircraft. The 19- and 30-passenger aircraft are marked as hybrids and are meant to limit their battery use to certain phases of the flight, and therefore typically need less recharging to top up the battery in between flights. The models assume the batteries are to be charged to 95% SOC after each flight for the purpose of this study, which we believe to be a higher SOC than the minimum required SOC to meet the next flight mission and as such will provide a conservative high end estimate of charging power requirements. Table 4 describes the modeled representative aircraft used in this study.

Table 4. 4Representative Study Aircraft

Aircraft Type	Battery Size (Capacity	Hybrid	Note
2-Passenger (Pax) (Flight School)	100 kilowatt-hours (kWh)	N	Take off and land at same airport
9 Pax (RAM)	448 kWh	N	Energy consumption equivalent to jet fuel use of same flight
19 Pax (RAM)	142 kWh	Y	Battery power used for take-off and climb only
30 Pax (RAM)	254 kWh	Y	Battery power used for take-off and climb only

3.1.2 EV Charger Specifications

Power rating and charging speed are two key factors in determining the hourly loads required to support electric aircraft charging demand. As mentioned, a maximum power rating of 3 MW was assumed for all chargers and 1C, 2C, and 4C charging rates were modeled for each airport. Site-specific charging infrastructure needs will vary based on aircraft battery sizes and desired charging speeds. A battery's charge and discharge rates are controlled by the battery C rate (a measure of current at which the battery is charged and discharged). Table 5 describes the service times for different C rates. These charger specifications follow the approach in Cox et al. (2023).

Table 5. 5C Rating and Time to Fully Charge a Battery

C Rating	Service Times
1C	60 minutes
2C	30 minutes
4C	15 minutes
5C	12 minutes
10C	6 minutes

Information from Power Sonic (2021) and adapted by NREL

Note: this study only considers 1C, 2C, and 4C charging cases

3.1.3 Energy Per Flight Calculation

Data provided by Georgia Tech included estimates for energy consumption required for passenger aircraft travel. As NREL developed flight school flight data, the research team needed to create similar estimates on energy consumption during flight. NREL used the AEROSim model,[7] which estimates energy consumption based on air speed, and other flight factors. Using the flight school tail numbers provided from McAir and Aims Community College and FlightAware data, the following average energy outputs for different types of aircraft were estimated, as summarized in Figure 2.

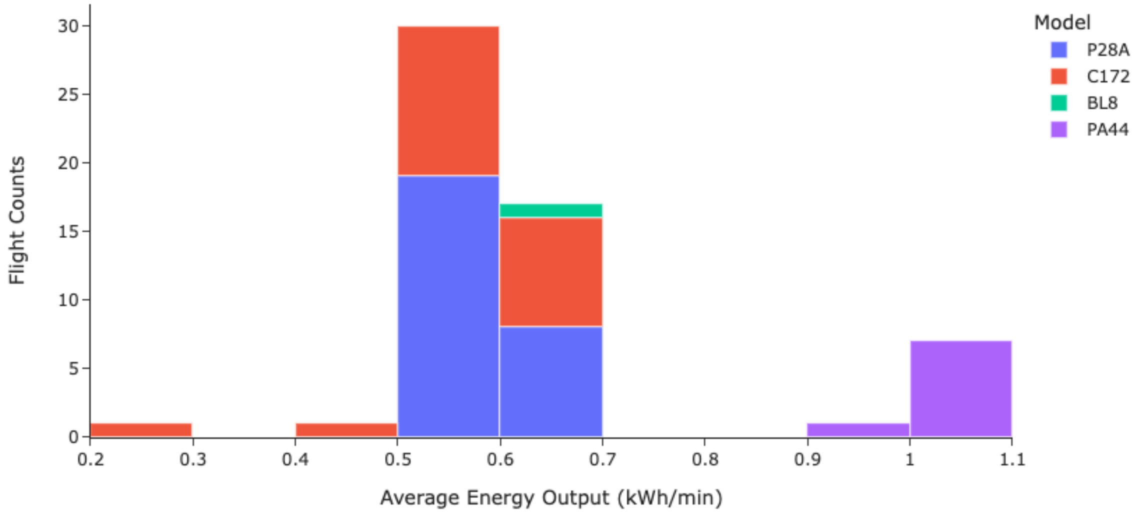

Figure 2. Energy used per minute during a flight based on airplane type

The average energy consumption per minute is summarized in Table 6.

Table 6. 6Average Energy per Minute for Airplane Type

Aircraft Model	Energy per Minute (kWh/min)
P28A	0.59
C172	0.57
PA4A	1.03

This information provided the research team with estimates on the amount of electricity that would be required to recharge flight-school aircraft following different types of training routes. The total electricity demand needed to recharge the flight school aircraft was combined with passenger RAM electrical loads for estimating EVSE requirements at the airport level.

3.1.4 Estimating Number of Chargers per Airport

We estimated the total number of chargers needed to meet charging demand and maintain flight schedules using a custom charging model that estimates charging durations based on arrival SOC, aircraft battery size, and 1C, 2C, or 4C charging rates and charge acceptance curves. To ensure that fast-charging operations were not limited by the maximum power draw, a default charger max power rating of 3 MW was used. The power rating required for a specific site should be determined by the peak power draw during charging. The charger estimation model

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[7] https://www.nrel.gov/docs/fy24osti/89450.pdf#page=1.00&gsr=0

assigns the first flight to a charger and determines how long that charger will be in use. If the charger is still in use by the time the next flight arrives, an additional charger is added to the site so that the next flight can begin charging after landing and taxi time. This process is repeated until all flights have been charged and the total number of chargers required for that scenario is stored and used as an input to the EVI-EnSite model that generates the hourly load profiles for each EVSE charger and scenario. This EVSE charger estimation method is prone to overestimating the required number of chargers, as it does not consider the possibility for arriving aircraft to wait in a queue if it has sufficient time to do so before its next departure. EVI-EnSite also does not take the next departure time into account and uses a first-come-first-served charging algorithm. The first-come-first-served charging algorithm can lead to unused, underused, and overused chargers in the model, potentially impacting peak load demand in the model. To address this issue would require a managed charging approach as opposed to the first-come-first-served charging model currently in place, which could be evaluated in future studies.

3.2 On-Site Renewable Energy Infrastructure to Offset Aircraft Charging Loads

3.2.1 Model Overview

NREL's Renewable Energy Optimization (REopt) model was used in this study to understand how on-site DERs can be used to offset the costs of serving electric-aircraft-related charging loads (NREL n.d.). Efforts complement related Engage modeling; however, a more detailed understanding of site-specific criteria is required. A total of six airports of specific interest were evaluated in detail with REopt.

This model is formulated as a mixed-integer linear optimization and takes a site-specific behind-the-meter (utility customer) perspective. Given all relevant inputs for a site, REopt can be used to find the least-cost way of operating on-site behind-the-meter DERs to minimize the cost of energy over the analysis period. This model is accessible as a web tool,[8] application programming interface,[9] and a Julia package,[10] with the latter two options enabling programmatic access. This model is being used in this study because it can help determine if on-site behind-the-meter DER investments make economic sense at airports. REopt results also include a dispatch strategy for any identified or existing DER system that describes how the system should be operated to maximize cost savings. Results presented in this report describe the system sizes and project economics, as well as the dispatch strategy for select scenarios. REopt can also be used to model resilience or energy goals or both along with the cost-minimization objective to identify how systems can help a site meet its operational goals. This analysis does not consider either resilience or energy goals per the current scope.

Key REopt inputs, outputs, and drivers are detailed in Figure 3. The model considers a site's electric and thermal loads and determines the optimal technology mix to meet those loads given site goals and other financial and economic drivers. Loads can be provided as measured interval data from the respective metering device or simulated in REopt based on DOE's Commercial

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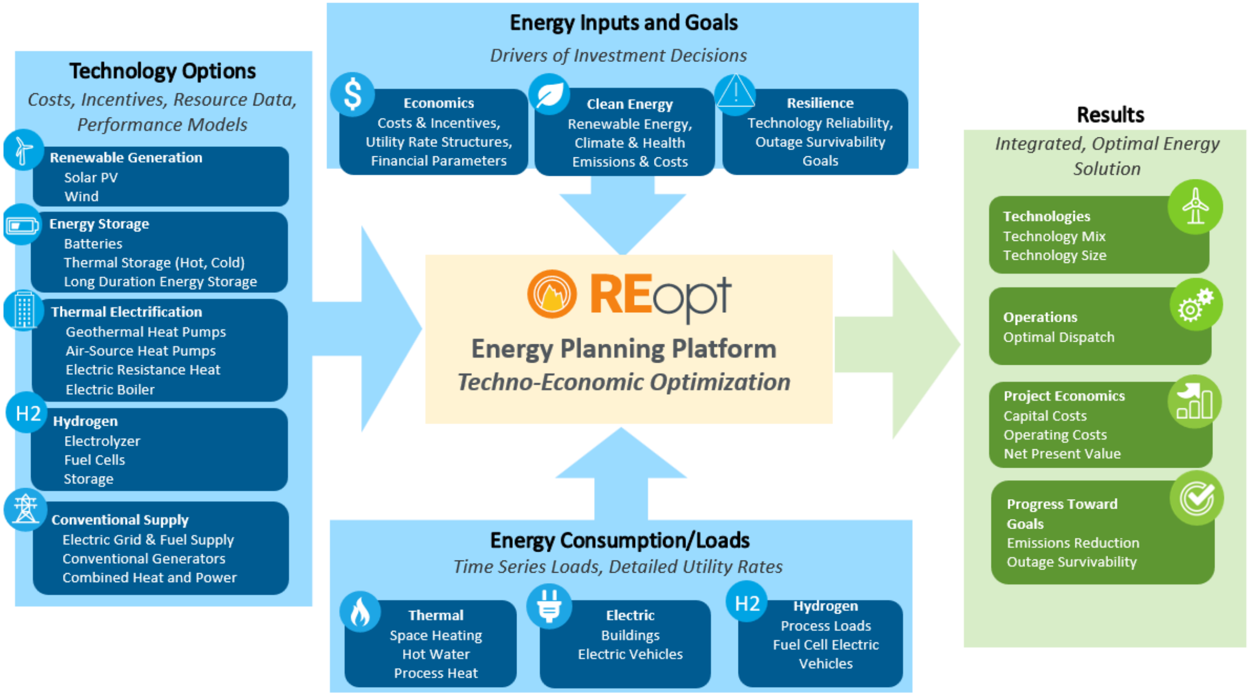
[8] https://reopt.nrel.gov/tool

[9] https://github.com/NREL/REopt_API

[10] https://github.com/NREL/REopt.jl

Reference Buildings dataset (Office of Energy Efficiency and Renewable Energy n.d.). This analysis considers EVSE load time series data developed by EVI-EnSite for quantifying electric loads. The input electrical load was only characterized for a single day, and was therefore duplicated to produce a year of electrical loads from passenger RAM and electrified flight training aircraft.



Formulated as a mixed integer linear program, REopt provides an integrated, cost-optimal energy solution.

Figure 3. REopt model inputs, outputs, and drivers

Another key model input is the electric tariff, which details how an electric utility charges the site for electricity consumed. Tariffs being considered under this analysis primarily comprise energy charges and demand charges, along with any extra adjustments as approved by a state's public utilities commission (also explained in Table 7). Typically, REopt users provide a label for the electric tariff of interest from OpenEI's Utility Rate Database[11] (OpenEI n.d.). This database is updated over time and contains a wide variety of tariffs that can be readily ingested by REopt. All tariffs being used in this analysis were obtained from the database and updated according to the latest public cost data provided by electric utility websites.

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[11] https://openei.org/wiki/Utility_Rate_Database

Table 7. Brief Explanations of Electric Tariff Components

Rate Component	What It Is	What It Would Mean in Terms of Driving
Energy Charges	Cost per unit of energy consumed in a month	A charge per mile traveled on a trip
Demand Charges	Cost of the quickest rate of energy consumption during a month	A surcharge on how quickly energy can be added during a month
Time of Use Charges	Variable pricing based on when energy or power is used	Variable charge based on when distance is covered or top energy transfer speed is achieved

REopt outputs comprise identified system sizes, investment economic details (such as cash flows), and dispatch strategies that highlight how technologies can be used to maximize cost savings. Figure 4 describes the model workflow for REopt. Given a site with valid inputs, a REopt "run" involves two individual optimizations. The first optimization is the business-as-usual, or BAU, scenario, which models the site's existing energy consumption and resulting costs. The second optimization is a financial case that allows the REopt tool to purchase and install new behind-the-meter DERs if these technologies can reduce costs over the analysis period. As a result of these optimizations, REopt calculates two different all-inclusive life cycle costs of serving electricity. The difference in life cycle costs between the optimized and the BAU case is the net present value (NPV). Note that the model has perfect foresight, therefore results provide an upper-bound estimate of the financial merit of the evaluated technologies. Furthermore, REopt results are sensitive to the combination of site-specific inputs provided and should not be extrapolated beyond the specific scenarios modeled. The NPV of cost savings calculated by REopt does not include any microgrid controller costs or costs for power system protection systems. Additionally, the cost savings do not include any costs avoided from potential distribution system upgrades that may have been required to serve load growth.

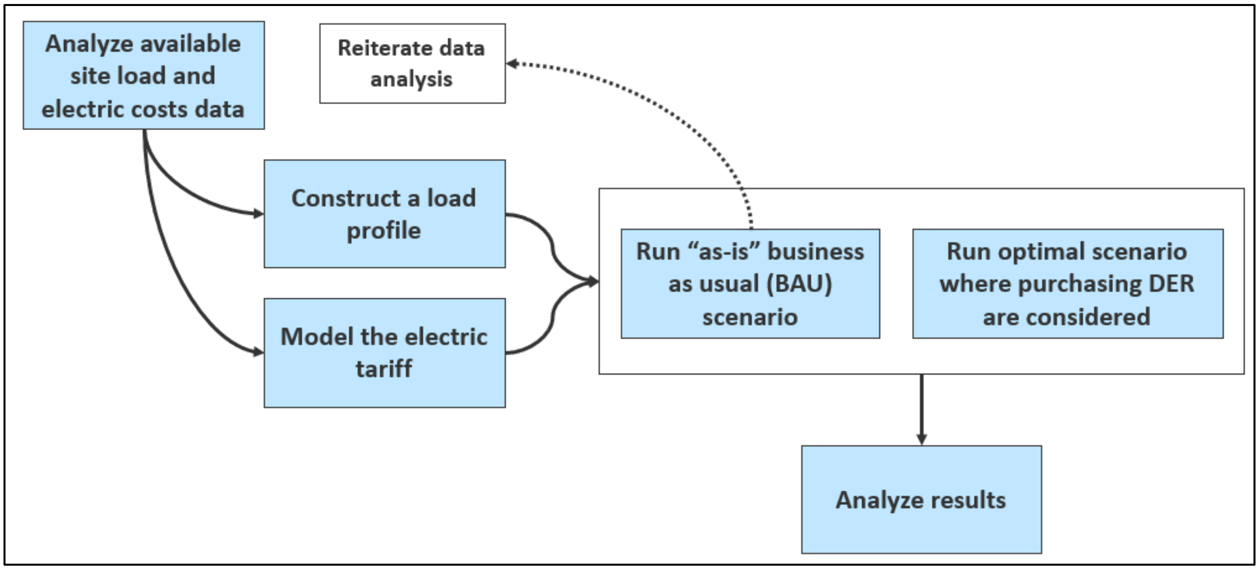

Figure 4. REopt modeling workflow

3.2.2 Averaging Electric Vehicle Service Equipment Demand for Demand Charges

EVI-Ensite was used to develop electrical loads from the EVSE chargers at a 1-minute (min) temporal resolution. However, the REopt analysis averages all time-series data to 15 min to match standard electric utility demand charge calculations. This step ensures cost minimization and on-site BESS sizing to reduce the 15-min-averaged charging peaks. Averaging demand results in a smoothing of the EVSE loads time series with on-site BESS not being sized to lower the per-minute charging peaks; however, Lowering EVSE charging peaks from an instantaneous peak demand perspective was not an objective in this step of the analysis.

3.2.3 Airports Selected for Detailed Site Modeling

Cost-optimal solar PV and BESS system sizes were identified to maximize electric utility bill savings under direct or third-party ownership models for 1C, 2C, and 4C C rates. It was assumed that the new RAM and flight school loads would be placed on a new meter, as opposed to an existing meter. Primary electric utility rates were used for this analysis. Additional details on the rate schedules and rationale for selections are detailed in the following subsections. The airports selected for detailed site analyses are listed in Table 8, along with whether RAM and flight school loads were considered, and which electric rate schedule was used for modeling.

Table 8. Airports Considered for Detailed REopt Analysis

Airport	RAM Loads	Flight School Loads	Electric Rate Schedule
Albuquerque International Sunport (ABQ)	Yes	Yes	Public Service of New Mexico large power service time of use/time of day
Rocky Mountain Metropolitan Airport (BJC)	Yes	Yes	Xcel Colorado’s primary EV rate
Colorado Springs Airport (COS)	Yes	Yes	City of Colorado Springs E8T rate
Denver International Airport (DEN)	Yes	No	Xcel Colorado’s primary EV rate
Durango-LaPlata County Airport (DRO)	Yes	Yes	La Plata Electric Association’s LP31
Grand Junction Regional Airport (GJT)	Yes	Yes	Xcel Colorado’s primary EV rate

In addition to EVSE loads, existing building electrical load data was considered, independently of EVSE loads at Durango-LaPlata County Airport (DRO) and Grand Junction Regional Airport (GJT). The purpose of this step was to identify opportunities for DERs such as PV and BESS to provide cost savings in electric utility bills and revenue benefit from exports to the grid under status quo at these two airports. These non-EVSE scenarios were executed using the REopt model, and detailed input parameters, modeling caveats, and results are provided in the corresponding results sections. Note that in absence of airport loads data for GJT, its electric load profile was simulated by scaling DRO’s electric load time series per GJT’s monthly billed electric consumption. These two airports were selected because they represent two rate structures that are relevant to most of the airports in the Colorado study.

The following sections describe additional assumptions used for the analysis.

3.2.3.1 *Albuquerque International Sunport*

Details on the Albuquerque International Sunport (ABQ) include the following:

- Location: Albuquerque, New Mexico
- Existing site peak demand of 870 MW and annual airport wide energy consumption of 13,637 megawatt-hours (MWh)
- Electric utility: Public Service of New Mexico (PNM)
- Rate schedule chosen for EVSE loads: Large Power Service Time-of-Use/Time-of-Day (schedule 4B). Note:

    - PNM provides a nonresidential charging station rate, but it is a pilot rate. Schedule 4B was used because it is a regular PNM rate that is suitable for EVSE whose loads can exceed 500 kW (see Table 9).

- The airport did not provide any information related to solar PV siting. Therefore, this analysis considers ground-mount PV placement around the EVSE meter without any area restrictions. This assumption can be revisited if large PV systems are identified by REopt modeling.
- The airport was only analyzed for situations with future aircraft loads.

Table 9. 7 PNM Large Power Service Time of Use/Time of Day (Schedule 4B)

Rate Component	Value	Notes
Monthly Base Charge	$666.65/month	Applies if the site's demand exceeds 500 kW for 12 months or more
Energy Charge	Summer on-peak: $0.0203688/kWh Summer off-peak: $0.0105786/kWh Winter on-peak: $0.0159947/kWh Winter off peak: $0.0105786/kWh	Summer: June, July, August On peak: 0800–2000 hours weekdays
Demand Charge (Public-Service-of-New- Mexico-Owned Transformer)	Summer: $30.74/kW Nonsummer: $22.09/kW	Applies only during on-peak periods
Other Energy Adjustments	Estimated to $0.04/kWh	Sum of the fuel charge rider $0.0318 and renewable energy adjustment, round up to 4 cents
Net Metering	Yes, but not modeled	Only 10 kW or smaller systems are permitted to net meter per the latest net energy metering (NEM) rate schedule
Voltage	Primary	

3.2.3.2 Rocky Mountain Metropolitan Airport

Details on the Rocky Mountain Metropolitan Airport (BJC) include the following:

- Location: Broomfield, Colorado
- Existing site peak demand of at least 0.15 MW and yearly energy consumption of at least 600 MWh
- Electric utility: Xcel Energy (Colorado)
- Rate schedule chosen for EVSE loads: Primary voltage EV rate (PEV; see Table 10)
- PV area availability: airport shared various parcels of land that are eligible for ground-mount solar PV installation that extends across the airport, totaling approximately 52.8 acres
- Assuming 6 acres/MW solar PV density used in REopt modeling, the maximum possible PV at BJC is approximately 8.8 MW.

  The airport was only analyzed for situations with future aircraft loads.

Table 10. Xcel Colorado Primary EV Rate

Rate Component	Value	Adjustments, Added to Charge
Monthly Base Charge	$894/month	Summer: June 1–September 30 Winter: October 1–March 31 On peak: 1400–2200 hours all nonholiday weekdays
Demand Charge	$2.74/kW	
Energy Charges	*Charges* Summer peak: $0.10685/kWh Summer off peak $0.02140/kWh Winter peak: $0.05334/kWh Winter off peak $0.01071/kWh *Final energy charges* Summer peak: $0.18583/kWh Summer off peak: $0.07996/kWh Winter peak: $0.13232/kWh Winter off peak: $0.06927/kWh	*Adjustments*[12] Summer peak: $0.07898/kWh Summer off peak $0.05856/kWh Winter peak: $0.07898/kWh Winter off peak $0.05856/kWh
Net Metering	Solar PV was allowed to net meter at this site, with the eligible PV system size limit set to 200% of annual EVSE energy consumption.	
Voltage	Primary	

3.2.3.3 Colorado Springs Airport

Details on the Colorado Springs Airport (COS) include the following:

- Location: Colorado Springs, Colorado
- Existing site peak demand of 0.58 MW and yearly energy consumption of 543 MWh
- Electric utility: City of Colorado Springs Utilities
- Rate schedule chosen for EVSE loads: Industrial Service–Time-of-Day 500 kW Minimum (E8T; Table 11); specifically:
    - The commercial EV charging rate was not available for privately owned EVSE.
    - Because off-peak hour peak demand is the same as peak hour peak demand due to the repetitive nature of EVSE loads, the off-peak demand charge was not modeled. As a result, demand charges only apply from 11 a.m. to 6 p.m. in summer and 4 p.m. to 10 p.m. in winter.
- PV area availability: airport shared various parcels of land that are eligible for a ground-mount solar PV installation that extends across the airport, totaling approximately 160 acres
- Per 6 acres/MW solar PV density used in REopt, maximum possible PV at COS is approximately 26 MW
- For this analysis, the focus was on evaluating future airport loads.

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[12] Adjustments include a demand-side management cost adjustment (1.439 cents/kilowatt-hour [kWh]), purchased capacity cost adjustment (1.1 cents/kWh), transmission cost adjustment (0.583 cents/kWh), electric commodity adjustment (varies from $2.042 cents/kWh, off-peak hours to 4.084 cents/kWh peak hours), transportation electrification program adjustment (0.239 cents/kWh), and extraordinary gas cost recovery rider (0.453 cents/kWh). The renewable energy standard adjustment was not modeled.

Table 11. City of Colorado Spring's Industrial Service–Time of Day 500-kW Minimum Rate

Rate Component	Value	Notes
Access and Facilities Charge	$22.7068/day	Peak demand determination: greatest measured demand over a 15-minute period Peak hours are April–September, 1100–1800 hours, October–March, 1600–2200 hours. All other hours are off peak. Off-peak demand determination includes: • Either off-peak maximum demand minus peak maximum demand OR • (Not modeled) 68% of the greatest demand from the last 12 months minus the peak demand[13]
Demand Charges **All Other hours – Off Peak**	$0.7838/kW/day; peak hours $0.0/kW/day; off-peak hours	
Electric Cost Adjustment	$0.0452/kWh $0.0200/kWh	
Electric Capacity Charge, per kWh	$0.0032/kWh	
Net Metering	Applicable	Excess PV compensation at ~$0.019/kWh; can size to 120% of site's annual kilowatt-hour consumption; maximum 150 kW alternating current for PV
Voltage	Primary	

3.2.3.4 Denver International Airport

Details on the Denver International Airport (DEN) include the following:

- Location: Denver, Colorado
- Existing site peak demand more than 40 MW and yearly energy consumption of 193,758 MWh
- Electric utility: Xcel Energy (Colorado)
  Rate schedule chosen for EVSE loads and net metering: Primary EV Rate (see Table 10)
- The airport did not provide any information related to solar PV siting. Therefore, this analysis considers ground-mount PV placement around the EVSE meter without any area restrictions. This assumption can be revisited if large PV systems are identified by REopt.
- For this analysis, only forecasted aircraft loads were evaluated. DEN has published significant analysis on future energy forecasts excluding aircraft.

3.2.3.5 Durango–La Plata County Airport

Details on the Durango-La Plata County Airport (DRO) include the following:

- Location: Durango, Colorado

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[13] One way to determine off-peak demand is to subtract maximum peak demand from 68% of the greatest demand from the last 12 months. The model is formulated in a way that prohibits subtracting demands, which is why that demand determination was not modeled.

- Existing site peak demand of 0.27 MW and yearly energy consumption of 1,439 MWh
- Electric utility: La Plata Electric Association (LPEA)
- We modeled existing airport loads[14] with peak demand of 268 kW and yearly energy consumption of 1,359 MWh using LPEA's Large Commercial rate (LP30). The rate includes a $15.21/kW/month demand charge and $0.0672/kWh fixed energy charge.
- The rate schedule chosen for EVSE loads was LPEA's Commercial Large General Service (Primary) rate (LP-31). Specifically:
    - This utility has an energy-charge-only EV rate offering but is categorized under the "residential" rate type per their website. Therefore, the LP31 rate schedule was included for modeling purposes (Table 12).
- PV area availability: airport shared the availability of 7.12 acres with existing utility access and ~114 acres without existing utility access
- Per 6 acres/MW solar PV density used in REopt, maximum possible PV at DRO is approximately 1.18 MW and 19 MW on land with no utility access
- For this analysis, both existing operations and forecasted aircraft loads were evaluated.

Table 12. La Plata Electric Association's Schedule LP31

Rate Component	Value	Notes
Monthly Base Charge	$100/month	
Energy Charge	$0.0905/kWh peak $0.0609/kWh off peak	Peak 1200-2200 hours Monday through Saturday Off-peak energy charge: all other hours
Demand Charge	$7.85/kW	
Net Metering	Yes	A limit of 1,000 kW was used in absence of a PV system size limit from utility resources.
Voltage	Primary	

3.2.3.6 Grand Junction Regional Airport

Details on the Grand Junction Regional Airport (GJT) include the following:

- Location: Grand Junction, Colorado
- Existing site peak demand more than 0.5 MW and yearly energy consumption of 2,100 MWh
- Electric utility: Xcel Energy (Colorado)
- In absence of data from the airport, the DRO existing building load profile was scaled up/down per billing data to synthesize existing airport loads for GJT. The resulting profile had a peak demand of 424 kW and yearly energy consumption of 2,100 MWh. Xcel Energy's Secondary General Service (Schedule SG) was used for the electric tariff.
- The rate schedule chosen for EVSE loads and net metering: Primary EV rate (see Table 10)
- PV area available:

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[14] Electric loads for terminal, aircraft rescue and firefighting, lighting, and airport road meters were added and converted to kilowatts (power) to form the input Durango-La Plata County Airport's existing buildings load profile time series.

    - Roughly 32 acres, which can include either ground-mount solar PV, or roof-mount PV installation (if the land parcel is developed into buildings). Rooftop PV is more expensive, but the costs may be justified using tax revenue brought in by businesses.
        - If PV was found to be cost-effective as ground-mount PV, the model was run again using roof-mount PV costs to assess the feasibility of both options for the airport
        - Roughly 12 acres were assumed to accommodate carport canopy solar PV, but this is most expensive installation option compared to ground-mount or roof-mount solar PV.
- For this analysis, both existing operations and forecasted aircraft loads were evaluated.

3.2.4 Techno-Economic Modeling Assumptions

This section details the techno-economic assumptions used in this analysis. As shown in Table 13, both direct and third-party ownership models were modeled at all sites, with a 0% effective tax rate for airports. The electricity cost escalation rate of +0.53% was calculated using National Institute of Standards and Technology rates (2024) with a 2.5% inflation rate for commercial projects in Colorado starting in 2025 and lasting for 25 years. Airports are considered tax exempt and qualify for direct pay under direct ownership, making them eligible for a 30% investment tax credit (ITC) per the Inflation Reduction Act (The White House n.d.). Both direct and third-party ownership of the solar PV or, where applicable, BESS were modeled. Evaluating a third-party ownership approach for the systems provided a comparison of the impacts of both modified accelerated asset and bonus depreciation.

Table 13.8 Financial Parameters

Parameter	Explanation
Technologies Evaluated	Solar photovoltaic (PV), battery energy storage system (BESS)
Objective	Minimize life cycle costs
Ownership Models	Direct airport ownership Third-party ownership (developer)
Analysis Period	25 years, typical for a REopt analysis
Inflation Rate	2.5% (National Renewable Energy Laboratory [NREL] 2023)
Discount Rate (Nominal)	Airport/developer: 6.38% (NREL 2023)
Electricity Cost Escalation Rate (Nominal)	0.53%/year per the National Institute of Standards and Technology’s (NIST) Energy Escalation Rate Calculator (NIST 2024)
Effective Tax Rate	Airport: 0% Developer: 26% (21% federal + 5% state per NREL (n.d.)

This analysis primarily focuses on the cost-effectiveness of ground-mount PV systems. As described earlier, DRO, GJT, BJC, and COS shared details on which land, rooftop, or carport area may realistically be considered for ground-mount, rooftop, or carport PV installations at each site. For ABQ and DEN, it was assumed that PV had no area restrictions. In all cases, a solar glare analysis should be considered to ensure PV placement will not interfere with flight operations. At these two locations, the optimal system sizes identified by REopt and their associated land requirements can be investigated by airport staff against the actual land available for development at the airports. Table 14 provides the parameters selected for the solar PV systems used in the REopt modeling.

Table 14. Solar PV System Parameters

Parameter	Explanation
System Type	Ground-mount, fixed, standard modules
Technology Resource	Site-specific typical meteorological year weather data from the National Solar Resource Database (NREL 2022)
Inverter Efficiency	96%
Azimuth	180 degrees (south facing)
Installed Capital Cost[15]	Ground mount: $1,790/kWdc Roof mount: $2,032/kWdc (derived from various internal sources)
Panel Tilt Angle	20 degrees
Direct Current (DC)/Alternating Current (AC) Ratio	1.2
Operation and Maintenance Cost	$18/kWdc/year
Incentives	Direct ownership: 30% investment tax credit (ITC) Third-party ownership: 30% ITC, 5-year Modified Accelerated Cost Recovery System (MACRS), 40% bonus depreciation in year 1 (U.S. Department of Energy Solar Energy Technologies Office 2024)

Table 15 provides the BESS technology input parameters used in this analysis for stationary on-site BESS. Key among these are the replacement cost and year, which is how REopt factors nonlinear battery degradation into the optimization. The analysis purchases the same BESS as year 0 in year 10 with the assumption that the second BESS lasts for the remainder of the analysis period.

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[15] The photovoltaic (PV) cost is a fully burdened install cost and includes equipment and labor for a typical distributed PV system per the cited source.

Table 15. BESS Technology Input Parameters

Parameter	Explanation
Battery Type	Lithium-ion
AC-AC Round-Trip Efficiency	89.9% (97.5% internal, 96% inverter, 96% rectifier)
Minimum State of Charge	20% (battery charge is managed to stay above this minimum)
Capital Costs	$910/kW + $455/kWh based on Wood Mackenzie's U.S. Energy Storage Monitor (2023)
Replacement Costs (Scheduled in Year 10)	$715/kW + $318/kWh based on Wood Mackenzie's U.S. Energy Storage Monitor (2023)
Allow the Utility Grid and Any On-site PV to Charge the Battery?	Yes
Incentives	Direct ownership: 30% ITC (Energy Star n.d.) Third-party ownership: 30% ITC and 5-year MACRS depreciation, no bonus depreciation

3.2.5 REopt Scenario Definitions

For each airport where EVSE loads were considered, the behind-the-meter system sizing focused primarily on the following scenarios:

- EVSE loads were varied between RAM only, FLS only, and RAM+FLS loads
    - For each, EV charging speeds were either 1C, 2C, or 4C
        - For each load and charging speed combination, direct and third-party ownership were considered.

These scenarios helped assess different charging loads at varying C-rate requirements. Variation between direct and third-party ownership allowed this work to explore the impact of Modified Accelerated Cost Recovery System (MACRS) and bonus depreciation on identified systems.

Sample analyses of existing airport operations (no new aircraft loads) were completed for two representative sites.

3.3 Aircraft Electrification Impacts on Grid and Regional Airport Infrastructure (Engage)

3.3.1 Model Overview

Where REopt optimizes DER build-out and dispatch at the site level, the Engage model enables users to account for distribution system upgrade costs when optimizing DER build-out and dispatch, allowing us to consider grid-level impacts from added EV charging demand. Using the electricity demand profiles for each case generated by EVI-EnSite, airport charging loads were modeled in Engage with the surrounding distribution system and the possibility of new on-site PV and BESS and additional distribution system capacity to serve the electrical load at minimum cost. Both models were performed to provide analysis for stakeholder use.

A standard airport layout was assumed and Engage models were run on all 40 airport locations in the study for multiple scenarios, including representative rates; however, not necessarily the specific rate for that location.

The NREL Engage capacity expansion web application[16] was used for techno-economic modeling of the airport charging, on-site assets, and upstream distribution system to explore the optimal sizing of on-site assets including utility and on-site distribution system upgrades. Engage is an accessible, flexible energy and commodity infrastructure planning model for exploring s across multiple energy sectors. Engage's cloud-based shared data model, intuitive interface, and visualization capabilities facilitate collaboration and communication among diverse stakeholder groups, teams, and experts modeling systems from the district energy/microgrid to national scales. Engage is hosted on NREL's computing infrastructure and is free to access and use online. Engage uses Calliope,[17] a multiscale energy systems modeling framework, to formulate its capacity planning problems and generate results datasets. Both Engage and Calliope are open-source and available for local installation including intranet hosting and custom installations.

Figure 5 describes the types of inputs required and the outputs the model generates.

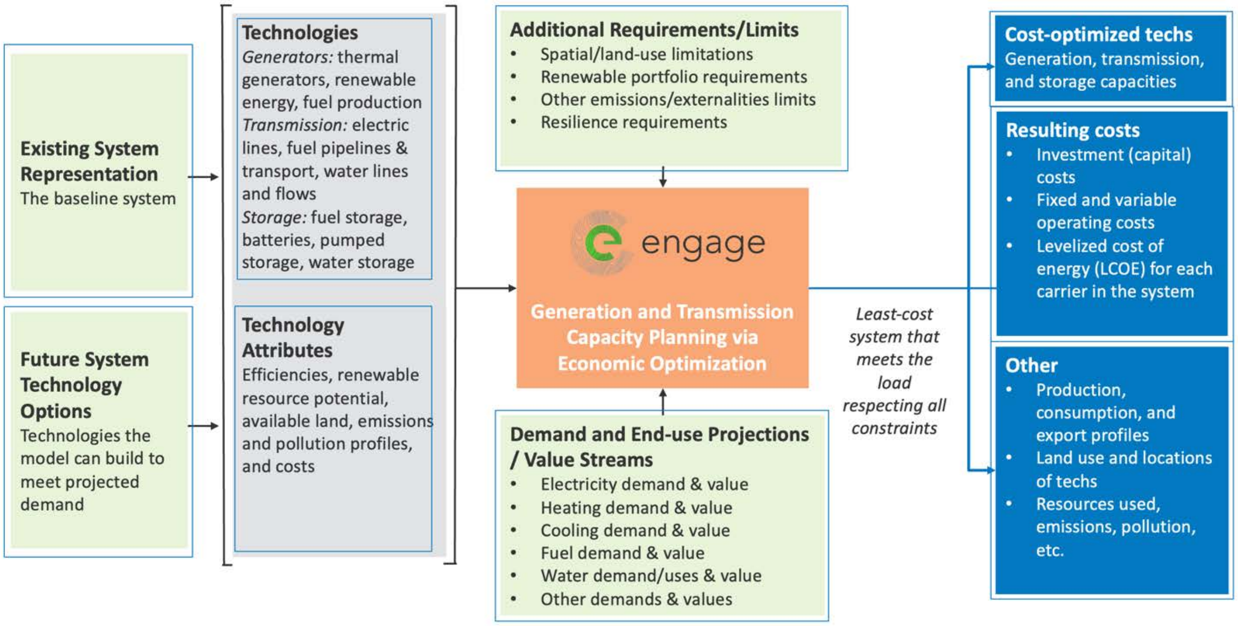

Figure 5. Input configuration and output results for the Engage web application

In typical use, a model of the existing, or baseline, system is configured in Engage. This comprises representations of existing technologies, which may include generators, transmission, and storage technologies. It could also include their attributes, such as efficiencies; resource potential; costs; embedded and generated emissions and other externalities; and other characteristics as determined relevant by the modeler. Baseline energy and/or commodity

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[16] https://www.nrel.gov/state-local-tribal/engage-energy-modeling-tool.html
[17] https://www.callio.pe/

demand (or related market prices so that demand depends on cost to generate being lower than the market price) are also configured. The baseline system model can be run in simulation mode to generate least-cost dispatch to meet baseline demand and sell energy into the market. In addition to the baseline system, options for building future technologies and infrastructure can be provided, and the model will least-cost optimize building these options to compete with technologies in the baseline system and/or meet growing load or market opportunities. Technologies can be programmed to retire on a schedule or when they are no longer economically feasible to own, maintain, and operate. Finally, the model can be configured to respect land-use limitations when constructing future technologies, as well as renewable portfolio requirements, emissions costs or limits, or specific resilience requirements, such as the ability to serve load through one or more specific outages or equipment failures.

Engage provides the least-cost combination of technologies and infrastructure and their generation, storage, and energy-carrying capacities that meet all constraints, demand, and market opportunities. It also provides investment costs and fixed and variable operating costs and calculates the levelized cost of each “carrier” in the system, in which carriers can be any energy form or commodity. It also provides externalities such as emissions as an output. Finally, it provides the least-cost dispatch of carriers, land used, and resources consumed to generate carriers, such as consumption of water.

In this study, Engage was used to find the least-cost approach to meet electrified aircraft charging loads and upgrades that would be required to on-site and utility electric distribution system infrastructure. These upgrades could include substation transformers, utility distribution feeders, on-site underground distribution feeders, and, as an alternative to these electric distribution system upgrades, on-site PV and BESS to meet the high demand peaks expected from DCFC aircraft charging. Engage is well-suited for evaluating least-cost approaches to load serving accounting for distribution system infrastructure cost because, in addition to optimizing capacities and dispatch of generation and storage technologies, it can be used to plan transmission (electrical lines). This capability was leveraged to model existing and optional distribution feeders as well as substation equipment that could be built to serve growing load with high demand for charging electrified aircraft.

Engage was also used to model a utility revenue meter, through which utility-supplied electricity was delivered to the airport distribution system. The model generated monthly costs based on specific utility tariff structures. Engage is appropriate for this study as it is well-suited for capacity modeling of the behind-the-meter airport infrastructure—including the on-site distribution system—in an integrated fashion with modeling the utility distribution system. The power-carrying capacities of these systems, along with the production and storage capacities of on-site solar PV and BESS, are relevant in assessing the combined capacity of the site’s resources and the grid to serve significantly growing electrical load, including DCFC of electrified RAM aircraft.

The high-demand load growth associated with implementing RAM electric aircraft charging, without additional generation and storage, extends beyond the airport. Individual DC fast chargers anticipated for larger RAM aircraft are projected to request megawatts of demand. The megawatt charging standard currently being finalized covers up to 3 MW of charging capability for heavy industrial loads. With multiple chargers, the peak charging load of an airport can eclipse existing load. Meeting this load using grid power alone can overtax the existing electric distribution system, leading to system instability and potential service interruption.

Many feeders do not have adequate capacity to accommodate a new load of this magnitude and would require upgrades to do so. When needed, costs of such upgrades may be assigned to the customer by the utility as a separate charge or incorporated into the tariff and a minimum energy use. PV and BESS are often a cost-effective alternative to utility-supplied electricity, depending on the load profile of the site and the existing electric tariff. The potential cost-effectiveness of on-site PV and BESS improves when one considers the cost of necessary distribution system upgrades. PV and BESS can also help reduce peak grid demand and avoid the cost of distribution system upgrades, often resulting in greater cost-optimal capacities of PV and BESS.

3.3.2 Template Site Layout

Although each airport has a unique electrical distribution system layout, different location(s) elected for DCFC, and varying quantities of available land for potential PV a template was created for every airport modeled. The template ensured modeling efficiency and was based on available airport and utility infrastructure data. To start, several regional airports were reviewed to determine representative distances between utility connections and potential PV locations. Figure 6 shows an example template layout for the BJC airport with a primary focus on a representative measure of distance between elements of the system to accurately cost on-site underground cables. BJC provided a summary of developable parcels for this effort, but detailed analysis of runway protection zones, etc. was not completed in this study. Locations are expected to be adjusted to meet airport layout plan requirements and related airport criteria.

Figure 6. Layout of template airport model at BJC

The model was configured with a quarter-mile-long underground cable connecting the meter/utility service point to the charging infrastructure and a half-mile-long underground cable connecting the potential PV installation to the charging infrastructure. The cost to dig the trench was modeled independently from the cost of the underground cables to capture the reduced incremental costs for higher capacity once a trench had been dug. Unit cost guides for Colorado or other neighboring states are not readily available, therefore costs were pulled from the 2024 utility Unit Cost Guides from Pacific Gas and Electric[18] and Southern California Edison.[19] Previous versions of these two cost guides have been used as the source of numerous models including the NREL Distribution Integration Solution Cost Options database/software.[20]

DCFC installations require primary voltage power that is located close to the chargers to reduce losses from pushing large amounts of electric current over distance at secondary voltage. Most regional airports are served at secondary voltage and use secondary voltage tariffs for their existing loads (e.g., buildings, runway lights). Thus, for the new DCFC loads, new primary voltage connections and accounts with appropriate primary voltage utility tariffs were modeled. With this configuration, the model does not use DERs to meet existing secondary voltage site load, which would be behind a different meter and account. Some larger airports, on the other hand, have their own distribution system networks or substations, which are served from single or dual interconnection points to the distribution or transmission system. Such airports may have a single or main utility account associated with a single revenue meter, and those configurations were not assumed for this study.

3.3.3 Distribution System Upgrade Costs

The conditions and overhead capacities of feeders serving airports differ from airport to airport. Newer feeders or those at larger airports may have spare capacity for new load, but the serving feeders could be constrained, requiring upgrades to accommodate significant additional load. Distribution system technical information, including capacity use of feeders, is often proprietary data requiring cooperation with the serving utility to obtain and use. To assess potential distribution costs without specific data, the study assumed a standard distribution system configuration for all airports. Small variations were analyzed in template configuration to gauge impacts of the distribution system conditions on modeling results.

The model was configured with three options for increasing available grid supply capacity as the distribution system is upgraded, to what extent, or not at all. The cases were run with two variations, each of either 2 MW or 3 MW of baseline spare capacity on the utility distribution feeder. The two spare capacity values were chosen based on conversations with the utilities involved in the study and the available feeder capacities at the airports they serve. Upgrades would be required to serve larger loads, meaning the first tier only applied cost for the necessary riser, and meter for new primary service. If the model elects to draw more power from the grid, it must build one or more distribution system upgrades with commensurate costs. The second tier of connection would involve reconductoring the feeder with higher capacity lines, giving up to 6 MW of capacity for new load. If the model requires more than 6 MW, it can choose to reconductor the line and upgrade distribution substation hardware for capacity up to 10 MW. Table 16 shows the three potential tiers of distribution system connections the model could choose from as well as the total costs associated with each.

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[18] https://www.pge.com/assets/pge/docs/about/doing-business-with-pge/unit-cost-guide.pdf

[19] https://www.sce.com/sites/default/files/custom-files/PDF_Files/2024_Unit_Cost_Guide.pdf

[20] https://github.com/NREL/disco

Table 16.9 Engage Grid Connection Tiers/Costs

Tier	Cost	Explanation
2-/3-MW Overhead	$60,000	No additional distribution upgrades needed
6-MW Reconductor	$1,661,600	Reconductoring the feeder and connection to substation
10-MW Substation Upgrade	$5,252,100	Reconductoring and upgrading substation hardware

The components of each tier of distribution system upgrades were sourced from the Distribution Integration Solution Cost Options database and utility unit cost guides. Tables 17−19 provide a breakdown of the components included in each tier and their costs.

Table 17. 10Cost Breakdown of 2-/3-MW Supply

Component	Cost
Overhead-to-Underground Riser	$45,000
New Primary Meter	$15,000

Table 18. 11Cost Breakdown of a 6-MW Reconductor

Component	Cost
Overhead-to-Underground Riser	$45,000
New Primary Meter	$15,000
New Overhead Feeder Back to Utility Distribution Substation	$1,395,000
Five -1.5-kilovolt- ampere and one 500-kilovolt-ampere transformers	$206,600

Table 12. Cost Breakdown of 10-MW Substation Upgrade

Component	Cost
10-MW Distribution Substation	$5,000,000
Six 1.5-megavolt-ampere and one 1-megavolt-ampere transformers	$252,100

3.3.4 Charging Infrastructure Costs

The charging capacity was not optimized in the model—it was determined by the charging load, which is defined by scenario—but getting a cost estimate for charging infrastructure is needed to determine the final cost to provide the charging electricity for each airport. Megawatt-level fast chargers are not currently on the market, but a McKinsey & Company article by Frode et. al. (2023) provides a range of capital and installation costs for 350-kW DCFC chargers. The costs used in the model were calculated by determining the per-kilowatt cost of the mean costs sourced from the McKinsey report, which came out to $714.29/kW. It is noted that for the developing loads, charging speeds were not limited to the size of readily available DCFC chargers that appear relevant to early adopters. RAM aircraft manufacturers to meet up-time requirements move past the 350-kW charging rates and are discussing using charging standards under development that are rated up to 3 MW (the megawatt charging standard). Additional information on actual charging needs is covered in related sections.

3.3.5 Commercial RAM Aircraft Load

Utilities often use 15 minutes as a standard time interval over which instantaneous real power is averaged to determine peak demand for billing, so Engage was configured to use 15-minute time steps in its simulations for calculating peak monthly demands for billing purposes to determine electric utility costs for charging at the airports. The charging loads from EVI-EnSite were resampled to match. Aircraft charging loads for all three charging strategy cases, 1C, 2C, and 4C, were used for all 40 airports in the study. All rate cases and charging strategies were run for each airport with just the commercial aircraft load.

3.3.6 Flight Schools

Flight school schedules and charging loads were only developed for a subset of the airports in the study. For those airports, charging loads for 1C, 2C, and 4C charging strategies were resampled to 15 min to match the utility rate billing increments. These loads were incorporated as additional load on top of the passenger service load for the airports with assigned flight school loads. The airports with flight school loads were then run for all scenarios with both passenger and flight school loads.

3.3.7 Utility Tariffs

In coordination with the REopt task, several primary and secondary voltage tariffs were assessed from utilities serving the airports in the study. Although many utilities have secondary voltage tariffs designed for residential or small commercial-scale charging, only a few have primary voltage EV charging tariffs. Two primary voltage utility tariffs were selected to explore different types of tariff effects on the economics of DERs and may vary from the actual tariff for the provider servicing the location. The first tariff, Xcel Energy's 2024 Schedule P-EV rate (Public Service Company of Colorado n.d.) is specifically designed for large-scale EV charging loads. The second rate, LPEA's 2024 Primary Service Rate[21] is a general-purpose primary voltage tariff that represents connections with smaller utilities that may not have a dedicated primary voltage EV tariff. Table 20 compares the prices of the rate components of both tariffs.

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[21] https://lpea.coop/lpea-2024-rates

Table 20. 13Primary Voltage Tariff Components

Rate Component	Xcel P-EV	LPEA PSR
Demand Charge	$2.74/kW	$7.85/kW
Energy Charge (Peak)	$0.10685/kWh	$0.0905/kWh
Energy Charge (Off Peak)	$0.02140/kWh	$0.0609/kWh
Energy Charge (Peak Winter)	$0.05344/kWh	No seasonal variation
Energy Charge (Off-Peak Winter)	$0.01071/kWh	No seasonal variation
Additional Charges (Peak)	$0.07898/kWh	No additional charges
Additional Charges (Off Peak)	$0.05856/kWh	No additional charges

Xcel also offers a critical peak pricing version of the P-EV tariff (P-EV-CPP).[22] These tariffs provide significantly reduced energy charges across all periods/seasons except during a predefined number of periods of peak load/stress on the system, during which the energy charge goes up significantly. The utility/grid operator can designate a critical peak period a day or two before the stress period based on day-ahead load and generation forecasting. Xcel's P-EV-CPP tariff defines the critical peak period as a consecutive 4-hour period between 2 and 10 p.m. and specifies a maximum of 15 such periods a year. Critical peak and other similar tariff structures are becoming increasingly popular as they allow utilities to encourage load reductions or recoup the costs for the most expensive hours for the grid to operate while allowing customers who can reduce/shift load from critical peak periods to save on their energy bills. With otherwise significantly lower energy charges, a customer could save on their bill compared to a standard rate by using PV and BESS to meet load during the critical peak periods, avoiding drawing from the grid during times of high energy charges. Because of the complexities of determining critical peaks for each utility/grid operator within the region, the noncritical peak version of the Xcel tariff was chosen for this analysis.

3.3.8 DER Costs

Distributed PV and battery costs were sourced from NREL's 2024 Annual Technology Baseline[23] (ATB) dataset for the Engage analysis. The ATB is an annual dataset that contains forward-looking cost predictions for select generation and storage technologies. It is widely used in energy system planning models. The ATB has aggressive, conservative, and moderate scenarios based on assumptions about the pace of development of the technologies in question and corresponding cost reductions. The moderate ATB scenario was used for both PV and battery costs for the year 2030 based on the proposed timeline of EV aircraft adoption. For PV and battery storage, the ATB has costs further categorized by installation size including residential, commercial, and utility scale. The commercial-scale installations used for pricing are in the 200- to 600-kW range, which made those costs appropriate for the scales being considered in this study. The model was permitted to optimize storage duration (i.e., the ratio of inverter

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[22] https://xcelnew.my.salesforce.com/sfc/p/#1U0000011ttV/a/8b000002Y8xL/kYe61yf.9xyigvh2701Az49XLgU2izDS8ShGaCXiwsQ

[23] https://atb.nrel.gov/

capacity to energy storage capacity based on the needs of the system). A linearization of projected costs of multiple durations of storage from the ATB was done to get appropriate per-kilowatt and per-kilowatt-hour cost assumptions for each component. Table 21 summarizes PV cost, life of asset, or loan financing amortization period interest rate or opportunity cost of capital used in the model.

Table 21. 14Engage PV Technology Input Parameters

Parameter	Explanation
PV Technology	Commercial-scale PV
PV Capital Cost	$1,439.557/kW
PV Fixed Operations and Maintenance	$15.246/kW
PV Lifetime	25 years
Interest Rate	5%

Table 22 summarizes BESS cost assumptions, life of asset, or loan financing amortization period and interest rate, or opportunity cost of capital and the performance characteristics that were used in the model.

Table 22. 15Engage Battery Energy Storage Technology Input Parameters

Parameter	Explanation
Storage Technology	Commercial-scale battery storage
Battery Type	Lithium-ion
AC-AC Round-Trip Efficiency	97.5% internal
Charging Practice	State of charge managed between 10% and 90%
Inverter Capital Cost	$967.43/kW
Storage Capital Cost	$160.621/kWh
Lifetime	25 years
Interest Rate	5%

3.3.9 Scenario Definitions

Table 23 provides scenario definitions by name, charge rate, and the electric utility tariff that was modeled.

Table 23. 16Scenario Definitions

Name	Charging Case	Utility Rate
1C Charging With La Plata PSR Tariff	1C	LPEA primary service rate
2C Charging With La Plata PSR Tariff	2C	LPEA primary service rate
4C Charging With La Plata PSR Tariff	4C	LPEA primary service rate
1C Charging With Xcel P-EV Tariff	1C	Xcel schedule P-EV
2C Charging With Xcel P-EV Tariff	2C	Xcel schedule P-EV
4C Charging With Xcel P-EV Tariff	4C	Xcel schedule P-EV

The six scenarios described earlier were run multiple times for all airports across several variations shown in Table 24. The first variation was run with 2 MW of available feeder capacity to explore the impact of a reduced feeder capacity on the economics of DERs. Additionally, the airports were run with modeled flight school loads for all six scenarios with 2 MW of feeder capacity.

Table 24. 17Scenario Variations

Name	Feeder Capacity	Flight School Loads	Airports Included
Default	3 MW	No	40
Feeder Capacity Variation	2 MW	No	40
Flight School Loads Variation	2 MW	Yes	6

4 Results

4.1 RAM and Flight School Electrified Flight Demand

Results begin with understanding the potential new energy loads before coupling those loads to the existing energy demands.

EVI-EnSite simulates electric vehicle charging, generating aggregated load profiles of specified temporal resolution for a given distribution of arrivals of electric vehicles (or aircraft) at a site, assuming a fixed number of chargers. For this project, EVI-EnSite was modified to accept a fixed schedule of electric aircraft arrivals and departures at airports, along with custom aircraft charging profiles to allow for simulated charging of electric aircraft. EVI-EnSite produced 1-min-interval charging load profiles for each modeled electric vehicle charger to inform REopt and Engage modeling analysis.

4.1.1 RAM Electrified Flight EVI-EnSite Results

Load profiles resulting from the model depend on the forecasted flight activity at the various airports selected for this study. EVI-EnSite generated load profiles for a 24-hour period for each airport and each charging C rate. Flight data produced by Georgia Tech included 41 airports within Colorado, Utah, Wyoming, and New Mexico. Of the 41 airports considered, all but one airport (Central Wyoming Regional Airport) had nonhybrid electric aircraft charging demand present in the provided flight data. The airports busiest with electrified flight according to the projected electrified flight data from Georgia Technical University were GJT, ABQ, COS, BJC, and DRO, with 53, 36, 34, 32, and 23 daily flight arrivals of electrified RAM aircraft, respectively.

4.1.1.1 Grand Junction Regional Airport charging demand

Total daily electricity consumption for charging electric aircraft at GJT based on the projected data developed by Georgia Tech amounted to 7,449 kWh. Figure 8 shows plots of hourly DCFC electrical charging demand for the three charging C rates at GJT. Figure 7 includes information regarding the total number of chargers, peak power draw, and whether the charging infrastructure was sufficient to charge all aircraft in the flight schedule for the airport.

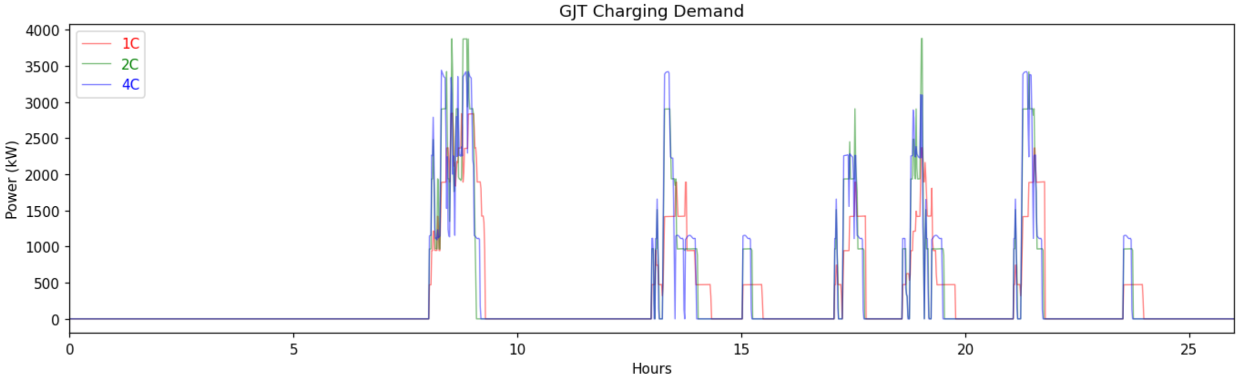

Figure 7. 24-hour simulated aircraft charging demand at GJT.

Total kWh daily consumption for charging 53 aircraft: 7,449 kWh

1C charging rate 2,845 kW peak demand; 6 chargers; 35-min maximum charge duration; 10 aircraft not fully charged before scheduled departure, minimum battery state of charge: 77%

2C charging rate: 3,881 kW peak demand; 5 chargers; 17-min maximum charge duration; all aircraft fully charged before scheduled departure

4C charging rate: 3,441 kW peak demand; 3 chargers; 14.5-min maximum charge duration; all aircraft fully charged before scheduled departure.

Note that the peak power draw for the 2C charging rate scenario was greater than the peak power draw for the 4C charging rate scenario; This outcome is because longer charge durations in the 2C rating led to a need for more chargers being used simultaneously by multiple aircraft to be able to maintain the flight schedule departure times, whereas the 4C rating allows aircraft to complete charging faster and reduce the number of aircraft charging simultaneously. An alternative charging strategy that allows aircraft to wait for a charger, if it has sufficient time before its next departure, could likely reduce the total number of chargers needed and reduce the peak power demand for each charging rating.

4.1.1.2 Durango-La Plata County Airport charging demand

Modeled daily electricity consumption at DRO totaled 4,059 kWh, with a peak power draw of 2,905 kW occurring in the 2C charging rate scenario, as shown in Figure 8.

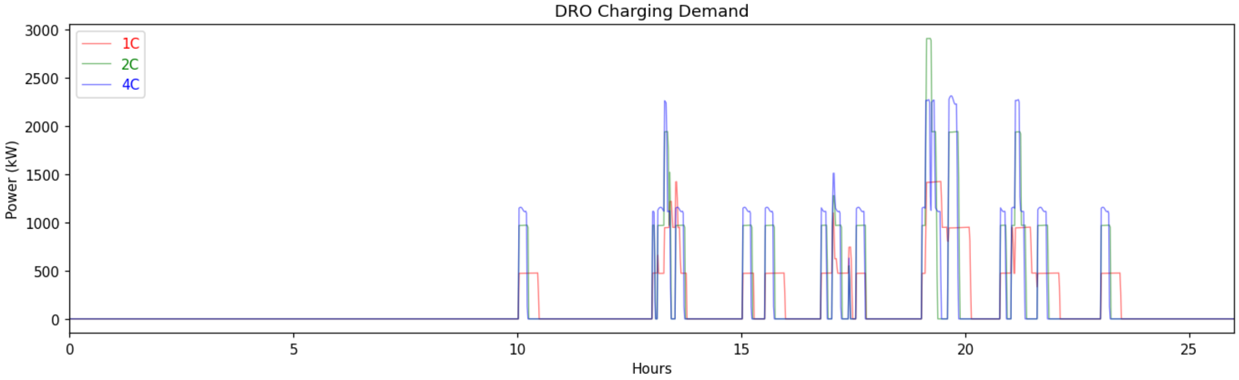

Figure 8. 24-hour simulated aircraft charging demand at DRO.

Total kWh daily consumption for charging 23 aircraft: 4,059 kWh

1C charging rate: 1,424 kW peak demand; 3 chargers; 30.5-min maximum charge duration; 3 aircraft not fully charged before scheduled departure, minimum battery state of charge: 72%

2C charging rate: 2,905 kW peak demand; 3 chargers; 14.5-min maximum charge duration; 1 aircraft not fully charged before scheduled departure, minimum battery state of charge: 93%

4C charging rate: 2,311 kW peak demand; 2 chargers; 16.5-min maximum charge duration; all aircraft fully charged before scheduled departure.

As with the GJT results, the 4C charging rate for DRO requires the lowest number of chargers while keeping the peak power draw lower than the 2C rate. The peak power draw for the 1C rate is the lowest at 1,897 kW; however, not all aircraft are able to charge in time to meet their scheduled departures at this rate. For DRO, only one aircraft does not reach the target SOC of 95% but the final SOC is close enough that a short flight delay would allow for all aircraft to fully charge with a peak power draw under 2,000 kW and four chargers. Alternatively, the target SOC of 95% may not be necessary for most flights and a lower target SOC that allows the flight to reach its next destination could significantly reduce charging demand. Future analysis could explore forward estimates on SOC required to complete the next leg of travel, and assume charging at the airport only needs to recharge to this requirement.

4.1.1.3 Denver International Airport charging demand

Total electricity consumption was modeled at DEN to be 2,561 kWh for the 20 electrified daily RAM flights in the provided schedule. The EVI-EnSite model was able to fully charge all flights with two chargers at a 1C charge rate and the peak power draw stayed under 1 MW. Figure 9 shows these charging patterns across the 24-hour period for DEN.

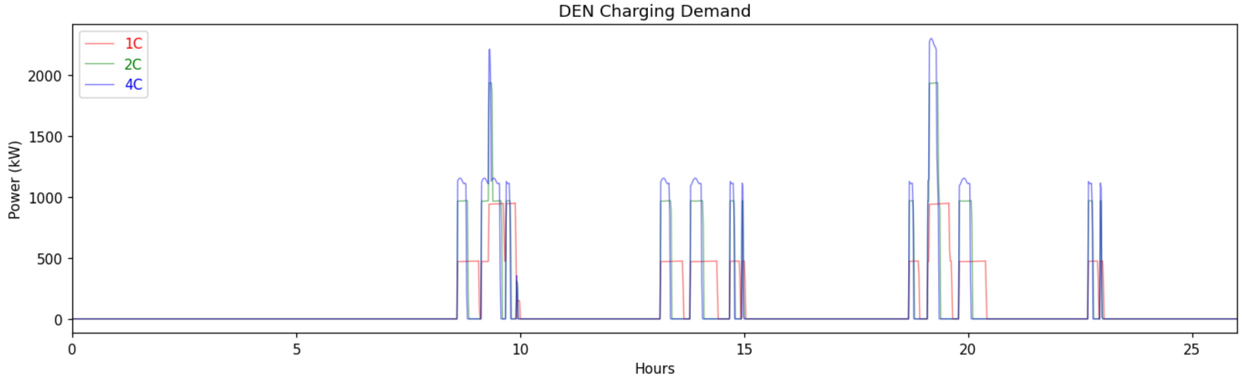

Figure 9. 24-hour simulated aircraft charging demand at DEN.

Total kWh daily consumption for charging 15 aircraft: 2,561 kWh

1C charging rate: 953-kW peak demand; 2 chargers; 36.5-min maximum charge duration; all aircraft fully charged before scheduled departure

2C charging rate: 1,941-kW peak demand; 2 chargers; 17.5-min maximum charge duration; all aircraft fully charged before scheduled departure

4C charging rate: 2,304-kW peak demand; 2 chargers; 15.5-min maximum charge duration; all aircraft fully charged before scheduled departure.

4.1.2 Electrified Flight School EVI-EnSite Results

Flight school charging demand modeling assumed that all single-engine aircraft at the flight schools would be electrified and that the aircraft operations at all airports would follow the same distribution of arrivals and departures as the sampled flight school. The busiest modeled flight school was BJC, with 27 total electrified flight school aircraft. COS was modeled assuming a flight school fleet size of 12 electrified aircraft. Flight school fleet sizes for GJT, DRO, and ABQ airports were not known for this analysis, and an assumed fleet size of five electrified trainer aircraft was used for each. Fight school fleet sizes for all modeled airports are included in Table 25.

Table 25. Flight School Fleet Assumptions

Airport	Aircraft Type	Aircraft Battery Capacity	Fleet Size
BJC	2-pax trainer	100 kWh	27
COS	2-pax trainer	100 kWh	12
GJT	2-pax trainer	100 kWh	5
DRO	2-pax trainer	100 kWh	5
ABQ	2-pax trainer	100 kWh	5

4.1.2.1 Rocky Mountain Metropolitan Airport flight school charging demand

Unlike the electrified RAM flight modeling, the flight school modeling simulation spanned a full week to try and capture daily variation in flight school operations. BJC, with a fleet size of 27 electrified planes, consumed 18,150 kWh to charge aircraft for a week of flight school operations, an average daily consumption of 2,593 kWh. Figure 10 shows an example flight school charging load for BJC for 1 week.

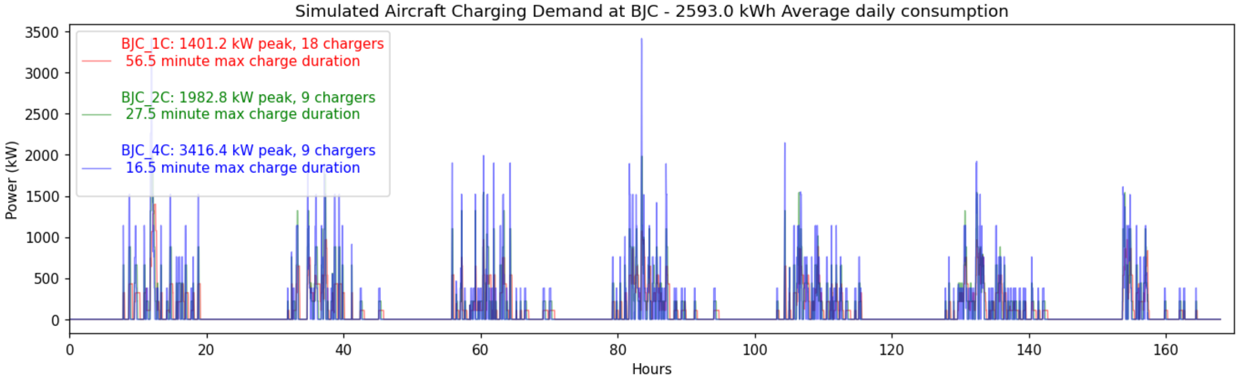

Figure 9. 1-week simulated flight school charging demand at BJC

Figure 10 shows the difference in peak power between the 2C and 4C charging rates to be about 1,400 kW for the same number of chargers. Peak power draw for the 4C rate is 3,416 kW and only 1,983 kW for the 2C rate, the key difference being that the speed at which electric aircraft can be recharged is cut down from 27.5 min using 2C charging to 16.5 min using 4C charging. The sooner the aircraft can become available for a new flight, the more flights that the flight school can include in their schedule. The additional costs incurred from faster charging speeds can be compared to the added economic benefit that the flight school gains for each additional flight operation.

4.1.2.2 Colorado Springs Airport flight school charging demand

The daily average electricity consumption required to charge electrified aircraft for the COS airport synthetic flight school schedule is 1,109 kWh. Figure 11 shows results for flight school charging at COS. The 2C and 4C cases both require five chargers and keep charge times under 30 min, allowing for more feasible flight school operations. The peak power draw needed to minimize charge times in the 4C case is 1,896 kW; however, peak power could be reduced to 1,102 kW with a maximum charge duration of 27.5 minutes in the 2C case.

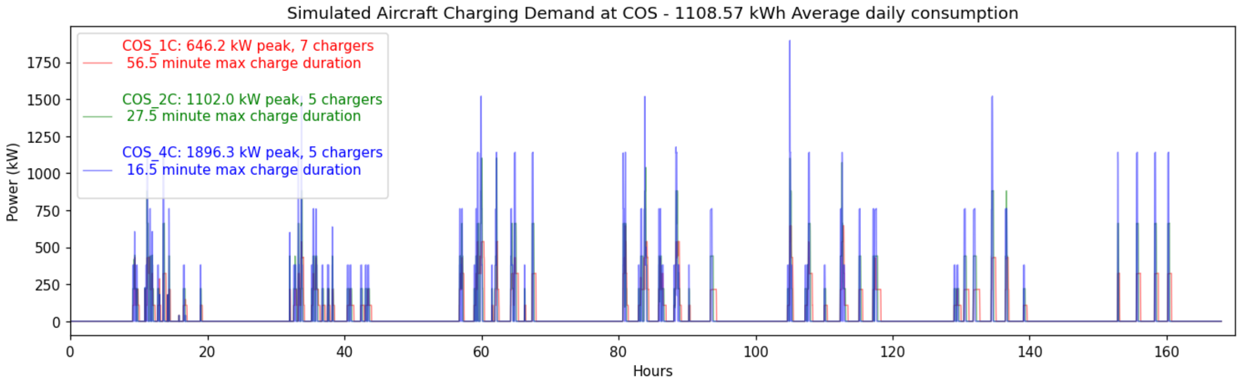

Figure 10. 168-hour simulated flight school charging demand at COS

Data on EVI-EnSite charging load profiles for the remaining airports, including maximum peak demand, number of chargers needed, maximum charging duration, and other findings at the airport level, can be found in Appendix B.

4.2 Airport Infrastructure Analysis Results (REopt)

Results from the REopt model focus on minimizing the life cycle cost of powering electrified aircraft at airports by identifying optimally sized airport infrastructure installations that offer cost minimization. These new assets could include on-site solar PV systems and on-site BESS to service electrified aircraft. In fact, as demonstrated by GJT and DRO results, on-site solar PV and BESS can be cost-effective even without the addition of forecasted electrified aircraft charging loads. Where exporting excess generation is allowed and compensated (net metering), the benefits of installing on-site energy assets increase significantly.

Results for each airport are provided as tables, with one for direct (airport) ownership of power-generating and storage assets, and another for third-party ownership of power-generating and storage assets. Results are presented by C Rate and scenario type within each table, where "FLS" represents flight school electric aircraft loads and "RAM" represents regional air mobility electric aircraft loads. These results highlight the NPV of cost savings and electric utility bill savings offered by placement of on-site PV and BESS systems. Because REopt is a site-specific model that employs a behind-the-meter perspective, these results do not include any line upgrade or distribution upgrade costs, and such costs are considered by Engage.

4.2.1 Modeled System Sizes and Project Economies at Individual Airports

4.2.1.1 Albuquerque International Sunport

Table 26 details the REopt identified results at ABQ for RAM-only electric vehicle service equipment loads, whereas Table 27 provides results for FLS-only electric vehicle service equipment loads. Table 28 provides REopt identified results for RAM+FLS electric vehicle service equipment loads. These tables provide business-as-usual grid consumption, peak demand, and marginal emissions and compare those numbers against the modeled values after on-site DERs have served part of the EVSE loads. These detailed results include the cost-optimal system sizes, economics of on-site power-generating assets for direct and third-party ownership, the cost-optimal grid, and on-site power generation consumption and marginal emissions.

As modeled, flight school loads at ABQ are a fraction of RAM passenger service loads. The 15-min-averaged RAM loads can add ~1.5 gigawatt-hours of energy annually with peak demand of 1.8 MW under the 1C charging rate. This peak demand increases to nearly 3 MW under the 2C and 4C rates, with the same total energy consumption of ~1.5 gigawatt-hours. Behind-the-meter solar PV systems and BESS can help offset part of this grid electricity consumption at the airport. The peak power consumption from the grid remains nearly identical between BAU and cost-optimal scenarios due to the electric tariff design at the airport, which only applies a demand charge on demand measured during on-peak time periods. Therefore, the BESS is not incentivized to offset charging loads outside on-peak times between 0800 and 2000 local time on weekdays.

Under both direct and third-party ownership of on-site power generation, on-site BESS offers the greatest cost savings. Across all scenarios and C rates, the NPV of cost savings ranges from a healthy $250,000 to nearly $6.5 million, simple payback period (SPP) of 4 years or less, and internal rate of return (IRR) between 20% and 30%. System sizes, cost savings, and project economics are nearly the same under third-party ownership, with property depreciation monetization offsetting the additional interest paid to the developer over the project life cycle. Third-party payments range from $18,000 per year to a maximum of $293,000 per year.

Table 26. ABQ Results for RAM-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,482	1,482	1,482	1,482	1,482	1,482
BAU Peak Demand Grid to EVSE [MW]	1.81	3	2.99	1.81	3	2.99
BAU Year 1 Electric Bill [$k]	613	959	957	613	959	957
BAU Marginal Carbon Dioxide (CO_2) Emissions [tCO_2/year]	217.4	217.4	217.2	217.4	217.4	217.2
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	1,518	1,522	1,524	1,518	1,522	1,524
Peak Grid Demand to EVSE [MW]	1.81	3	2.99	1.81	3	2.99
Peak Grid Demand to BESS [MW]	1.48	2.66	2.65	1.48	2.66	2.65
Marginal CO_2 Emissions [tCO_2/year]	230.1	230.5	228.2	230.1	230.5	228.2
PV [kWdc]	0	0	0	0	0	0
BESS [MWh/MW]	1.36 / 1.48	1.40 / 2.66	1.39 / 2.64	1.36 / 1.48	1.40 / 2.66	1.39 / 2.64
NPV [$million]	3.37	6.6	6.57	3.37	6.6	6.57
Annual Payment to Third Party [$k]	Not applicable (N/A)	N/A	N/A	180	281	280
Simple Payback Period (SPP)/Internal Rate of Return (IRR) [Years/%]	3.2 / 27%	2.7 / 31%	2.7 / 31%	13.5 / 6%	13.5 / 6%	13.5 / 6%
Capital Costs After Incentives [$million]	1.41	2.2	2.19	1.05	1.63	1.62
Annual Demand Charge Savings [$k]	431	774	771	431	774	771
Annual Energy Charge Savings [$k]	-0.9	-1	-1.1	-0.9	-1	-1.1

Table 27. ABQ Results for FLS-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	85	85	85	85	85	85
BAU Peak Demand Grid to EVSE [MW]	0.32	0.33	0.4	0.32	0.33	0.4
BAU Year 1 Electric Bill [$k]	56	76	106	56	76	106
BAU Marginal CO_2 Emissions [tCO_2/year]	9.5	9.4	9.4	9.5	9.4	9.4
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	41	39	33	41	39	33
Peak Grid Demand to EVSE [MW]	0.32	0.33	0.39	0.32	0.33	0.39
Peak Grid Demand to BESS [MW]	0.11	0.18	0.28	0.11	0.18	0.28
Marginal CO_2 Emissions [tCO_2/year]	4.9	4.6	4	4.9	4.6	4
PV [kWdc]	29	31	36	29	31	36
BESS [MWh/MW]	0.12/ 0.11	0.14/ 0.17	0.17/ 0.28	0.12/ 0.11	0.14/ 0.17	0.17/ 0.28
NPV [$million]	0.25	0.43	0.71	0.25	0.43	0.71
Annual Payment to Third Party [$k]	N/A	N/A	N/A	18	25	35
SPP/IRR [Years/%]	4.0 / 21%	3.5 / 24%	3.2 / 27%	13 / 6%	13 / 6%	13 / 6%
Capital Costs After Incentives [$million]	0.15	0.21	0.29	0.11	0.15	0.21
Annual Demand Charge Savings [$k]	34	54	85	34	54	85
Annual Energy Charge Savings [$k]	2.5	2.6	2.9	2.5	2.6	2.9

Table 28.18 ABQ Results for RAM + FLS EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,568	1,568	1,568	1,568	1,568	1,568
BAU Peak Demand Grid to EVSE [MW]	1.81	3	2.99	1.81	3	2.99
BAU Year 1 Electric Bill [$k]	618	964	961	618	964	961
BAU Marginal CO_2 Emissions [tCO_2/year]	226.6	226.8	226.7	226.6	226.8	226.7
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	1,393	1,414	1,420	1,393	1,414	1,420
Peak Grid Demand to EVSE [MW]	1.81	3	2.99	1.81	3	2.99
Peak Grid Demand to BESS [MW]	1.46	2.65	2.64	1.46	2.65	2.64
Marginal CO_2 Emissions [tCO_2/year]	209.6	213.2	214.2	209.6	213.2	214.2
PV [kWdc]	123	113	111	123	113	111
BESS [MWh/MW]	1.34/1.46	1.38/2.64	1.39/2.64	1.34/ 1.46	1.38/ 2.64	1.39/ 2.64
NPV [$million]	3.32	6.54	6.51	3.32	6.54	6.51
Annual Payment to Third Party [$k]	N/A	N/A	N/A	193	293	293
SPP/IRR [Years/%]	3.4/25%	2.9/30%	2.9/30%	13.5/6%	13.5/6 %	13.5/ 6%
Capital Costs After Incentives [$million]	1.55	2.33	2.32	1.15	1.72	1.72
Annual Demand Charge Savings [$k]	428	772	769	427	772	769
Annual Energy Charge Savings [$k]	10	9.2	8.9	10	9.2	8.9

As shown in Figure 12, BESS is the only technology identified by REopt as being cost optimal at ABQ (and associated utility rates) for a RAM electric vehicle service equipment loads-only scenario (not considering flight school aircraft loads). As modeled, several EVSE charging spikes occur overnight on July 26, but the BESS only begins serving load at 0800 local time that day. It recharges from the grid immediately after 2000 local time and then cycles during the peak hours of July 27. An implication of time-varying energy and demand rates is observed on the night of July 25 when BESS dispatches right before 2000 hours local time but charges back up immediately after the peak ends. Consistent peak shaving to reduce peak demand observed by the utility would mean ensuring maximum consumption from the electric utility is managed across all times during the day through controlled charging of BESS.

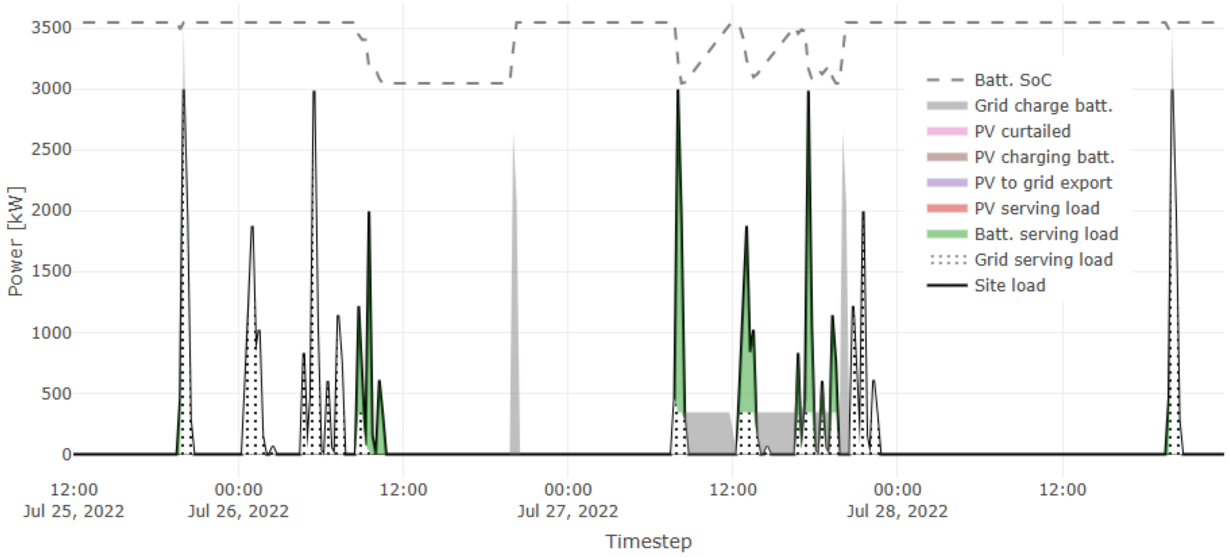

Figure 12. ABQ optimal DER dispatch strategy for modeled RAM-only EVSE loads.

Note: The battery SOC (%) is shown on the secondary y-axis as dashed lines. The range of this axis is between 20% and 98%.

Figure 13 shows the RAM+FLS (RAM passenger service and flight school loads) scenario to emphasize the major role of BESS in providing cost savings at this airport. Note the small PV system can serve FLS loads that typically occur during the day and charge the BESS instead of curtailing power. An increase in flight school loads could result in the larger PV system being cost-effective, which would change the optimal BESS dispatch strategy as well.

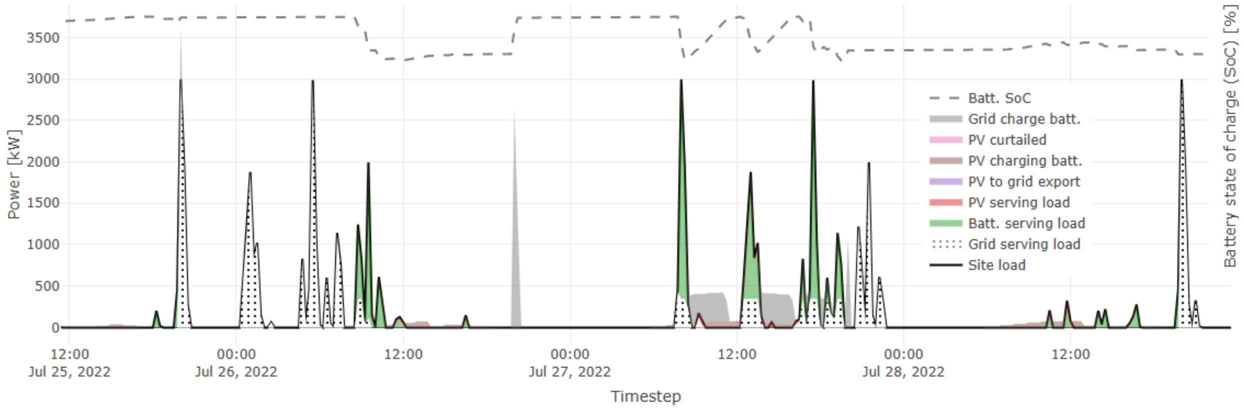

Figure 13. ABQ optimal DER dispatch strategy for modeled RAM + FLS EVSE loads.

Note: Battery SOC (%) is shown on the secondary y-axis as dashed lines. The range of this axis is between 20% and 98%.

Note that PNM offers a nonresidential EV charging rate[24] that only consists of energy charges. Under this schedule, EVSE energy consumption is charged at 6–12 cents/kWh more during on-peak hours compared to off-peak hours. Such a rate schedule that costs energy consumption but not demand may provide economic justification toward investment in solar PV. However, lack of demand charges negates the value of a BESS that can offer peak shaving at charging stations. This rate is a pilot rate and hence was not considered in the study.

4.2.1.2 Rocky Mountain Metropolitan Airport

Table 29 details the REopt-identified results at BJC airport for RAM-only EVSE loads, whereas Table 30 provides results for FLS-only EVSE loads. Table 31 provides REopt-identified results for RAM+FLS EVSE loads. These tables provide business-as-usual grid consumption, peak demand, and marginal emissions and compare those numbers against the modeled values after on-site DERs have served part of the EVSE loads. These detailed results include the cost-optimal system sizes, economics of on-site power-generating assets for direct and third-party ownership, the cost-optimal grid, and on-site power generation consumption and marginal emissions.

The rate schedule at BJC airport is energy-charge heavy with a small demand charge. Given this rate input, REopt chose to build solar PV at BJC to maximize cost savings through energy charge reduction. The model does not suggest building BESS as the peak demand reduction does not provide sufficient savings to offset the costs of purchasing the BESS. Because savings occur via energy charges and PV exports for net billing are allowed, the identified PV system sizes do not change based on the C rate. The RAM-only and FLS-only scenarios identify PV system sizes between 550 and 650 kW. The RAM+FLS scenarios identify PV system sizes that are mathematical sums of the systems sized based on the individual loads alone. The NPV of cost savings is ~$30,000 for RAM only and ~$100,000 for FLS-only scenarios. However, the FLS+RAM scenario's NPV is less than the sums of the individual net present values for the 1C

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[24] For more information, see the Schedule 3F nonresidential charging station pilot: https://www.pnm.com/documents/28767612/28775078/3F++Non-Residential+Charging+Station-Pilot.pdf/c102a8a4-2afc-ce9d-d9a3-71d3d72f2823?t=1706050349654.

charging rate. At 2C and 4C charging rates, the NPV is at least $30,000 higher than the sums of the individual net present values, with the 2C NPV being the highest.

The cost-effectiveness of PV results in a considerable reduction in grid electricity purchased across all scenarios and C rates. Note that in the FLS-only scenarios, a 50%+ year 1 grid-to- site energy reduction is observed but the same grid energy reductions are not observed in the RAM-only scenarios. A reason for this is the underlying schedule of the aircraft. Most modeled RAM passenger service traffic occurs overnight at BJC, when PV cannot offset grid energy consumption. However, FLS loads are served during the day when PV can offset grid purchases. The lack of an on-site BESS results in no substantial peak electrical demand reduction from the BAU case.

When third-party ownership is considered, the identified PV system sizes do not change. BESS is not cost-effective, despite the monetization of asset depreciation. Monetization of PV depreciation results in an increase in NPV across scenarios and C rates by $15,000 to $25,000. Annual payment to the developer was identified as $80,000 to $150,000 per year, with overnight capital costs decreasing due to the monetization of MACRS and bonus depreciation.

Table 29.19 BJC Results for RAM-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	808	808	808	808	808	808
BAU Peak Demand Grid to EVSE [MW]	1.14	1.75	1.87	1.14	1.75	1.87
BAU Year 1 Electric Bill [$k]	113	133	136	113	133	136
BAU Marginal CO_2 Emissions [tCO_2/year]	143.5	143.5	143.5	143.5	143.5	143.5
Identified Cost-Optimal Solutions	***Direct***			***Third Party***		
Year 1 Energy Required With DERs [MWh]	691	716	725	691	716	725
Peak Grid Demand to EVSE [MW]	1.14	1.75	1.87	1.14	1.75	1.87
Peak Grid Demand to BESS [MW]	0	0	0	0	0	0
Marginal CO_2 Emissions [tCO_2/year]	51.7	51.7	51.7	51.7	51.7	51.7
PV [kWdc]	552	552	552	552	552	552
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$million]	0.03	0.03	0.03	0.04	0.04	0.04
Annual Payment to Third Party [$k]	0	0	0	69	69	69
SPP/IRR [Years/%]	12/7%	12/7%	12/7%	11 / 6%	11 / 6%	11 / 6%
Capital Costs After Incentives [$million]	0.71	0.71	0.71	0.52	0.52	0.52
Annual Demand Charge Savings [$k]	0	0	0	0	0	0
Annual Energy Charge Savings [$k]	9	7	6	9	7	6

Table 30.20 BJC Results for FLS-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	9,367	942	947	9,367	942	947
BAU Peak Demand Grid to EVSE [MW]	1.37	1.81	2.41	1.37	1.81	2.41
BAU Year 1 Electric Bill [$k]	129	144	164	129	144	164
BAU Marginal CO_2 Emissions [tCO_2/year]	120.8	121.5	122.2	120.8	121.5	122.2
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required with DERs [MWh]	396	464	492	396	464	492
Peak Grid Demand to EVSE [MW]	1.35	1.8	2.4	1.35	1.8	2.4
Peak Grid Demand to BESS [MW]	0	0	0	0	0	0
Marginal CO_2 Emissions [tCO_2/year]	14.4	14.5	14.6	14.4	14.5	14.6
PV [kWdc]	639	643	646	639	643	646
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$M]	0.1	0.1	0.11	0.12	0.12	0.12
Annual Payment to Third Party [$k]	0	0	0	80	80	80
SPP/IRR [Years/%]	11/8%	11/8%	11/8%	11 / 6%	11 / 6%	11 / 6%
Capital Costs After Incentives [$million]	0.82	0.83	0.83	0.6	0.6	0.6
Annual Demand Charge Savings [$k]	5	5	5	5	5	5
Annual Energy Charge Savings [$k]	47	41	39	47	41	39

Table 31. BJC Results for FLS + RAM EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,745	1,750	1,755	1,745	1,750	1,755
BAU Peak Demand Grid to EVSE [MW]	1.46	2.21	2.44	1.46	2.21	2.44
BAU Year 1 Electric Bill [$k]	208	232	240	208	232	240
BAU Marginal CO_2 Emissions [tCO_2/year]	264.3	265	265.6	264.3	265	265.6
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required with DERs [MWh]	900	991	1,023	900	991	1,023
Peak Grid Demand to EVSE [MW]	1.38	2.11	2.39	1.38	2.11	2.39
Peak Grid Demand to BESS [MW]	0	0	0	0	0	0
Marginal CO_2 Emissions [tCO_2/year]	66.1	66.2	66.3	66.1	66.2	66.3
PV [kWdc]	1,191	1,195	1,198	1,191	1,195	1,198
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$million]	0.13	0.19	0.17	0.15	0.22	0.2
Annual Payment to Third Party [$k]	0	0	0	150	150	151
SPP/IRR [Years/%]	11/7%	11/8%	11/8%	11/6%	11/6%	11/6%
Capital Costs After Incentives [$million]	1.53	1.54	1.54	1.11	1.12	1.12
Annual Demand Charge Savings [$k]	4	10	8	4	10	8
Annual Energy Charge Savings [$k]	72	64	62	72	64	62

4.2.1.3 Denver International Airport

Only RAM loads were evaluated at DEN. Table 32 provides the business-as-usual and REopt-identified cost-optimal results for these loads and includes system sizes, grid electrical consumption, peak demands, marginal emissions, and project economics. Across all C rates, the model identified approximately 400 kW of PV capacity that would save the airport ~$57,000 over the 25-year analysis period with an 11-year payback period at a 7% internal rate of return. The presence of PV results in lower grid energy consumption in comparison to the BAU case, with the reduction decreasing as the C rate increases. This outcome can be attributed to the changing load curves, which tend to have more frequent spikes in peak power draw over short durations, therefore not allowing PV to offset as much grid purchase. Third-party ownership results in a higher NPV due to both asset depreciation and bonus depreciation. Annual payments to the developer are ~$52,000. Year 1 BAU energy required is 623.18 MWh. DEN's peak demand (40+ MW) is far greater than that caused by EVSE RAM loads.

Table 32. 21DEN Cost-Optimal Grid Consumption and Emissions

	Direct Ownership			Third-Party Ownership		
C Rate	**1C**	**2C**	**4C**	**1C**	**2C**	**4C**
Year 1 Energy Required With DERs [MWh]	521.05	536.4	537.32	521.05	536.4	537.32
Peak Demand Grid to EVSE BAU [MW]	0.95	1.29	1.33	0.95	1.29	1.33
Peak Demand Grid to EVSE With DERs [MW]	0.95	1.29	1.33	0.95	1.29	1.33
Marginal CO_2 Emissions BAU [tCO2/year]	109.1	109.9	110	109.1	109.9	110
Marginal CO_2 Emissions [tCO2/year]	38.9	39.7	39.9	38.9	39.7	39.9
PV [kWdc]	410	410	410	410	410	410
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$million]	0.06	0.06	0.06	0.07	0.07	0.07
Annual Payment to Developer [$k]	0	0	0	52	52	52
SPP / IRR [Years/%]	11/7%	11/7%	11/7%	11/6%	11/6%	11/6%
Capital Costs After Incentives [$million]	0.53	0.53	0.53	0.38	0.38	0.38
Year 1 Electric Bill BAU [$k]	90	100	102	90	100	102
Annual Demand Charge Savings [$k]	0	0	0	0	0	0
Annual Energy Charge Savings [$k]	8.38	6.97	6.91	8.38	6.97	6.91

4.2.1.4 Grand Junction Regional Airport

This section provides results for estimated building loads and EVSE loads that apply to GJT. REopt identifies a small PV system and a large BESS as cost-effective at this airport for current operations. Identification of such a system can be driven by the electricity rate structure (Xcel Colorado's Secondary General rate), which has demand charges ranging from $15/kW (winter months) to $21/kW (summer months), allowing BESS to provide value via monthly peak shaving. This tariff's energy charges are less than 5 cents per kWh, which does not offer a substantial incentive for solar PV to provide value, resulting in only 3.24 kW of capacity being identified as cost optimal. A small system like this is unlikely to curtail or export energy during operations, thereby only providing a modest reduction in energy charges. Results for GJT's non-EVSE scenario are presented in Table 33. These results consider ITC and asset depreciation incentives and use ground-mount PV installed costs. BESS installed costs are the same as those in the EVSE results. Variations in these costs and incentive values can also result in changes to the identified system sizes and cost savings.

Table 33. GJT Non-EVSE Loads REopt-Identified Results

Result Metric	PV Exports Allowed
Total Annual Non-EVSE Electric Loads at GJT	2,100 MWh
Year 1 Energy Supplied From the Grid to Loads After PV/BESS	2,091 MWh
Peak Demand Grid to EVSE BAU [kW]	424
Peak Demand Grid to EVSE With DERs [MW]	379
Marginal CO_2 Emissions BAU [tCO_2/year]	390
Marginal CO_2 Emissions [tCO2/year]	389
PV [kWdc]	3.24
BESS [kWh/kW]	81/45
NPV	$34.7k
SPP/IRR [Years/%]	7.51/13%
Capital Costs	$83.8k
Capital Costs After Incentives	$43.9k
Year 1 Electric Bill BAU	$181.3k
Annual Demand Charge Savings	$9.2k
Annual Energy Charge Savings [$k]	$0.2k
PV Annual Energy Produced [MWh]	5.22
PV Annual Energy Exported [MWh]	0.0
Year 1 Export Benefit [$]	0.0

Figure 14 presents a dispatch plot for the non-EVSE scenario at GJT to highlight how PV and BESS are providing cost savings. The figure shows both BESS shaving peaks during the day to avoid monthly peak demand charges and solar PV offsetting grid consumption.

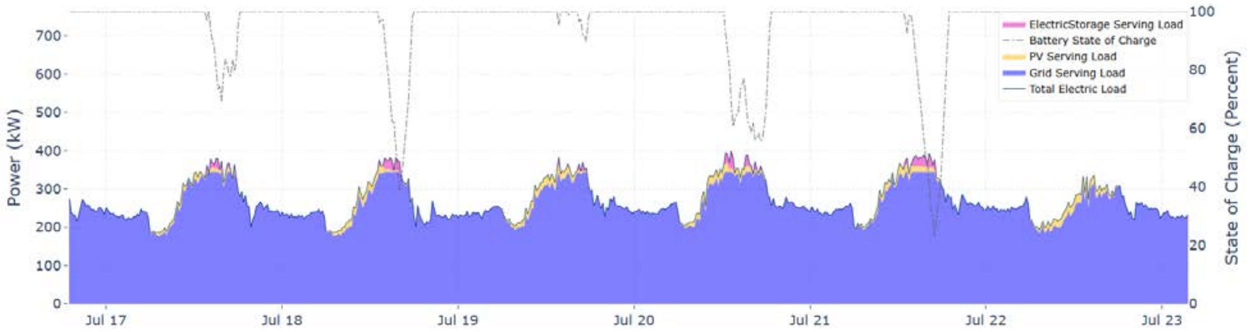

Figure 14. GJT dispatch plot for building loads only

In addition to the status quo analysis, future aircraft loads were evaluated at GJT as well. Table 34 details the REopt-identified results at GJT for RAM-only EVSE loads, whereas Table 35 provides results for FLS-only EVSE loads. Table 36 provides REopt- identified results for RAM+FLS EVSE loads. These tables provide business-as-usual grid consumption, peak demand, and marginal emissions and compare these numbers against the modeled values after on-site DERs have served part of the EVSE loads. These detailed results include the cost-optimal system sizes, economics of on-site power-generating assets for direct and third-party ownership, the cost-optimal grid, and on-site power generation consumption and marginal emissions.

Like BJC and DEN, only solar PV was identified as cost optimal at GJT due to the rate structure comprising both high-energy and low-demand charges. This outcome is expected as each location is serviced by the same energy provider.

RAM loads dominate the FLS loads at GJT. Solar PV can offset between 20% and 30% of grid consumption across scenarios and C rates without any substantial reduction in peak demand. NPV of cost savings is $250,000 or higher when RAM loads are considered regardless of ownership type and charging rates. Like other sites being served by Xcel Colorado, third-party ownership does not result in changes in cost-optimal system sizes at GJT. Depreciating the PV investment using MACRS and bonus depreciation results in a slight increase in NPV compared to airport ownership for all scenario types and charging rates.

Table 22. GJT Results for RAM-Only EVSE Loads

Data Point C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,812.6	1,812.6	1,812.6	1,812.6	1,812.6	1,812.6
BAU Peak Demand Grid to EVSE [MW]	2.55	3.31	3.12	2.55	3.31	3.12
BAU Year 1 Electric Bill [$k]	256	280	274	256	280	274
BAU Marginal CO_2 Emissions [tCO_2/year]	321	321.7	321.7	321	321.7	321.7
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	1,526.43	1,584.8	1,591	1,526.43	1,584.8	1,591
Peak Grid Demand to EVSE [MW]	2.55	3.31	3.12	2.55	3.31	3.12
Peak Grid Demand to BESS [MW]	0	0	0	0	0	0
Marginal CO_2 Emissions [tCO_2/year]	117.4	118.1	118.2	117.4	118.1	118.2
PV [kWdc]	1158	1158	1158	1158	1158	1158
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$million]	0.25	0.25	0.25	0.27	0.27	0.27
Annual Payment to Third Party [$k]	0	0	0	146	146	146
SPP/IRR [Years/%]	10.35/ 8%	10.35/ 8%	10.35/ 8%	11.04/ 6%	11.04/ 6%	11.04/ 6%
Capital Costs After Incentives [$M]	1.49	1.49	1.49	1.08	1.08	1.08
Annual Demand Charge Savings [$k]	0	0	0	0	0	0
Annual Energy Charge Savings [$k]	23.43	18.44	17.98	23.43	18.44	17.98

Table 23. GJT Results for FLS-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	156.62	157.51	157.51	156.62	157.51	157.51
BAU Peak Demand Grid to EVSE [MW]	0.32	0.38	0.48	0.32	0.38	0.48
BAU Year 1 Electric Bill [$k]	27	29	32	27	29	32
BAU Marginal CO_2 Emissions [tCO_2/year]	21.7	21.6	21.5	21.7	21.6	21.5
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	107.14	118.33	123.93	107.14	118.33	123.93
Peak Grid Demand to EVSE [MW]	0.32	0.37	0.48	0.32	0.37	0.48
Peak Grid Demand to BESS [MW]	0	0	0	0	0	0
Marginal CO_2 Emissions [tCO_2/year]	4.1	3.9	3.8	4.1	3.9	3.8
PV [kWdc]	100	101	101	100	101	101
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$million]	0.03	0.04	0.03	0.03	0.04	0.04
Annual Payment to Third Party [$k]	0	0	0	13	13	13
SPP/IRR [Years/%]	9.69/ 9%	9.47/ 9%	9.55/ 9%	11.04/ 6%	11.04/ 6%	11.04/ 6%
Capital Costs After Incentives [$million]	0.13	0.13	0.13	0.09	0.09	0.09
Annual Demand Charge Savings [$k]	0.81	1.11	1	0.81	1.11	1
Annual Energy Charge Savings [$k]	4.47	3.53	2.96	4.47	3.53	2.96

Table 24. GJT Results for FLS + RAM EVSE Loads (Assuming Ground-Mount PV)

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,969.2	1,970.1	1,970.1	1,969.2	1,970.1	1,970.1
BAU Peak Demand Grid to EVSE [MW]	2.6	3.33	3.49	2.6	3.33	3.49
BAU Year 1 Electric Bill [$k]	273	297	302	273	297	302
BAU Marginal CO_2 Emissions [tCO_2/year]	342.7	343.3	343.2	342.7	343.3	343.2
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	1,558.1	1,616.8	1,623.3	1,558.1	1,616.8	1,623.3
Peak Grid Demand to EVSE [MW]	2.6	3.31	3.33	2.6	3.31	3.33
Peak Grid Demand to BESS [MW]	0	0	0	0	0	0
Marginal CO_2 Emissions [tCO_2/year]	121.6	122.1	121.9	121.6	122.1	121.9
PV [kWdc]	1,258	1,259	1,259	1,258	1,259	1,259
BESS [MWh/MW]	0/0	0/0	0/0	0/0	0/0	0/0
NPV [$million]	0.27	0.28	0.34	0.3	0.31	0.36
Annual Payment to Third Party [$k]	0	0	0	158	158	158
SPP/IRR [Years/%]	10.35/8%	10.31/8%	10.01/8%	11.04/ 6%	11.04/ 6%	11.04/ 6%
Capital Costs After Incentives [$million]	1.62	1.62	1.62	1.18	1.18	1.18
Annual Demand Charge Savings [$k]	0	0.7	5.1	0	0.7	5.1
Annual Energy Charge Savings [$k]	35.21	30.26	29.75	35.21	30.26	29.75

If GJT were to consider roof-mount solar PV systems instead of ground-mount, identified PV systems that maximize cost savings are nearly identical in capacity as detailed in Table 37.

However, there is a drop in NPV of cost savings compared to ground-mount results because rooftop PV is costlier.

Table 25. GJT Rooftop PV BESS System Sizes and Economics

Scenario Type	C Rate	PV [kWdc]	BESS [MWh/MW]	NPV [$milion]	Capital Costs After Incentives [$million]
Direct Ownership					
FLS	1C	100	0/0	0.01	0.15
	2C	101	0/0	0.02	0.15
	4C	101	0/0	0.02	0.15
RAM	1C	1,162	0/0	0.04	1.69
	2C	1,162	0/0	0.04	1.69
	4C	1,162	0/0	0.04	1.69
RAMFLS	1C	1,262	0/0	0.05	1.84
	2C	1,262	0/0	0.06	1.84
	4C	1,262	0/0	0.11	1.84
Third-Party Ownership					
FLS	1C	100	0/0	0.02	0.11
	2C	101	0/0	0.02	0.11
	4C	101	0/0	0.02	0.11
RAM	1C	1,162	0/0	0.07	1.23
	2C	1,162	0/0	0.07	1.23
	4C	1,162	0/0	0.07	1.23
RAMFLS	1C	1,262	0/0	0.08	1.34
	2C	1,262	0/0	0.09	1.34
	4C	1,262	0/0	0.14	1.34

4.2.1.5 Durango-La Plata County Airport

This section provides results for DRO building loads and EVSE loads that apply to the airport. REopt identifies a large PV system and a modest BESS as cost-effective for DRO's non-EVSE loads. The underlying electric tariff includes charges of 6.72 cents/kWh for all electricity purchased from the grid and $15.21/kW for each month's peak demand. This tariff therefore offers an opportunity for both PV and BESS to provide value and offset the cost of electricity. As modeled, the PV system is allowed to export surplus generation to the grid at the retail rate, which can result in an additional estimated export benefit of $55.6k in the first year of service. This export benefit is in addition to energy charge savings provided by the PV system in utility bills. As modeled, the site is not allowed to export more electricity than it purchases from the grid on an annual basis. Therefore, the identified PV system size exports 828 MWh of electricity annually, which equals the airport's grid purchases after PV and BESS are placed in service. Were the model allowed to become a net exporter of electricity, the utility would compensate for any excess exports at an avoided cost rate. This potential rate modification could further incentivize installation of solar PV if cost-effective and change the REopt-identified results.

Another takeaway from DRO's non-EVSE load results is the importance of net metering. Without the ability to export to the grid, the model identifies only 170 kW of solar PV and a similarly sized BESS as cost-effective. The NPV of this investment would be $27.0k, less than half the NPV of systems identified to support forecasted aircraft loads. Larger PV systems also allow BESS to charge more frequently from on-site PV generation instead of the grid, thereby providing more cost savings.

System sizes and economics identified, as shown in Table 38, for building loads include ITC and asset depreciation incentives and use ground-mount PV installed costs. BESS installed costs are the same as those in EVSE results. Variations in these input costs and incentive values can also result in changes to the identified system and cost savings.

Table 38. DRO Buildings REopt Results

Result Metric	No Export Allowed	PV Can Export
Total Annual Non-EVSE Electric Loads at DRO	1,326 MWh	1,326 MWh
Year 1 Energy Supplied From Grid to Non- EVSE Loads	1,053 MWh	827 MWh
Year 1 Energy Supplied From Grid to Electric Storage	0.6	0.4
Peak Demand Grid to EVSE BAU [kW]	268	268
Peak Demand Grid to EVSE With DERs [MW]	222	218
Marginal CO_2 Emissions BAU [tCO_2/year]	246	246
Marginal CO_2 Emissions [tCO_2/year]	214	94
PV [kWdc]	170	843
BESS [kWh/kW]	40/26	34/26
NPV	$27.0k	$66.1k
SPP/IRR [Years/%]	11.3/8%	11.3/7%
Capital Costs	$0.34 million	$1.51 million
Capital Costs After Incentives	$180,000	$788,000
Year 1 Electric Bill BAU	$130,000	$130,000
Annual Demand Charge Savings	$5,200	$6,380
Annual Energy Charge Savings	$18,300	$33,600
PV Annual Energy Produced [MWh]	274	1,360
PV Annual Energy Exported [MWh]	0	828
Year 1 Export Benefit From PV	$0	$55.6k

Figure 15 provides the dispatch plot for a potential rate structure at DRO where PV is allowed to export. Because the electric utility would bill DRO on net energy consumed, any exported electricity would simply offset grid purchases made in the absence of solar. Even though BESS is identified in the solution, its main use is monthly peak shaving, which is not readily visible in the 7-day results presented.

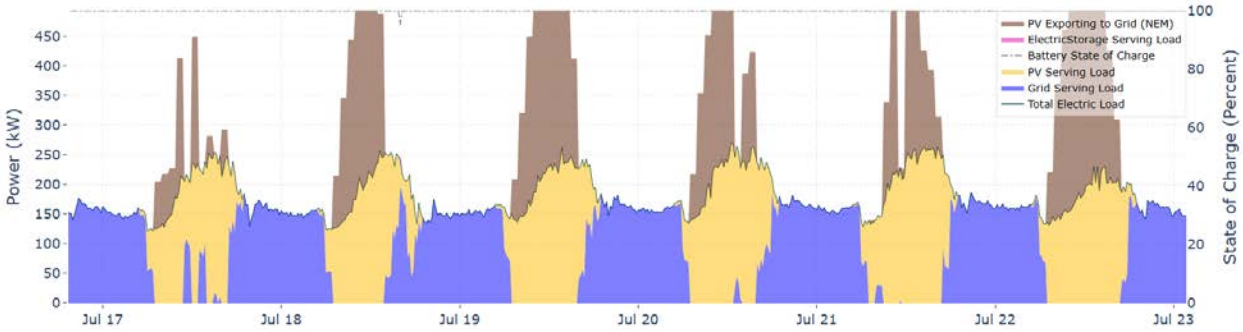

Figure 15.11 DRO buildings dispatch with PV export allowed

Alternatively, Figure 16 shows the building load dispatch plot when PV is not allowed to export. In this case, PV is sized only to offset the site load and not benefit from exporting to the grid.

Figure 16. DRO loads-only dispatch without the PV export benefit

Table 39 details the REopt-identified results at DRO airport for the RAM-only EVSE loads, whereas Table 39 provides results for the FLS-only EVSE loads. Table 26 provides REopt-identified results for RAM+FLS EVSE loads. These tables provide business-as-usual grid consumption, peak demand, and marginal emissions and compare these numbers against the modeled values after on-site DERs have served part of the EVSE loads. All EVSE loads are assumed to be serviced through new electric meters independent of existing meters. These detailed results include the cost-optimal system sizes, economics of on-site power-generating assets for direct and third-party ownership, the cost-optimal grid, and on-site power generation consumption and marginal emissions.

REopt identifies similarly sized PV and BESS systems as cost-effective at DRO regardless of C rate, scenario type, or system ownership. The NPV of cost savings ranges from $30,000 to $60,000 under direct ownership and from $30,000 to $80,000 under third-party ownership. The identified system sizes do not increase under third-party ownership where asset depreciation is available. Instead of shaving the large peaks of this scenario type, the model prefers to let the grid serve the load to maximize the NPV of cost savings. There is a large gap in the size of identified systems between FLS only and other scenario types, likely due to the forecasted flight school size in comparison to the forecasted RAM passenger service.

For example, the 1C FLS-only scenario requires 133 MWh of electricity with peak demand of 370 kW, but the 1C RAM-only scenario requires 986 MWh of electricity with peak demand of approximately 1,370 kW. BESS sizes under the 4C charging cases are noticeably smaller than the 2C charging cases under all scenarios. This difference can be a result of the peak demand dropping from 2C to 4C charging rate scenarios due to fewer number of EVSE chargers being required. Figure 17 shows the EVSE loads required for the 2C RAM-only scenario, wherein peak demand hovers around 1,800 kW. Per Table 38, the peak demand under 4C scenarios reduces to ~1,450 kW. Peak demand at 4C C rates are lower than 2C in FLS and RAM+FLS scenarios as well.

Table 39. DRO Results for RAM-Only EVSE Loads

Data Point/ C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	986.46	986.46	986.46	986.46	986.46	986.46
BAU Peak Demand Grid to EVSE [MW]	1.37	1.81	1.45	1.37	1.81	1.45
BAU Year 1 Electric Bill [$k]	203.1	244	210.3	203.1	244	210.3
BAU Marginal CO_2 Emissions [tCO_2/year]	176.5	176.9	176.6	176.5	176.9	176.6
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required Gith DERs [MWh]	796.89	834.03	857.29	796.89	834.03	857.29
Peak Grid Demand to EVSE [MW]	0.94	0.95	1.26	0.94	0.95	1.26
Peak Grid Demand to BESS [MW]	0.44	0.85	0.19	0.44	0.85	0.19
Marginal CO_2 Emissions [tCO_2/year]	64.2	64.1	64.2	64.2	64.1	64.2
PV [kWdc]	609	613	608	609	613	608
BESS [MWh/MW]	0.14/0.43	0.28/0.85	0.06/0.18	0.14/0.44	0.28/0.85	0.06/0.18
NPV [$million]	0.04	0.05	0.03	0.05	0.06	0.04
Annual Payment to Third Party [$k]	0	0	0	119	160	95
SPP/IRR [Years/%]	13.36/7%	14/7%	12.66/7%	12.84/6%	13.33/6%	12.04/6%
Capital Costs After Incentives [$million]	1.12	1.44	0.92	0.82	1.06	0.67
Annual Demand Charge Savings [$k]	41.27	80.69	17.46	41.27	80.69	17.46
Annual Energy Charge Savings [$k]	14.76	12.52	9.89	14.76	12.52	9.89

Table 40. DRO Results for FLS-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	133.4	135.68	135.68	133.4	135.68	135.68
BAU Peak Demand Grid to EVSE [MW]	0.37	0.49	0.4	0.37	0.49	0.4
BAU Year 1 Electric Bill [$k]	45.2	56.4	48	45.2	56.4	48
BAU Marginal CO_2 Emissions [tCO_2/year]	17.3	17.5	17.5	17.3	17.5	17.5
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	92.09	101.72	107.43	92.09	101.72	107.43
Peak Grid Demand to EVSE [MW]	0.32	0.2	0.34	0.32	0.2	0.34
Peak Grid Demand to BESS [MW]	0.05	0.2	0.06	0.05	0.2	0.06
Marginal CO_2 Emissions [tCO_2/year]	2.4	4	2.4	2.4	4	2.4
PV [kWdc]	82	85	84	82	85	84
BESS [MWh/MW]	0.02/ 0.05	0.09/ 0.28	0.02/ 0.06	0.02/ 0.05	0.09/ 0.28	0.02/ 0.06
NPV [$million]	0.03	0.05	0.04	0.03	0.06	0.04
Annual Payment to Third Party [$k]	0	0	0	15	39	16
SPP/IRR [Years/%]	11.63/ 8%	12.56/ 8%	10.54/ 9%	12.69/ 6%	13.4/ 6%	12.76/ 6%
Capital Costs After Incentives [$million]	0.14	0.33	0.15	0.11	0.24	0.11
Annual Demand Charge Savings [$k]	6.65	29.99	8.07	6.65	29.99	8.07
Annual Energy Charge Savings [$k]	3.19	2.95	2.18	3.19	2.95	2.18

Table 41. DRO Results for RAM+FLS EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,119.85	1,122.14	1,122.14	1,119.85	1,122.14	1,122.14
BAU Peak Demand Grid to EVSE [MW]	1.38	1.84	1.67	1.38	1.84	1.67
BAU Year 1 Electric Bill [$k]	213.8	257.8	241.4	213.8	257.8	241.4
BAU Marginal CO_2 Emissions [tCO_2/year]	193.9	194.4	194.1	193.9	194.4	194.1
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	822.68	871.59	883.14	822.68	871.59	883.14
Peak Grid Demand to EVSE [MW]	1.01	1.02	1.18	1.01	1.02	1.18
Peak Grid Demand to BESS [MW]	0.37	0.83	0.49	0.37	0.83	0.49
Marginal CO_2 Emissions [tCO_2/year]	67	67.7	67.3	67	67.7	67.3
PV [kWdc]	691	697	694	691	697	694
BESS [MWh/MW]	0.12/0.37	0.27/0.83	0.16/0.49	0.12/0.37	0.27/0.83	0.16/0.49
NPV [$million]	0.04	0.06	0.04	0.05	0.08	0.06
Annual Payment to Third Party [$k]	0	0	0	123	169	135
SPP/IRR [Years/%]	13.06/7%	13.79/7%	13.32/7%	12.54/6%	13.31/6%	12.83/6%
Capital Costs After Incentives [$million]	1.17	1.53	1.27	0.85	1.12	0.93
Annual Demand Charge Savings [$k]	34.75	78.6	46.27	34.75	78.6	46.27
Annual Energy Charge Savings [$k]	22.84	19.98	18.6	22.84	19.98	18.6

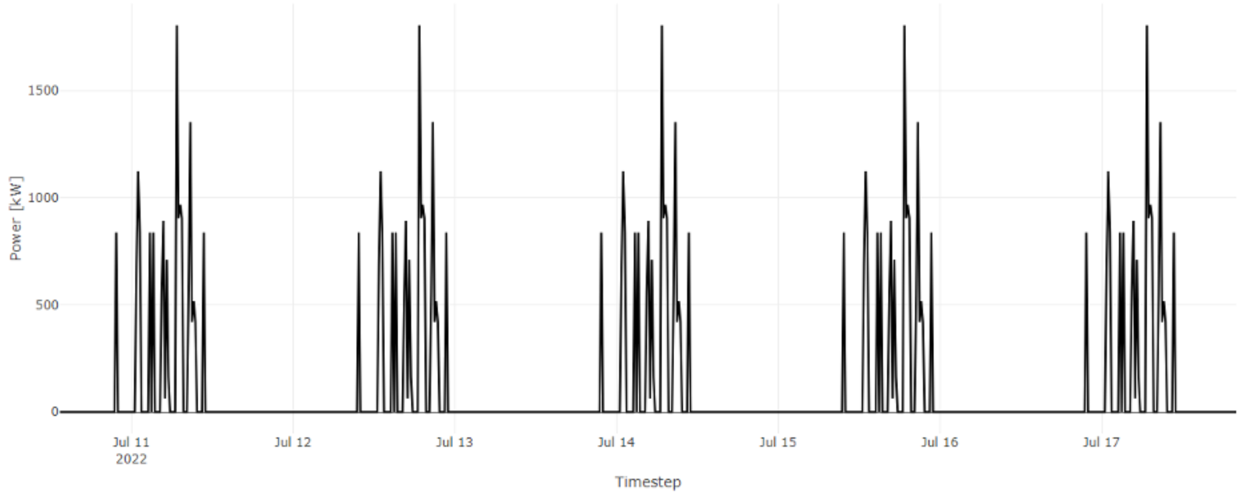

Figure 17.12 The RAM-only 2C EVSE load profile at DRO

4.2.1.6 Colorado Springs Airport

Informing this discussion is previous work on COS for existing building loads under NASEM (2022). Previous analysis indicated that solar and BESS were cost-effective for COS for existing buildings. Results indicated that a small PV and battery system serving 3%–5% of the annual site load via direct purchase was cost-effective as well as a third-party financed alternative that increased sizing to accommodate 20% of the load (NASEM 2022). Noted that COS operates under a municipal utility rate that differs from both DRO and GJT.

The current analysis expands on this effort by exploring RAM and FLS loads. Table 42 details the REopt-identified results at COS for RAM-only EVSE loads, whereas Table 43 provides results for FLS-only EVSE loads. Table 44 provides REopt-identified results for RAM+FLS EVSE loads. These tables provide business-as-usual grid consumption, peak demand, and marginal emissions and compare these numbers against the modeled values after on-site DERs have served part of the EVSE loads. These results include the cost-optimal system sizes, economics of on-site power-generating assets for direct and third-party ownership, the cost-optimal grid, and on-site power generation consumption and marginal emissions.

REopt results for COS identify both solar PV and BESS as being cost optimal under all charging rates across all FLS and RAM+FLS scenarios. When only RAM loads are considered, BESS is cost-effective because as modeled, these loads are partially present overnight where PV does not provide value (see Figure 18). 13In comparison, FLS loads (Figure 19) are present during the day, which allows PV to provide value at that time. When RAM and FLS loads are considered, the model identifies similar sizes of solar PV, but the BESS has a larger energy capacity and higher maximum charge/discharge power.

Solar PV is the primary source of cost savings per NPV and project economics under the FLS and FLS+RAM scenarios. Under all scenario types and C rates, the BESS does not have a financial incentive to peak shave outside of peak hours because the off-peak hours demand charge is effectively zero. Therefore, the results indicate minimal reduction in peak demand from the grid to EVSE despite the presence of BESS. RAM-only scenarios also lose out on cost savings because the BESS capacity is not sized to shave peak outside peak hours. Under third-party ownership, the system sizes remain the same as direct airport ownership, with the annual payment to the developer ranging from $52,000 to $140,000 across scenarios and C rates. Capital cost savings from monetizing incentives appear to cancel out the developer’s interest rate requirements.

Table 42. COS Results for RAM-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,507.91	1,507.9	1,507.9	1,507.9	1,507.9	1,507.9
BAU Peak Demand Grid to EVSE [MW]	1.9	3.42	3.35	1.9	3.42	3.35
BAU Year 1 Electric Bill [$k]	212.1	278.7	273.5	212.1	278.7	273.5
BAU Marginal CO_2 Emissions [tCO_2/year]	266.5	266.5	266.5	266.5	266.5	266.5
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	1,511.6	1,515.7	1,514.9	1,511.6	1,515.7	1,514.9
Peak Grid Demand to EVSE [MW]	1.9	3.42	3.35	1.9	3.42	3.35
Peak Grid Demand to BESS [MW]	0.54	1.14	1.09	0.54	1.14	1.09
Marginal CO_2 Emissions [tCO_2/year]	267.6	269.3	269.3	267.6	269.3	269.3
PV [kWdc]	0	0	0	0	0	0
BESS [MWh/MW]	0.18/0.54	0.38/ 1.14	0.36/ 1.08	0.18/ 0.54	0.38/ 1.14	0.36/ 1.08
NPV [$million]	0.02	0.03	0.03	0.02	0.03	0.03
Annual Payment to Third Party [$k]	0	0	0	52	111	106
SPP/IRR [Years/%]	14.43/7%	14.43/ 7%	14.42/ 7%	13.48/ 6%	13.48/ 6%	13.48/ 6%
Capital Costs After Incentives [$million]	0.41	0.87	0.83	0.3	0.64	0.61
Annual Demand Charge Savings [$k]	0	0	0	0	0	0
Annual Energy Charge Savings [$k]	0.28	0.6	0.59	0.28	0.6	0.59

Table 43. COS Results for FLS-Only EVSE Loads

Data Point/C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	404.19	404.36	404.36	404.19	404.36	404.36
BAU Peak Demand Grid to EVSE [MW]	0.58	0.88	0.94	0.58	0.88	0.94
BAU Year 1 Electric Bill [$k]	135.8	196.5	217.3	135.8	196.5	217.3
BAU Marginal CO_2 Emissions [tCO_2/year]	56	55.7	55.5	56	55.7	55.5
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	309.21	279.55	275.34	307.76	279.55	274.3
Peak Grid Demand to EVSE [MW]	0.57	0.8	0.8	0.57	0.8	0.8
Peak Grid Demand to BESS [MW]	0.41	0.61	0.72	0.41	0.61	0.72
Marginal CO_2 Emissions [tCO_2/year]	47.4	34.7	34.8	47.1	34.7	34.4
PV [kWdc]	114	180	178	115	180	180
BESS [MWh/MW]	0.40/ 0.41	0.39/ 0.61	0.38/ 0.72	0.40/ 0.41	0.39/ 0.61	0.38/ 0.72
NPV [$million]	0.73	1.24	1.46	0.73	1.25	1.46
Annual Payment to Third Party [$k]	0	0	0	65	90	99
SPP/IRR [Years/%]	4.53/ 18%	4.11/ 21%	3.92/ 22%	13.42/ 6%	13.41/ 6%	13.42/ 6%
Capital Costs After Incentives [$million]	0.55	0.76	0.83	0.4	0.56	0.61
Annual Demand Charge Savings [$k]	0	0	0	0	0	0
Annual Energy Charge Savings [$k]	7.15	8.35	8.5	7.2	8.35	8.55

Table 44. COS Detailed System Sizes and Project Economics

Data Point C Rate	1C	2C	4C	1C	2C	4C
BAU Year 1 Energy Required [MWh]	1,912.1	1,912.26	1,912.26	1,912.1	1,912.26	1,912.26
BAU Peak Demand Grid to EVSE [MW]	2.22	3.86	3.9	2.22	3.86	3.9
BAU Year 1 Electric Bill [$k]	317.7	426	434.8	317.7	426	434.8
BAU Marginal CO_2 Emissions [tCO_2/year]	322.5	322.2	322.1	322.5	322.2	322.1
Identified Cost-Optimal Solutions	**Direct**			**Third Party**		
Year 1 Energy Required With DERs [MWh]	1,809.29	1,766.03	1,771.31	1,808.13	1,766.03	1,771.31
Peak Grid Demand to EVSE [MW]	2.21	3.86	3.89	2.21	3.86	3.89
Peak Grid Demand to BESS [MW]	0.69	1.17	1.18	0.69	1.17	1.18
Marginal CO_2 Emissions [tCO_2/year]	315.4	302.7	302.6	315.2	302.7	302.6
PV [kWdc]	106	180	180	107	180	180
BESS [MWh/MW]	0.44/0.69	0.47/1.17	0.47/1.18	0.43/ 0.69	0.47/ 1.17	0.47/ 1.18
NPV [$million]	0.85	1.52	1.69	0.86	1.52	1.7
Annual Payment to Third Party [$k]	0	0	0	89	141	141
SPP/IRR [Years/%]	4.72/17%	4.49/18%	4.26/19%	13.44/6%	13.44/6%	13.44/6%
Capital Costs After Incentives [$million]	0.73	1.15	1.15	0.54	0.85	0.85
Annual Demand Charge Savings [$k]	0	0	0	0	0	0
Annual Energy Charge Savings [$k]	7.6	9.7	9.47	7.64	9.7	9.47

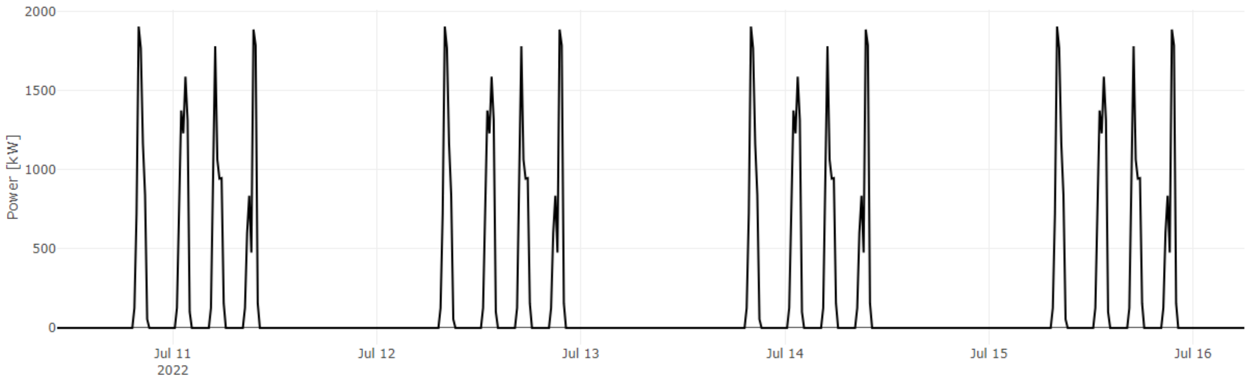

Figure 18. COS RAM-only 1C load profile

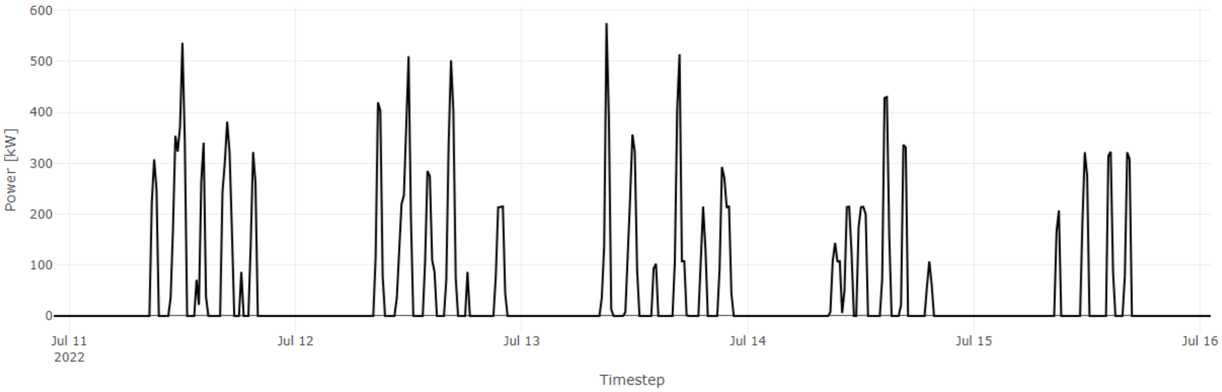

Figure 19. COS FLS-only 1C load profile

4.2.2 Key Findings – Airport Infrastructure Analysis

Key findings from the REopt analysis include the following:

- Solar PV is cost-effective (at a fully burdened installed cost of $1,790/kWdc, with a 30% ITC) at nearly all airports considered with forecasted EVSE loads.
- Airports should seek grants and financial assistance to bring the net per-unit cost of carport or rooftop PV as low as possible.
- Absence of net metering policies (currently available in Colorado) can also influence the cost-effectiveness of PV, as noted in ABQ.

An additional takeaway from this study is the importance of the ITC as system sizes identified under direct ownership (ITC only) do not change drastically under third-party ownership (ITC + asset depreciation write offs + bonus depreciation) scenarios.

Rate structures and method of recoupment of upstream upgrades that the utility provider offers can have significant impacts on how to best deploy DERs on-site.

4.3 Regional Airport Infrastructure Analysis Results (Engage)

We ran Engage across the 40 study airports with modeled nonhybrid RAM loads and six scenarios, with some sensitivities, for a total of over 500 individual optimizations. Comparing results across scenarios and sensitivities can show the large-scale regional impacts on DERs and grid infrastructure of potential new charging loads, as well as how specific considerations can vary that impact. To explore the impacts of different tariff structures across a wide range of airports, this initial screening uses two reference tariffs that vary in how energy is being billed: the La Plata TSR, and the Xcel Energy P-EV. The build-outs chosen by the model across all combinations of airports, scenarios, and sensitivities can be largely categorized into three types: all grid, some combination of DERs and the grid, or all DERs.

4.3.1 Type 1: All Grid

This category of outcomes contains those in which no DERs are installed, and the model chooses to meet charging loads from passenger RAM and electrified flight school charging with the new primary voltage utility connection. These outcomes are most common with smaller airports with charging loads well below the 2 or 3 MW cutoff for grid interconnection and peak charging loads that are not high enough to incur significant demand charges. Figure 20 shows the BJC dispatch and demand of the 1C charging case with the La Plata PSR tariff. It shows that the charging demand and grid power dispatch mirror one another as the charging demand is fully met by the grid.

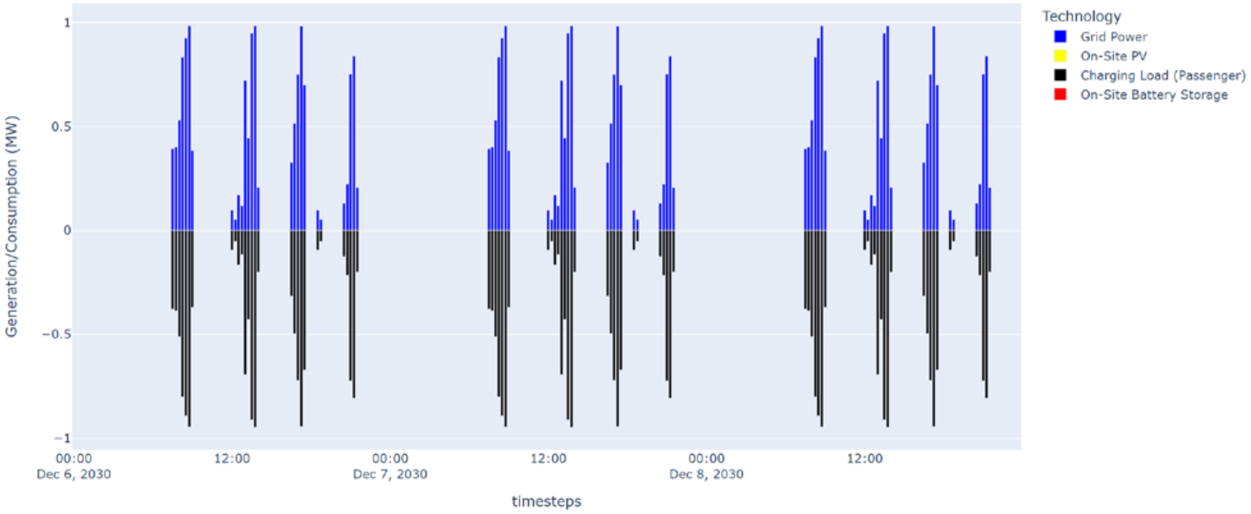

Figure 20. BJC 1C charging with the La Plata PSR tariff

4.3.2 Type 2: Hybrid (Grid+DERs)

This category of outcomes includes those for which the model determined that a combination of grid power and DERs was economic to meet charging load. This build-out was most common in the larger/busier airports or the airports with additional flight school loads. The share of consumption and demand provided by the grid versus DERs varied among airports and scenarios, with some just using the grid connection to help meet peak power demand and reduce the need for inverter capacity on the DERs. Figure 21 shows the Provo, Utah (PVU) dispatch and charging demand profiles for the 1C charging case with the La Plata PSR tariff.

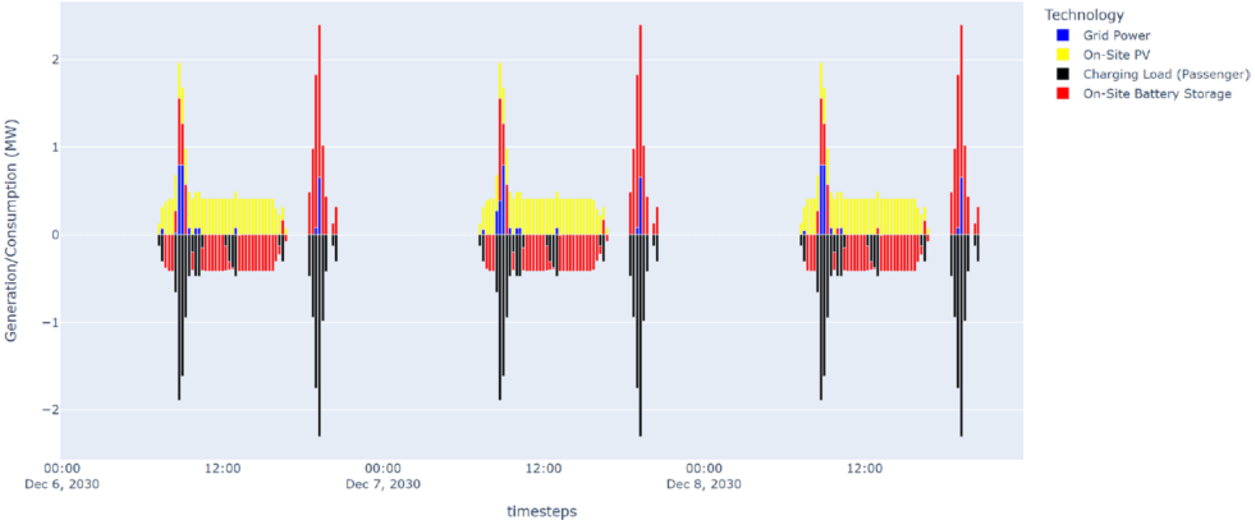

Figure 21. PVU 1C charging with the La Plata PSR tariff

Other airports use the grid connection more regularly to meet charging load, using DER PV and especially batteries to help shave the charging demand peaks and ensure additional distribution upgrades are not required. One interesting dispatch strategy that the model identifies is discharging the batteries to help meet charging load even during the day. With intermittent loads on the system, the PV can be used to charge batteries when there is no charging load. By dispatching the batteries during daytime charging, airports can significantly reduce the additional PV capacity needed to keep the peak grid load down. This strategy would be most useful when there are fewer charging events in the morning, thereby giving the batteries enough time to charge from the PV before being used in the afternoon, as shown in Figure 22 which displays the DRO 1C dispatch plot.

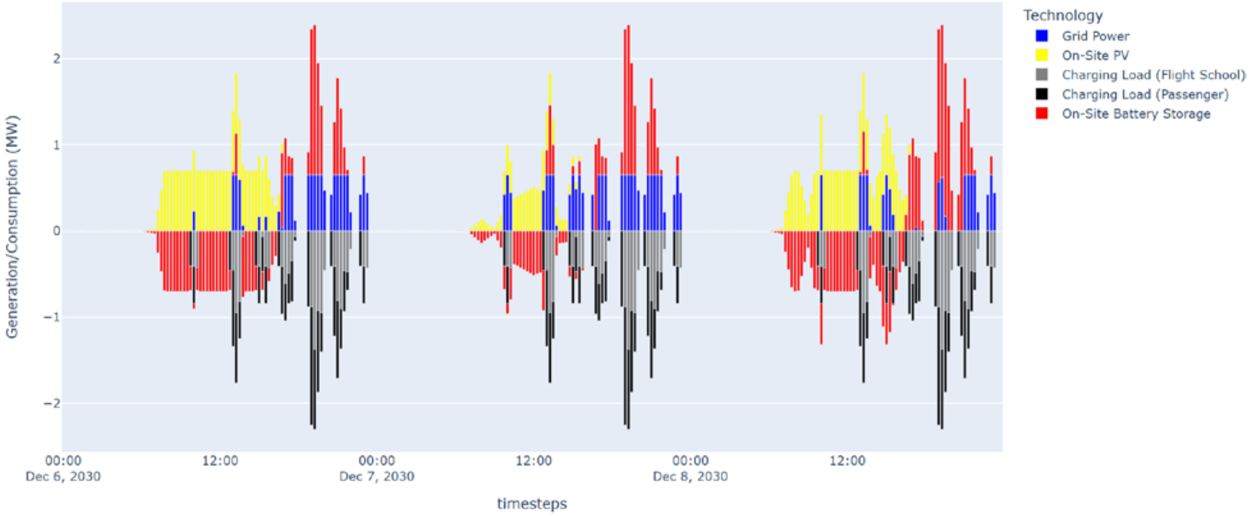

Figure 22. DRO 1C charging with the La Plata PSR tariff

4.3.3 Type 3: All DERs

This category of outcomes includes those for which the model determined that DERs without grid support would be most economic for meeting the consumption and demand of charging. This was the case with some of the smaller airports, such as those with only one or two charging events, making it easy for a small PV investment to charge a short-duration battery to meet those loads without the need for grid power. Figure 23 shows the dispatch and demand plot for the 40U 1C charging case under the La Plata PSR tariff.

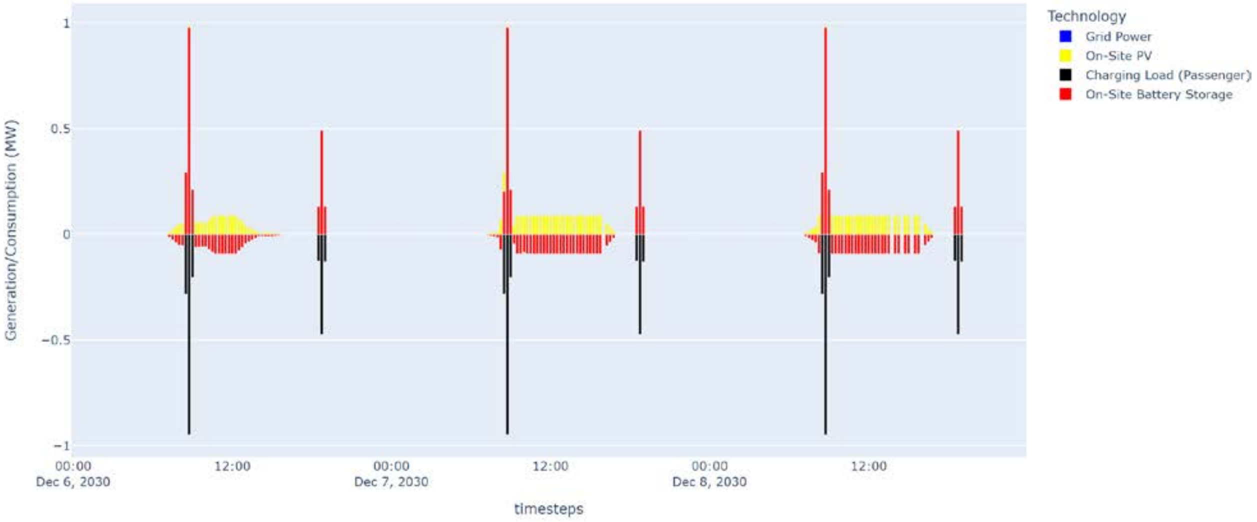

Figure 23. 40U 1C charging with the La Plata PSR tariff

4.3.4 Impacts of Charging Strategies and Utility Tariffs

The results of the forecasted demand study (using Engage) indicate that for lower-utilization airports without flight schools, grid build-out of infrastructure is usually the most cost-effective system configuration. This does not factor in energy resilience considerations which may drive further DER buildout beyond what is strictly economic in blue-sky operation.

For higher-use locations, available rate structures exhibit more influence on deployment of energy generation assets. In the analysis, the La Plata tariff resulted in significantly more DER build-out, especially with batteries, and had the only instances of 100% DER systems. The Xcel scenarios used the grid more grid utilization, implying that that tariff is more competitive with DERs than the La Plata tariff when meeting DCFC loads. This result appears to be significantly influenced by the tariff structure favoring optimizing grid demand around time of day billing and/or high demand rates. Table 45 summarizes the scenario results for all the airports without flight school loads incorporated. Additional detail regarding flight school loads follows.

Table 45. Scenario Results for All Airports, No Flight School Loads

Scenario	All Grid Build-Outs	Hybrid Build-Outs	All DER Build-Outs	PV Total Capacity	Battery Total Capacity
1C Charging With La Plata PSR Tariff	30	7	2	3.333 MW	10.884 MW/21.279 MWh
2C Charging With La Plata PSR Tariff	24	9	6	4.484 MW	21.503 MW/31.964 MWh
4C Charging With La Plata PSR Tariff	24	9	6	4.614 MW	21.991 MW/33.430 MWh
1C Charging With Xcel P-EV Tariff	31	8	0	3.340 MW	6.168 MW/18.991 MWh
2C Charging With Xcel P-EV Tariff	32	7	0	2.743 MW	7.124 MW/16.511 MWh
4C Charging With Xcel P-EV Tariff	32	7	0	2.660 MW	6.913 MW/16.034 MWh

4.3.5 Impacts of Potential Flight School Electrification

The five airports that had identified flight school loads—ABQ, BJC, COS, DRO, and GJT—also had some of the most prevalent RAM activity. These airports accounted for a large proportion of the built DER capacities in the base scenarios. Even with forecasted commercial charging demand, the estimated load for a high-use, moderately sized electric aircraft trainer fleet exceeds the potential RAM electrical demand, such that electrification of the flight schools at these airports would require as much or more infrastructure investment as the corresponding commercial passenger service. Table 46 summarizes the scenario results for airports with identified flight schools prior to inclusion of flight school loads.

Table 46. RAM-Only Scenario Results for ABQ, BJC, COS, DRO, and GJT

Scenario	All Grid Build-Outs	Hybrid Build-Outs	All DER Build-Outs	PV Total Capacity	Battery Total Capacity
1C Charging With La Plata PSR Tariff	1	4	0	2.335 MW	5.788 MW/ 15.697 MWh
2C Charging With La Plata PSR Tariff	0	5	0	2.669 MW	9.709 MW/ 18.125 MWh
4C Charging With La Plata PSR Tariff	0	5	0	2.602 MW	9.655 MW/ 17.839 MWh
1C Charging With Xcel P-EV Tariff	0	5	0	2.579 MW	4.958 MW/ 16.064 MWh
2C Charging With Xcel P-EV Tariff	1	4	0	2.109 MW	5.064 MW/ 13.065 MWh
4C Charging With Xcel P-EV Tariff	1	4	0	2.016 MW	4.788 MW/ 12.389 MWh

Once flight school loads are added to the RAM passenger loads, the recommended PV generation capacity more than doubled for all scenarios. Battery storage capacity doubled or nearly doubled in all scenarios, and battery energy capacity was also drastically increased, especially in the scenarios using the Xcel PEV tariff. Table 47 summarizes the scenario results for airports with flight schools (and with the flight school loads incorporated).

Table 47. Scenario Results for ABQ, BJC, COS, DRO, and GJT With Flight School Loads

Scenario	All Grid Build-Outs	Hybrid Build-Outs	All DER Build-Outs	PV Total Capacity	Battery Total Capacity
1C Charging With La Plata PSR Tariff	0	5	0	5.235 MW	12.052 MW/ 33.463 MWh
2C Charging With La Plata PSR Tariff	0	5	0	5.430 MW	15.282 MW/ 35.614 MWh
4C Charging With La Plata PSR Tariff	0	5	0	5.412 MW	14.610 MW/ 35.472 MWh
1C Charging With Xcel P-EV Tariff	0	5	0	5.307 MW	9.339 MW/ 33.371 MWh
2C Charging With Xcel P-EV Tariff	0	5	0	5.407 MW	12.370 MW/ 34.670 MWh
4C Charging With Xcel P-EV Tariff	0	5	0	5.381 MW	12.156 MW/ 34.317 MWh

4.3.6 Impacts of Feeder Congestion/Spare Capacity

A key element that can typically only be answered through close coordination with the utility provider is what spare capacity currently exists supporting the area being evaluated. For analysis purposes, spare capacity was assumed for the distribution lines, which reduced it to 2 MW from 3 MW. Available capacity can have a dramatic effect on the calculated least-cost energy system configuration. For many of the airports/charging scenario combinations in the study, the peak load is either below 2 MW or well above 3 MW, meaning that reducing that assumed spare feeder capacity has little-to-no impact on the least-cost build-out. For some airports with peak load around or above 2 MW; however, the reduced assumed spare feeder capacity can drive significant additional adoption of DERs. An example of a significant impact of a lower assumed spare feeder capacity is indicated in the results for PVU in Table 48 at a high charge rate (4C).

Table 48. PVU Scenario, 4C Charging Case With Xcel P-EV Tariff

Airport	Scenario	PV Capacity With 3 MW	Battery Capacity With 3 MW	PV Capacity With 2 MW	Battery Capacity With 2 MW
PVU	4C charging with Xcel P-EV tariff	0 kW	0 kW	287.03 kW	782.33 kW/1,652.36 kWh

The peak charging demand is between 2 MW and 3 MW during two charging events, one in the day and one at night. With 3 MW of available capacity on the feeder, the least-cost system configuration relies solely on grid power, as shown in Figure 24.

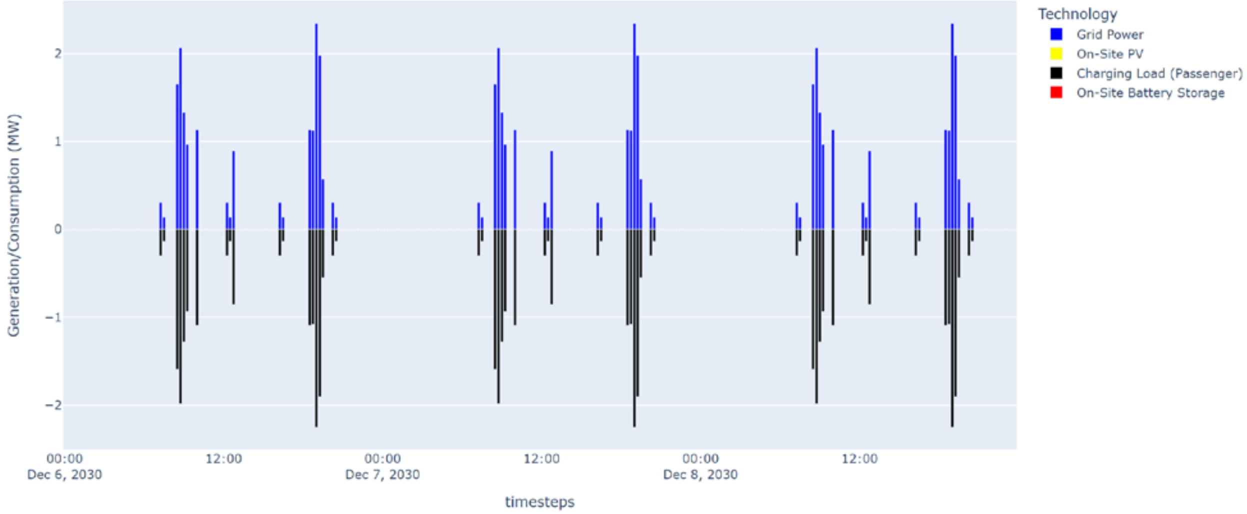

Figure 24. PVU dispatch for 4C charging with the Xcel PEV tariff and 3-MW spare feeder capacity

When there is only 2 MW of available capacity, rather than building just enough PV/battery to keep the peak grid draw below 2 MW, the analysis suggests building a significant amount of PV and battery storage. Figure 25 shows the dispatch plot for PVU for the 4C charging chase with the Xcel PEV tariff and 2-MW spare feeder capacity.

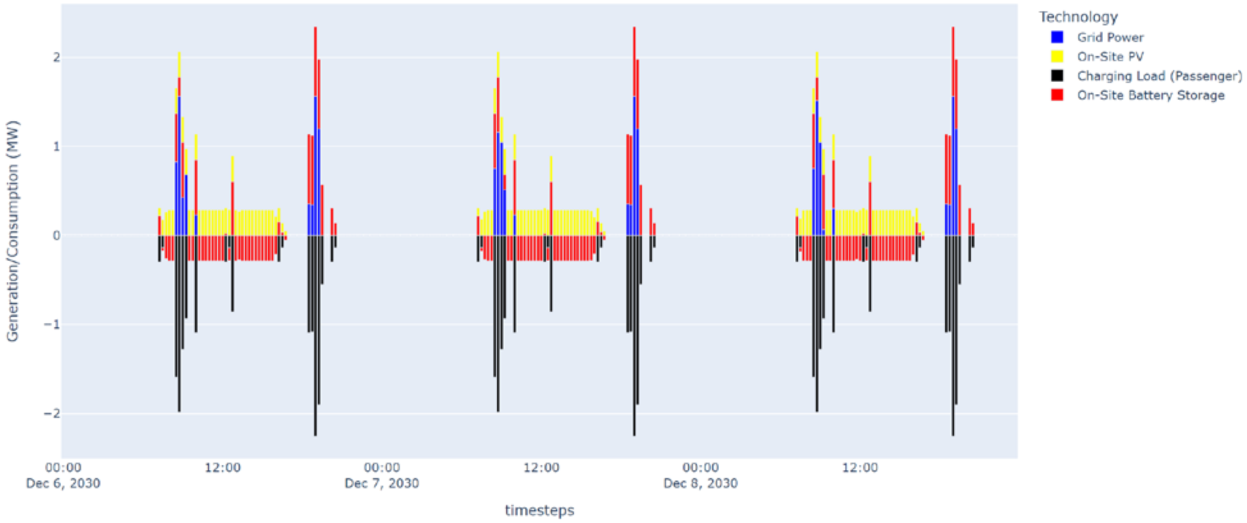

Figure 25. PVU dispatch for the 4C charging case with the Xcel PEV tariff and 2-MW spare feeder capacity

The dramatic difference in system configurations between the two variations also implies that DERs and the Xcel utility rate are cost competitive with each other, such that build-outs of different levels of DERs are close in total costs to the cost of grid usage without significant feeder upgrades. When feeder upgrades are necessary, and not incorporated in the per-unit rate structure, installation of on-site DERs defers feeder upgrade costs and brings energy generation closer to the point of use.

In areas of significant energy congestion, impacts would be even more pronounced if a feeder had little-to-no available capacity. However, for high-congestion areas, a utility may be more willing to pay for upgrading a busy feeder through the normal process of rate recouperation if that feeder was already earmarked for growth. The impact of spare feeder capacity will vary from airport to airport and, if significant charging demand is anticipated, may require negotiation with the utility.

4.3.7 Key Findings – Regional Airport Infrastructure Analysis

Key findings from the Engage modeling analysis of the full airport network include the following:

- When upstream capital costs were considered at higher use airports in the study, DER assets became more financially viable.
- The cost effectiveness of DER assets was significant when considering combined peak loads of both flight school and RAM charging loads.
- Smaller airports focused on flight training could see even more drastic changes to existing energy needs if a flight school were to electrify. With minimal existing electrical loads, rural airports must first confirm on-site availability of three-phase power, and this study's assumption of spare feeder capacity and the estimated cost for reconductoring might be over- and underestimated, respectively. If the smaller airports in the study have severe restrictions on the existing distribution infrastructure, it could support the use of on-site DER assets for electrifying aircraft flight beyond the amounts found economic in this study.

- Available feeder capacity could have a major impact on the economic opportunities for additional DER assets beyond what the utility rate would suggest. Specifically:
    - Utilities typically design distribution systems to meet peak demand regardless of any load-shaving opportunities that DERs or other behind-the-meter technologies offer.
    - With potentially megawatts of peak charging demand, this typical design approach by the utility providers could require expensive upgrades to the distribution systems at airports, which would likely be passed on to the airport.

There is a strong economic case to use additional DERs to reduce costs for both the airport and utility, but it would require the utility to adjust its distribution system design strategy. This process would require the airport operators to coordinate with the utilities and potentially the public utility commission to determine if an appropriate agreement could be reached. The agreement could limit the maximum load that the utility would need to serve, with the airport ensuring that enough DERs are built to meet any critical loads in excess of that limit. In parallel with the REopt analysis, the Engage model was used to investigate two rate structures for all sites regardless of energy provider to explore infrastructure costs. The model assumes off-site grid infrastructure costs are not incorporated in the rates, requiring additional capital costs to upgrade the distribution system to support the new charging loads. Comparing the two rates analyzed across all study airports, there are two major differences that lead to different optimal system configurations. The Xcel PEV rate has significantly higher peak energy prices (when surcharges are included), whereas the La Plata PSR rate has a significantly higher demand charge. The higher La Plata demand charges incentivized DER build-out to avoid charges for the more intensive peak demands associated with DCFC charging loads—in several cases making it economically attractive to exclusively use DERs to meet charging load and avoid any demand charges at all. The comparison between the two rate structures also points to the more pronounced differences in results between the 1C and 2C/4C charging scenarios present in the La Plata PSR analysis. The 2C/4C charging strategies experienced significantly higher load peaks compared to the 1C case. These higher load peaks would raise the cost of a hybrid or grid-only system when paired with a rate with a high demand charge. The least-cost optimization, therefore, elects all-DER systems as well as increased DER capacity across the airports to keep demand charges low in these high-peak charging loads cases.

5 Regulatory Review

For airport- and system-level financial planning, existing regulatory frameworks were identified that significantly rely on base assumptions that are evolving: aircraft weight, energy carrier efficiency, and other related efforts. Current revenue frameworks have evolved to recover costs and maintain the aviation system based on the assumption that energy will be delivered by the gallon, aircraft will get lighter over the flight, and efficiency improvements have not shifted significantly enough to warrant reinvestigating base assumptions. The state of Colorado's aviation revenue system has accounted for the economic inflation via a sales tax, whereas others are based solely on a physical unit of measure.

This analysis underscores the need for adaptable strategies that can respond to technological transitions in energy carriers in the airport system, aircraft design, battery technology, changes in energy prices, and evolving environmental policies. Airports and regulators may need to explore new revenue models that account for the shift from per-gallon fuel sales to alternative energy carrier delivery, and type of propulsion system.

Although methods for revenue generation may shift, the transition to electric aircraft may also present opportunities for airports and regulatory agencies. Should lower operating costs prevail in electrified aviation, more frequent use of local or regional airports becomes more economically viable, potentially increasing overall traffic and revenue (Reichmann 2024). The reduced operating costs of electric aircraft—up to 90% reduction in fuel costs and 50% cut in maintenance versus traditional aircraft—could lead to increased flight frequency and new routes, boosting airport activity and ancillary revenues (Toptal n.d.). It is noted that flight training aircraft are currently fueled predominantly with leaded aviation gasoline. Electrification could be utilized to reduce leaded gas use, in lieu of pursuing FAA special type certification (aircraft specific approval for alternate fuel use) on legacy systems.

Airports and organizations that proactively plan for this transition are likely to be better positioned for accommodating emerging markets and able to reduce related aviation impacts such as noise and emissions onto adjacent communities. Methods to prepare include proactively modifying revenue streams and determining appropriate infrastructure business models relevant to the local community. A few specific methods to offset potential revenue losses include implementing electricity sales models that are similar to traditional fuel sales, establishing fixed fees for electric aircraft operators, and introducing infrastructure fees to recover investment costs (Hooper 2022). Airports are also considering revenue generation from ancillary services offered during aircraft charging times, such as placing charging infrastructure near restaurants or general aviation terminals.

This potential transition also comes with significant infrastructure challenges. For example, global demand for hydrogen and electric aircraft has been estimated to require 600–1,700 terawatt-hours of clean energy by 2050, with large airports potentially consuming 5–10 times more electricity than they do today (World Economic Forum 2023). Although these numbers are dramatic, the rate of transitions is heavily related to policy and technical progress. For the State of Colorado and tributary aircraft traffic areas, initial analysis began with reviewing current fuel quantities before evaluating potential unique demand that was analyzed in this study. To meet these demands, airports may need to invest in on-site renewable energy production and smart charging solutions. For the forecasted activity in this report, initial adoption rates see a significant increase in local airport electrical usage, but relatively small increases in regional electrical generation demand.

To assist with the financing required for this effort, federal, state, and local governments along with their companion trade organizations are actively working on policies, funding mechanisms, and incentives to help integrate electric and hybrid aircraft into the aviation ecosystem. The following section provides an overview of current aviation revenue streams and various funding opportunities and incentives available for airports by level of government.

5.1 Federal Funding Streams and Tax Considerations

The transition to electric aircraft presents a challenge to traditional aviation fuel tax revenues, which are a primary funding source for the Federal Airport and Airway Trust Fund (AATF). As the use of electric aircraft grows, new funding mechanisms may be necessary to replace or supplement those revenues, which are used to fund FAA, its operations, and the Airport Improvement Program (AIP). This situation is relatable to the multidecade discussions regarding user fees and the impacts of energy efficiency improvements on revenues tied to fuel flowage. As efficiency increases societal benefits, including lower ticket prices must be weighed against collecting less revenue per passenger entering the AATF. Airports and policymakers are exploring various strategies to generate revenue from electric aircraft operations.

One potential approach is for regulators to modify the AATF to charge electric aircraft operators for the electricity used to charge their aircraft, in a comparable fashion to revenue from fuel sales. This could be implemented through an hourly rate or fixed fee structure. Policy-level discussion regarding small aircraft user fees has been a recurring topic of legislation, specifically whether general aviation user fees are an appropriate funding mechanism and should be considered an approach to this topic. Other opportunities include potentially modifying the FAA's existing mandatory aircraft registration program, which could levy higher aircraft registration fees for electric or hybrid aircraft to offset the reduction in aviation fuel tax revenues.

Government incentives and subsidies could also play a role in supporting the development of electric aircraft infrastructure and offsetting potential revenue impacts for airports (WSDOT 2020). The AIP could potentially be redirected to support infrastructure developments for electric and hybrid aircraft, pending updates in policy to include such technologies as eligible expenses (FAA 2023a). The FAA Reauthorization Act, signed into law on May 16, 2024, includes several provisions that support the adoption of electric and hydrogen-powered aircraft. The act establishes a new electric aircraft infrastructure program, which allows up to 10 airports to acquire and install charging equipment and infrastructure for electric aircraft. It also directs the FAA to develop a viable path for certifying hydrogen-powered commercial aircraft, expands hydrogen aviation research through the ASCENT program, adds hydrogen refueling infrastructure to the list of eligible projects for consideration under the AIP, and establishes a hydrogen aviation federal advisory committee (Morton 2024).

In April 2024, the FAA announced $270 million in supplementary discretionary grants, which include provisions for SAF growth. These grants could support field processing, storage, and distribution of SAF that provides at least a 50% reduction in lifecycle greenhouse gas emissions. Eligible projects may include the construction or expansion of pipelines, rail lines and spurs, loading and offloading facilities, blending facilities, and storage tanks (Epstein 2024). These grants add to the $92 million invested by the FAA in 2023 to support airport infrastructure electrification and solar power projects (FAA 2023a).

5.1.1 State and Local Revenue Considerations

Similar to federal revenues streams, state and local revenue authorities may wish to evaluate alternative funding mechanisms to replace traditional airport revenue streams, such as fuel taxes and flowage fees. Depending on the rate of adoption, state and local jurisdictions should evaluate the balance between revenue generation at the airport and within the community and its impact on desired community goals. Early-stage revenue goals may be neutral or net-negative, similar to Colorado's initial support to offset the premium currently charged for unleaded aviation gasoline. Should higher rates of adoption occur, more revenue-neutral approaches could be favored as the market matures and costs stabilize.

One potential solution for maintaining state-level revenues is implementing electricity usage fees for aircraft charging on a site-specific basis when an appropriate level of adoption is reached. It is recommended that policy analysis evaluate trade-offs amongst goals for regional needs. For example, hangar charging, which is likely to be a preferred method for some general aviation owners, presents a unique challenge for quantifying energy use with the varied meter ownership throughout typical airport facilities. Potential factors in developing regional policy could include providing support for existing business models, responding to community concerns regarding leaded fuels, lessening airport noise impacts, encouraging adoption of new technologies while supporting an established aviation industry, and reaping the revenue benefits from levying adjusted revenue streams to maintain funding for related infrastructure.

A technical factor of note: should there be a desire to apply an equivalent cost per unit of electrons to compare with a gallon of petroleum, it is recommended that equivalency for unrelated power trains be evaluated. Efficiencies of various systems differ and the purpose of the calculation could influence how to properly quantify the desired outcome. Potential purposes for these calculations could be looking to incentivize technologies, maintain existing revenues, calculate the respective impacts on the airport system, and so on. An example of potential trade-off analysis could include comparing the efficiency of various systems versus infrastructure impacts. A heavier, higher-efficiency vehicle regardless of energy carrier could have a different infrastructure impact than a comparable vehicle of lower efficiency that provides more revenue on a per-unit energy basis. This technology-based analysis could complement revenue methods that may index to relevant indices. For example, a sales tax may more closely index to rising construction costs than a cost per unit of energy.

At the local level, fuel flowage fees may be impacted by not incorporating equivalent electrical equivalencies, when negotiating/re-negotiating lease agreements with tenants that may wish to perform vehicle charging (Fixed Base Operators, hangar owners, etc.)A similar discussion to state requirements could follow, balancing the need to increase the desirability of the airport and potential shift away from traditional petroleum aircraft with the economic requirements of operating the facilities in a near term cost-effective manner. Airports have additional mechanisms that could be explored, such as including adjusting parking and landing fees for electric aircraft, which could help compensate for lost fuel revenue (NASEM 2022). Some airports may choose to own and operate the charging facilities themselves, generating revenue from related fees charged to users. This approach provides the highest revenue, but comes with the highest amount of airport capital cost and requires electrical system maintenance. Third-party ownership, similar to many current fueling operations, may be more relevant, including if long-term, fixed-base operator agreements address “fueling” in a broad manner. Furthermore, airports can explore trade-offs that may occur through other funding streams such as increasing revenue from landside sources, such as renewable energy generation, parking, rental cars, and advertising, along with any induced demand that encouraging new technology may generate (e.g., new tenants, businesses, and so on).

5.1.2 State and Local Funding Mechanisms

A cursory review of western state-level policies currently in place helped identify that some state organizations have chosen to incentivize the new aerospace industry at this early adoption phase rather than initially move toward establishing revenue pathways. Two of these states, Washington and Utah, are summarized next. Additional discussion on infrastructure follows in Section 5.1.3.

The state of Washington has taken a proactive approach by conducting a feasibility study to propose locations for charging infrastructure for small commercial electric aircraft. The study aimed to improve mobility for specific communities and included public funding and financing mechanisms at local, state, and federal levels (WSDOT 2020; Schwab et al. 2021). To support the electric aircraft industry, the state’s department of revenue offers tax credits and exemptions to eligible manufacturing and retail businesses. These incentives are designed to limit the tax liability of these businesses, thereby reducing operating costs and exposure to market risk.

Utah has also provided a blueprint for advanced air mobility (AAM) operations at the state level. The state’s vision includes potential funding mechanisms such as fees for landing, airspace usage, or permitting, as well as sales or excise taxes on services related to AAM. Utah is exploring various financing options, such as issuing bonds, appropriating general revenues, or using green-revolving funds to support AAM projects (Daleo 2023). At the local level, municipalities looking to add infrastructure can apply for loans or issue general or revenue-obligated bonds if they expect to generate revenue from those sites. This approach allows municipalities to finance large-scale infrastructure projects by borrowing against future revenue generated from the infrastructure.

5.1.3 Incentives and Initiatives for Infrastructure Development

Although some efforts are more broadly encouraging growth in the aerospace industry on a state and local level, other various incentives and initiatives have been established at the federal, state, and local levels to support infrastructure.

5.1.3.1 Federal Incentives

As of early 2025, the following federal programs were identified in the U.S. aviation industry. The FAA Reauthorization of 2024 (Public Law 118-63) provides the current baseline for FAA-related efforts.

VALE, administered by the U.S. Department of Transportation, provides funding through the AIP and Passenger Facility Charge Program for the purchase of low-emission vehicles, development of fueling and recharging stations, implementation of gate electrification, and other airport air quality improvements (FAA 2024). The Inflation Reduction Act includes provisions for clean hydrogen production and SAF, offering tax credits that could support the infrastructure for hybrid aircraft that use these fuels (Sobel 2022). The Clean Hydrogen Production Tax Credit provides up to $3 per kilogram of clean hydrogen produced, which could incentivize the development of hydrogen fuel infrastructure at airports (Alternative Fuels Data Center [AFDC] 2023).

The SAF Grand Challenge is a joint initiative between multiple federal agencies including U.S. Department of Energy and U.S. Department of Transportation that aims to scale up SAF production to at least 3 billion gallons per year by 2030. This initiative includes funding opportunities to support SAF projects and fuel producers, which could indirectly support infrastructure for electric and hybrid aircraft by enhancing the availability of alternative fuels (The White House 2021). The Airport Zero Emissions Vehicle and Infrastructure Pilot Program aims to support airports' efforts in improving local air quality. Eligible projects include zero-emission airport vehicles (electric- or hydrogen-powered) and the infrastructure required to operate them. Priority is given to applications that achieve the greatest air quality benefits. Cost-sharing percentages are equal to the AIP program and apply to the total project cost. Vehicles must remain at the airport for their useful life and be used exclusively for airport purposes.

5.1.3.2 State Incentives

At the state level, infrastructure incentives for emerging energy industries have a variety of methodologies being explored. States can use low-carbon fuel standards (LCFS) to incentivize clean hydrogen and other low-carbon fuels. These programs require a reduction in the carbon intensity of transportation fuels that are sold, supplied, or offered for sale. Some states have already included aviation fuels as opt-in fuels under their LCFS programs, demonstrating a model that other states could follow to support clean hydrogen-derived fuels (Sadler et al. 2024). Additionally, many offer various incentives to support the adoption of electric and hybrid technologies applicable to the aviation sector. For example, the New York Power Authority provides $40 million in funding through its EVolve program to support airport charging hubs (AFDC 2024a). The Alabama Department of Economic and Community Affairs offers grants for light-duty EV charging stations and replacement of qualified medium-and heavy-duty diesel vehicles with new diesel or alternative fuel vehicles, including airport ground support equipment (AFDC 2024c). California's EV Incentives for Medium- and Heavy-Duty Fleets program offers rebates for electric fleet vehicles, including airport ground support equipment (AFDC 2024).

Other state-level incentives with provisions for airport ground support equipment and vehicles include Montana's heavy-duty vehicle replacement grants, Idaho's medium- and heavy-duty diesel vehicle replacement rebates, Indiana's medium- and heavy-duty grant program, Michigan's medium and heavy duty grant program, Pennsylvania's off-road electric equipment grants, and the New York State Department of Environmental Conservation's vehicle emissions reduction and EV charging station project funding program.

The New York State Energy Research and Development Authority offers the Hydrogen and Clean Fuels Program, which provides technical assistance and commercialization support for the development of clean hydrogen and other low-carbon fuels. This program supports infrastructure development for hydrogen, which can be used in hybrid aircraft (New York State Energy Research and Development Authority 2023). It also invests in clean hydrogen production using renewables and infrastructure, including transmission, distribution, and storage. These investments support the broader adoption of hydrogen technologies, which can be crucial for hybrid aircraft operations.

In Colorado, HB23-1272 "Tax Policy That Advances Decarbonization" was passed in 2023. Among other incentives, this legislation establishes state income tax credits for producing sustainable aviation fuel in the state, which specifically:

"Creates a refundable income tax credit for income tax years commencing on or after January 1, 2024, but before January 1, 2033, for a percentage of the actual costs incurred to construct, reconstruct, or erect a sustainable aviation fuel production facility in the state. The credit can be claimed by an aviation business, a sustainable aviation fuel producer, or an airport for the income tax year in which the production facility is put in service and is subject to the following aggregate caps for each income tax year for which the credit can be claimed.

Additional information regarding tax credit certificates issued to taxpayers:

- For the 2024 income tax year, the aggregate amount of all tax credit certificates issued to taxpayers must not exceed $1 million.
- For the 2025 and 2026 income tax years, the aggregate amount of all tax credit certificates issued to taxpayers must not exceed $2 million for each year.
- For the 2027 through 2032 income tax years, the aggregate amount of all tax credit certificates issued to taxpayers must not exceed $3 million for each year.

Additionally, the credit is subject to recapture if the sustainable aviation fuel production of a facility comprises less than 60% of the total fuel production of the facility in any of the 3 taxable years immediately following the taxable year that the facility was placed in service." (HB23-1272 Bill Summary, Colorado General Assembly)

5.1.3.3 Local Incentives

At the local level, incentives targeted at electrification are beginning to be adopted in areas that have indicated a desire to encourage early adoption. Incentives such as the commercial electrification rebates from Jacksonville Electric Authority provide rebates for electric aircraft tractor and pushback, as well as EV charging stations (AFDC 2024b). The Miami-Dade County Urban Air Mobility Policy Framework is under development to integrate urban air mobility technology into the county's transportation network. This framework includes planning for the required infrastructure, such as vertiports and energy infrastructure, to support electric and hybrid aircraft (Miami-Dade Transportation Planning Organization 2023).

5.1.4 Federal Policies and Guidance Updates

The FAA is actively developing policies to support the integration of electric and hybrid aircraft to support broader AAM including regional air mobility services. One of the most significant steps is the planned release of a performance-based vertiport design advisory circular, which will provide guidance on the infrastructure necessary for various AAM operations, such as eVTOL (FAA 2023b). This advisory circular will address the specific infrastructure requirements to ensure the safe accommodation of these new types of aircraft and their unique operational needs.

In addition to the vertiport design advisory circular, the FAA is actively collaborating with industry stakeholders to establish a regulatory framework that promotes the safe and efficient integration of electric and hybrid aircraft into the national airspace system (FAA 2023c). The framework will also focus on meeting the requirements of the FAA Reauthorization Act of 2024, which includes General Accounting Office analysis of electrified aviation needs and advance air mobility research needs for entrance into service of hydrogen-powered aircraft. This effort also includes developing certification standards for electric and hybrid propulsion systems, as well as creating pilot training and licensing requirements specific to these new technologies (FAA 2023c).

5.1.5 Conclusion

The policy environment for electric aircraft is rapidly evolving, with federal, state, and local governments implementing a wide range of policies, funding mechanisms, and incentives to support a range of goals that relate to sustainable aviation. As the industry continues to advance, collaboration between policymakers and stakeholders is crucial to ensuring the development of a robust infrastructure network that can accommodate the unique requirements of advance air mobility aircraft including electric and hybrid aircraft.

The FAA is leading the way in developing policies and guidance to support the safe integration of these new technologies into the national airspace system. Federal funding streams and tax considerations currently do not address these alternative energy carriers in these early stages of market maturity. Similarly, great advancements in energy efficiency that have occurred over the past decades impact revenues not indexed to passenger operations. As a result, states and local governments are exploring alternative funding mechanisms and offering various incentives to encourage the adoption of electric and hybrid aircraft.

As the aviation industry progresses, the policy environment will continue to play a critical role in facilitating the development and deployment of electric and hybrid aircraft. By providing the necessary support and infrastructure, policymakers can help accelerate the transition to cleaner, more efficient aircraft while ensuring the safety and security of the traveling public.

6 Discussion and Conclusions

Airports considering investment in energy assets to offset future EVSE charging loads may benefit from installing PV and BESS systems earlier than the EVSE forecasted demand needs. Currently in the Colorado market, excess distributed generation can be returned to the grid, for an immediate export benefit that can be leveraged should EVSE loads expand. However, utility rates vary by provider, resulting in varied economic consideration depending on regional tariffs and levelized cost of energy delivered. Depending on the rate negotiated with the operator and method of infrastructure cost recoupment for the utility, solutions will vary. At this time, with available land, the most cost-effective generation assets are solar coupled with battery storage. Results vary with rate structure and cost optimal approaches for current facility loads.

Key assumptions and insights:

- Potential flight demand was completed and anonymized to develop charging loads that supported both flight school and estimate regional air mobility operations.
    - Loads were varied based on known flight school operations, with forecasted packages starting with five aircraft and potential forecasted demand for regional air mobility.
    - In addition, charging demands were based on a limited sample of data, assuming a consistent schedule for the full year. Seasonal variations such as long weekends, weather, or high-traffic events could be utilized to improve forecasts.
    - Forecasts should be scrutinized with more local considerations prior to implementation.
- Site charging was approximated from a conservative perspective for peak energy demand.
- Analysis to date assumes new meters were used to service new aircraft charging loads.
- Many facilities analyzed would benefit from improving power delivery.
    - For more rural locations, a key enabling asset for charging demands is the availability of three-phase 480-volt power.
- Localized energy generation is a potential alternative that can improve power availability, affordability, and potentially accelerate access to any utility managed line upgrades.
- Adjusting flight operations to minimize the number of aircraft charging concurrently can significantly reduce peak load, and potential infrastructure impacts, however, it may also impact desired flight scheduling.

The following observations were made regarding typical charger sizing:

- The emerging megawatt charging standard (MCS) at the 1-MW level was modeled for RAM loads. This approach aligns with industry feedback and avoids limiting operations due to peak power demands and avoids constraining the number of chargers per site.
- 350-kW chargers are likely sufficient for any flight school operations and align with current requests from eVTOL operators using similar infrastructure. Shared charger capacity (multiple connectors for one service) may be desired depending on operations and may provide increased optimization. Current standard aligns predominantly with light-duty automotive fast charging standards.

With peak demand reaching upward of 4 MW per site in the fastest charging cases, it is critical for airports to engage their local electric utility early in the planning and design phases of EVSE sizing and installation as electric rate structures are a key driving factor in cost-effective deployment. Utility rate structures are set primarily at the state level in coordination with each individual utility operator. Coordination with utilities and the Public Utility Commission on consistent rate structures for airport purposes could be considered to reduce uncertainty and streamline infrastructure deployment. For comparison to typical Colorado markets, the ABQ site has a rate structure that incentivizes buildup of BESS that helps the utility operator regulate demands across the market. The on-site energy storage offers a pathway to substantial cost savings while assisting in reducing utility impacts, and potentially off-site infrastructure expansion. However, the demand charges in the ABQ rate only apply during the day, leaving no incentive for a BESS to shave EVSE charging peaks outside of those hours. Any cost savings provided by BESS can be eliminated by required upstream grid infrastructure upgrades to accommodate the new off-peak demand. Aircraft schedules are driven by anticipated travel patterns, as modeled by Georgia Tech, and as a result may not be flexible to ABQ's rate schedule. Therefore, sites like ABQ will have to work with their electric utility to come up with custom rates that ensure peak demand reduction per the anticipated flight schedule.

Potential next steps for CDOT aeronautics and associated airports:

- Collaborate with utility providers on potential infrastructure upgrade needs (one-phase to three-phase power, alternate rate tariffs, and so on)
- Consider evaluating early-adoption locations and a phased approach to potential adoption
- Consider reviewing current revenue structures at the state level for any adjustments in revenue methodologies
- Analyze lease structures for opportunities to provide energy generation leasing in accordance with FAA and National Environmental Policy Act requirements
- Decide on any on-site generation and storage assets that may benefit existing conditions.
- Confirm site-specific opportunities based on specific rate tariffs and available property assets, including both energy generation and power reliability solutions

To support electrified RAM and flight school operations, airports must understand the potential capital and operating costs required. This initial effort identifies the potential opportunities and constraints for consideration regarding energy infrastructure and provides an initial framework for airport operators to expand upon.

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Appendix A. Alternatively Powered Aircraft Under Development

To understand the near-term timelines for advanced aircraft development, the National Renewable Energy Laboratory conducted a literature review to identify fixed-wing regional air mobility (RAM) aircraft and electric vertical takeoff and landing (eVTOL) aircraft development characteristics and milestones. The following tables include the current publicly available information as of early 2025.

It is noted that as a novel industry, significant evolution is occurring with various efforts adjusting to available capital, market demands, policy, technological breakthroughs, and ability to weather the highly capital-intensive process of bringing new aircraft to service. Although some companies in this new market sector have seen significant advancements and market growth, others have folded and/or slowed. This process will continue as the market matures, which parallels the early automotive industry.

A.1 Fixed-Wing RAM Aircraft

The following table identifies aircraft in development between 4 and 76 seats.

Table A-1. Summary of Battery-Electric Models (Fixed-Wing RAM)

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information
Eviation Alice	57.1 feet (ft) (17.4 meters [m]) length by 12.6 ft (3.8 m) height; 63 ft (19.2 m) wingspan	9 passengers/ 2,500 pounds (lb)	1,400 kilowatts (kW) (700 kW for each power plant)/ magniX magni650 (two electric propulsion units)	Not applicable (N/A)	220 miles/ (N/A)	32,000 ft	Yes (first flight in Sept. 2022)	Certification aimed for 2025/entry to service by 2027 – As of early 2025, Eviation has ramped down staffing	480-volt, three-phase power at 500 amps (similar to magniX Cessna Caravan)
Beta Technologies ALIA CX300	50 ft (15.2 m) wingspan	Five passengers/three industrial cargo pallets (approximately 900 lb)	(N/A) /sealed battery packs below cabin, other details unknown; electric pusher propulsion only	N/A	386 miles/ (N/A)	N/A	Yes	Test flights still underway (22,000 flight miles amassed since 2020); already has military certification/entry to service by 2025	50-minute (min) charge time
Elysian E9X	138 ft (42 m) wingspan	90 passengers (# of seating could change)	Battery electric with distributed energy propulsion	360 watt-hours (Wh)/kilogram (kg) energy density for	500 miles (N/A)	N/A	No (scale model in 2–3 yrs, full-scale prototype by 2030)	Service aimed for 2033	45-min charge time

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information
				battery pack					
Vaeridion Microliner	N/A	Nine passengers	N/A	N/A	310 miles (N/A)	N/A	No	Certification aimed for before 2030	45-min charge time

*N/A indicates that information in this category was not found

Eviation's Alice was the first all-electric commuter plane, and its ongoing evolution has led to three prototype versions: a nine-seat commuter model, a six-seat executive model, and a cargo model. Despite leadership transitions and weather-related delays, the company continues to target obtaining certification and beginning deliveries by 2027 (Korn 2022). Recently, a redesign to the fuselage was announced. This change allows for simpler manufacturing and maintenance, allowing for Eviation to make further upgrades or introduce newer models in the future (Weitering 2024a). As the fixed-wing electrical conventional take-off and landing iteration of the ALIA-250, Beta Technologies' CX300 retains the same airframe, battery pack, and avionics as the ALIA but lacks vertical takeoff and landing capabilities due to having no tilting rotors (Freedman 2023). This modification was strategically made to introduce an electric aircraft to the market sooner. With evaluations completed by the Federal Aviation Administration (FAA), Air Force, and Army pilots and having covered 22,000 flying miles across different states, CX300 is the only electric aircraft to have traversed the most crowded Class B and C airspace in the United States and holds the record for the longest series of electric flights (Emir 2023).

Within the past year, additional aircraft were announced by other companies from Elysian to Vaeridion. Elysian's E9X is still under the concept phase but a scale model is planned for within the next 3 years with a full-scale prototype scheduled for completion by 2030. The intention is for the E9X to have a wingspan larger than a Boeing 737 or an Airbus A320, with batteries placed not in the fuselage but the wings (Prisco 2024). Vaeridion is similarly working on their Microliner aircraft with the intention of achieving certification for Georgia flights by 2030. Partnerships have been formed to introduce the Microliner for commercial and air ambulance services (Daleo 2024).

Table A-2. Summary of Hybrid-Electric Models (Fixed-Wing RAM)

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information (if applicable)
Heart Aerospace ES-30 (Revamped ES-19)	72.6 ft (22.0 m) length; 101 ft (30.77 m) wingspan	30 seats/7495.7 lb (3.4 tons)	4 electric motors; Reserve-Hybrid 800 kW turbogenerators	11,000-pound batteries housed in a large fairing under the fuselage; batteries developed by BAE Systems	124 miles on all-electric mode, 248 miles on electric + hybrid mode, 496 miles on electric + hybrid 25-pax mode	20,000 ft	No (HX-1 demonstrator unveiled in 2024, first fully electric flight scheduled for the second quarter of 2025, HX-2 will be a preproduction prototype)	Still under development/ entry to service by 2028	30 min for fast charging
Ampaire Eco Caravan (Retrofit of Cessna Grand Caravan)	37.7 ft (11.5 m) length by 14.8 ft (4.5 m) height; 52.2 ft (15.9 m) wingspan (preretrofit)	Nine seats/ 2,500 lb (post-retrofit)	570 kW/ AMP-H570 hybrid-electric powertrain and battery pack (Red Aircraft 410-kW A03 compression ignition engine and electric engine (160-kW electric motors and battery packs)	Battery density at 200 Wh/kg	1,000+ miles/(N/A)	Climbed up to 3,500 ft in test flights	Yes (successful ground test using SAF)	No new updates. Timeline for certification and service to be determined, originally scheduled for 2024.	2,000 fast-charge cycles before battery replacement expected

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information (if applicable)
Ampaire EEL (Retrofit of Cessna 337 Skymaster)	29.75 ft (9.1 m) length by 9.2 ft (2.8 m) height; 38.2 ft (11.7 m) wingspan (preretrofit)	Three passengers/ 450 lb (postretrofit)	A parallel hybrid, with one conventional combustion engine and an independent electric drivetrain (possibly a 310-horsepower Continental IO-550 tail-mount with a 130-kW electric motor in the nose)	N/A	400+ miles/ 1.25 hours	N/A	Yes (12-hour hybrid-electric flight achieved)	Certification expected by end of 2024/entry into service by 2027	480-volt, three-phase power for 60-kW chargers
Faradair BEHA M1H Aircraft	48.2 ft (14.7 m) by 14.8 ft (4.5 m) height; 57 ft (17.4 m) wingspan	18 passengers/5 tons (10,000 lb)	500-kW electric motor (twin)/ magniX twin magni500 electric propulsion units	N/A	1,000+ miles/(N/A)	14,000 ft	No (first test flight targeted for 2024)	Still under development/ entry into service by 2026. All-electric BEHA by 2030.	SAF-fueled
VoltAero Cassio 330	29.3 ft (8.9 m) length by 10.5 ft (3.2 m)	Five seats/ 1,056 lb	330-kW/ Kawasaki 4-cylinder thermal engine and Safran's	41.5-kW capacity for batteries	648 miles (no reserve)	N/A	No (first Cassio 330 prototype will fly by	EU Aviation Safety Agency type certification sought for by end of 2025	25 min for fast charging at 180 amps; 58 min for slow charging at 60 amps

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information (if applicable)
	height; 32.7 ft (10 m) wingspan		ENGINeUS 100 smart electric motor				end of 2024)		
VoltAero Cassio 480	30 ft (9.16 m) length by 10.7 ft (3.3 m) width; 40.58 ft (12.4 m) wingspan	Six seats/ 1,550 lb	480-kW/ Kawasaki 6-cylinder thermal engine	168-kW capacity for batteries	648 miles (no reserve)	N/A	No (to be determined [TBD])	Under development (TBD)	25 min for fast charging at 415 amps; 58 min for slow charging at 200 amps
VoltAero Cassio 600	36.3 ft (11.1 m) length by 14.3 ft (4.4 m) height; 40.6 ft (12.4 m) wingspan	12 seats/ 1,911 lb	600 kW/(N/A)	215-kW capacity for batteries	648 miles (no reserve)	N/A	No (TBD)	Under development (TBD)	25 min for fast charging at 650 amps; 58 min of slow charging for 300 amps
Pratt & Whitney DHC 8-100 (Retrofit of De Havilland	73 ft (22.5 m) length by 24.6 ft (7.5	37 passengers (pre-retrofit)	2-MW propulsion system combining a Pratt & Whitney	N/A	1,174 miles (pre-retrofit)	25,000 ft	No (test flight of demonstrator scheduled for 2024)	Still under development/ entry into service not scheduled	SAF-fueled

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information (if applicable)
Canada Dash DHC 8-100)	m) height; 84.8 ft (25.9 m) wingspan (pre-retrofit)		engine with a 1-MW electric motor in parallel with a hybrid configuration with a 50/50 power split from Collins Aerospace						
Ampaire Eco Otter (Retrofit of DHC Twin Otter)	51.75 ft (15.8 m) length by 19.5 ft (5.9 m) height; 65 ft (19.8 m) wingspan (pre-retrofit)	19 passengers/ 4,000 lb (post-retrofit)	N/A	N/A	700+ miles/ (N/A)	25,000 ft	N/A (project under the National Aeronautics and Space Administration)	Still under development, aims to stay under FAA's Part 23 aircraft category to "ease" certification requirement/entry into service soon after	n/a

*N/A indicates that information in this category was not found

The Ampaire Eco Caravan and its integrated propulsion system enables a 70% reduction in fuel consumption and emissions and up to a 40% reduction in operating costs (Ampaire 2022). Similar benefits are demonstrated with 40% fuel savings for the Ampaire EEL compared to the original Cessna Skymaster (which inspired the EEL). The EEL is designed for general-aviation pilots but can be used for commercial use and is available through two different propulsion systems with customizable seating options (Cormack 2022). Another aircraft in Ampaire's growing fleet is the 19-seat Eco Otter, with additional plans for 30- or 50-seat hybrid electric regional airliners. The 30- or 50-seat models are expected to become available in the 2030s (Alcock 2023). Furthermore, the company has teamed up with Tamarack Aerospace Group to develop aerodynamics upgrades for Ampaire's hybrid electric aircraft fleet, intending to leverage Tamarack's SMARTWING winglets for enhanced fuel efficiency and range. This combination seeks to further augment cost savings and performance, particularly for the Eco Caravan and Eco Otter (Wildes 2022).

With the BEHA aircraft from Faradair, magniX and Honeywell have contributed to a powertrain that will be compatible with SAF. Some significant benefits of this model are expected to be its ability to take off and land on runways as short as 984 feet (300 meters), its expected usefulness for military applications, and the substantial groundwork that development of the BEHA has laid for an eventual all-electric version of the aircraft (Alcock 2021; Airframer 2018). Pratt & Whitney and Collins Aerospace, both subsidiaries of Raytheon, have teamed together on a retrofit project for the DHC 8-100. Following a successful 2022 test, Raytheon announced a hybrid-electric engine (combining a Pratt & Whitney powertrain and a 1-megawatt (MW) electric motor from Collins Aerospace) that advertises a 30% reduction in carbon dioxide emissions (Venckunas 2022). More rounds of testing are expected to continue into 2024 to further validate the 1-MW powertrain. Work on the DHC 8-100 has gained interest from other companies including ZeroAvia, which has plans for an alternative DHC 8-100 version to incorporate its proprietary hydrogen-electric 2-MW+fuel cell power plant (Ahlgren 2022). Meanwhile, VoltAero's Cassio series (330, 480, 600) is set to serve various sectors, including cargo, air taxi, and medevac. The 330, which is already airborne and expected to have another prototype by 2024, will pioneer the company's hybrid-electric propulsion system. This system will use electric power for takeoffs, landings, taxiing, and short-range missions, and hybrid power for range extension and backup (VoltAero 2023).

Additionally, Heart Aerospace has announced their latest timeline for test flights with the ES-30 aircraft for the start of 2025. This follows other announcements by Pratt & Whitney and Faradair with DHC 8-100 and M1H test flights scheduled for the end of 2024. Ampaire has secured additional support from the U.S. Air Force to develop a megawatt-scale hybrid powertrain while they continue their existing partnerships surrounding the Eco Otter and other aircraft models within the company's portfolio (Hardee 2023).

Table A-3. Summary of Hydrogen/Fuel-Cell-Based Models (Fixed-Wing RAM)

Aircraft Manufacturer & Model	Dimen-sions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline
ZeroAvia Dornier 228 (Retrofit of original Dornier 228)	54.5 ft (16.6 m) length by 16.1 ft (4.9 m) height; 55.8 ft (17 m) wingspan (preretrofit)	19 seats/ 4,850 lb (preretrofit)	600 kW/ powertrain comprises: 1) ZA-600 engine on left wing, 2) a Honeywell TPE-331 stock engine on right wing for surplus power during takeoff and safety events, and 3) a hydrogen electric engine on the left wing	N/A	300 miles/ (N/A)	27887.1 ft (8,500 m) for original Dornier 228	Yes (flight tested in the United Kingdom with certification application underway)	Under consideration for certification by the Civil Aviation Authority in the UK as of 2024. FAA timeline unknown. Intended entry to service was set for 2025.
Alaska Airlines Bombardier Q400 (ZeroAvia Retrofit of Q400/Dash8-400)	107.6 ft (32.8 m) length by 27.6 ft (8.4 m) height (preretrofit)	76 seats/ 4,710 lb (preretrofit)	2-5 MW/ZA2000 hydrogen propulsion system (will include ZeroAvia's high-temperature proton-exchange membrane fuel cells and liquid hydrogen storage)	N/A	500 miles	27,000 ft (pre-retrofit)	No (no further updates)	Zeroavia is targeting powertrain certification for retrofit across multiple airframes; 2027 timeframe.
ATR 72-600 (Retrofit)	89.1 ft (27.2 m) length by 25.1 ft (25.1 m) height; 88.7 ft (27.0 m)	72 seats (44- and 78 options also available) (preretrofit)	Universal Hydrogen's fuel-cell-electric, megawatt-class powertrain (fuel cells derived	N/A	758 miles/(N/A) (preretrofit)	25,000 ft	Yes, as of 2024 Universal Hydrogen's efforts were shuttered	Test flights under the Federal Aviation Administration's Special Airworthiness Certificate underway

Aircraft Manufacturer & Model	Dimen-sions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline
	wingspan (preretrofit)		from Plug Power's ProGen family of fuel cells); motor is a modified magni650 electric propulsion unit; power electronics are from magniX					(2-year campaign)/entry to service by 2025

*N/A indicates that information in this category was not found

Alaska Airlines and ZeroAvia have partnered to retrofit the Bombardier Q400, also known as the Dash 8-400, with a new hydrogen-electric powertrain. This retrofit was planned for completion in 2024, when test flights were also expected to be underway, but no recent announcements regarding the completion have been published. Upon successful certification and delivery, this partnership will have created the largest airplane powered by hydrogen fuel cells. Table A-3 outlines other hydrogen aircraft models.

A key piece to ZeroAvia's future in aircraft development is their HyperCore motor module program. As part of a demonstration for a 1.8-MW motor configuration, the HyperCore operates as a high-speed 900-kilowatt (kW) permanent-magnet radial flux machine at 20,000 revolutions per minute (Sampson 2023). Its 15-kW/kilogram motor power density matches standard turbine engine speeds (Sampson 2023). With initial integration of the HyperCore system with the Bombardier's Q400's engine gearbox and propeller proving to be successful, these features introduce the potential for ZeroAvia's technology to replace stock turbine engines. Major developments from the company extend beyond the Q400 as ZeroAvia's retrofitted Dornier 228, the world's largest hydrogen-electric aircraft flown to date, took its maiden flight in January 2023 (Sampson 2023). This aircraft is fueled by compressed gaseous hydrogen produced on-site and leverages the company's 600-kW ZA600 hydrogen-electric engine. In the future, passenger capacity could expand up to 90 seats under a 2- to 5-MW powertrain (ZeroAvia 2023).

ZeroAvia has set timelines for the release of their next-generation powertrains. By 2025, the 600-kW ZA600 is expected to retrofit a greater abundance of aircraft accommodating up to 19 seats and supporting flights up to 300 miles. Under development, the modular 2- to 5-MW ZA2000 is set for a 2027 release, which could retrofit aircraft with up to 80 seats for flights spanning 500 miles (Sampson 2023). Simultaneously, Universal Hydrogen is teaming up with Jet Blue and Connect Airlines to retrofit ATR 72-600 aircraft for commercial use, advancing hydrogen conversion kit development (Universal Hydrogen 2023). The ATR 72-600 along with the Dash 8 are expected to become compatible with ZeroAvia's ZA2000 by 2027 (Bailey 2023).

As of the time of this writing, no further updates have been made available for most hydrogen-fueled aircraft retrofits with the exception of ZeroAvia, per a recent announcement regarding their agreement with American Airlines to convert 70-seat Bombardier CRJ700s to hybrid aircrafts using the company's hydrogen-electric engines (Alcock 2024). Furthermore, ZeroAvia's Dornier 228 conversion has completed additional flight testing in the United Kingdom and is under consideration for certification by the United Kingdom's Civil Aviation Authority with the FAA timeline unknown.

Table A-4. Summary of Battery-Electric Models (General Aviation)

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/ No)	Certification & Service Timeline	Charging Information
Bye Aerospace eFlyer 2	24 ft (7.3 m) length by 3.8 ft (1.2 m) cabin width by 7.5 ft (2.3 m) height; 38 ft (11.6 m) wingspan	Two seats/450 lb	110 kW/150-horsepower Safran ENGINeUS 100 air-cooled with 110-kW motor	High-density lithium battery	220 miles/3 hours	14,000 feet	Yes (production for prototype has begun as of Sept. 2024)	Still under certification process, but achieved status as world's first Part 23 Amendment 64 FAA-certified fixed-wing aircraft and FAA approval of G-2 "Means of Compliance for Certification"	N/A
Pipistrel Velis Electro (A Textron Company)	21.3 ft (6.5 m) length, 6.23 ft (1.9 m) height;	Two seats/378 lb	57.6 kW/ Pipistrel E-811 EASA type-certified with Pipistrel P-812-164-F3A	345 VDC 24.8-kWh battery pack. Two lithium-ion batteries	37 miles/50 min	12,000 feet	Yes	Received type certificate (EASA.A.573) as world's first, only	1 hr and 20 min for a charge time to go from 35% to 90% (using a

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/ No)	Certification & Service Timeline	Charging Information
	35.1 ft (10.7 m) wingspan		certified propeller	connected in parallel for redundancy. Both weigh 70 kg each.				received experimental worthiness certification under FAA/already in service and available for purchase/ flight training schools and individual pilots can now fly unrestricted with recent exemption from light sport aircraft regulations	CHAdeMO connection with a 32-amp supply charging at 20 kW). A full charge from 30% to 100% takes up to 2 hours.
Diamond eDA40	N/A	Two seats/(N/A)	130 kW/ Safran ENGINeUS 100	N/A	(n/a)/90 min	N/A	Yes (first flight took place in July 2023)	Certification aimed for 2025 (will be the first European Union Aviation Safety (EASA)/FAA Part 23 certified electric aircraft with DC fast-charging	20 min for fast charging

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/ No)	Certification & Service Timeline	Charging Information
								capabilities)/ entry to service soon after	
Bye Aerospace eFlyer 4	48-inch cabin width; 38-ft wingspan	Four seats/860 lb	200-kW (268 horsepower) all-electric propulsion system	N/A	Approximately 500 miles	17,500 ft	Unknown (first flight originally scheduled for early 2021. No new information since then)	In the process of obtaining FAA Part-23 certification for air taxi, cargo, and advanced training uses; complete certification expected within a “year or so” of the eFlyer 2	N/A

*N/A indicates that information in this category was not found

The Pipistrel Velis Electro became the first fully electric aircraft to secure a type certificate from the European Union Aviation Safety Agency (EASA), marking a significant step forward for electric aircraft (NASEM 2022). It has been noted as a candidate for flight training, providing operational costs as low as $3 per hour for electricity compared to fuel costs for a conventional two-seater piston aircraft (Washington Department of Transportation 2020). The company also has plans to expand its offerings with a four-seater version boasting a range of 200 miles. Similarly, the eFlyer 2, produced by Bye Aerospace, could potentially slash costs to a fifth of those associated with a gas-fueled fleet (Washington Department of Transportation 2020). This effort aligns with the industry’s ambitions to replace an aging training fleet of 11,000 conventional aircraft, some of which have been in operation for half a century. Austria’s Diamond Aircraft introduced the eDA40, setting its sights on becoming the first EASA/FAA Part 23 certified electric airplane equipped with DC fast charging (Phelps 2023). Lastly, Bye Aerospace has also developed the eFlyer 4, designed around a conventional fixed-wing airframe for optimal energy efficiency. The company asserts that the combination of an electric power plant and an efficient fixed-wing airfoil with a lift-to-drag ratio of 20.6, surpasses the performance of most eVTOL concepts reliant on rotors (Alcock 2025a). With production now underway for the prototype corresponding to the eFlyer2, Bye's eFlyer4 should follow right behind for the eFlyer2. The company is intent on successful certification and service entry for within the next 24 to 30 months. To support their certification bid, Bye has announced another round of fundraising (Weitering 2024b).

A.2 eVTOL Aircraft

Table A-5 provides a partial summary of battery electric vertical takeoff and landing (eVTOL) aircraft currently known to be in development.

Table A-5. Summary of Battery-Electric Models (eVTOL)

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/ No)	Certification & Service Timeline	Charging Information
Lilium Jet	27.9 ft (8.5 m) length; 45.6 ft (13.9 m) wingspan	Seven seats/ (N/A)	36 electric motors, 36 electric vectored thrust fans, batteries	>300 kilowatt-hours of stored energy	155 miles	Cruise altitude of 10,000 ft	Yes (proof-of-concept and prototype flights already completed) –	First eVTOL with both EASA and FAA certification basis/flight testing (**Folded in late 2024)**	Full charge in 30 min; charges up to 80% in 15 min; uses the ABB MegaWatt Ultra-Charging System
Joby Aviation S4 2.0	21 ft (6.4 m) length; 38 ft (11.6 m) wingspan	Five seats/ (N/A)	Six electric motors, four on wing and two on the v-tail; distributed electric motors with dual redundant inverters. Relies on four liquid-cooled lithium-ion	Energy density of 300 Wh/kg	150 miles	Cruise altitude of 15,000 ft	Yes (prototypes flown, another round of test flights of near-final version to occur later this year)	Achieved type certification (approval of aircraft design and component parts)/ entry to service in 2025	N/A

Aircraft Manufacturer & Model	Dimen-sions	Seating/ Payload	Power/ Power-train	Battery Size/ Weight	Range/ Flight Time	Alti-tude Ceiling	Flown (Yes/ No)	Certifi-cation & Service Timeline	Charging Information
			battery packs						
Beta ALIA-250	50 ft (15 m) wingspan	Five seats/ 1,400 lb	Distributed direct-drive electric system with four horizontally mounted rotors and a single rear propeller; five electric motors with batteries	Custom-ized batteries below cabin	250 miles	N/A	Yes	Pilot training with manufacturer and FAA personnel authorized by FAA/complete certification by FAA in 2026. First production aircraft in operations.	50-min charge time using Beta's Rapid Charging System which is 480 V C three-phase at 60 hertz with an AC grid, current of 450 ampere (A) and a continuous power rating of 350 kilovolts ampere. The battery charge range goes up to 950 V DC with a continuous charge current of 350A and boost charge (fast charge) current of 500A.
Wisk Generation 6	50 ft (15.2 m) wingspan	4 seats/ (N/A)	12 propellers with 12 electric motors and battery packs	N/A	90 miles	Cruise altitude of 2,500–4,000 ft	No (first flight aimed for end of 2024)	Still under development/ entry to service within next 5 years	15-min charge time

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/ No)	Certification & Service Timeline	Charging Information
Overair Butterfly	N/A	Six seats/ 1,100 lb	Four electric motors with batteries	N/A	100 miles	N/A	Reported to have been assembled and ready for test flights in early 2024 (no confirmation available online)	Still under development with aim for certification by 2025/entry to service by 2026 (specifically for United States and South Korea)	N/A
Archer Midnight	N/A	Five seats/ 1,100 lb	12 electric motors with batteries (six independent battery packs)	N/A	100 miles	Cruise altitude of 2,000 ft	Yes (402 flight tests completed thus far in 2024)	Achieved military airworthiness by the U.S. Department of Defense/FAA certification by 2025/hybrid electric military alternative announced late 2024	12-min charge time for back-to-back 20-mile flights (3,000 consecutive flight cycles before battery replacement)
Eve Air Mobility Eve	N/A	Up to 6	Battery packs and 10 electric motors	N/A	60 miles	2,600–3,300 ft	No (prototypes recently unveiled)	FAA certification aimed for by 2026	N/A

Aircraft Manufacturer & Model	Dimen-sions	Seating/ Payload	Power/ Power-train	Battery Size/ Weight	Range/ Flight Time	Alti-tude Ceiling	Flown (Yes/ No)	Certifi-cation & Service Timeline	Charging Information
Supernal S-A2	N/A	Four seats (1,000 lb)	Battery packs and eight electric motors	N/A	60 miles	1,5000 ft	No	Service aimed by 2028 – initial ground testing late 2024	N/A
eViation Nexus	N/A	Three seats (660 lb)	Battery packs with six electric motors	N/A	115 miles	N/A	No	N/A	N/A
Jaunt Air Mobility Journey	50 ft (15.24 m) wingspan , 14.85 ft (4.53-m) height	Four seats (N/A)	Battery packs with five electric motors	N/A	80–120 miles	6,000 ft	Yes (demon-strators have flown)	Service/ delivery aimed for 2027	N/A

*N/A indicates that information in this category was not found

The eVTOL industry has made progress in expanding options for advanced air mobility with companies like Joby Aviation, Archer Aviation, and Lilium introducing aircraft to serve a variety of customers and use cases. With a final production model nearing and FAA certification and deliveries on the horizon, Joby's S4 is slated to be the first eVTOL delivered to a customer for testing in 2024, moving to Edwards Air Force Base in California as part of the company's $131 million Agility Prime contract with the Air Force (Joby Aviation 2023). Similarly, the Air Force has another $142 million contract for the Midnight model from Archer Aviation to serve a wide range of mission profiles with the first delivery recently made for the Midnight aircraft in August 2024 (Manuel 2024). Through the support of other partners such as United Airlines and Stellantis, Archer's long-term vision is to build an air taxi network and effectively serve dense markets (Archer Aviation, Inc. 2023; Doll 2023).

Other companies have taken novel approaches to their eVTOL development. Lilium has been focusing its efforts on the Lilium Jet powered by their proprietary ducted electric vectored thrust propulsion system. This advanced technology features 36 individually controllable wing flaps, each equipped with an electric fan (Verdict Media 2021a). Beta's contribution to the eVTOL space has been the ALIA-250 and its rapid charging system, which is versatile and deployable as a stand-alone fixture for airport operations or as an off-airport charging pad (Verdict Media 2021b). With its Generation 6 aircraft, Wisk Aero has set its sights on being the first company to introduce an autonomous eVTOL passenger aircraft to the market with initial test flights set for the end of 2024 (Lynch 2024). In addition to its cutting-edge autonomous capabilities, the Generation 6 aircraft is designed to accommodate a wide demographic of passengers, including those with hearing, vision, and mobility impairments (Wisk Aero LLC 2025). Overair has taken a unique approach to eVTOL technology with their Butterfly model, which employs their patented Optimum Speed Tiltrotor technology. The Butterfly outperforms typical tiltrotors due to its variable-speed tilting electric rotors, unique blade design, lightweight composite blades, and advanced aerodynamics (Electric VTOL News 2025). In partnership with Uber to elevate their growing AAM ecosystem, Overair has attempted to optimize hover and cruise efficiency with the Butterfly, positioning it as a vehicle for AAM (Electric VTOL News 2025).

Although earlier battery-electric eVTOL aircraft projects have made further progress during the past year with additional test flights or production prototypes now completed, other competitors have entered the space. Newer eVTOLs announced include Supernal's S-A2, eAviation's Nexus, and Jaunt Air Mobility's Journey, all of which warrant closer monitoring as they undergo their own timelines with aspirations for service entry by 2028 for all three. These companies have expressed interest in serving different markets, needs, and have begun soliciting agreements for future deliveries upon certification.

Table A-6. Summary of Hybrid-Electric Model (eVTOL)

Aircraft Manufacturer & Model	Dimensions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certification & Service Timeline	Charging Information
Dufour Aerospace Aero3	39 ft (12 m) length by 13 ft (4 m) height; 44.6 ft (13.6 m) wingspan	Eight seats/1,650 lb	Distributed electric propulsion with six main motors/propellers and two tail motors/propellers	N/A	551 miles/3 hours	N/A	No (2025-2026 when development is complete)	Certification and service timelines shifted. No set timeframe	N/A
Ascendance Atea	N/A	Five seats/882 lb	Kerosene combustion engine and battery packs used for vertical takeoff and landing flight and charged during forward flight with a turbine engine. Hybrid system is	N/A	249 miles/2 hours	N/A	No (production scheduled for 2025)	Certification aimed for in 2027	N/A

Aircraft Manufacturer & Model	Dimen-sions	Seating/ Payload	Power/ Powertrain	Battery Size/ Weight	Range/ Flight Time	Altitude Ceiling	Flown (Yes/No)	Certifi-cation & Service Timeline	Charging Information
			proprietary and referred to as STERNA.						

*N/A indicates that information in this category was not found

The tilt-wing design of Dufour Aerospace's aircraft family combines the ability to take off and land vertically with the efficiency and speed of a conventional aircraft—according to the company, without the constraints and limitations of other eVTOL designs. Dufour views the Aero3 design as a suitable replacement for helicopters, with 80% of current operations capable of being performed by this new model (Electric VTOL News 2025). The company plans to offer this eVTOL aircraft (in addition to an Aero2 drone) for emergency medical transportation and private air taxi operations (Alcock 2025b). Though the aircraft is still under development, the Aero3's propulsion system is in its final design stage with a recent partnership announced between Loft Dynamics, a flight simulation company with virtual reality flight training solutions. With additional simulation capabilities now for the production team, this collaboration should aid in ensuring the aircraft stays on track for its completion. Furthermore, Ascendance is in the development stage of another aircraft whose prototype is expected to undergo test flights in 2025 (Foster 2024).

Appendix B. Full EVI-EnSite Modeling Results

The tables in this appendix provide the electrified regional air mobility aircraft charging demand for all airports in all three cases of 1C, 2C, and 4C charging rate. Each table reports the total energy used in a 24-hour period for the specified charging case, the table also includes the peak power demand, required number of chargers, maximum charge duration, number of aircraft not able to fully charge to the 0.95 state of charge (SOC) threshold, and what the minimum SOC was for the aircraft that were not fully charged. Note that while some aircraft did not fully charge to 0.95 SOC, the minimum SOC achieved could still be sufficient for the aircraft to reach its next destination. For the purposes of this study, a 0.95 SOC was used to determine if a flight was fully charged or not. Additionally, this study did not size chargers for specific sites but used an oversized charger with a maximum power rating of 3 MW for all sites. More detailed site analysis is required to recommend specific charging infrastructure.

Table B-1. 1C Aircraft Charging Characteristics

Airport	Total Energy (kilowatt -hours [kWh]	1C Peak Power (kilowatt [kW])	1C No. Chargers	1C Max Charge Duration (minutes)	1C Aircraft Not Charged	1C Min. SOC
GJT	7,026	2,845.6	6	35.5	10	0.77
MTJ	1,442	952.9	2	33.5	0	0.95
BJC	3,253	1,415.6	3	38.5	2	0.88
RIL	1,860	476.4	1	31.5	0	0.95
COS	6,199	2,364.9	5	34.5	0	0.95
ASE	971	477.7	1	28.5	0	0.95
LXV	1,390	951	2	30.5	0	0.95
EGE	821	477.7	1	33.5	0	0.95
DRO	3,760	1,423.7	3	30.5	3	0.72
SAF	419	476.4	1	26.5	0	0.95
SLC	1,303	476.1	1	39.5	0	0.95
GUC	1,053	476	1	22.5	0	0.95
CFO	203	475.7	1	12.5	0	0.95
AJZ	2,445	950.2	2	36.5	0	0.95
TEX	1,476	477.6	1	34.5	0	0.95
AEG	1,127	476.2	1	37.5	0	0.95
RCV	1,520	478.1	1	34.5	1	0.93
DEN	2,561	952.6	2	36.5	0	0.95
HDN	1,383	475.8	1	32.5	0	0.95
FMN	1,942	1425.5	3	30.5	0	0.95
ALS	1,206	475.8	1	31.5	0	0.95
ABQ	6,083	1,897.3	4	39.5	1	0.93
CAG	852	477.5	1	29.5	0	0.95
PVU	4,031	2,367.5	5	41.5	1	0.83

Airport	Total Energy (kilowatt -hours [kWh]	1C Peak Power (kilowatt [kW])	1C No. Chargers	1C Max Charge Duration (minutes)	1C Aircraft Not Charged	1C Min. SOC
69V	434	475.9	1	13.5	0	0.95
VEL	731	476.8	1	24.5	0	0.95
CNY	1,157	950.7	2	32.5	0	0.95
PNA	1,148	949.1	2	37.5	0	0.95
PSO	924	477.1	1	29.5	0	0.95
SKX	490	476	1	20.5	0	0.95
CEZ	1,048	477.1	1	33.5	0	0.95
U42	2,621	1,424.7	3	39.5	0	0.95
AFO	1,198	949.3	2	32.5	0	0.95
BCE	1,249	476.1	1	39.5	0	0.95
BDU	91	478.1	1	7.5	0	0.95
HCR	265	476.3	1	33.5	0	0.95
GNB	122	478.1	1	8.5	0	0.95
ANK	111	477.8	1	14.5	0	0.95
40U	540	951.1	2	23.5	0	0.95
RIW	0	0	1	-0.5	0	0.96
RTN	245	478	1	31.5	0	0.95

Table B-2. 2C Aircraft Charging Characteristics

Airport	Total Energy (kWh)	2C Peak Power (kW)	2C No. Chargers	2C Max Charge Duration (minutes)	2C Aircraft Not Charged	2C min SOC
GJT	7,026	3,881.6	5	17.5	0	0.95
MTJ	1,442	1,942.1	2	16.5	0	0.95
BJC	3,253	1,940.9	3	18.5	0	0.95
RIL	1,860	970.2	1	15.5	0	0.95
COS	6,199	3,878.7	4	16.5	0	0.95
ASE	971	971.4	1	13.5	0	0.95
LXV	1,390	970.6	1	14.5	0	0.95
EGE	821	971.3	1	16.5	0	0.95
DRO	3,760	2,905.3	3	14.5	1	0.93
SAF	419	969.9	1	12.5	0	0.95
SLC	1,303	970.5	1	19.5	0	0.95
GUC	1,053	971.7	1	11.5	0	0.95
CFO	203	970.8	1	6.5	0	0.95
AJZ	2,445	1,937.5	2	17.5	0	0.95
TEX	1,476	972.5	1	16.5	0	0.95

Airport	Total Energy (kWh)	2C Peak Power (kW)	2C No. Chargers	2C Max Charge Duration (minutes)	2C Aircraft Not Charged	2C min SOC
AEG	1,127	970.2	1	18.5	0	0.95
RCV	1,520	970.9	1	16.5	0	0.95
DEN	2,561	1,940.8	2	17.5	0	0.95
HDN	1,383	971.9	1	16.5	0	0.95
FMN	1,942	2,907.1	3	15.5	0	0.95
ALS	1,206	970.1	1	15.5	0	0.95
ABQ	6,083	3,875.2	4	19.5	0	0.95
CAG	852	971.5	1	14.5	0	0.95
PVU	4,031	3,878.4	4	20.5	1	0.93
69V	434	969.9	1	6.5	0	0.95
VEL	731	969.9	1	11.5	0	0.95
CNY	1,157	970.8	1	15.5	0	0.95
PNA	1,148	1,940.6	2	18.5	0	0.95
PSO	924	970.6	1	14.5	0	0.95
SKX	490	971.7	1	10.5	0	0.95
CEZ	1,048	970.2	1	16.5	0	0.95
U42	2,621	1,940.6	2	19.5	0	0.95
AFO	1,198	1,939.6	2	16.5	0	0.95
BCE	1,249	970.5	1	19.5	0	0.95
BDU	91	971.8	1	3.5	0	0.95
HCR	265	970.3	1	16.5	0	0.95
GNB	122	971.7	1	4.5	0	0.95
ANK	111	969.9	1	6.5	0	0.95
40U	540	1,939.7	2	11.5	0	0.95
RIW	0	0	1	-0.5	0	0.96
RTN	245	971.5	1	15.5	0	0.95

Table B-3. 4C Aircraft Charging Characteristics

Airport	Total Energy (kWh)	4C Peak Power (kW)	4C No. Chargers	4C Max Charge Duration (minutes)	4C No. Aircraft Not Charged	4C min. SOC
GJT	7,026	3,441.2	3	14.5	0	0.95
MTJ	1,442	2,306	2	13.5	0	0.95
BJC	3,253	2,310.1	2	16.5	0	0.95
RIL	1,860	1,156.1	1	13.5	0	0.95
COS	6,199	4,587.2	4	14.5	0	0.95
ASE	971	1,156.1	1	11.5	0	0.95
LXV	1,390	1,156	1	12.5	0	0.95
EGE	821	1,156.1	1	13.5	0	0.95
DRO	3,760	2,310.9	2	12.5	0	0.95
SAF	419	1,156	1	11.5	0	0.95
SLC	1,303	1,156	1	16.5	0	0.95
GUC	1,053	1,155.8	1	9.5	0	0.95
CFO	203	1,124.1	1	5.5	0	0.95
AJZ	2,445	1,156.1	1	15.5	0	0.95
TEX	1,476	1,155.6	1	14.5	0	0.95
AEG	1,127	1,156.1	1	15.5	0	0.95
RCV	1,520	1,156.1	1	14.5	0	0.95
DEN	2,561	2,303.9	2	15.5	0	0.95
HDN	1,383	1,156.1	1	13.5	0	0.95
FMN	1,942	3,423	3	12.5	0	0.95
ALS	1,206	1,156.1	1	13.5	0	0.95
ABQ	6,083	3,412.2	3	16.5	0	0.95
CAG	852	1,155.8	1	12.5	0	0.95
PVU	4,031	3,458.2	3	17.5	0	0.95
69V	434	1,128.8	1	5.5	0	0.95
VEL	731	1,155.8	1	10.5	0	0.95
CNY	1,157	1,156	1	13.5	0	0.95
PNA	1,148	2,270	2	15.5	0	0.95
PSO	924	1,155.7	1	12.5	0	0.95
SKX	490	1,156.1	1	8.5	0	0.95
CEZ	1,048	1,156.1	1	14.5	0	0.95
U42	2,621	2,304.1	2	16.5	0	0.95
AFO	1,198	1,156.1	1	13.5	0	0.95
BCE	1,249	1,156	1	16.5	0	0.95
BDU	91	1,115.5	1	3.5	0	0.95
HCR	265	1,156	1	14.5	0	0.95
GNB	122	1,115.5	1	3.5	0	0.95

Airport	Total Energy (kWh)	4C Peak Power (kW)	4C No. Chargers	4C Max Charge Duration (minutes)	4C No. Aircraft Not Charged	4C min. SOC
ANK	111	1,130.7	1	6.5	0	0.95
40U	540	2,310	2	9.5	0	0.95
RIW	0	0	1	-0.5	0	0.96
RTN	245	1,156.1	1	12.5	0	0.95

Appendix C. Summary Statistics of Modeled Aircraft by Airport

Table C-1 describes the quantity and type of electric or hybrid aircraft flights modeled for each airport.

Table C-1. RAM Flights by Aircraft Type

Airport	Aircraft Type	No. Flights
40U	9 passengers (pax)	3
69V	9 pax	4
ABQ	19 pax	8
ABQ	30 pax	3
ABQ	9 pax	25
AEG	9 pax	4
AFO	9 pax	5
AJZ	9 pax	12
ALS	9 pax	5
ANK	9 pax	1
ASE	9 pax	6
BCE	9 pax	4
BDU	9 pax	3
BJC	19 pax	9
BJC	9 pax	23
CAG	9 pax	4
CEZ	9 pax	6
CFO	9 pax	2
CNY	9 pax	5
COS	19 pax	4
COS	9 pax	30
DEN	19 pax	1
DEN	9 pax	14
DRO	19 pax	1
DRO	30 pax	2
DRO	9 pax	20
EGE	9 pax	5
EGE	19 pax	1
FMN	9 pax	10
GJT	19 pax	2
GJT	30 pax	8
GJT	9 pax	43
GNB	9 pax	2
GUC	9 pax	6

Airport	Aircraft Type	No. Flights
HCR	9 pax	1
HDN	9 pax	6
LXV	9 pax	8
MTJ	9 pax	9
PNA	9 pax	4
PSO	9 pax	4
PVU	9 pax	19
PVU	19 pax	1
RCV	9 pax	6
RIL	9 pax	11
RIW	19 pax	2
RTN	9 pax	1
SAF	19 pax	4
SAF	9 pax	2
SKX	9 pax	3
SLC	19 pax	2
SLC	30 pax	6
SLC	9 pax	4
TEX	19 pax	4
TEX	9 pax	7
U42	9 pax	11
VEL	9 pax	4

Appendix D. Aircraft Specifications

Fixed-Wing RAM

Battery Electric

1. Eviation Alice
    a. Dimensions
        i. https://www.eviation.com/aircraft/
    b. Seating/Payload
        i. https://www.eviation.com/aircraft/
    c. Power/Powertrain
        i. https://www.eviation.com/aircraft/
    d. Battery Size/Weight
    e. Range/Flight Time
        i. https://www.ainonline.com/aviation-news/futureflight/2024-04-29/eviation-reveals-latest-redesign-alice-electric-airplane
    f. Altitude Ceiling
        i. https://www.flightglobal.com/airframers/eviation-changes-alice-design-performance-specifications-shift/144376.article
    g. Flown (Yes/No)
        i. https://airwaysmag.com/ceo-eviation-alices-trajectory/
    h. Certification and Service Timeline
        i. https://airwaysmag.com/ceo-eviation-alices-trajectory/
    i. Charging Information
        i. Julia Roa and Joseph Oldham. 2022. "Feasibility Study of Regional Air Mobility Services for High Priority Transportation in the San Joaquin Valley." *Mineta Transportation Institute Publications*. https://doi.org/10.31979/mti.2022.2129.
    j. Background
        i. https://www.cnn.com/2022/09/27/tech/eviation-alice-first-flight/index.html
2. Beta Technologies ALIA CX300
    a. Dimensions
        i. https://www.beta.team/aircraft/
    b. Seating/Payload
        i. https://www.beta.team/aircraft/
        ii. https://fastcompanyme.com/impact/this-electric-plane-could-be-in-the-sky-by-2025/
    c. Power/Powertrain
        i. https://aviationweek.com/aerospace/advanced-air-mobility/beta-technologies-cx300-0
    d. Battery Size/Weight
    e. Range/Flight Time
        i. https://aviationweek.com/aerospace/advanced-air-mobility/beta-technologies-cx300-0
    f. Altitude Ceiling
    g. Flown (Yes/No)
        i. https://www.axios.com/2023/03/14/electric-airplanes-beta-technologies-ectol-certification
    h. Certification and Service Timeline
        i. https://www.ainonline.com/aviation-news/futureflight/2024-07-15/us-air-force-deploys-betas-alia-electric-aircraft-prototype
    i. Charging Information
        i. https://aviationweek.com/aerospace/advanced-air-mobility/beta-technologies-cx300-0
    j. Background
        i. https://www.axios.com/2023/03/14/electric-airplanes-beta-technologies-ectol-certification
        ii. https://interestingengineering.com/transportation/betas-cx300-electric-plane-takes-off-just-like-conventional-planes

3. Elysian E9X
    a. https://www.elysianaircraft.com/
    b. https://www.cnn.com/travel/elysian-electric-plane-90-passenger-spc/index.html
4. Vaeridion Microliner
    a. https://www.flyingmag.com/news/electric-regional-aircraft-developer-lands-battery-manufacturing-hub/
    b. https://vaeridion.com/

Hybrid Electric

1. Heart Aerospace ES-30
    a. Dimensions
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
    b. Seating/Payload
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
    c. Power/Powertrain
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
    d. Battery Size/Weight
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
        ii. https://www.reuters.com/business/aerospace-defense/bae-systems-work-with-heart-aerospace-electric-airplane-battery-2023-03-30/
    e. Range/Flight Time
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
    f. Altitude Ceiling
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
    g. Flown (Yes/No)
    h. https://flightplan.forecastinternational.com/2024/09/18/heart-aerospace-unveils-full-scale-demonstrator-for-es-30-program/
    i. Certification and Service Timeline
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
    j. Charging Information
        i. https://aviationweek.com/aerospace/advanced-air-mobility/heart-aerospace-es-30
2. Ampaire Eco Caravan
    a. Dimensions
        i. https://cessna.txtav.com/en/turboprop/caravan
        ii. https://www.aviationtoday.com/2022/11/23/ampaires-hybrid-electric-grand-caravan-takes-flight/ (mentions the Eco Caravan is a retrofitted Grand Caravan)
    b. Seating/Payload
        i. https://www.aerospacetechreview.com/ampaire-announces-firm-order-for-hybrid-electric-eco-caravans/
    c. Power/Powertrain
        i. https://newsroom.aviator.aero/ampaire-receives-order-for-up-to-six-eco-caravan-upgrades-from-azul-conecta/
        ii. https://www.ainonline.com/aviation-news/air-transport/2022-11-18/hybrid-electric-ampaire-eco-caravan-makes-first-flight
    d. Battery Size/Weight
        i. https://www.futureflight.aero/news-article/2022-11-18/ampaires-hybrid-electric-eco-caravan-makes-first-test-flight
    e. Range/Flight Time
        i. https://www.aviationtoday.com/2022/11/23/ampaires-hybrid-electric-grand-caravan-takes-flight/
        ii. https://www.aviationtoday.com/2022/11/23/ampaires-hybrid-electric-grand-caravan-takes-flight/
    f. Altitude Ceiling
        i. https://www.aviationtoday.com/2022/11/23/ampaires-hybrid-electric-grand-caravan-takes-flight/

        ii. https://simpleflying.com/ampaire-eco-caravan-first-flight/
    g. Flown (Yes/No)
        i. https://www.flyingmag.com/ampaire-eco-caravan-conducts-first-flight/
    h. Certification and Service Timeline
        i. https://www.flyingmag.com/ampaire-eco-caravan-conducts-first-flight/
    i. Charging Information
        i. https://www.futureflight.aero/news-article/2022-11-18/ampaires-hybrid-electric-eco-caravan-makes-first-test-flight
    j. Background Information
        i. https://www.prnewswire.com/in/news-releases/ampaire-flies-first-hybrid-electric-regional-aircraft-301683143.html
        ii. https://www.flyingmag.com/ampaire-and-tamarack-announce-mou-on-aerodynamic-upgrades/

3. Ampaire EEL
    a. Dimensions
        i. https://www.globalair.com/aircraft-for-sale/specifications?specid=437
    b. Seating/Payload
        i. https://www.ampaire.com/vehicles/Electric-EEL-Aircraft
    c. Power/Powertrain
        i. https://simpleflying.com/ampaire-longest-nonstop-hybrid-electric-mission/
        ii. https://www.avweb.com/aviation-news/ampaire-electric-eel-completes-cross-country-test-flight/
    d. Battery Size/Weight
    e. Range/Flight Time
        i. https://www.ampaire.com/vehicles/Electric-EEL-Aircraft
    f. Altitude Ceiling
    g. Flown (Yes/No)
        i. https://www.aviationtoday.com/2022/07/26/ampaire-hybrid-electric-demonstrator-nonstop-flight/
    h. Certification and Service Timeline
        i. https://www.aviationtoday.com/2022/07/26/ampaire-hybrid-electric-demonstrator-nonstop-flight/
        ii. https://www.flyingmag.com/ampaire-completes-hybrid-electric-ground-test-using-pure-saf/
    i. Charging Information
        i. Julia Roa and Joseph Oldham. 2022. "Feasibility Study of Regional Air Mobility Services for High Priority Transportation in the San Joaquin Valley." *Mineta Transportation Institute Publications*. https://doi.org/10.31979/mti.2022.2129.
        ii. https://robbreport.com/motors/aviation/ampaire-eel-hybrid-electric-aircraft-record-1234730374/
    j. Background
        i. https://robbreport.com/motors/aviation/ampaire-eel-hybrid-electric-aircraft-record-1234730374/

4. Faradair BEHA M1H Aircraft
    a. Dimensions
        i. https://www.faradair.com/
    b. Seating/Payload
        i. https://www.faradair.com/
    c. Power/Powertrain
        i. https://www.futureflight.aero/news-article/2021-05-25/faradair-close-completing-design-bio-electric-hybrid-aircraft
        ii. https://www.magnix.aero/
        iii. https://www.aerospace-technology.com/projects/faradair-beha-m1h-aircraft/
    d. Battery Size/Weight
    e. Range/Flight Time
        i. https://www.aerospace-technology.com/projects/faradair-beha-m1h-aircraft/

f. Altitude Ceiling
   i. https://www.ainonline.com/aviation-news/air-transport/2020-12-17/faradairs-beha-hybrid-aircraft-boosted-partnerships
g. Flown (Yes/No)
   i. https://www.futureflight.aero/news-article/2021-05-25/faradair-close-completing-design-bio-electric-hybrid-aircraft
h. Certification and Service Timeline
   i. https://www.futureflight.aero/news-article/2021-05-25/faradair-close-completing-design-bio-electric-hybrid-aircraft
i. Charging Information
j. Background
   i. https://www.airframer.com/news_story.html?release=70404
   ii. https://www.futureflight.aero/news-article/2021-05-25/faradair-close-completing-design-bio-electric-hybrid-aircraft

5. VoltAero Cassio 330
   a. Dimensions
      i. https://www.voltaero.aero/en/the-vision/specifications/
   b. Seating/Payload
      i. https://www.voltaero.aero/en/the-vision/specifications/
   c. Power/Powertrain
      i. https://www.voltaero.aero/en/propulsion/
      ii. https://www.voltaero.aero/en/the-vision/specifications/
      iii. https://www.airport-technology.com/features/what-tech-is-onboard-voltaeros-cassio-electric-hybrid-aircraft/
      iv. https://www.safran-group.com/pressroom/voltaero-selects-safran-s-engineustm-100-electric-motor-equip-cassio-330-electric-hybrid-aircraft-2022-07-20
   d. Battery Size/Weight
      i. https://www.voltaero.aero/en/the-vision/specifications/
   e. Range/Flight Time
      i. https://www.voltaero.aero/en/propulsion/
   f. Altitude Ceiling
   g. Flown (Yes/No)
      i. https://www.airport-technology.com/features/what-tech-is-onboard-voltaeros-cassio-electric-hybrid-aircraft/
   h. Certification and Service Timeline
      i. https://aviationweek.com/shownews/ebace/voltaero-track-first-cassio-330-flight-year-end
   i. Charging Information
      i. https://www.voltaero.aero/en/the-vision/specifications/
   j. Background
      i. https://www.voltaero.aero/en/press-releases/voltaero-cassio-330-electric-hybrid-aircraft-paris-air-show/
6. VoltAero Cassio 480
   a. Dimensions
      i. https://www.voltaero.aero/en/the-vision/specifications/#480
   b. Seating/Payload
      i. https://www.voltaero.aero/en/the-vision/specifications/#480
   c. Power/Powertrain
      i. https://skiesmag.com/press-releases/voltaeros-cassio-330-makes-world-debut-at-paris-air-show/
      ii. https://www.voltaero.aero/en/propulsion/
   d. Battery Size/Weight
      i. https://www.voltaero.aero/en/the-vision/specifications/#480
   e. Range/Flight Time
   f. https://www.voltaero.aero/en/the-vision/specifications/#480
   g. Altitude Ceiling
   h. Flown (Yes/No)

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    i. Certification and Service Timeline
        i. https://www.flyingmag.com/voltaero-shows-off-cassio-330-hybrid-electric-aircraft/
    j. Charging Information
        i. https://www.voltaero.aero/en/the-vision/specifications/#480
    k. Background
        i. https://www.voltaero.aero/en/press-releases/voltaero-cassio-330-electric-hybrid-aircraft-paris-air-show/

7. VoltAero Cassio 600
    a. Dimensions
        i. https://www.voltaero.aero/en/the-vision/specifications/#600
    b. Seating/Payload
        i. https://www.voltaero.aero/en/the-vision/specifications/#600
    c. Power/Powertrain
        i. https://www.voltaero.aero/en/propulsion/
        ii. https://www.voltaero.aero/en/the-vision/specifications/#600
    d. Battery Size/Weight
        i. https://www.voltaero.aero/en/the-vision/specifications/#600
    e. Range/Flight Time
        i. https://www.voltaero.aero/en/the-vision/specifications/#600
    f. Altitude Ceiling
    g. Flown (Yes/No)
        i. https://www.flyingmag.com/voltaero-shows-off-cassio-330-hybrid-electric-aircraft/
    h. Certification and Service Timeline
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    i. Charging Information
        i. https://www.voltaero.aero/en/the-vision/specifications/#600
    j. Background
        i. https://www.voltaero.aero/en/press-releases/voltaero-cassio-330-electric-hybrid-aircraft-paris-air-show/

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    a. Dimensions
        i. https://www.globalair.com/aircraft-for-sale/specifications?specid=663
    b. Seating/Payload
        i. https://www.globalair.com/aircraft-for-sale/specifications?specid=663
    c. Power/Powertrain
        i. https://www.collinsaerospace.com/news/news/2022/07/collins-complete-preliminary-design-of-1mw-electric-motor-for-pratt-whitney-canada
    d. Battery Size/Weight
    e. Range/Flight Time
        i. https://www.globalair.com/aircraft-for-sale/specifications?specid=663
    f. Altitude Ceiling
        i. https://www.globalair.com/aircraft-for-sale/specifications?specid=663
    g. Flown (Yes/No)
        i. https://www.collinsaerospace.com/news/news/2022/07/collins-complete-preliminary-design-of-1mw-electric-motor-for-pratt-whitney-canada
        ii. https://www.futureflight.aero/news-article/2022-05-19/h55-supply-battery-system-pratt-whitneys-hybrid-electric-regional-aircraft
    h. Certification and Service Timeline
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    i. Charging Information
    j. Background

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    a. Dimensions
        i. https://www.vikingair.com/twin-otter-series-400/technical-description
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    b. Seating/Payload
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    c. Power/Powertrain
    d. Battery Size/Weight
    e. Range/Flight Time
        i. https://www.ampaire.com/vehicles/eco-otter-aircraft
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    g. Flown (Yes/No)
        i. https://www.ampaire.com/projects/NASA-Project
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    a. Dimensions
        i. https://www.airlines-inform.com/commercial-aircraft/dornier-228.html
    b. Seating/Payload
        i. https://www.flyingmag.com/zeroavia-tests-dornier-228-with-hydrogen-electric-engine/
    c. Power/Powertrain
        i. https://www.aerospacetestinginternational.com/news/electric-hybrid/zeroavia-flies-largest-hydrogen-fuel-cell-powered-aircraft-yet.html
        ii. https://www.flyingmag.com/zeroavia-tests-dornier-228-with-hydrogen-electric-engine/
    d. Battery Size/Weight
    e. Range/Flight Time
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    f. Altitude Ceiling
    g. Flown (Yes/No)
        i. https://www.flyingmag.com/zeroavia-tests-dornier-228-with-hydrogen-electric-engine/
        ii. https://zeroavia.com/flight-testing/
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- e. Range/Flight Time
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    - a. Dimensions
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    - b. Seating/Payload
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    - c. Power/Powertrain
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    - d. Battery Size/Weight
    - e. Range/Flight Time
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General Aviation and Training

Battery Electric

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    a. Dimensions
        i. https://www.futureflight.aero/aircraft-program/eflyer
        ii. https://byeaerospace.com/electric-airplane/
    b. Seating/Payload
        i. https://www.futureflight.aero/aircraft-program/eflyer
    c. Power/Powertrain
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    d. Battery Size/Weight
        i. https://byeaerospace.com/electric-airplane/
    e. Range/Flight Time
        i. https://byeaerospace.com/electric-airplane/
    f. Altitude Ceiling
        i. https://byeaerospace.com/electric-airplane/
    g. Flown (Yes/No)
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    a. Dimensions
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    b. Seating/Payload
        i. https://www.pipistrel-aircraft.com/products/velis-electro/
    c. Power/Powertrain
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    d. Battery Size/Weight
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    e. Range/Flight Time
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    - a. Dimensions
    - b. Seating/Payload
        - i. https://www.diamondaircraft.com/en/service/electric-aircraft/
    - c. Power/Powertrain
        - i. https://www.diamondaircraft.com/en/service/electric-aircraft/
    - d. Battery Size/Weight
    - e. Range/Flight Time
        - i. https://www.diamondaircraft.com/en/service/electric-aircraft/
    - f. Altitude Ceiling
    - g. Flown (Yes/No)
        - i. https://www.diamondaircraft.com/en/service/electric-aircraft/
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        - i. https://www.diamondaircraft.com/en/service/electric-aircraft/
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    - a. Dimensions
        - i. https://byeaerospace.com/electric-airplane/
        - ii. https://www.futureflight.aero/aircraft-program/eflyer
    - b. Seating/Payload
        - i. https://www.futureflight.aero/aircraft-program/eflyer
    - c. Power/Powertrain
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    - e. Range/Flight Time
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    h. Certification and Service Timeline
        i. https://www.futureflight.aero/aircraft-program/eflyer
    i. Charging Information
    j. Background
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Electric Vertical Takeoff and Landing

Battery Electric

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    b. Seating/Payload
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        ii. https://evtol.news/lilium-gmbh-lilium-jet-7-seater
    c. Power/Powertrain
        i. https://evtol.news/lilium-gmbh-lilium-jet-7-seater
    d. Battery Size/Weight
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    e. Range/Flight Time
        i. https://www.aerospace-technology.com/projects/lilium-7-seater-evtol-jet/
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    g. Flown (Yes/No)
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    j. Background
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        i. https://evtol.news/joby-s4
        ii. https://aviationweek.com/aerospace/advanced-air-mobility/joby-aviation-s4-program
    b. Seating/Payload
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    c. Power/Powertrain
        i. https://aviationweek.com/aerospace/advanced-air-mobility/joby-aviation-s4-program
    d. Battery Size/Weight
        i. https://aviationweek.com/aerospace/advanced-air-mobility/joby-aviation-s4-program
    e. Range/Flight Time
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    f. Altitude Ceiling
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    g. Flown (Yes/No)
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    j. Background
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    b. Seating/Payload
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        i. https://evtol.news/beta-technologies-alia/
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        i. https://evtol.news/beta-technologies-alia/
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    j. Background
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    a. Dimensions
        i. https://www.greencarcongress.com/2022/10/20221004-wisk.html
    b. Seating/Payload
        i. https://simpleflying.com/wisk-generation-6-new-evtol/
    c. Power/Powertrain
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    d. Battery Size/Weight
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    j. Background
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    a. Dimensions
    b. Seating/Payload
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    c. Power/Powertrain
        i. https://evtol.news/overair-butterfly/
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    g. Flown (Yes/No)
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    h. Certification and Service Timeline
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    a. Dimensions
    b. Seating/Payload
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        ii. https://www.archer.com/midnight
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        i. https://evtol.news/archer/
        ii. https://www.archer.com/midnight
    d. Battery Size/Weight
    e. Range/ Flight Time
        i. https://www.archer.com/midnight
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    j. Background
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    b. Certification and Service Timeline
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    c. https://wisk.aero/
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        i. https://evtol.news/textron-eaviation-evtol
    b. Timeline
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    a. All
        i. https://jauntairmobility.com/
    b. Timeline
        i. https://flightplan.forecastinternational.com/2024/04/18/uam-snapshot-jaunt-air-mobility-journey/

Hybrid Electric

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    a. Dimensions
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    b. Seating/Payload
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