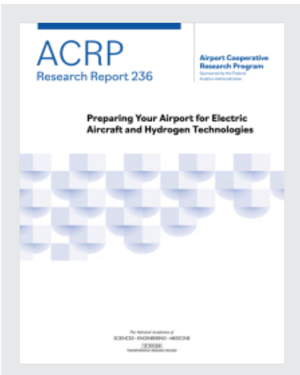

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AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP RESEARCH REPORT 236

Preparing Your Airport for Electric Aircraft and Hydrogen Technologies

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2022

AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

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FOREWORD

By Joseph D. Navarrete
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ACRP Research Report 236: Preparing Your Airport for Electric Aircraft and Hydrogen Technologies and its accompanying electronic toolkit offer an introduction to the emerging electric aircraft industry, give estimates of potential market growth, and provide guidance to help airports estimate the potential impacts of electric aircraft on their facilities and to be prepared to accommodate them. The report and toolkit will be of particular interest to practitioners who wish to explore the benefits and challenges of accommodating this new technology in an airport setting.

Design innovation for electrically powered and hybrid-electric aircraft is accelerating rapidly. While there are many potential benefits of electric aircraft and hydrogen technologies, not all air service can be replaced by electrically powered aircraft in the near term. The advent of electric aircraft offers both significant opportunities and disruptions for airports and their surrounding communities. Airports may have new roles to play regarding energy generation and transmission; at the same time, electric aircraft may affect revenue from fuel sales. Airports needed research to help prepare for the introduction and accommodation of electric aircraft into the airport environment.

The research, led by WSP USA, began with a review of literature related to electric aircraft and hydrogen technologies. A market assessment was then performed. To identify areas of the market that would be of greatest interest to airports, the research team also developed a framework for market segmentation based on aircraft payload and range, technology type, and mission profile. This was followed by incorporating risks and challenges (e.g., policy and regulatory uncertainty, infrastructure investment). The research effort continued with a detailed airport impact evaluation, including not only operational and facility considerations but also financial and economic implications. Once these were considered, the team identified strategies to address facility requirements. Given the level of uncertainty of this nascent technology, the effort included considerable stakeholder outreach through thought leader interviews and workshops with an ad hoc stakeholder working group to ensure the guidance was broad yet realistic. The analysis and findings from the research were then used to prepare the report and develop the toolkit.

The report provides an introduction to electric aircraft, a market assessment, a discussion of federal and state policies, and a description of potential airport impacts and facility needs to accommodate electric aircraft. The report then offers general guidance to airports to help them incorporate electric aircraft into their operations and long-range planning. This is done by identifying two market segments: air carrier/military and air taxi/commuter/general aviation and three forecast scenarios: a “downside scenario,” a “baseline scenario,” and an “upside scenario,” each having a higher share of electric aircraft activity relative to overall airport activity. The guidance then examines airport facility needs with a focus on charging infrastructure and hydrogen supply chain, airside requirements, and passenger terminal facility needs. Finally, the report offers guidance to account for electric aircraft in airport master plans and other long-term planning documents. A series of appendices, available from the TRB website (trb.org) by searching for "ACRP Research Report 236" provides details on the assumptions and methods used in the research as well as helpful references for airport planning. The toolkit, available at https://www.dropbox.com/s/db0x3kemf8r3b0d/A236_toolkit.zip?dl=0, includes a database of more than 100 electric aircraft and may be used by airports to estimate future electric power requirements at their airport based on local characteristics (e.g., climate, aviation activity levels, existing electrical demand).

CONTENTS

Note: Photographs, figures, and tables in this report may have been converted from color to grayscale for printing. The electronic version of the report (posted on the web at www.trb.org) retains the color versions.

SUMMARY

Preparing Your Airport for Electric Aircraft and Hydrogen Technologies

In pursuit of more environmentally friendly transportation, as well as the prospect of lower operating costs, the aviation community has widely accepted the idea that adopting alternative power and energy sources for aircraft will be necessary across future generations of aircraft. With these considerations in mind, the industry has set goals toward reducing greenhouse gas (GHG) emissions and evaluating noise implications and aviation energy use in the global industry. Sustainable aviation fuels, electric aircraft (also known as e-aircraft), and hydrogen technologies are key elements toward achieving net-zero aviation by 2060.

Although there are no commercial electric aircraft flying to date, the deadline is fast approaching, and airports should start considering the potential impacts of electric aviation. The Airport Cooperative Research Program (ACRP) Project 03-51 investigated how the advent of electric aircraft will impact the infrastructure, operations, funding, and environment of airports. It also provides guidance for the airport industry (airport operators, flight operators, aircraft ground support providers, aircraft manufacturers, air navigation service providers, and industry and professional organizations) and the energy sector (utility providers or the hydrogen industry) on how to account for electric aircraft operations in their planning efforts. This research effort focused on fixed-wing manned aircraft and only partially addresses topics on small unmanned aerial systems (UAS) and electric vertical takeoff and landing (eVTOL) vehicles.

The market assessment predicts that 3,500 electric aircraft will operate from U.S. airports at the 2030 horizon, which should account for approximately 2 percent of the entire U.S. aircraft fleet. The first electric aircraft in service will be small capacity and more suitable to ensure missions for private and recreational flights, training purposes, air taxi services, small commuter flights, and regional aviation. Electric aircraft could facilitate the emergence of regional air mobility, with smaller aircraft (2 to 20 seaters) used for rapid connectivity between small communities as well as from these communities to larger metropolitan areas. More than 50 percent of all flights worldwide are shorter than 3 hours of flight time. A renewal of smaller point-to-point regional mobility with small commuter aircraft could be expected and calls for specific discussions at the planning level.

Integrating electric aircraft into airports and aviation systems would require infrastructure upgrades and operational changes for the airport to adapt and accommodate these new airside users. Integrating electric aircraft activities with airport operations would differ from one airport to another. It will depend on the expected aircraft technologies to be accommodated at the airport—including the type of energy vector (electricity or hydrogen), the process for recharging or refueling, flight operators' preferences, and the ownership model of the support equipment. An Assessment Tool was developed as part of

this project to help airports and their stakeholders plan for the introduction and growth of electric aviation.

The main cost of electric aircraft implementation at airports will be for airport operators, their stakeholders, or new third parties to procure and maintain electric aircraft charging systems. The integration of electric aviation could require some airports to upgrade their overall power supply and connection to the electric grid as well. The financial burden might be shared between the stakeholders as, today, these projects are mostly not eligible for federal funding. Lastly, some airports may elect to develop on-site power generation to reduce their vulnerability and dependency, increase their operational resiliency, and lower their carbon footprint.

Power management would be essential to provide the necessary power needs to accommodate the demands of electric aircraft. Transitioning to electric aircraft also requires considering scenarios in the event of a sustained power outage, such as climate-related or natural disaster emergency. A reliable supply of power is an important factor when considering the transition to all-electric operations. There is the need for airports to consider emergency backup power. Along with traditional backup systems, new technologies such as hydrogen fuel-cell power generation systems, large battery energy storage can provide efficient and eco-friendly alternative.

Electric aircraft raise the question of the evolution of standards and policies for taking these new users into consideration. Also, electric aviation provides considerable environmental benefits such as reduced noise and emissions. Anticipating these different impacts will inevitably impact the planning processes, and more particularly airport master plans or statewide aviation plans.

Introduction

Background

Electric aircraft are on the horizon. Several prototypes of general aviation and small transport electric aircraft are already flying, and it is likely that some of them will be certified in the United States within 5 years. There are many potential benefits of electric aircraft, including lower operating and maintenance costs and reduced environmental impacts. However, not all air service can be replaced by electrically powered aircraft at the short- and medium-term horizons. Indeed, today's batteries are heavy and less energy-dense compared with conventional aviation fuels, and hydrogen fuel cell technologies for aviation are still emerging.

In certain applications (e.g., short-haul and cargo service), electric power may be more efficient than traditional power. The early short-haul electric aircraft could provide an alternative for part of the more than 50 percent of all flights worldwide that have a flight time shorter than 3 hours. The advent of electric aircraft offers both significant opportunities and disruptions for airports and their communities. Airports may have new roles to play regarding the generation, storage, and distribution of electricity and hydrogen as new energy vectors used by both airside and landside users. At the same time, electric aircraft may impact revenue from fuel sales. The aviation community needs guidance to be ready for the introduction and accommodation of electric aircraft into the airport environment.

ACRP Project 03-51, "Electric Aircraft on the Horizon—An Airport Planning Perspective" aimed to research the implications of the emergence of electric aviation for airports and aviation systems and how to plan for their accommodation. A Guidebook and Toolkit were developed to provide the findings and guidance in a way that is most accessible for regular users. The Toolkit also includes an electric aircraft Assessment Tool, which processes long-term forecasts and other airport data entered by the user to compute figures on the facility requirements (e.g., electric aircraft chargers) and electricity demand useful for airside and utilities planning purposes.

Who Is the Audience for the Guidebook and Toolkit?

The Guidebook and Toolkit are intended to be used by all the stakeholders of electric aviation who are looking for (1) general information on electric aircraft and their evolution; (2) perspectives on the emerging electric aircraft market; (3) discussions of the level of uncertainty about electric aircraft technology development and adoption; (4) guidance and trend analyses for aviation traffic forecasting purpose; (5) a summary of the potential impact of electric aircraft on airport facilities, terminal airspace, operations, planning, finances, and environmental sustainability; (6) technical resources and analyses for airside planning and design purpose; and (7) related electric industry trends—including renewable and distributed generation, microgrids and energy storage, and strategic electrification.

Typical users will include airport operators, air traffic control towers, flight operators, ground handlers, fixed-base operators (FBOs), tenants, aircraft and original equipment manufacturers (OEMs), consultancy firms, state departments of transportation, and federal agencies, but also non-traditional aviation stakeholders such as electric and utility companies, industrial gases producers and distributors, and federal and state regulators of these industries.

How to Use the Guidebook and the Toolkit

The Guidebook provides extensive analyses on the emergence of electric aircraft and guidance on how to account for them in airport planning and design.

Chapters 1 to 5 introduce airport practitioners to electric aircraft, describing the trajectory of electric aviation from the 1970s to the first model to be certified by a national aviation authority. The anatomy of electric aircraft is described, with a technical presentation of main components and powertrain configurations. A medium-term market assessment is outlined in Chapter 4, with further details provided in Appendix A (Market Assessment: Other Segments of Electric Aircraft Value Chain) and Appendix B (Market Assessment: Model Assumptions). Chapter 5 offers a qualitative economic impact outlook.

Chapter 6 evaluates and discusses the various issues related to the introduction of electric aircraft in terms of federal and state policies, including environmental regulations. The chapter provides information on the federal regulatory framework for aircraft certification, as well as perspectives on emerging policy issues regarding the resell and charge of electricity as an aviation energy vector.

Chapters 7 to 9 focus on aircraft/airport compatibility, covering the potential impact of electric aviation on aviation demand and passenger traffic. Airside requirements of electric aircraft are discussed with great detail regarding their operational aspects. Chapters 8 and 9 feature guidance for long-term planning purposes, especially for airport master plans and statewide aviation system plans. Appendices C to E are supplements to this part of the report. Appendix C provides technical characteristics of electric aircraft for airfield planning purposes based on known information provided by aircraft and OEMs on their experimental vehicles and future projects. Appendices D and E assess the safety implications of electric aircraft operations and the need for standardization of the electric aircraft/airport interface, respectively.

Chapters 10 to 13 are about power supply requirements. Relevant electric industry trends are presented. The growth of the overall airport electric demand and the need for a smart and resilient approach to power generation and management at airports are discussed. These pages are useful for utilities planning, beyond the introduction of electric aircraft, in the context of the broader electrification of aviation facilities.

Chapters 14 to 17 provide guidance for developing implementation scenarios for planning purposes, covering infrastructure upgrades, financial planning, airport scenario planning, and the integration of electric aircraft into airport master planning and statewide aviation system planning. Chapter 16 on airport scenario planning features extensive instructions for the electric aircraft Assessment Tool available in the Toolkit.

Appendix F summarizes the main takeaways of electric aircraft industry workshops that were held by the project team as part of ACRP Project 03-51 from November 2020 to February 2021.

Accompanying this report is the Toolkit, which features a selection of narrative contents from the Guidebook, as well as an airport electricity demand Assessment Tool, a database of electric aircraft characteristics for airport planning (spreadsheets), a glossary of terms, a list of abbreviations, and an electronic library.

CHAPTER 1

Emergence of Electric Aviation

1.1 Introduction

Future generations of aircraft require moving from current fuel sources to alternative sources for aircraft power and energy, and the global aircraft industry is setting ambitious goals toward reducing greenhouse gas (GHG) emissions and evaluating noise implications and aviation energy use. Sustainable aviation fuels, electric aircraft, and hydrogen technologies are key elements toward achieving net-zero carbon emissions by 2060.

Did you know? Aviation has been working aggressively to reduce its environmental footprint since at least the 1970s, and the carbon-specific awareness has accelerated throughout the 1990s. In 1999, the Intergovernmental Panel on Climate Change of the United Nations released its special report, *Aviation and the Global Atmosphere*, which triggered research and development efforts around the world that led to significant emissions reductions on the newest aircraft technologies. Through its *Waypoint 2050* report (published in 2020), the Air Transport Action Group identified several pathways it could take to follow its pledge to reduce net carbon dioxide (CO_2) emissions by 50 percent in 2050 compared to 2019 levels. With the support of governments and the research community, global aviation will be in a position to reach net-zero CO_2 emissions by 2060.

The strategic thrust set forward by industry groups has been met with a host of new technologies and proposed operational concepts for future aircraft systems. Electric aircraft propulsion systems are one of the most disruptive of these ideas (requiring the most change), where electric motors provide all or part of the mechanical power required to drive the aircraft's propulsive device (one or more propellers or turbines). These configurations can draw stored energy through various combinations of electrochemical solutions, including batteries, fuel cells converting hydrogen into electricity, or more conventional thermic-electric generators using hydrocarbon aviation fuels.

1.2 A Brief History of Electric Aviation

Attempts at electric propulsion started in the early years of the aviation industry. In 1917, the Austro-Hungarian Petróczy-Kármán-Žurovec (PKZ-1) was the first electric-powered helicopter ever flown. The helicopter featured four arms with 3.9 m four-bladed rotors. The vehicle was powered by a 140-kilowatt (kW), 190-horsepower (hp) motor and was able to fly three people. Three flights were carried out before the motor failed, and the vehicle was abandoned.

The advent of nickel-cadmium batteries brought a renewed interest in electric aircraft. The Militky-Brditschka MB-E1 was the first manned, fixed-wing electric aircraft, which flew on October 23, 1973, in Austria. The flight lasted less than 15 minutes. The aircraft was a conversion of a small Austrian HB-3 motor glider with an electric-engine Bosch KM77 of 10 kW. The first solar-powered plane took to the air six years later, on April 29, 1979, at Flabob Airport, Rubidoux, California. The plane was an experimental conversion as well and based on a UFM Easy Rider motor glider retrofitted with a Bosch 2.6-kW electric engine and nickel-cadmium batteries. It flew for a few minutes for half a mile, about 40 feet above the ground. Other small experimental aircraft were built and flown throughout the next decades.

The long-endurance solar-powered e-aircraft. From 1983 to 2003, NASA and AeroVironment, Inc. developed and tested the following high-altitude, long-endurance, solar-powered, unmanned electric aircraft: Pathfinder, Pathfinder Plus, Centurion, and Helios. In October 2010, Solar Impulse 1 performed a 26-hour-long flight. In 2015 and 2016, André Borschberg and Bertrand Piccard flew Solar Impulse 2 around the world in 17 legs for a total flight time of 558 hours and 7 minutes. These performances demonstrated the feasibility of long-endurance, zero-emission electric flight.

The first commercially available electric plane was the Alisport Silent Club "self-launching" glider of 1997 that was optionally equipped with a 13-kW electric motor and a 1.4 kilowatt-hour (kWh) battery. The next decade saw the electric aircraft concept gaining traction with new batteries and fuel-cell technologies being developed and the world realizing more and more the climate change threat. In 2003, the Lange Antares 20E was the first electric aircraft to receive an airworthiness certificate. The Lange Antares 20E is another self-launching glider, using a 42-kW motor and lithium-ion batteries to facilitate its climb up to 3,000 meters (at the time of this report, 50 Lange Antares aircraft have been produced). In 2007, the Comparative Aircraft Flight Efficiency Foundation held the first Electric Aircraft Symposium in San Francisco, California. Boeing flew its one-seat Fuel Cell Demonstrator based on a Diamond HK-36 Super Dimona the following year.

The National Aeronautics and Space Administration (NASA) organized its first Green Flight Challenge in 2011, which was won by the Pipistrel Taurus G4. The Taurus G4 (powered by lithium-ion batteries) is a two-seat, self-launching sailplane able to fly up to 17 minutes and reach 2,000 meters using its single 40-kW motor. In 2009, the Yuneec E430 was the first electric aircraft developed for commercial production in volume, either as a kit or as a light-sport aircraft for the U.S. market. It can last 2.5 hours with a useful load of 390 pounds and features a 40-kW brushless motor powered by lithium-polymer battery packs that can be recharged within 4 hours using regular electric plugs. In 2013, the Long ESA (a Rutan Long-EZ retrofitted with an electric powertrain) outperformed several 100LL-powered aircraft in comparative flights under the control of the Fédération Aéronautique Internationale (or World Air Sports Federation). Figure 1 offers a timeline perspective.

1.3 Toward Electric Air Transportation

Current limitations in battery-specific energy density have curbed the capabilities of electric airplanes and their appeal to the market. While current electric aircraft programs have demonstrated the feasibility of these aerial vehicles, they have also highlighted their

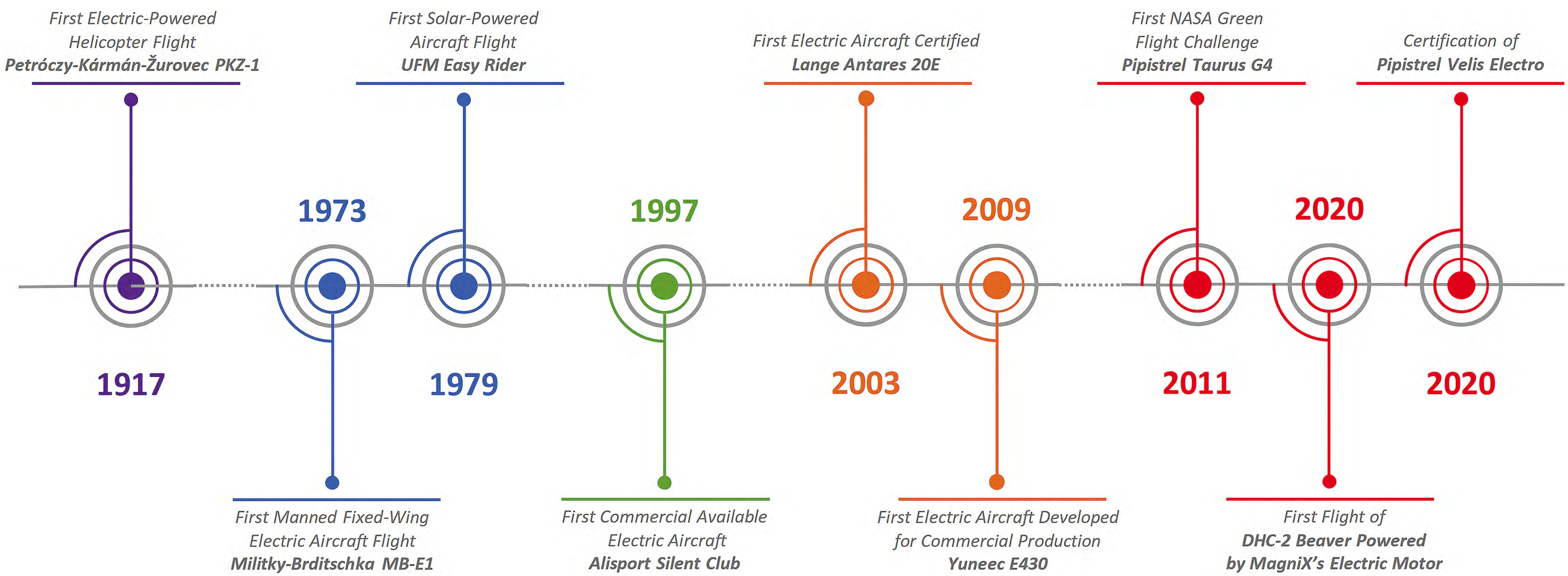


Figure 1. Timeline of the emergence of electric aviation (1917–2020).

shortcomings in terms of range, endurance, and payload. These limitations explain why these aircraft have mostly targeted the gliding and the flight training businesses: training flights are usually shorter with limited payload requirements, allowing the carriage of batteries.

Fully electric configurations are commonplace for small-scale aircraft and unmanned aerial systems (UAS). Recent improvements in battery-specific energy density are sufficient enough to make smaller aircraft more attractive and to warrant economically viable electric transport aircraft. As improvements in battery technology, electric machines, power electronics, power distribution, and circuit protection systems continue to occur, high-power electrified aircraft concepts have become increasingly feasible. Even now, prototypes of clean-sheet aerial vehicles and experimental variants of existing aircraft retrofitted with electric powertrains have provided a growing number of demonstration flights. Electric aircraft configurations with up to a nine-passenger capacity have been flown to date, with future programs planning expansion to larger platforms.

A thriving community of OEMs. Since the early 2010s, the number of electric aircraft projects—including electric vertical takeoff and landing (eVTOL) vehicles—has skyrocketed. No fewer than a hundred original equipment manufacturers (OEMs) are working on components or full aircraft concepts, with a majority being based in the United States. The advanced maturity of the technology, the commitment of the industry toward a "greener" aviation, and the capabilities and cost models of these vehicles being able to provide a different type of air mobility have attracted investors, entrepreneurs, innovators, and engineers with the support of governments and institutions.

Recent programs tend to seek a "type certificate" or "supplemental type certificate" to get out of the experimental aircraft niche. For instance, Harbour Air and electric powertrain manufacturer magniX flew a retrofitted DHC-2 Beaver seaplane in December 2019 and has applied to the Federal Aviation Administration (FAA) for a supplemental type certificate. In 2020, the two-seater Pipistrel Velis Electro became the first fully electric aircraft to receive a type certificate from the European Union Aviation Safety Agency (EASA). This development represents an important milestone for electrified aircraft systems, signifying the advent of practical, certifiable electric aircraft into the aviation ecosystem. Also, in 2020, magniX started trials of a retrofitted Cessna 208B Grand Caravan and announced a partnership with Universal Hydrogen to develop a solution for converting the De Havilland Canada Dash 8 (Q-Series) to an electric propulsion system powered by fuel cells. (See Figure 2.)

Figure 2. Nearly 50 years of e-Aviation: Militky-Brditschka MB-E1, Pipistrel Velis, and magniX Cessna e-Caravan.

CHAPTER 2

What Are Electric Aircraft?

2.1 Electric Aircraft Concepts

Around 100 electric aircraft designs are under development worldwide, each somewhat unique in their configurations and capabilities and reflecting the assumptions made by their designers and the different markets they target. These designs can be best understood by grouping them based on their configuration, capabilities, and missions (Figure 3). The ACRP Project 03-51 research effort focused on fixed-wing manned aircraft used for private and recreational flights, training purposes, air taxi services, small commuter flights, and regional aviation. It does not cover small UAS and eVTOL vehicles even though they are considered electric aircraft, per se. Although the current state of the technology does not yet meet their mission requirements, larger commercial service electric aircraft are also discussed. Long-endurance, unmanned, aerial electric vehicles primarily used by the Department of Defense, law enforcement, and federal and state agencies are not specifically addressed in this report. Their needs are mostly similar to those of manned aircraft with regard to the airport operational challenges and the electricity demand.

The lower gravimetric energy density of batteries compared to jet fuel limits the capabilities of pure electric vehicles, and in particular, their range and passenger capacity. Larger aircraft may have to be equipped with hybrid-electric powertrains (either parallel or turboelectric) to increase range and passenger capacity. As a result, many of the electric aircraft that are under development are smaller and have lower capacity. These vehicles will fly shorter missions, whether urban, suburban, or regional air mobility. These emerging aviation markets operated with new generations of electric aircraft are also known as advanced air mobility (AAM).

Urban air mobility (UAM) missions typically require a vertical takeoff and landing (VTOL) capability owing to the limited ground footprint available to design and build vertiports over valuable land close to city centers. These vehicles provide connectivity within a dense metropolitan area, and with other modes of transportation including existing airports. São Paulo, Brazil, is one of the few cities in the world with an effective UAM system, operated with conventional helicopters. Its downtown accommodates more than 400,000 operations per year. Use of eVTOLs might facilitate the implementation of UAM at many more large cities over the coming decades since they are significantly quieter, greener, and potentially cheaper to operate than conventional VTOLs (helicopters).

Some short-haul inter-urban connections—suburban or community air mobility—might use constrained facilities with runways shorter than 5,000 feet (1500 meters) that cannot be expanded because of encroachment or other physical limitations. On-demand and scheduled flights could be performed by short takeoff and landing (STOL) capable aircraft. Most of these aircraft should have a slightly higher capacity and range than VTOLs. Billy Bishop Toronto City Airport in Canada and London City Airport in the United Kingdom are the

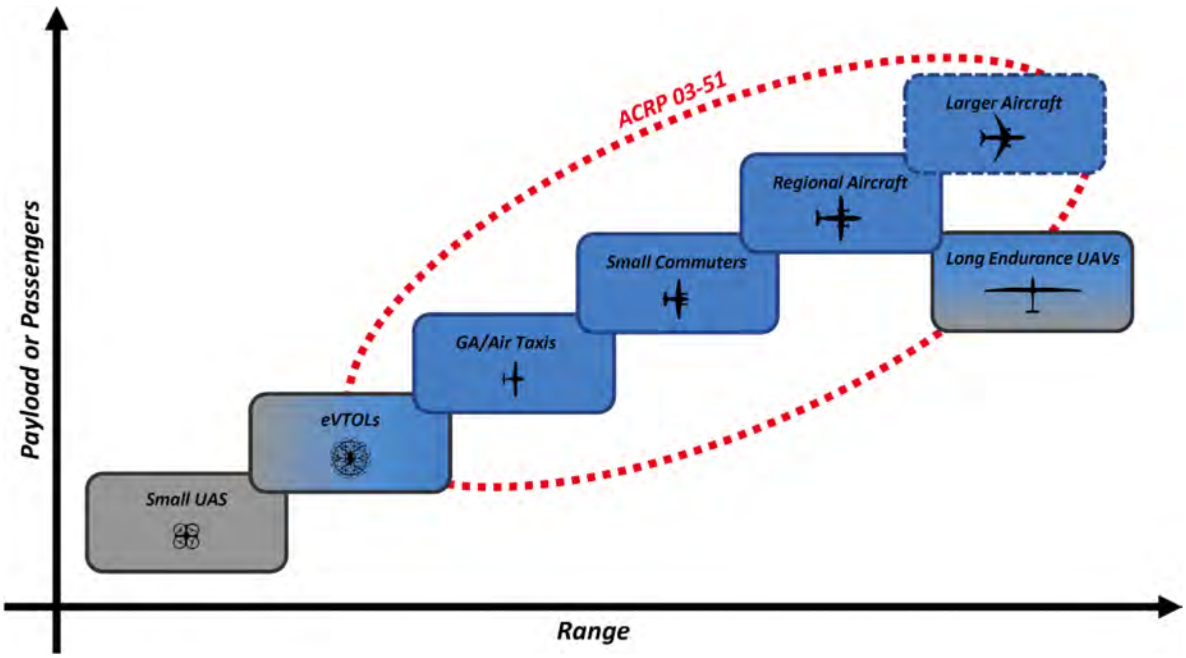


Figure 3. Electric aircraft market segments.

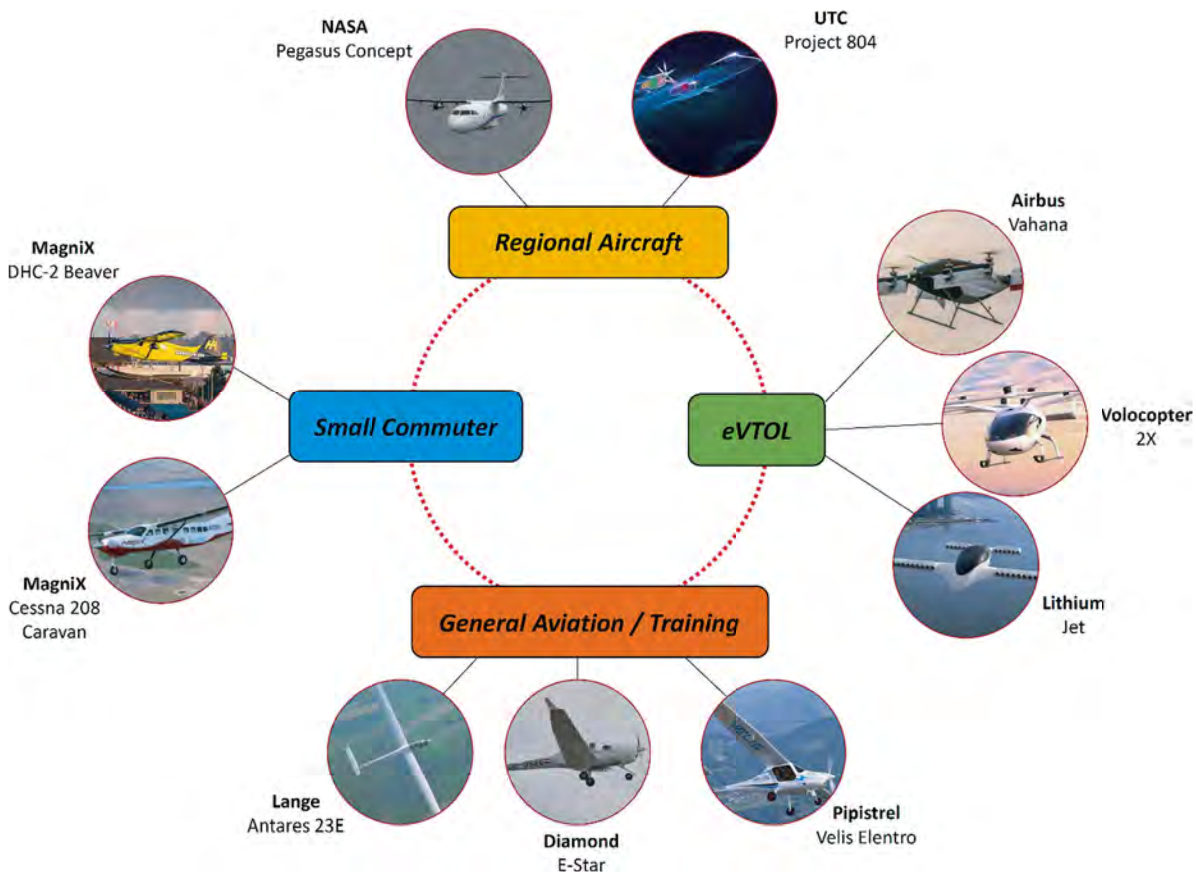
busiest urban STOLports in the world. As for UAM, electric aircraft can provide more socially acceptable operations than conventional aircraft and revive the interest for STOL facilities.

Regional air mobility missions—at least, initially—are flown by horizontal (or "conventional") takeoff and landing vehicles (CTOL), owing to the longer-range requirements and the resulting need for greater energy efficiency. On-demand and scheduled flights should be offered from smaller airports to other community airports or larger aviation facilities. The current operations of air carriers such as Cape Air in the northeast region and Harbour Air in the Puget Sound (Seattle-Vancouver area) have regional air mobility features. Cape Air operates from small facilities (e.g., Nantucket Memorial Airport) and large hub airports as in Boston Logan International Airport (BOS) and St. Louis Lambert International Airport (STL).

This will depend on local geographical constraints, local regulatory constraints, and market demand. Consequently, a diverse subset of configurations has been explored by the industry, in addition to traditional fixed-wing aircraft designs. Figure 4 highlights a subset of designs that are capable of VTOLs.

Each configuration has a different level of energy efficiency, which affects both the type of mission that it is optimized for and the nature of the infrastructure required to support operations. Figure 5 details the relative efficiency of various configurations of VTOL vehicles. For these configurations and for comparison, the maximum takeoff weight (MTOW) is set at 5,000 pounds, the cruise speed is set at 150 miles per hour (mph), and the mission length is set at 24 miles.

An exhaustive review of each of the 170 aircraft designs is beyond the scope of this report. Instead, the various electric-vehicle designs are characterized according to their overall configuration and overall size, classified into eight primary categories. These include the fixed-wing aircraft category, which is further divided according to passenger capacity into the 1- to 4-seat, the 6- to 9-seat, and the 40- to 80-seat categories, as well as the helicopters, the tilt rotors, the tilt wing, and the lift plus cruise.



Note: United Technologies Corporation (UTC) Project 804 Concept in terms of regional aviation.

Figure 4. Examples of electric aircraft per mission.

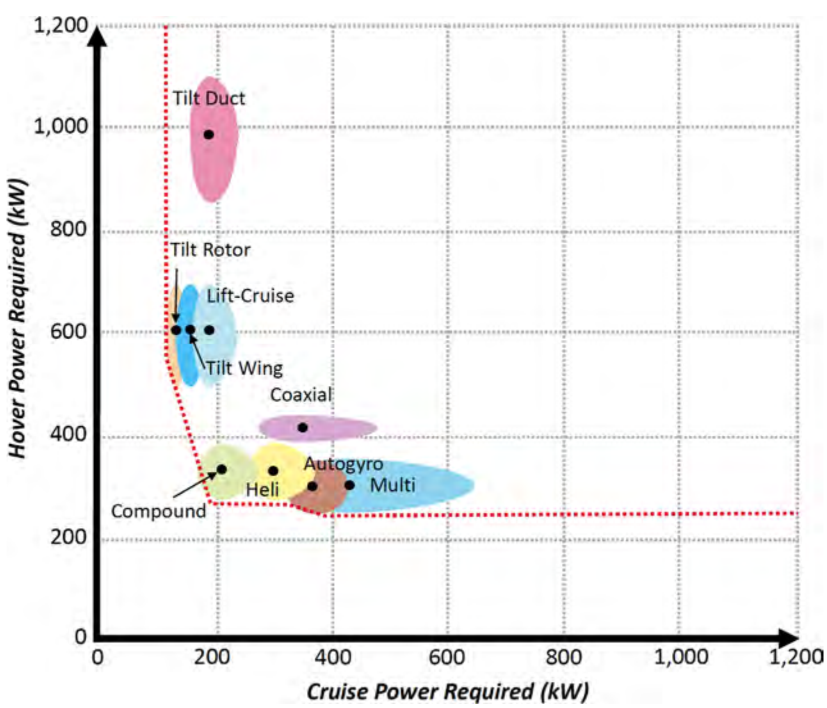


Figure 5. Energy efficiency in vertical flight of various aircraft configurations.

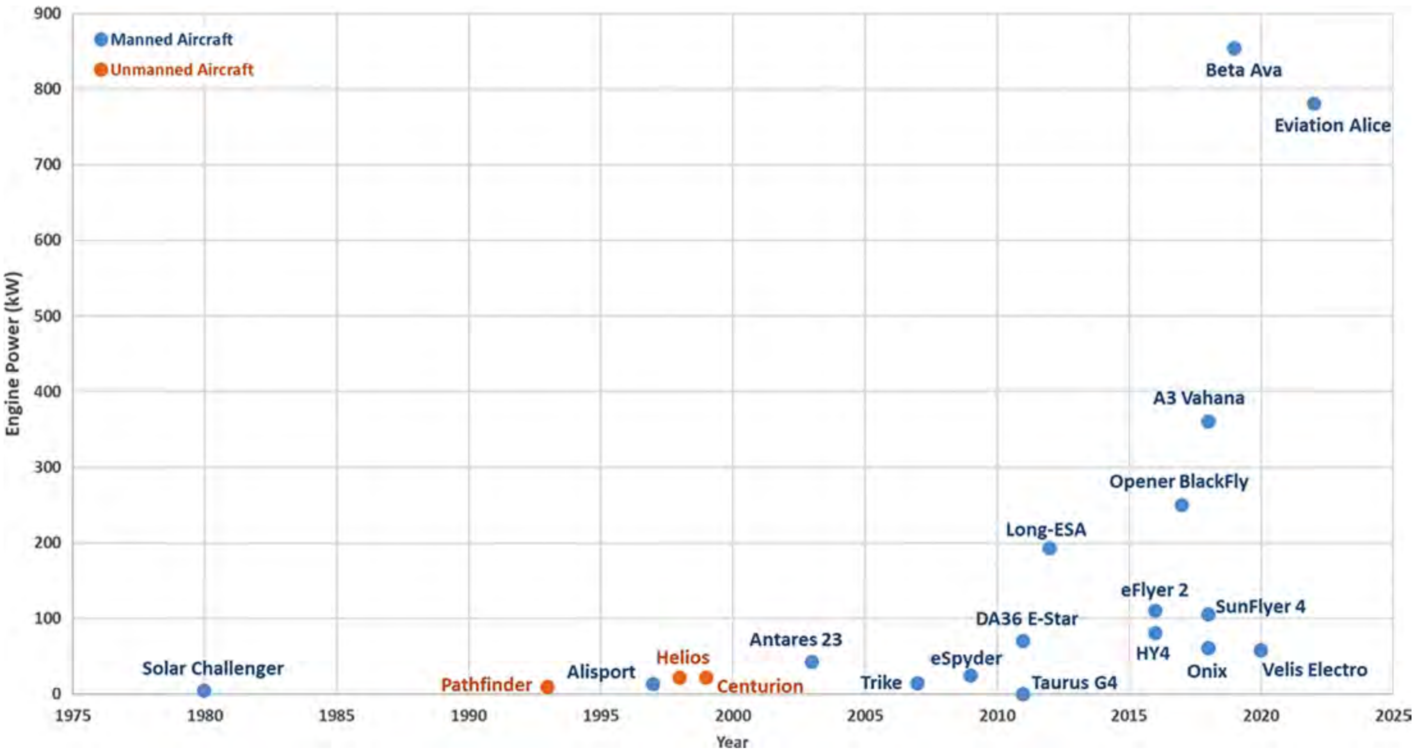


Figure 6. Evolution of the electric aircraft engine power.

Figure 6 and Figure 7 show the evolution of the engine power and battery capacity for electric aircraft per their year of effective or expected first flight.

Meanwhile, high-level characteristics are shown in Table 1, and the baseline aircraft retained for the study of six use-case scenarios that will be defined in the subsequent section are found in Table 2.

2.2 Electric Aircraft Energy Efficiency

With the higher energy efficiency of electric powertrains (Figure 8) and the relatively stable energy cost of electricity against jet fuel (Figure 9), several aerospace industry groups have implemented sizable development programs to further advance electrified aircraft platforms for larger scale, commercial applications. Several key challenges still exist, however, when moving toward these commercial aircraft platforms. The following top priorities to enable future electrified aircraft platforms remain:

- Required improvements in areas related to specific energy (weight reduction) of electrical energy storage systems;
- Increased specific and rated power;
- Aviation-compatible packaging of electric machines;
- Strategic approaches to thermal management; and
- Integration impact assessments.

Assuming success is achieved in these key areas, many aircraft developers are targeting entry into service date ranges of approximately 2030 to 2035 for electrified variants of regional aircraft (fewer than 30 to 80 passengers) and dates closer to 2050 for electrified variants of single-aisle aircraft (130 to 180 passengers).

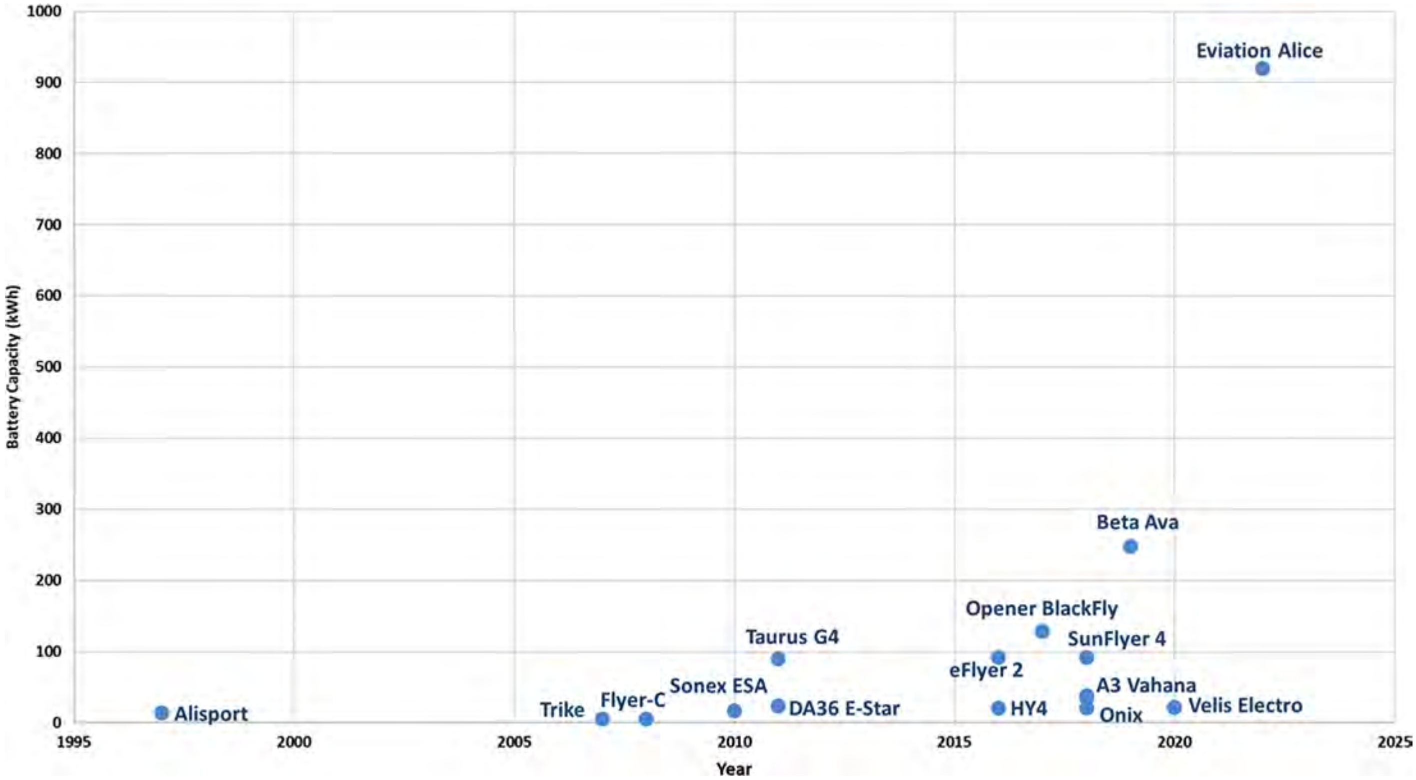


Figure 7. Evolution of electric aircraft battery capacity.

Table 1. Configuration and classes of electric vehicles.

	Conventional Takeoff and Landing Capability (CTOL)			Vertical Takeoff and Landing Capability (VTOL)				
								
Configuration	Small All-Electric Tube & Wing	Commuter All-Electric Tube and Wing	Regional Hybrid-Electric Tube and Wing	Small Electric Helicopter	Electric Multi Copter	Electric Tilt Rotor	Electric Tilt Wing	Electric Lift and Cruise
Typical Capacity	1 – 4 passengers	6 – 9 passengers	35 – 80 passengers	1 – 2 passengers	1 – 4 passengers	1 – 4 passengers	1 – 4 passengers	1 – 4 passengers
Typical Range	100 – 300 miles	200 – 600 miles	400 – 600 miles	10 – 15 miles	10 – 25 miles	100 – 200 miles	10 – 35 miles	60 miles
Typical Cruise Speed	150 – 180 mph	200 – 250 mph	300 – 380 mph	70 – 95 mph	50 – 80 mph	150 – 250 mph	100 – 180 mph	150 – 180 mph
Typical Payload	200 – 400 lbs.	1,200 – 1,800 lbs.	8,000 – 15,000 lbs.	200 – 400 lbs.	200 – 1,000 lbs.	200 – 1,000 lbs.	200 – 1,000 lbs.	200 – 1,200 lbs.
Typical Gross Weight	1,000 — 3,000 lbs.	9,000 – 15,000 lbs.	40,000 lbs.	1,500 – 2,500 lbs.	1,000 – 2,000 lbs.	2,000 – 4,000 lbs.	1,000 – 2,000 lbs.	4,000 – 6,000 lbs.
Typical Power Requirement	60 – 150 kW	200 – 800 kW	1,000 – 3,000 kW	120 – 160 kW	90 – 150 kW	120 – 250 kW	200 – 400 kW	5 Motors
Typical Energy Storage	Batteries	Batteries	Jet Fuel &Batteries	Batteries	Batteries	Batteries	Batteries	Batteries
Typical Ground Footprint	1,800 – 2,500 ft²	3,000 – 5,000 ft²	8,000 – 12,000 ft²	900 – 3,600 ft² helipad				
Current Aircraft and Emerging Concepts	Pipistrel Alpha Electro ByeAero SunFlyer2 Yuneec E430 Diamond E-Star Siemens Extra 300 Lange Antares 23E	Eviation Alice Ampaire Tailwind Zunum ZA10	NASA Pegasus Concept UTC Project 804	Solution F Helicopter Tier I Engineering R44 Aquinea Volta Sikorsky Firefly	Volocity Volocopter Ehang 184 Ehang 216 Airbus CityAirbus EmbraerX Astro Aerospace Elroy	Beta Ava AgustaWestland Project Zero Joby S4 Bell Nexus Kittyhawk Cora Karem Butterfly Aurora	Ling-Temco-Vought XC-142 Lilium Jet Airbus Vahana	Jaunt Air Mobility Rosa Aurora Pegasus PAV Zee Aero Z-P1 SKYLYS Aircraft AO Napoleon Aero VTOL

Table 2. Baseline aircraft concepts for use cases.

						
Configuration	Small All-Electric Tube & Wing	Small All-Electric Tube & Wing	All-Electric Tube and Wing Commuter	Hybrid-Electric Tube and Wing Regional	All-Electric Multi Copter	All-Electric Tilt Rotor
Examples	Pipistrel Alpha Electro	Bye Aerospace SunFlyer 4 / eflyer 4	Eviation Alice	UTC Project 804	Beijing Yi-Hang Creation EHang 184	Bell Nexus 4EX/ Joby S4
Capacity	1 pilot + 1 passenger	1 pilot + 3 passengers	2 pilots + 9 passengers	2 pilots + 39 passengers	2 passengers	1 pilot + 4 passengers
Range / Endurance	1 hr. + reserve (Circuits) 45min + reserve (Cross country)	4 hours / 420 miles	650 miles	700 miles	25 miles	60 miles
Cruise Speed	98 mph	190 mph	300 mph	280 mph	81 mph	150 mph
Payload	400 lbs.	800 lbs.	2,750 lbs.	200 lbs.	570 lbs.	800 lbs.
Weight	1,212 lbs.	2,700 lbs.	14,000 lbs.	35,000 lbs.	1,320 lbs.	7,000 lbs.
Power Requirement	1 motor 60 kW	1 Motor 105 kWh (141hp)	3 Motors 260 kWh each (350hp)	2 Parallel-hybrid engines 2MW each	16 Motors 200hp / 152 kW	4 Motors 200 kW total
Energy Storage	Samsung Li-Ion 21 kWh total 399V, 2 packs, 53kg each	Li-ion LG Chem "MJ1" 120 kWh 4 Packs	Aluminum-Air battery with a Lithium-Polymer buffer battery 900 kWh (8,200 lbs.)	Jet Fuel Batteries capacity estimate of 800 kWh	Li-Ion battery Estimated 30 kWh	Li-Ion Cobalt Manganese Oxide Batt 635 kg Estimated 130 kWh
Charging	Swap battery 45min @ 20 kW 1hr05min @ 14 kW 1hr40min @ 10 kW 6hr00min @ 3 kW	45min@60kW/480V/80A 1h35min @24 kW/480V/ 30A 3hr45min @10KW/240V /50A	30min for 1hr flight @ 400 kW 45min for 1.5hr flight @ 400 kW	Unspecified Assumed fast charger @ 600 kW	2hr @ fast charge	35% Capacity in 7 min @ 600 kW
Ground Footprint	34 ft. x 21 ft.	38 ft.	40 ft. x 52 ft.	90 ft. x 73 ft.	18.4 ft. x 18.4 ft.	40 ft. x 40 ft.
Runway/FATO Requirements	RDC A-I	RDC A-I	RDC B-II	RDC B-III	900 ft² helipad	900 ft² - 3600 ft² helipad
Use Case	Flight-Training Operations	Recreational Air Taxi Operations	Commuter Operations Air Cargo Operations	Regional Airline Operations	Air Taxi Operations	Air Taxi Operations

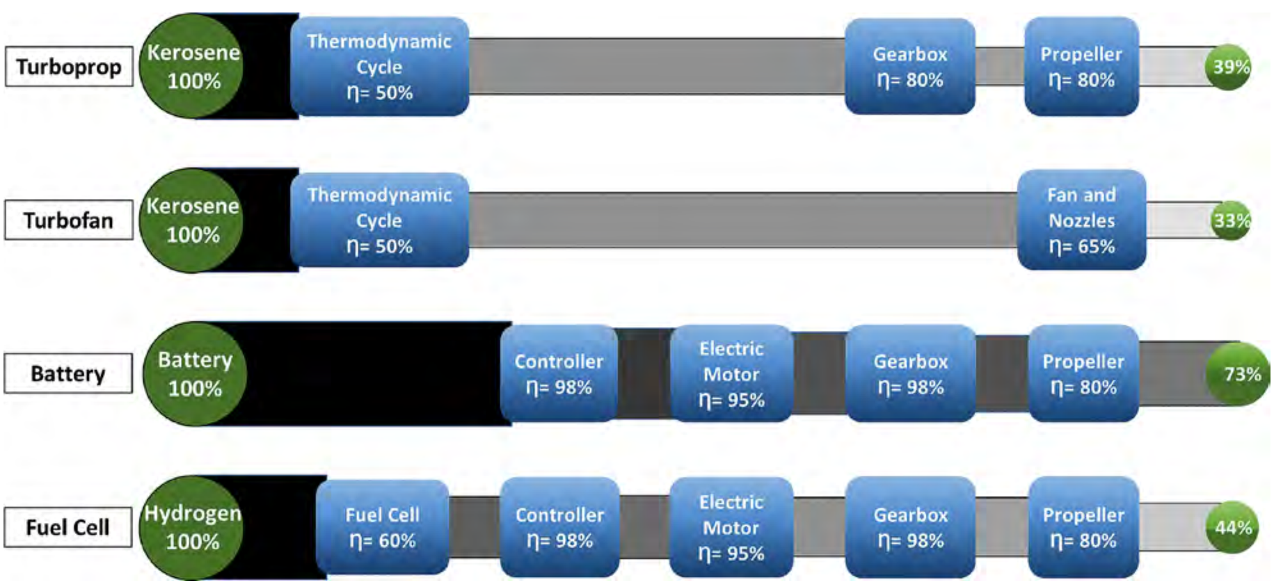


Figure 8. Efficiency of traditional and electrified powertrains.

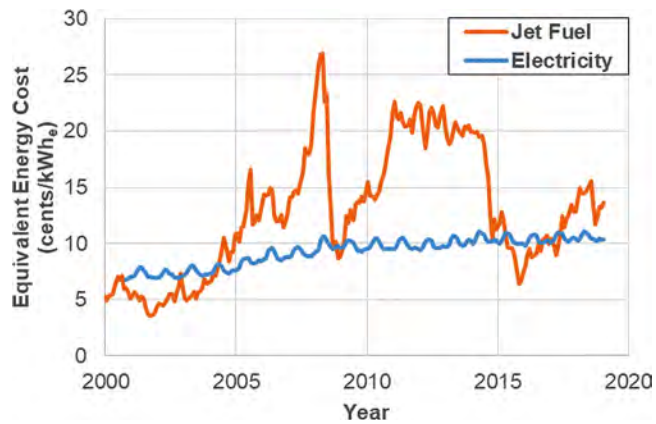


Figure 9. Propulsion equivalent energy costs for jet fuel and electricity.

Successfully implementing electrified aircraft hinges on not only the technical feasibility and production capability of the aircraft in isolation, but also on broader support infrastructure for these aircraft to be implemented at scale. Given transportation's large energy requirements, broadly, growth in the capacity of electricity generation is needed, either on-site or across a national grid. Additional factors also include several items within airport planning related to space, ground support equipment (GSE), service personnel, and technicians, and power and energy delivery capacities. These considerations must also be further developed to truly realize growth in electrified aircraft.

2.3 Integral Electric Aircraft Components

Energy Storage

Energy storage technologies, such as batteries, are key components of all-electric vehicles. A battery is an individual cell that converts chemical energy to electrical energy through electrochemical reactions. When a current is sent into the battery, this chemical reaction can be reversed. A battery pack is a collection of two or more cells connected in a series or parallel configuration.

The design and performance of battery packs are crucial components of electric vehicles. In these types of vehicles, battery packs are the main source of energy and contribute significantly to the overall vehicle weight. Common parameters to describe the performance of the many types of batteries are as follows:

- **Specific Energy (Watt-hours per kilogram or Wh/kg)** is the most commonly used battery performance parameter and is used in estimating electric-vehicle endurance. It describes the amount of electrical energy stored per unit of battery mass.
- **Specific Power (Watts per kilogram or W/kg)** is the amount of power delivered per unit mass of the battery. This parameter can be used to describe how fast a battery can take in energy and release it.

These two parameters are most commonly used when comparing battery technologies. A battery's capacity decreases as the discharge time increases. A vehicle that operates at a high-power setting will quickly deplete its batteries. Likewise, a vehicle with high specific energy batteries will have low specific power characteristics.

Charge capacity is another important battery parameter that affects the performance of electric aircraft. How quickly a battery is discharged will affect the total energy the battery can provide. The slower the current draw is, the more energy can be extracted from the battery.

Additional battery considerations that affect the performance and operations of electric vehicles include the following:

- **Specific Power**: 1 kW/kg for most applications, although some applications might require 2 to 3 kW/kg.
- **Cycle Life**: The number of discharge charge cycles the battery device can experience before it fails to meet specified performance criteria. The number of battery cycles depends on the type of operations.
- **Cold Weather Performance**: Lithium-ion batteries show faster degradation outside acceptable temperature ranges.

Rechargeable battery technology has a relatively low energy density compared to fossil fuels (Figure 10), which limits the range and scope of operations for electric aircraft. However, energy density of batteries is increasing and has grown by 8 percent each year in recent years (Figure 11).

Battery technology performance is projected to continue to grow. A 2017 NASA Battery Technologies Workshop provided the following industry projections on battery technologies:

- Specific energy is expected to increase by 5 to 8 percent per year.
- Implementation of innovative concepts that can improve packing and integration, such as the following:
  - Lightweight container structure (e.g., cellular, lattice block);
  - Multifunctional structures with load-carrying capability for packaging materials;
  - Advanced thermal management techniques (e.g., phase change materials if the cost is not a factor, high conductivity materials);
  - Integrated thermal management system to cool battery packs;
  - Polymer heat exchangers; and
  - Larger cells.

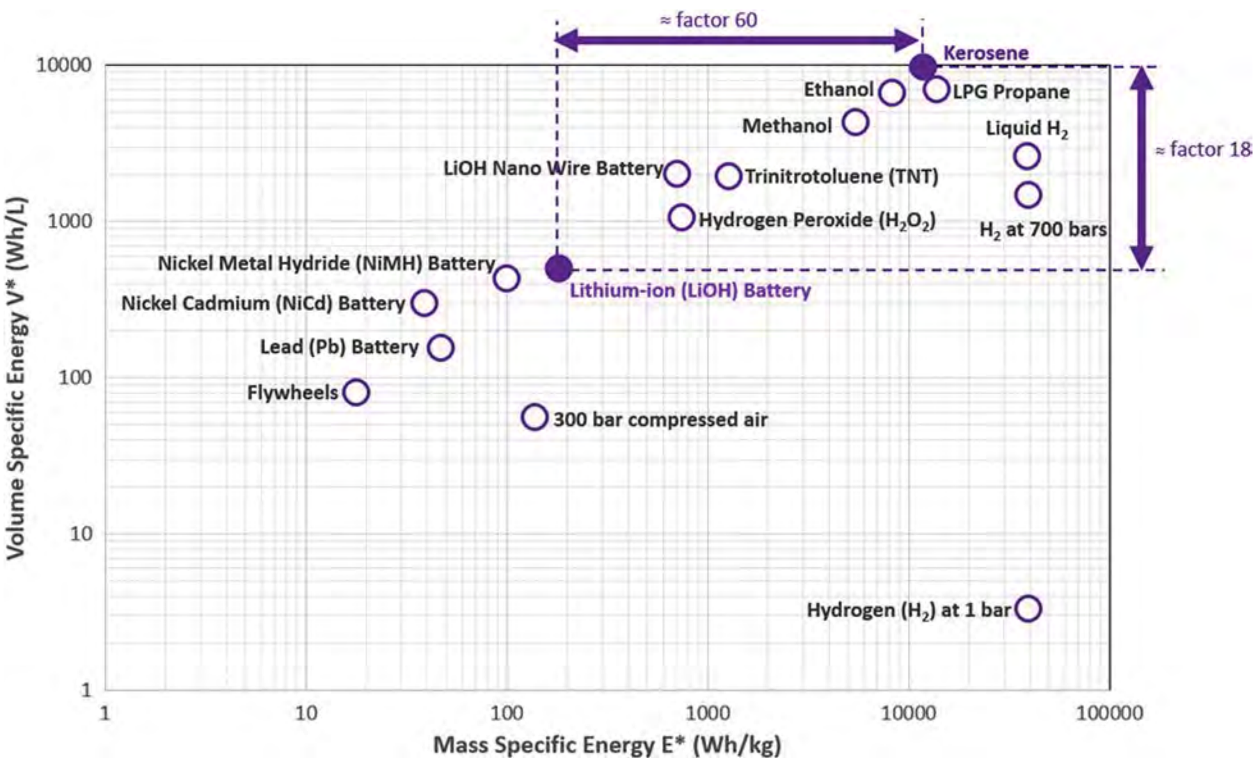


Figure 10. Volume and mass-specific energy characteristics of different energy storage systems.

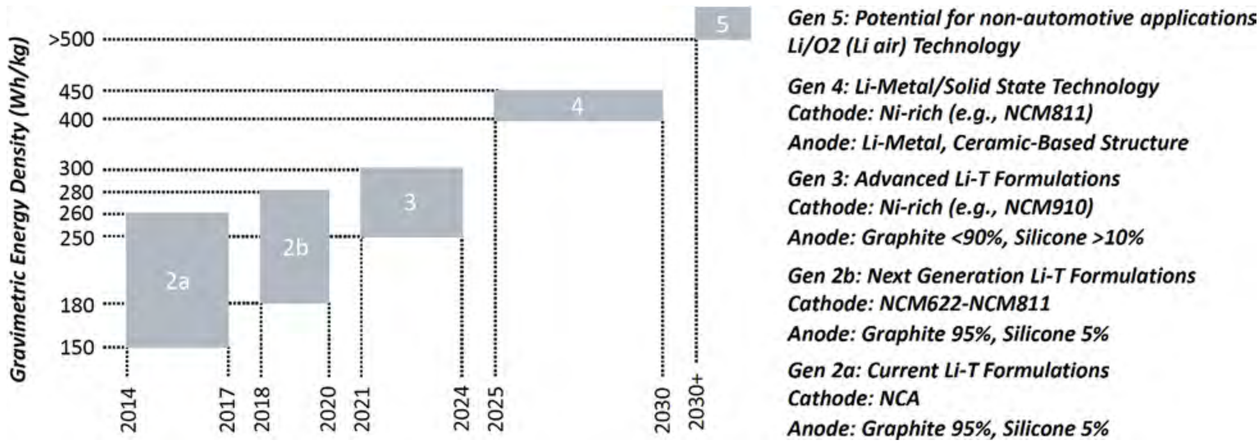


Figure 11. Roadmap for lithium-ion battery technology.

- Innovation in battery health management, such as moving to a software-based battery health management system for state-of-charge and state-of-health estimation.

The U.S. Department of Energy, the battery industry, academia, and National Labs have raised their performance expectations to 300 Wh/kg at pack level (approximate 400 Wh/kg at cell level) for automotive and industrial applications but have not focused on electric aircraft applications. Electric aircraft will need to verify their performance, safety, and integration to bolster battery-related research.

Beyond this approximate 400 Wh/kg capability at the cell level, the aeronautics community can focus on developing batteries with 600 Wh/kg specific energy at the cell level (400 to 500 Wh/kg at pack level), which is believed to be an achievable target. Higher levels of specific energy, on the order of greater than 700 Wh/kg at the pack level, are almost impossible to achieve at the short-term horizon, assuming current technologies (Figure 12).

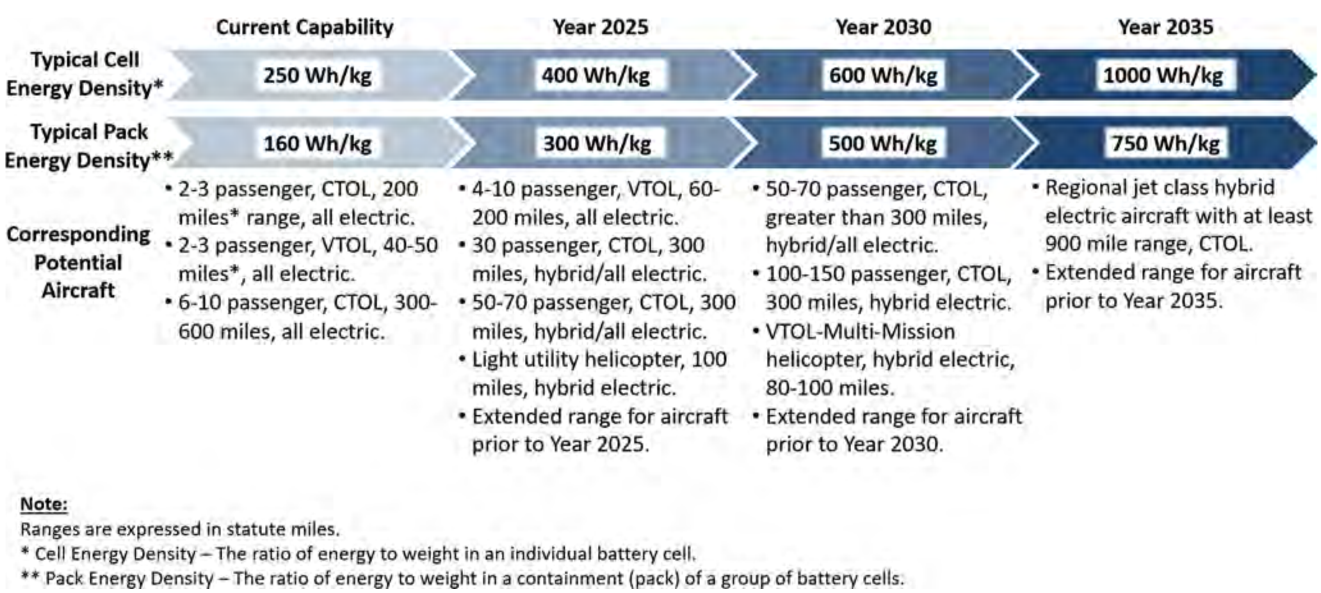


Figure 12. Battery requirements for different classes of vehicles.

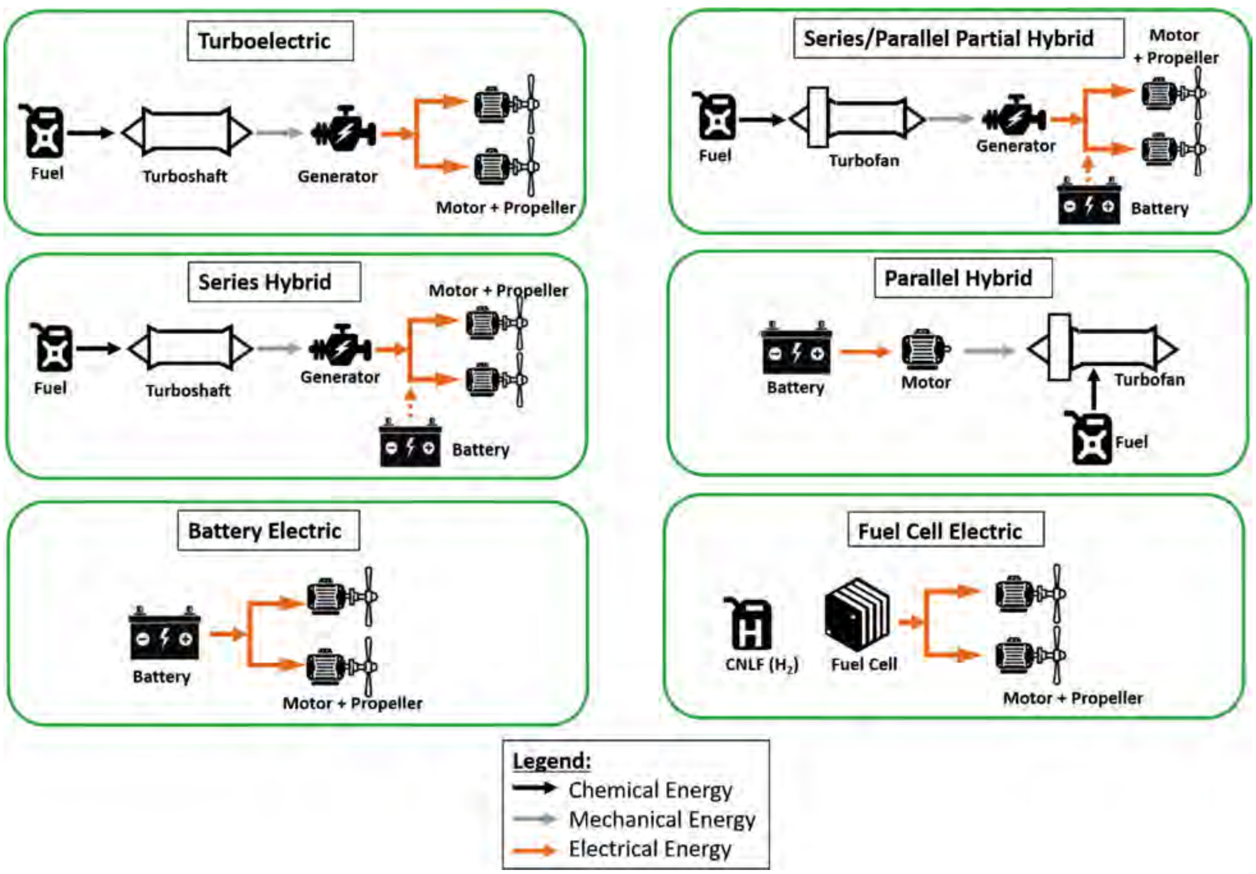
Powertrain Architectures

There are many variants of electric and hybrid-electric propulsion architectures. One way to categorize aircraft propulsion architectures is by their *degree of hybridization,* which describes how much of their energy source and power comes from batteries and electric motors. Figure 13 illustrates the typical powertrain architectures.

Hybrid-electric architectures, for which there are various possible configurations, provide additional power to an existing propulsion system such as a turbofan by including an electric motor. The energy source for the motor can be a battery or a generator. Hybrid systems are less efficient at energy storage but are more efficient at energy conversion.

Turboelectric architectures use kinetic energy from a fuel-burning turboshaft engine to drive a generator, which produces the energy to drive the electric motor. Finally, all-electric powertrain architectures have motors that rely entirely on batteries as the only source of energy. These systems are highly efficient compared to traditional combustion.

The main electric components of an electric aircraft powertrain are listed in Figure 14.



Note: "Fuel" can be hydrocarbon fuel (e.g., Jet A1) or (in the near future) hydrogen.

Figure 13. Electrical propulsion architectures.

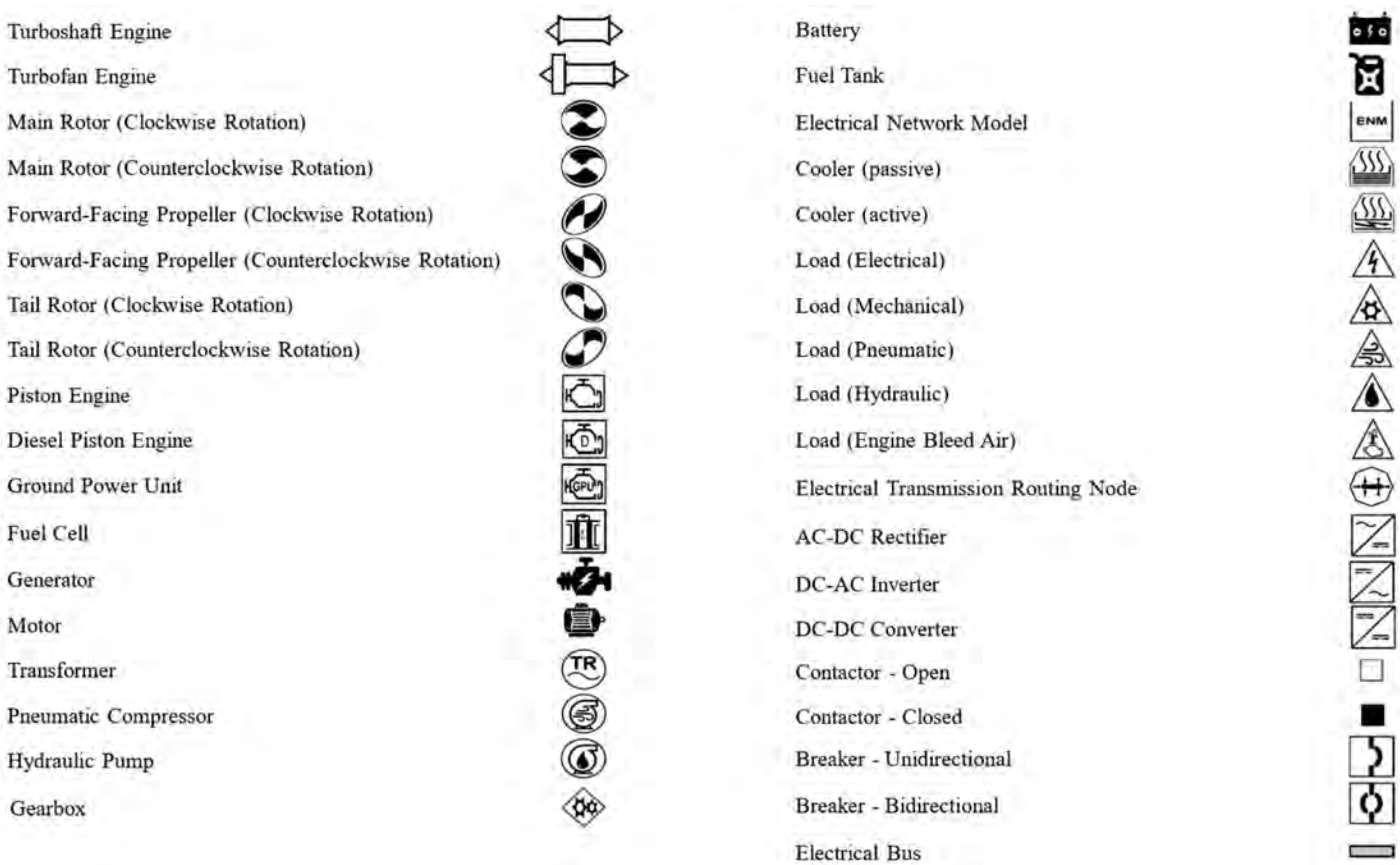


Figure 14. Main electric aircraft components.

CHAPTER 3

The Stakeholder Ecosystem

3.1 Electric Aviation Stakeholders

Stakeholders Inventory

Aircraft electrification involves a wide range of stakeholders with different purposes and objectives. The potential stakeholders that will be involved or affected by the development of electric aircraft can be internal or external and may vary significantly from one airport to another, depending on factors such as the size of the airport. Table 3 outlines the different stakeholders that can significantly affect or be affected by the development and implementation of electric aircraft.

Non-Typical and Emerging Stakeholders

New OEMs have emerged to develop clean-sheet technologies, equipment, and aircraft for electric aviation. Some of these startups have signed agreements with flight operators (Table 4). Others have teamed with legacy OEMs, providing funding and technical support. Legacy OEMs have also created specialized teams, departments, or subsidiaries for developing innovative electric aircraft technologies. Altogether, these firms constitute a thriving community of over a hundred members worldwide. As the electric aircraft industry emerges and becomes more mature, consolidation should be expected over the coming years.

Most electric aircraft are powered through chemical batteries, or fuel cells converting hydrogen into electricity. Today, the electric power industry is not a primary aviation stakeholder. Aviation accounts for a small fraction of the total electricity demand in the United States (less than 1 percent). However, electric aircraft and the overall electrification of airports will bring additional needs in terms of power supply and resiliency. Electricity has recently started to be used as a "fuel" or energy vector on the landside with electric vehicles as well as on the airside with the electric ground support equipment (eGSE) and aircraft power supply at the gate. Increased demand for resilient electrical energy shared between a growing number of applications will require coordination between the airport stakeholders, investments in the connection to the grid, distributed generation solutions (e.g., airport microgrid), and power management. Research organizations such as the National Renewable Energy Laboratory of the U.S. Department of Energy are exploring these issues.

Industrial gas companies producing and providing hydrogen are not aviation stakeholders today. However, with the emergence of electric aircraft equipped with fuel cells, flight operators will need to be supplied with hydrogen, and early short-haul electric aircraft will use gaseous hydrogen. These supply chains will need to meet the specificities of aviation operations and the airport environment. The logistics to provide large volumes of hydrogen to aviation users have yet to be developed. Initially, they might involve deliveries by trucks and storage at the airport

Table 3. Electric aviation stakeholders.

Stakeholder Group	Definition and Role(s) at the Airport	Example(s)
Air Navigation Service Provider	The Air Traffic Organization of the FAA is the air navigation service provider within the U.S. National Airspace System (NAS).	FAA air traffic control towers, FAA Terminal Radar Approach Control Facilities (TRACON), FAA technical operations, federal contract tower contractors, etc.
Aircraft Ground Support Providers	Aircraft ground support includes a wide variety of servicing activities toward the aircraft on the ground.	Aircraft fueling, multi-service ground handlers, etc.
Airport Facility Operators	Third-party terminals and other facilities operators can include FBOs, third-party passenger terminal facilities, and contractors that provide critical management services.	Terminal operators, FBOs, etc.
Airport Operators	This category includes the internal stakeholders of the airport operator concerned with airport operations and management.	Aviation services, airport operations, emergency management, engineering and maintenance, etc.
Apron Management Services/Ramp Towers	These providers include airline hub control centers and all entities that provide ramp control services, gate planning, and resource allocation, and other apron management- or ramp control-related services.	Hub Control Center of the main air carrier, ramp towers, etc.
Electric Power Industry & Regulators	The electric power community includes the producers, providers, and suppliers of electricity, as well as the federal and state regulators and local energy commissions.	Power generation companies, electricity suppliers, electricity providers, utility commissions, U.S. Department of Energy, etc.
Flight Operators	Flight operators are a broad category that includes but is not limited to air carriers. Advanced air mobility providers fall under this category.	Air carriers, air taxis/UAM-based air ambulances and aerial work services, commuters, etc.
Hydrogen Industry	Electric aircraft can be powered by fuel cells using hydrogen. Producers and providers can supply hydrogen or production units to aviation users.	Hydrogen producers, hydrogen providers, small hydrogen production units, etc.
Industry and Professional Organizations	These organizations represent the interests of and advocates for specific groups within the aviation industry. Through their outreach, they inform their members, gather task forces, and publish papers that can facilitate the integration of electric aircraft.	American Association of Airport Executives (AAAE), Airports Consultants Council (ACC), Airports Council–North America (ACI–NA), Air Line Pilots Association, International (ALPA), Aircraft Owners and Pilots Association (AOPA), Experimental Aircraft Association (EAA), General Aviation Manufacturer’s Association (GAMA), Light Aircraft Association (LAA), National Association of State Aviation Officials (NASAO), statewide aviation associations, etc.
OEMs	OEMs are the companies that develop or manufacture electric aircraft, parts, and accessories. OEMs include “legacy” OEMs of various sizes and more recent electric aircraft startups.	Aircraft system, battery, electric aircraft, powertrain, etc., manufacturers.
Other Aviation Tenants	Other aviation tenants that do not fall under one of the previous categories and could have an impact or be affected by the introduction of electric aircraft.	Maintenance, repair, and overhaul (MRO) centers, etc.

Table 4. Existing partnerships between OEMs and flight operators.

Flight Operator	OEM(s)	Partnership
Finnair	Heart Aerospace	Finnish air carrier Finnair has signed in March 2021 a letter of interest with Heart Aerospace for up to 20 of the 19-seater ES-19 electric aircraft for use on shortest haul routes.
Harbour Air	magniX H55	The companies announced a partnership to certify the electric Beaver commuter airplane through a Supplemental Type Certificate (STC) program with Transport Canada.
Mokulele Airlines	Ampaire	In 2020 and 2021, Ampaire has flown demo flights of the hybrid-electric EEL aircraft through a partnership with Hawaiian regional carrier Mokulele Airlines under the FAA's Experimental-Market Survey category.
Sydney Seaplanes	magniX Dante Aeronautical	The companies announced a partnership in December 2020 to work toward the certification of the electric Cessna Caravan under an STC by Australia's Civil Aviation Safety Authority (CASA).
United Airlines	Archer	Under a February 2021 agreement, United will contribute its expertise in airspace management to assist Archer with the development of battery-powered, short-haul eVTOL aircraft. Once the aircraft have met Unite's operating and business requirements, United and Mesa Airlines would acquire up to 200 aircraft that would be operated by a partner to fly customers to United's hub airports and commute in urban environments "within the next 5 years."
Widerøe	Tecnam Rolls-Royce	Tecnam and Rolls-Royce are teaming with Norwegian regional airline Widerøe to deliver an all-electric passenger aircraft (the P-Volt) for the commuter market, ready for revenue service in 2026.

in fixed tanks or individual pods for aviation usage. Because the aviation market will be a small activity for industrial gas companies, the segment from the production plant to the final aviation user (aircraft) might be handled by a combination of specialized brokers, ground handling companies, and air carriers. Small units producing hydrogen by electrolysis of water could be installed as well at some airports. Later, with the emergence of a broader hydrogen economy, aviation could benefit from supply chains implemented to deliver hydrogen for a wide variety of applications.

3.2 Change Impact Assessment

Impact on Organizations and Knowledge Management

The introduction of electric aircraft will require new skills and knowledge within the aviation workforce (Table 5).

Ground support crew training will be necessary and will center on safely and efficiently recharging, refueling, or replacing electric batteries and hydrogen tanks. New skills and knowledge for battery-based powertrains include, but are not limited to, operating high-voltage aircraft charging systems, identifying aircraft battery failure modes, and providing appropriate responses to occurrences such as thermal runaway or toxic gas emissions. For fuel-cell-powered powertrains, they include the handling of hydrogen and the risks associated with this gas.

There is still uncertainty on the regulatory aspects of some of these operations. For example, if the FAA considers the replacement of batteries and hydrogen tanks (also known as battery or

Table 5. Electric aircraft-specific skills, knowledge, and abilities to acquire by stakeholders.

Skills, Knowledge, and Abilities	State Dept. of Transp.	Air Traffic Control	Apron Mgmt. Services	Ground Handling	Airport Operators	Other Facility Operators	Flight Operators	Fixed-Base Operators	Original Equipment Manufacturers	Maintenance, Repair, & Overhaul Centers	Electric Power Industry
E-aircraft facilities planning & design	3	0	0	0	2-4	2	0	0	2	0	[b]
E-aircraft flight operations	1	2	2	1	2	1	4	3	3	1	0
Regulatory assurances & obligations	2	0	3	4	4	4	3	4	2	3	0
Battery/hydrogen recharge	0	1	1	2-4[a]	1	2	2-4[a]	2-4[a]	4	4	0
E-aircraft rescue and firefighting	1	1	2	3	4	2	3	2	4	2	0
Maintenance of powertrains	0	0	0	1	0	0	2-4[a]	2-4[a]	4	4	0

0 = No skills | 1 = Awareness | 2 = Basic knowledge | 3 = Perform basic tasks | 4 = Perform all tasks
[a]Pending FAA classification of the recharge and swapping operations of batteries and hydrogen tanks.
[b]Electric power industry stakeholders might be involved with specific tasks of airport planning and design (e.g., power management).

container swapping) as a major repair or alteration of the aircraft, this will not be considered a typical ground handling operation that can be performed by trained ground agents. The replacement will be operated by licensed mechanics, which might significantly reduce the interest for this option.

Beyond ground-crew training, airports or some of their stakeholders could hire and train personnel to service or outsource the maintenance and repair of aircraft charging equipment. This would largely depend on the charger-ownership model and could be a responsibility of FBOs or could be contracted through a third-party supplier.

Airports will also need to ensure that their aircraft rescue and firefighting and emergency personnel are appropriately trained and equipped to operate aircraft that are equipped with electric powertrains and that carry large-capacity batteries and/or hydrogen tanks. This includes handling situations that involve electrical systems, hydrogen gas, toxic gas emissions, etc. The aircraft rescue and firefighting (ARFF) community is now familiar with powerful batteries that are onboard aircraft as they equip some of the most recent commercial aircraft types (e.g., Airbus A350 and Boeing 787). Aircraft manufacturers provide procedures and guidance that have been developed by the National Fire Protection Association (NFPA).

For the sake of operational efficiency and resiliency, certain stakeholders not directly involved with the ground support of electric aircraft might benefit from a basic understanding of electric aircraft specificities and their operations. This includes the acting staff of the air traffic control towers, apron management services, and the airfield operations of airport organizations. *ACRP Research Report 229: Airport Collaborative Decision-Making (ACDM) to Manage Adverse Conditions* provides information on the importance of stakeholder awareness, joint training, and collaborative decision-making.

Fuel Revenues

The primary impacts to fuel revenues are expected in the long term beyond 2030. As the prevalence of electric aircraft grows, the federal and state governments, airport operators, FBOs, and fueling service providers could begin to experience revenue erosion from aircraft fueling operations. Additionally, at many airports, FBOs are the primary fueling service provider, collecting revenue from airlines and private operators and passing a portion through to the host airport.

Many FBOs rely heavily on the revenue stream of providing fuel for business, commercial, and general aviation. Because these impacts will develop over the long term, airports and service providers should develop approaches to offsetting lost airport revenue and maintaining profitable relationships. The business model of electric charging stations, and the regulation of aircraft battery charging at airports, might influence the future of these stakeholders. The most critical situation might be if a significant portion of aircraft becomes electric and providing fueling services to the rest of the fleet is no longer profitable at some airports.

Policies and Standards

Most current, if not all, policies focus on the current conventional aircraft and the facilities that support it. The introduction of electric aircraft and its accompanying technological trajectory would raise the need for new or modified all-inclusive policies, and the relevant authorities would need to make those modifications. For example, making electric aircraft charging infrastructure projects eligible for funding would require a change of policy from the FAA. Rationales that could motivate this change include supporting environmentally friendly federal policies and initiatives on clean air and climate change and ensuring the continued accessibility of the National Airspace System (NAS) to aviation users if electric aircraft successfully penetrate the market—a success that, in return, depends in part on the availability of chargers.

Terminal Operations

If electric aviation delivers lower capital expenditures and operating costs to flight operators, it might induce lower air fares and the emergence of a revitalized regional air mobility. An increase in the regional flight demand at some airports at the 2030 horizon would require adapting the passenger terminal facilities to accommodate such demand. Accommodating this additional traffic calls for specific discussions at the planning level, which could involve the air traffic control. A renewal of smaller point-to-point regional mobility with small commuter aircraft might be accommodated on remote ramps or "non-contact" gates (i.e., without jet bridges). Passengers typically walk to the hold room and then walk to the plane by foot. Most of the time, passengers must take stairs or elevators to descend from the main terminal floor to the ramp level. Some airports have provided canopies from the terminal building to the aircraft stand, for example, the former regional jet gates at John F. Kennedy International Airport's (JFK) Terminal 2. Yet, passengers are often exposed to outside weather conditions.

While such processes are typical at smaller airports, many larger hub airports are getting rid of them because of the inferior passenger experience they provide. The re-emergence of smaller regional aircraft under electrification could prompt the passenger journey to be reimagined.

Airside Operations

Beyond 2030, electric aircraft technologies and capabilities are expected to significantly improve, potentially driving an increase in investment and utilization among flight operators, which also is likely to affect airport operations. Although this shift is expected to occur gradually—likely taking over a decade to manifest, starting no earlier than 2030—it will have a meaningful impact on the airside ecosystem as it exists today. Significant changes are likely, key areas of which could include gate facilities, aircraft charging infrastructure, aircraft fueling activities, GSE, airport electrical infrastructure, and sources of funding.

Electricity Demand

Currently, terminal buildings consume 60 percent of the electricity at a typical airport, and airfields consume the remaining 40 percent. This balance could be shifted with the emergence of electric aircraft. The overall electric demand on the airside will grow, especially beyond the 2030 horizon, requiring the development of aircraft-specific power supply requirements.

The airport electric infrastructure is likely to be affected by the integration of electric aviation into existing airport ecosystems. Increasing electrification across airport technologies and infrastructure as part of the "electrification of everything" trend, coupled with the introduction of high-power fast charging for electric aircraft, could place a strain on existing airport power grids. Airports must collaborate with their energy providers to match the needed electric demand.

CHAPTER 4

Market Assessment

4.1 Electric Propulsion System Application

The electric and hybrid-electric approaches of electric propulsion allow manufacturers to take on different operational use cases. The electric aircraft and electric propulsion technologies under development broadly apply to five primary aviation use cases: regional aviation, commuter aircraft, light air cargo operations, flight training, and personal use general aviation.

Regional Aviation

Regional flights are currently performed by small jet or turboprop aircraft. On most markets, they are used for passenger-carrying and belly cargo purposes, typically having between 15 and 100 seats. Flight operations for aircraft in this class are typically less than 2 hours, covering an average of 330 nautical miles (NM). Aircraft designs in this category include the Faradair Aerospace BEHA, Heart Aerospace ES-19, and United Technologies Corporation (UTC) Project 804.

Commuter Aircraft

Aircraft in this class conduct passenger-carrying operations under the FAA's Part 135, which allows them to provide unscheduled flight services, such as air taxis and charters, as well as limited scheduled operations. Aircraft typically carry 2 to 20 passengers and use both piston and turboprop propulsion systems that produce between 250 and 1,500 kW of power. These aircraft fill the roles of commercial intercity transport and business aviation, with flights averaging 117 NM (135 statute miles) and lasting less than 1 hour. Designs are under development for both fully electric and hybrid-electric aircraft. Programs in this category include the Ampaire Electric EEL, Bye Aerospace eFlyer 800, Eviation Alice, magniX eCaravan, and Tecnam P-Volt.

Light Air Cargo/Mail

This class of aircraft is used for the transport of light freight and parcels over an average distance of 125 miles. Flights usually take less than an hour. This group encompasses aircraft with cargo capacities up to around 7,500 pounds and that leverage both piston and turboprop propulsion to provide between 200 and 2,000 kW of power. Operations include services between cargo hub airports and smaller aviation facilities, as well as freight deliveries between rural areas; remote communities; and islands such as Alaska, Hawaii, and the U.S. Pacific Trust Territories. This class of aircraft could comprise most of the small passenger commuter aircraft mentioned above.

Flight Training

Pilot training aircraft typically share three primary characteristics: cheap to acquire and operate, reliable, and easy to fly. These aircraft typically use piston engines, producing between 100 and 200 kW, and accommodate 1 to 3 passengers for roughly a couple of hours of flight time. These aircraft tend to have high utilization for aircraft of their size, averaging around 400 flight hours per year. Ongoing projects encompass both designs of new aircraft and the adaptation of existing airframes. The Bye Aerospace eFlyer 2 is an example of electric training aircraft.

Personal-Use General Aviation

Aircraft in this class are primarily used for private flight activities, and they do not involve the commercial transportation of passengers or cargo. Aircraft of this class typically carry 1 to 9 passengers. Today, they are primarily powered by piston or turboprop engines that provide between 100 and 300 kW of power. Utilization is much lower for personal-use aircraft, which average around 72 flight hours per year. Some OEMs are developing electric and hybrid-electric variants of existing aircraft, such as Pipistrel's fully electric Alpha Electro. Other companies have entered the market as well, including Bye Aerospace with its two- and four-seat variants of the eFlyer.

4.2 Market Assessment

Electric aviation is still nascent, with over 10 concepts across phases of design and development. The FAA's revision of Title 14 Code of Federal Regulations (CFR) Part 23 certification requirements for normal category airplanes opened the door for smaller electric aircraft. However, no OEM has yet completed the certification process for electric aircraft in the United States. In contrast, for larger commercial aircraft, certification pathways for electrification do not yet exist, because 14 CFR Part 25 on transport category airplanes does not currently cover electric propulsion. Given these fundamentals, airport practitioners can see this future market through the following three adoption scenarios.

Baseline: Mild Savings, Tech on Schedule, Conversion Market

The baseline scenario predicts an active fleet of more than 3,500 electric aircraft operating across the NAS by 2030, producing a $900 million market across manufacturing, maintenance, fleet operations, and infrastructure development. This outcome is based largely on the following driving variables: operating costs, certification timeline, technology development, and fleet operator incentives. Market size results and discussion are as follows:

- **Lower operating costs**: Both fully electric and hybrid-electric aircraft are expected to have lower operating costs than comparable aircraft powered with conventional "thermal" engines. Reduced maintenance costs and decreased fuel costs should provide financial benefits for flight operators. Lower overhead costs will lead operators to consider increasing the utilization of electric aircraft.
- **Timely certification**: This scenario assumes that the first certification of an electrically powered aircraft under 14 CFR Part 23 will occur in 2021 and that numerous aircraft platforms will have followed by 2025. Later in the 2020s, additional standards work from industry and regulatory stakeholders could amend 14 CFR Part 25 standards to cover electric propulsion, paving the way for certification of the first electric commercial airline aircraft.
- **Technology development proceeds as predicted by industry**: Development of electric motor technology will proceed with high-powered 1+ megawatt (MW) electric motors and

hybrid-electric propulsion systems in development and expected to enter the commercial market by 2029. Additionally, advances in battery charging technology, led by a significant build-out in the automotive industry, will lead to cost reductions on the order of $100 per kW.

- **Certification of electric propulsion systems (independently of aircraft) will lead to the creation of a secondary market for converting conventional aircraft**: Given the significant investment necessary for conversion assumed in the baseline, fleet operators have only a modest incentive to drive electrification across the fleet. Fleets with a higher remaining service life ("young fleets") may see early adoption, while aging fleets may adopt a "wait-and-see" attitude toward conversion. General aviation may account for a larger portion of the conversion market than other aircraft use cases, primarily due to larger active fleet size with a newer fleet mix.

Upside: Lower Costs, Mature Tech, and Rapid Certification

In this more bullish market view (high scenario), operating costs fall further, aircraft certification timelines pull to the left, and rapid advances in applicable technologies result in increased adoption rates across use cases. The end result is nearly a doubling in total market size and active electric aircraft over the baseline scenario.

- **Significant reduction in operating costs**: In this scenario, operating costs for hybrid- and fully electric aircraft undercut that of conventional aircraft by between 30 and 50 percent. The significant opportunity for savings leads to increased adoption rates across the use cases. Fleet operators are expected to increase utilization rates beyond that of the base case to maximize revenue. Additionally, commuter service providers lower their fares, which results in an increased load factor.
- **Rapid certification of commercial airline platforms**: This scenario supposes that, while certification of Part 23 aircraft follows the same timeline as the base case, regulators, industry, and standards organizations collectively work to enact rewrites of 14 CFR Part 25 and enable certification of fully electric and hybrid-electric large commercial aircraft by 2025.
- **Accelerated technology development**: This use case proposes that rapid and high-impact breakthroughs accelerate electric propulsion research and development beyond the timeline predicted by the industry. Development areas include electric and hybrid-electric motor technology, battery design, and fast charger technology. These advances, bringing high-power electric propulsion technologies to market in 2025, reduce the per kW-cost of charging a system by almost $200, and enable high-energy density batteries that increase the effective payload of electric aircraft.

Downside: Higher Costs, Delayed Tech, Little Infrastructure

In this bearish scenario for airport planners that represents the lower boundary of electric aircraft (low scenario), the initial introduction of platforms will be delayed by 3 to 5 years across the use cases, primarily due to the following:

- **Total cost of ownership remains higher than anticipated**: In this outcome, maintenance and operating costs for electric aircraft are marginally lower than those of conventional aircraft. However, modest savings from operational benefits—primarily fuel and maintenance—do not justify investments needed to drive an uptick in aircraft purchases or at-scale conversion. By adding new cost factors, such as additional training for mechanics and warehousing additional parts, the operational savings do not offset the upfront investments, posing economic limitations to the introduction of electric aircraft into the current fleet.
- **Delays in certification**: In this scenario, the first 14 CFR Part 23 electric aircraft certifications are delayed due to unforeseen challenges or events such as resistance from regulatory bodies,

design alterations, or safety events involving electric aircraft. And, as such, the first electric aircraft certification is not completed before 2025, delaying widespread certifications until 2027. That said, 14 CFR Part 25 certifications of electric aircraft do not occur before 2030.

- **Stagnant technology development**: Electric motor development activities do not produce 1+ MW motors before 2030, limiting aircraft size and therefore carrying capacity to 10 to 13 passengers or 6,000 to 8,000 pounds. As a result, larger passenger electric aircraft in the 40- to 90-passenger range come to the market beyond the 2025 to 2030 window. Similarly, battery technology research does not progress past its current state and does not enable increased usable payloads. While battery charging technologies will make modest technological advances, these will not make an appreciable impact on the cost per kW.
- **Lack of widespread and reliable charging or hydrogen infrastructure drives up ownership costs and limits the geography of operations**: Airports are not widely accessible to electric aircraft due to the lack of charging or hydrogen infrastructure. This places downward pressure on initial adoption as the availability of charging facilities directly determines viable bases and destinations. Scaling charging infrastructure is highly sensitive to installation and per-unit charger costs, as well as intermodal integration with existing municipal, airport power grids, and supply chains.

4.3 Infrastructure Development Market Assessment

Infrastructure Developers

At most domestic airports, electric aircraft will be able to make use of existing runways, hangars, terminals, and gates. As a result, open infrastructure needs will likely center on developing new battery charging systems. The market size of charging infrastructure is determined by anticipated fleet size, number of chargers required, charger capacity, and charger cost. In assessing these factors, the model makes a number of assumptions.

Charger Capacity

For each use case, the list below shows the required charger capacity factors in estimated power consumption during a typical flight and an assumed target charging time, based on operational tempo. Due to the range of aircraft battery capacity, charging times and required capacity will vary between specific airframes:

- **Turboprop Airliner** requires the highest total charging capacity at around 1,300 kW based on a targeted 30-minute charge time.
- **Commuter Aircraft** require an average charger size of 850 kW based on an estimated 30-minute charging target.
- **Light Air Cargo**, although similar in size to commuter aircraft, requires an average charger size of 150 to 200 kW as the targeted charge time is 3–4 hours.
- **Flight Training** aircraft required the lowest average charging capacity at 75 kW, assuming a 1-hour charging time.
- **General Aviation** required an average of 100 kW of charging capacity based on a 1-hour charge time.

Charger Cost

Charger cost estimates are based on current and forecast costs for 120 kW automotive direct current (DC) fast chargers. The model assumes that installation costs are fixed and are factored into the calculated per kW cost. For all five use cases, the baseline charger cost is $464 per kW, the upside is $395, and the downside is $553.

Number of Chargers

The number of chargers necessary to support electric aircraft operations is expressed by an estimated number of chargers required per aircraft. This number is based on assumptions about the expected pace of operations, target charging times, and the density of operations.

- **Turboprop Airline** will require an estimated three chargers for every four aircraft due to the expected high pace and relatively concentrated pace of operations.
- **Commuter Aircraft** will require an estimated one charger for every two aircraft. While these aircraft will expect a high tempo of operations, the high number of potential destinations thins traffic and will reduce charger demand at a given time.
- **Light Air Cargo** will require an estimated one charger for every five aircraft. This number is due to the relatively low pace of operations, long charge times, and the large number of destinations served.
- **Flight Training** also requires one charger for every two aircraft. This number is based on an operational cadence of four times 1-hour flights, with 1-hour charging cycles during an 8-hour operating day.
- **General Aviation** has the lowest charging needs with only one charger for every 10 aircraft. Most airports experience relatively low general aviation traffic, there is typically little urgency of operations, and most charging for general aviation aircraft will be conducted at low power over long periods of time.

Market Size in 2025: Discussion

Table 6 displays the infrastructure developer market segment projections for each use case in the 2025 and 2030 time period. In 2025, the commuter aircraft use is predicted to make up the largest portion of the market across the three scenarios, followed by general aviation, flight training, and turboprop airliner.

The infrastructure developer market supporting the commuter aircraft use case is the largest in 2025 at $10 million in the baseline and $14 million in the upside. This market size is likely due to the relatively high power and cost necessary for commuter aircraft charging equipment. This model assumes that operators will choose to leverage charging technology. However, the high cost may drive some to perform battery swap overcharging.

General aviation is the next largest component of the market. It represents $0.2 million on the downside, $6.6 million on the baseline, and $11.1 million on the upside. While nascent, a general aviation infrastructure market may emerge in the downside scenario as general aviation is expected to be an early adopter of electric aircraft. Because the chargers necessary to support electric general aviation aircraft will likely be lower in cost than other use cases, the volume will be the primary driver for market size. While requiring a few fast-on per aircraft basis, the large number and likely geographic diversity of active electric general aviation aircraft will drive the early market.

Table 6. Infrastructure developer market size ($ million, 2020).

	2025			2030		
Use case	Downside	Baseline	Upside	Downside	Baseline	Upside
Turboprop Airliner	0.0	0.0	1.7	0.0	9.1	25.7
Commuter Aircraft	0.0	10.1	13.8	2.7	43.0	55.2
Light Air Cargo	0.0	0.3	0.3	0.0	0.7	0.8
Flight Training	0.0	2.5	5.6	0.9	3.1	6.8
General Aviation	0.2	6.6	11.1	4.5	34.1	58.4

The flight training use case represents $2.5 million on the baseline and $5.6 million on the upside. While requiring more chargers per aircraft than the general aviation use case, flight training operations charges have lower power requirements and therefore lower cost. Additionally, flight training operations will likely be more concentrated than general aviation.

In 2025, the turboprop airliner use case will likely not emerge in the downside or baseline scenarios due to technology and certification delays preventing the integration of hybrid aircraft. The upside market size, $1.7 million, is predicted to be small due to the slow initial adoption of hybrid-electric aircraft. As with the commuter aircraft use case, fleet operators may choose to use battery swap overcharging to reduce operating costs.

Light air cargo is expected to make up the smallest portion of the market representing $0.3 million in both the baseline and upside scenarios. The size of this market is largely attributed to slow initial adoption by fleet operators and the limited number of routes electrified.

Market Size in 2030: Discussion

In 2030, commuter aircraft will remain the largest portion of the electric infrastructure market, growing by an estimated factor of 5 in the baseline and upside scenarios. The market size predictions are $2.7 million on the downside, $43 million on the baseline, and $55.2 million on the upside. This market size will likely be the effect of operators increasing the number of electrified flight routes as larger portions of the active fleet are converted to electric propulsion, and advancing technologies that lead to increased aircraft capabilities.

General aviation continues to represent the second-largest portion of the market in 2030, and it is estimated at $4.5 million on the downside, $34 million on the baseline, and $58 million on the upside. Growth in the active fleet size is the primary driver in the estimated five-fold increase in market size. Added factors include an increasing number of owners desiring private charging facilities and airports serving general aviation operations identifying the value of readily available fast-charging capabilities.

In 2030, the implementation of hybrid turboprop airliners projects to grow the baseline significantly to $9.1 million and increase the upside nearly twenty-fold to $25.7 million. With the expected growth of the electric fleet size between 2025 and 2030, high charger costs will drive the market size.

The flight training infrastructure market is expected to see limited growth between 2025 and 2030 across the scenarios and represent $0.9 million on the downside, $3.1 million on the baseline, and $6.8 million on the upside. The modest growth will be due to similarly modest growth in aircraft fleet size and the fact that operators with partially electric fleets will require less investment in infrastructure as they add more electric aircraft.

As in 2025, the 2030 light air cargo market will represent the smallest portion of the electric infrastructure market at $0.7 million on the baseline and $0.8 million on the upside. Growth will be driven by operators increasing the number of electrified flight routes. However, the small airport size and remoteness of operations will likely limit the economic viability of many destinations.

Note: Section 4.3 of this market assessment does not consider hydrogen technologies.

4.4 Drivers of Electric Market Demand (Discussion)

As the literature on electric aircraft expands, U.S. airport practitioners will benefit from understanding the primary drivers of demand for that market: what will motivate airlines and excite passengers to adopt these new aircraft, and what might dim enthusiasm? At its core, the development and introduction of electric aircraft for commercial aviation requires a business case to support and drive operator investment. The rate of adoption for all five electric aircraft use cases hinges on reductions in the total cost of ownership over aircraft lifecycle and changes in federal incentives and public support for lower carbon emissions.

Major Variable: Lifecycle Cost Reductions

A primary pillar of the business case for electrically powered aircraft is the potential for operational savings by minimizing the variable costs historically tied to aviation operations. Electric aircraft cost reductions are primarily due to decreased maintenance requirements, increased energy efficiency, and lower energy costs.

Electric aviation propulsion systems are expected to be considerably more reliable than turbines or piston engines of similar power. Reliability of propulsion is usually tied to the complexity inherent in engine designs: the more parts operating in very tight sensitivity ranges, the greater the risk of failure. Because electric motor designs would eliminate hundreds or thousands of parts (e.g., rotors, stators, and fuel injectors) compared to conventional engine designs, scheduled maintenance and overhaul activities will require significantly less time and expense. For the Alpha Electro, Pipistrel recommends a motor overhaul every 2,000 flight hours, which costs around $1,000 and requires 12 hours of labor. In comparison, while conventional engine manufacturers recommend an overhaul every 2,000 flight hours for piston engines and up to as many as 6,000 flight hours for a turboprop, significantly higher costs and timeframes are required for maintenance and overhaul. A piston-engine overhaul can cost upward of $20,000 while turboprop overhauls range from around $205,000 for commuter aircraft platforms (e.g., Cessna 208 P&W PT6A) to over $800,000 for turboprop airliners (e.g., ATR-72 P&W PW127B).

Energy efficiency is another key draw of electric aircraft propulsion. In commercial aerospace, efficiency is the effectiveness at which a propulsion system converts the chemical, or electrical, energy in fuel into thrust. A fully electric, battery-powered propulsion system can achieve an overall efficiency up to 73 percent after the controller, motors, gearbox, and propeller losses. Conversely, a typical conventionally powered system can expect, at best, 40 percent efficiency in turboprops and an even lower 28 percent efficiency in piston engines. Higher efficiency means that less power, and therefore money, is used during operations. Fuel costs can account for 20 percent of airline operating costs, and a doubling in energy efficiency could prove decisive in airline economics—and significantly drive adoption rate.

Beyond the increased energy efficiency of electric propulsion—in both hybrid and fully electric models—such aircraft provide cost-savings opportunities because electricity is cheaper than aviation fuel. Industry members believe that hybrid propulsion systems, intended for use on 40- to 90-seat turboprop aircraft, may reduce fuel consumption by up to 30 percent over conventionally powered aircraft by reducing engine power and providing supplemental thrust during takeoff with electric motors. On a 380-mile flight, an ATR 72 will burn around $800 worth of fuel. Hybrid-electric propulsion can potentially reduce that cost by $240 while replacing expended electricity, assuming charging on the ground, will cost only $80. With fully electric models, where no fuel is required, the cost reduction benefit is even higher. Pipistrel estimated that its Alpha Electro trainer costs only $3 per flight hour in electricity while a similarly sized and equipped conventional aircraft like the Cessna 152 incur fuel costs around $30 per flight hour.

Major Variable: Emissions and Sustainability

Aviation operations currently account for over 2 percent of the global human-produced carbon dioxide (CO_2) emissions and 12 percent of emissions from transportation. However, aviation emissions are projected to grow by 3 to 4 percent per year—at a rate faster than population growth—and as governments and technology drive down emissions from other sources, aviation could increase its share of global emissions by 300 to 700 percent by 2050. As a result, several influential international institutions and initiatives such as the International Civil Aviation Organization (ICAO), Advisory Council for Aeronautics Research in Europe (ACARE), the European Commission, and the Clean Sky Joint Undertaking have developed programs, such as the European Commission's Flight Path 2050 intended to build on current programs for responsible growth—balancing both the significant socioeconomic benefits of mobility with a responsibility to manage aviation emissions.

Industry observers are considering potential parallels in the automotive sector, where many countries have enacted "carrot-and-stick" legislation to incentivize consumer adoption with tax breaks and limit automotive CO_2 emissions with tiered penalties. While emission standards exist for aviation gas-turbine engines to curtail the venting of pollutants such as raw fuel, smoke, carbon monoxide (CO), and nitrogen oxides (NOx), aviation GHG emissions remain largely unregulated in the United States. However, in May of 2019, the U.S. Environmental Protection Agency (EPA) announced plans to issue standards that would, at a minimum, meet the proposed ICAO requirements to reduce CO_2 emissions by 4 percent over 12 years. While groundbreaking for aviation, environmentalists view ICAO standards as too lenient. Public call for change could lead to regulatory tightening in the near future. Strict measurement and management of emissions may press fleet operators to consider alternative technology.

Further, fleet operators may identify the value and potential competitive edge of establishing a reputation for being "green" conscious among potential consumers. Flight service providers (FSPs) must carefully consider this customer's willingness to pay when setting ticket prices. In addition to reduced emissions, an expected benefit of electric aircraft propulsion is reduced noise pollution. While current literature provides little in the way of quantitative predictions as to the extent of this improvement, it is likely to be significant enough that current aviation noise regulations and restrictions will have little to no impact on electric aircraft operations.

A potentially more substantial benefit of reduced aviation noise is the reduction of "unwanted sound" in communities near airports. Aircraft noise can have detrimental effects on surrounding communities, including general annoyance, sleep disruption, adverse impact on the academic performance of children, and increased risk of cardiovascular disease in people living in the vicinity of airports. The current FAA standard for acceptable noise pollution is 65 DNL or Day-Night Average Sound Level. Locations affected by levels higher than this are eligible for aid with noise abatement. Electric aircraft present an opportunity to reduce airport operational noise levels without impacting air traffic and increase the social acceptance of urban and suburban aviation activities.

Major Variable: Technological Drivers

The potential socioeconomic benefits presented by electric aircraft hinge on the assumption that electric platforms will be capable of meeting the mission requirements of each use case. The primary driving technologies behind electric aircraft performance are batteries and electric motors.

Across the industry, the key measures of a battery system's capabilities are energy density and effective cycle life. Battery developers seek to maximize both of these metrics to produce high-power, lightweight, and long-lasting batteries. Energy density is of particular importance in the commuter aircraft and light air cargo use cases where developers must strike a balance between range and payload. At the current energy densities, conversion developers magniX and Ampaire can only achieve ranges around 100 miles while maintaining aircraft payload. Such range restrictions greatly limit aircraft utility and flexibility and would likely depress demand. Battery energy density will likely also be a factor in the design of hybrid-electric propulsion systems for the turboprop airliner use case. Industry members claim that hybrid propulsion will reduce fuel burn by 30 percent while cutting aircraft range by only 40 percent, leaving an effective range between 500 and 1,000 miles depending on the aircraft. This is significantly more than required for the majority of regional flights, which average 1 hour and approximately 250 miles. Improving battery energy densities will benefit hybrid-electric turboprop operation by providing further reductions in fuel burn, and potentially increasing operational range.

The second key measure of a battery system's ability is its effective cycle life. Cycle life is the number of times a battery can be fully discharged and recharged before its capacity drops below a threshold, defined by the manufacturer, and must be replaced. It is a significant factor across all of the use cases because battery replacement will likely make up a major portion of maintenance costs. Pipistrel estimates that the batteries for its Alpha Electro can undergo 300 to 700 cycles before replacement, which costs between $13,000 and $20,000 and represents a significant portion of the estimated hourly operating costs. While it is likely that operators will take steps to maximize battery life through proper handling, improving battery cycle life will increase the attraction of electric aircraft.

Battery technologies are currently improving at a significant rate, with one venture, Innolith, claiming to have developed a 1,000 Wh/kg battery that could be commercially available by 2022. This represents more than a factor three improvement from current densities and would greatly increase the potential draw of electric aviation to fleet operators. From the perspective of battery cycle life, the automotive industry is a driving force in the development and improvement of battery technologies and approaches to maximizing effective life. Using techniques such as battery buffering, where vehicle systems will not allow operators to fully drain a battery, manufacturers have developed systems that allow for thousands of charge cycles before major degradation occurs. Leveraging these approaches, electric aircraft manufacturers can increase battery cycle life and maximize the economic benefits of going electric.

4.5 Projected Barriers to Electrification (Discussion)

As a balance to the economic and ecological benefits presented by electric aviation, a business case must consider the potential drawbacks and barriers that must be overcome before achieving economically effective implementation. Understanding these challenges will be key to airport planners as they assess how electric aviation may impact their plans in the years to come. These barriers primarily center on aircraft technology, certification policy, and infrastructure.

Major Barrier: Electric Aircraft Battery, Motor, and Electronics Technologies

Energy storage is a key component in any aircraft propulsion system. For electric and hybrid aircraft designs, energy storage is entirely or partially enabled by battery packs, where current challenges center on energy density and battery safety and reliability.

While current battery technology can potentially support much of the short-range portion operations across all five use cases, energy densities are at a level where significant mass is required to store the necessary energy. The Eviation Alice requires an estimated 8,000 pounds of batteries to enable its 600-mile range. Comparable conventional aircraft require roughly one-fourth of that weight in fuel to achieve twice the range. This drawback will likely have a significant effect on the potential business cases for light air cargo, commuter aircraft, and turboprop airliner use cases, where reduced capacity leads to lower revenue. As battery technologies and available energy densities improve, aircraft range and payload economics will be revised. It is widely accepted in the industry that 500 Wh/kg is the minimum energy density required to achieve commercially acceptable load and range characteristics.

The second challenge for electric aircraft battery technology is safety and reliability. Aircraft manufacturers and fleet operators have long experience managing the safety challenges presented by fuel-based propulsion, and safety regulations and technology are well established. While batteries are also a recognized safety hazard in aviation, the industry has much less experience managing the risks and failure modes of batteries such as thermal runaway leading to combustion, toxic gas emission, and high voltage short circuits. Battery durability, particularly in the event of a crash, is another potential safety risk, and, because no aircraft with large battery packs has faced a crash to date, uncertainty in this area is high. Understanding the safety implications that electric aviation may present to airport operations is key as industry and regulators work to develop methods of safely preventing or managing these risks.

An additional technology challenge faced by electric aircraft designers is developing high-power and low-weight electric motors and power management systems. Current electric motor technology has achieved approximately 750 kW motors and is capable of supporting operations for the majority of the examined use cases. However, turboprop airliners and some light air cargo vehicles are anticipated to require 1+MW motors. In addition to developing the motors, developers of electric propulsion systems must design lightweight power electronics, such as inverters, rectifiers, and controllers, capable of efficiently converting and managing the high-power levels necessary. A primary challenge for these technologies is heat management. In conventional turbine engines, the majority of waste heat is exhausted from the engine to the surrounding air. Electric propulsion requires cooling systems to dissipate heat buildup before performance is affected. Until these technologies are developed, electric aircraft operations will likely be limited to small (13 passengers) platforms.

Major Barrier: Aircraft Certification and Development of Favorable Regulatory Policies

As with all technology developed in the aviation field, electric aircraft technologies will require regulatory backing before introduction to the market. New airframe designs and electric propulsion systems will require airworthiness certifications and regulator acceptance for their support technologies such as high-power batteries and power electronics. The rewrite of 14 CFR Part 23 opened the door to electrically propelled aircraft by implementing performance-based rather than prescriptive standards. Most electric aircraft in the general aviation, commuter aircraft, light air cargo, and flight training use cases will be certified under this part as it encompasses smaller aircraft up to 19,000 pounds and carrying 19 passengers or less. While no electric aircraft has fully completed the certification process under Part 23, there are several companies currently involved in the necessary testing operations. These companies are developing a certification pathway that can be followed to streamline the process for future electric aircraft developers.

Turboprop airliners are a notable exception. They will require certification under 14 CFR Part 25 for transport class aircraft. In their current state, 14 CFR Part 25 standards are prescriptive and do not enable pathways to certification for hybrid- or fully-electric aircraft. Developing and implementing a rewrite of 14 CFR Part 25 will likely be an extremely lengthy and expensive process. The rewrites of 14 CFR Part 23 took nearly 7 years from when the FAA chartered an Advisory and Rulemaking Committee to final implementation. A rewrite of 14 CFR Part 25 will likely face greater scrutiny and possibly wider resistance as it governs standards for commercial passenger-carrying aircraft. Ensuring operational safety will be paramount. The status of 14 CFR Part 25 certification standards will primarily impact the turboprop airliner use case.

Major Barrier: Deployment and Cost of Developing Electric and Hydrogen Infrastructure

Supporting infrastructure is key to enabling electric aircraft operations in today's airport environment. Challenges to implementation of electric aircraft primarily center on meeting aircraft charging needs with appropriately powered battery charging systems and the supporting power infrastructure, as well as options for hydrogen supply for aircraft equipped with fuel cells. Because aircraft battery sizes, power expenditure, and required charging time vary between the use cases, the charger size necessary to support these operations varies as well.

General aviation aircraft for personal use will likely require the least supporting infrastructure due to the low average annual utilization and the short average flight length of 45 minutes. This use case is not expected to demand fast-charging capabilities, and charging will require a relatively low power level of 10 kW, which can be easily supported by today's technology.

Flight training aircraft will have slightly higher charging infrastructure requirements than general aviation. Due to the much higher pace of operations typical of pilot training schools, fast charging—less than 1 hour per charge—capabilities will be necessary. However, because these aircraft are expected to have relatively small battery capacities—approximately 21 kWh—required charger power levels will be around 20 kW. This, like general aviation chargers, falls well within the capabilities of modern charging technologies.

The light air cargo use case represents a step up in the charging infrastructure requirements. The low operational tempo expected for light air cargo will allow for long charging times of 3 to 4 hours. However, aircraft sizes will require higher power propulsion and larger battery packs to support average operations. Therefore, relatively high-power—about 200 kW—charging will still be necessary. This is on the higher end of consumer electric vehicle charging capabilities but well within the capabilities of commercial systems.

Charger requirements to support commuter aircraft operations present the first significant infrastructure challenge. As fleet operations look to maximize aircraft utilization, turnaround time, and therefore available charging time, is expected to be low, between 15 and 25 minutes. Charger power levels necessary to allow this turnaround time are extremely high (i.e., 600+ kW). Chargers of this power level have been developed for charging buses and other heavy equipment. The installation and the maintenance of the charging infrastructure could be funded by airport operators, flight operators, FBOs, specialized third parties, and other tenants (e.g., flight schools). Also, similarly to Tesla in the domain of ground electric vehicles, OEMs may invest in the charging infrastructure to ensure accessibility of their aircraft to the regional and national aviation systems.

As a potential alternative, operators may choose instead to leverage battery swap approaches, which would require operators to obtain equipment and facilities to transport, store, and charge spare battery packs. Idle battery packs will likely be charged at lower power over the course of a full day, requiring only low-power chargers—in the range of 60 kW. The adoption of battery swap is largely dependent on the categorization of this change by the FAA. If battery swap is considered as a major alteration per 14 CFR Part 43, requirements will be more stringent, making this operation potentially longer and more expensive.

Electric turboprop airliners will likely present the most significant challenge to charging infrastructure and technology. Operations will likely call for rapid aircraft turnaround time as operators aim to minimize aircraft downtime. The small charging window will require very high-power charging capabilities—1 MW or more—that is on the cutting edge of current charging technology development. Until high-power charging technology matures, operations may resort to battery swapping rather than charging. As with commuter aircraft operations, fleet operators will need facilities and equipment for transportation, storage, and charging of swapped battery packs. However, unlike commuters, these flights will operate out of larger and more highly trafficked regional and hub airports. Operators will likely wish to minimize the inventory of expensive batteries at any given airport and maximize utilization. Thus, battery handling facilities will likely use chargers at high power (i.e., 600 kW) to enable multiple battery uses per day.

In addition to the technology challenges presented by charging equipment, airport practitioners must be aware of the strategic planning challenges associated with building an effective electric aircraft charging network. Airport operators must consider the type and density of electric aircraft traffic expected when determining the number, size, and placement of charging facilities. Beyond the charging infrastructure, the airport must consider the overall condition of its on-site power infrastructure because high traffic times may increase power demand by more than 1 MW. Transmission of such high-power levels may place a strain on existing electrical capacity, especially at smaller aviation facilities in remote areas. Upgrading electrical systems across an airport may be an expensive proposition, potentially prohibitively so to smaller airports. However, many airports are exploring opportunities to enhance their power capacity with on-site power generation or through leveraging microgrid technologies. Microgrids are localized groups of interconnected loads and distributed energy sources that act as a single entity with respect to the grid. Local power generation, with or without an accompanying microgrid, is being implemented at many airports through solar, wind, or hydrocarbon-based technologies.

CHAPTER 5

Economic Impact

5.1 Economic Aspects and Policy Considerations

The primary financial aspects associated with integrating electric aviation will be the cost of meeting new facility requirements imposed by electric aviation, the applicability of and impacts on federal funding sources, and the potential impacts on regional economies that could be brought about by electric aviation.

Short-term impacts would stem primarily from readying airports to support electric aircraft operations and evaluating potential avenues for federal funding or state green grants during this time period. New revenues could come from user fees on the chargers. In the longer term, impacts would result from the growth of electric aviation among the local aviation operations and the expansion of air service connectivity. Both impacts will result from the maturation of electric aircraft technologies and air carriers' full realization of the cost-savings potential of electric aviation over conventional platforms.

Integration Costs

Perhaps the most important and immediate factor to consider would be the costs associated with integrating electric aircraft operations into the airport ecosystem. Purchasing and installing electric aircraft charging systems would be the leading costs.

The base components of these costs would be the per-unit cost of the chargers themselves. The estimate in Figure 15 is scaled to a 120-kW charger based on the estimated purchase price of electric bus chargers, which is the most relevant proxy currently on the market. This price point is expected to vary widely based on the power level and pace of charging. For example, Pipistrel developed and sells a 15-kW, $40,000 charging system to support its Alpha Electro electric trainer aircraft. Installation costs would be the second and perhaps larger component of aircraft charger costs. Electric equipment (e.g., cabling, transformers, switchboards, fuse boxes), construction and materials (e.g., concrete, trenching, boring, hardware), and labor would be the primary costs. The power requirements of the charger unit would be a driver of installation costs because these requirements would dictate the capabilities of the supporting electrical equipment. The placement of charger equipment would be another factor that airport planners must consider because it would influence installation costs.

Beyond the immediate costs of purchasing and installing charging equipment, the integration of electric aviation could require some airports to upgrade their overall power supply and connection to the electric grid. Costs, which would vary widely from airport to airport based on current capabilities and the scale of required upgrades, could prove to be cost-prohibitive for smaller airports. Airport planners should develop an airport energy strategy and plan to account for aircraft electrification as well as other future electrification projects.

Electric charger costs for aircraft (120 kW), three development scenarios until 2030
$, USD

Components	Downside	Baseline	Upside
Unit cost per charger	93,500	82,750	74,500
Installation costs	143,900	143,900	143,900
Total	**237,400**	**226,650**	**218,400**
Scenario characteristics	• No meaningful cost savings through scale	• Partially optimized sites • Moderate vendor management	• Optimized larger sites • Significantly improved vendor

"Therefore, investment costs for the majority of airports would be between 15 000 EUR and 50 000 EUR, while for the airport with the most frequent number of flights, the infrastructure may cost around 200 000 EUR.
~ mahepa[1] Ground infrastructure investment plan report"

Takeaways

- Depending on the adoption of (hybrid-) electric aircraft, the price of charger might scale with optimized production sites and improved vendor management.
- Installation costs likely the same in all scenarios as the required groundwork does not scale, only in cases where multiple chargers are installed in very close proximity (not beneficial for aircraft charging).
- The costs of 200k–250k per charger are well within the size of projects usually funded through the VALE program, providing airports are clear path towards funding infrastructure projects for electric aircraft.
- Other sources put the required investment costs to accommodate electric aircraft for airports even lower, making it potentially even cheaper.
- Sources suggest that it is economically beneficial to charger electric aircraft through several smaller chargers (120kW) simultaneously rather than through one large charger (800kW).

1 Modular Approach to Hybrid Electric Propulsion Architecture, EU-funded project to develop new powertrains and associated solutions
Source: Vale project documents, mahepa project

Figure 15. Estimated infrastructure costs associated with electric aircraft are within historical funding capabilities of the FAA's Voluntary Airport Low Emissions (VALE) Program.

A final potential cost to airports would be the installation of an on-site power generation such as a microgrid. Although not all airports would choose to take this path, many have decided that the added costs would be worth the increased operational resilience and reduced reliance on power grids. Costs associated with installing these systems can vary widely—from $250,000 for small systems up to $100 million for larger multimode systems. The generation component of the system typically accounts for most of the cost. Redwood Coast—Humboldt County Airport in California—and several other local facilities, including a U.S. Coast Guard air station—is working to install a 2.3 MW solar microgrid for approximately $5 million to support airport electricity demand.

Sources of Funding

The final factor that airport practitioners must appropriately plan for is the funding and ownership of aircraft charging systems. Currently, it is largely unclear who would pay to install aircraft chargers. Funding could come through federal grant money, airline investment, private investment, or directly from airport funds. Because airlines are likely to be a driving force for installing charging facilities, they could prove to be viable partners for funding and managing charging facilities in a private-public partnership context. Existing FBOs could also be likely partners because forward-looking firms could seek to protect their operations and ensure they are prepared for the growth of electric aircraft operations.

A primary source of federal grant funding for airport infrastructure planning and development projects is the FAA's Airport Improvement Program (AIP), funding for which is allocated annually from the Airport and Airway Trust Fund (AATF), which in turn is funded by collecting various aviation excise taxes. Passenger tickets, cargo fare, the use of facilities by international airlines, and fuel sales are among the taxed items. Under the AIP, large and medium primary-hub airports can expect grants to cover 75 to 80 percent of eligible costs, while small, reliever, and general aviation airports can expect 90 to 95 percent coverage.

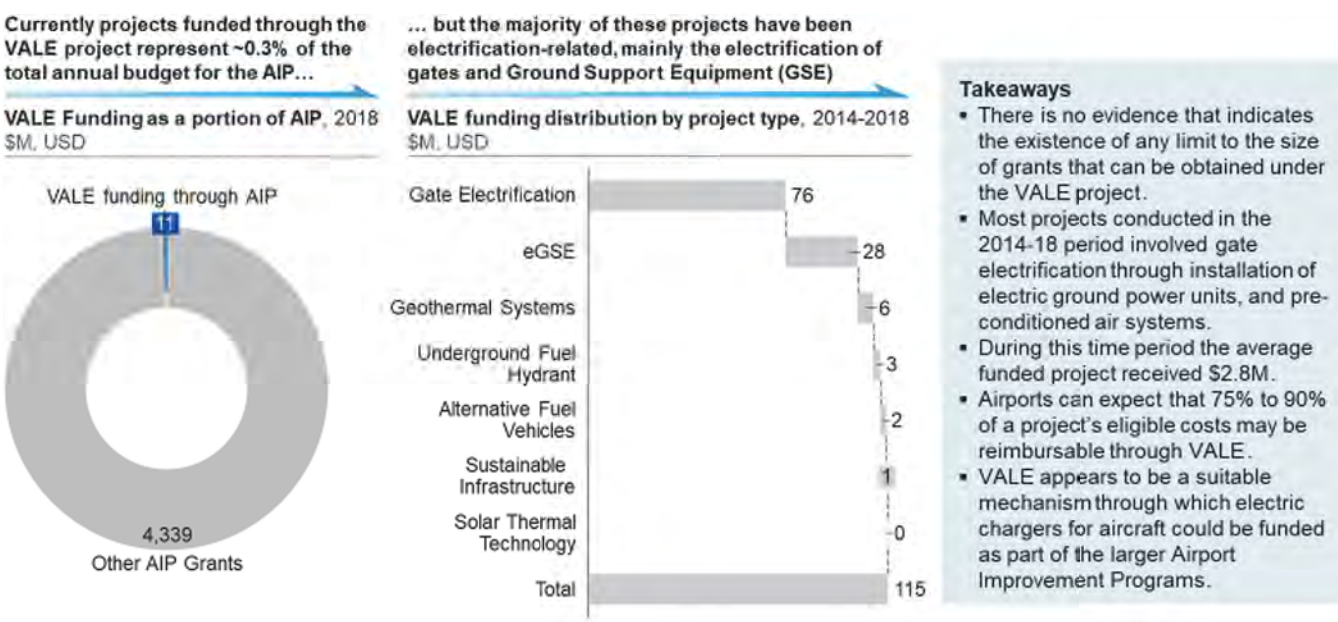
The FAA's VALE Program was established to encourage airport sponsors to implement clean technology projects that improve air quality. While it is targeted primarily at commercial airports in areas that have not maintained National Ambient Air Quality Standards (NAAQS), this program has provided funding for projects such as gate electrification, eGSE, and solar projects. Under this program, 75 to 90 percent of a project's eligible costs could be reimbursable (Figure 16).

Eligible VALE Program projects can be funded through the AIP, or through the passenger facility charge (PFC) program, which collects fees from passengers for use of commercial airports controlled by public agencies. The VALE Program has provided an average of $15 million in grants funded per year since 2005, with state programs providing matching funds totaling an additional $4 million per year.

As of today, electric aircraft projects (and especially charging stations) are not eligible for funding through the FAA's AIP. It is not clear either if there is a case for the VALE Program under current rules because funding would require justifying that these electric chargers would significantly reduce emissions directly linked or attributed to the airport activity.

Making electric aircraft charging infrastructure projects eligible for funding would require a change of policy from the FAA. Rationales that could motivate this change include supporting environmentally friendly federal policies and initiatives on clean air and climate change and ensuring the continued accessibility of the NAS to aviation users if electric aircraft successfully penetrate the market—a success that, in return, depends in part on the availability of chargers.

It is likely that the introduction of electric aviation would have a growing impact on the tax revenues from fuel sales. Those effects that occur would likely stem from the long-term growth of electric and hybrid-electric aviation and the corresponding decrease in fuel consumption and purchases in the very long term (beyond 2040). While most funding for the AATF comes from passenger fees, revenue from aviation fuel taxes made up 4 percent of the fund's total excise



Source: Vale project documents

Figure 16. The VALE Program funds projects that reduce on-airport emissions but has historically focused on gate electrification and eGSE.

tax revenue in 2018. Reductions in fuel tax, while not significant at the beginning, could affect funding availability for some projects or lead to increases in passenger fees to compensate, which could adversely affect aviation ridership.

Ownership Model

In addition to evaluating funding opportunities, it would be important that airports determine suitable ownership and usage models for charging systems. Airports could seek to maintain direct ownership of charging infrastructure and charge airlines and private owners' fees for usage. However, this approach could have significant long-term impacts on airport FBOs. The growing use of electric aircraft could drive down fuel sales revenues, and airport ownership of charging facilities could limit FBOs' access to new revenue streams.

A likely approach that could address these impacts would resemble the current structure of fueling operations at many airports. FBOs would provide aircraft charging services to airlines and private owners and pass a portion of the revenue to the host airport. In cases where airlines help fund the installation and operation of aircraft chargers, it would be important that airport practitioners ensure equal access to all airlines to prevent a monopoly as already specified in today's grant assurances.

One question to address would be "Can aircraft owners and operators self-service their own aircraft and charge their batteries with their own equipment?"—a question that arose on aircraft fueling over safety and environmental concerns. Unlike with fueling, preventing this might violate the FAA Grant Assurance 22(f) on Economic Nondiscrimination that specifies "a sponsor will not exercise or grant any right or privilege which operates to prevent any person, firm, or corporation operating aircraft on the airport from performing any services on its own aircraft with its own employees (including, but not limited to, maintenance, repair, and fueling) that it may choose to perform."

Also, several states have laws that regulate "utility submetering," which is defined as the implementation of meter systems that allow the operator or owner of a building or facility to bill tenants for individual utility usage through the installation of additional meters behind a utility meter. Some of these laws could prevent airports and states from charging an additional fee on electricity for aviation purposes. If airports and states decide to establish such taxes, they might have to restrict the use of the revenues to aviation and aeronautical purposes to prevent money diversion and other conflicts with FAA rules.

Impact on Aircraft Fueling Services

Until electric aircraft adoption reaches a point of critical mass, hydrocarbon-powered aircraft will remain the primary means of powered flight and represent most of the active commercial and privately owned aircraft. Estimates indicate that electric aircraft could account for 4 percent of all active aircraft by 2030; thus, aircraft fueling will remain a central service to the airport ecosystem. Airports, FBOs, and airlines will continue to require fueling equipment, infrastructure, and personnel both in the short- and medium-term timeframes.

The primary impacts are expected in the long term beyond 2030. As the prevalence of electric aircraft grows, airports, FBOs, and fueling service providers could begin to experience reduced revenue from aircraft fueling operations. Fueling revenues—in the form of sales revenue, flowage fees, and retained fuel taxes—represent a large portion of airports' non-passenger aeronautical revenues, making up about 18 percent (a total of $418 million) in 2018. Additionally, at many airports, FBOs are the primary fueling service provider, collecting revenue from airlines and private operators and passing a portion through to the host airport.

At many airports, FBOs rely heavily on the revenue stream of providing fuel for business, commercial, and general aviation. Due to the long-term nature of these impacts, airports and service providers should develop approaches to offsetting lost airport revenue and maintaining profitable relationships. The business model of electric charging stations, and the regulation of aircraft battery charging at airports, might influence the future of these stakeholders. The most critical situation might be if the portion of e-aircraft became so significant that it would no longer be profitable to offer fueling services to the rest of the fleet at some airports.

5.2 Economic Impact to Regional Gross Domestic Product (GDP)

Long-term economic impacts of electric aviation are expected to stem from an ongoing evolution of U.S. air service connectivity. As electric aviation proliferates throughout commercial air operations, the economic benefits could enable regional air carriers to open new routes and expand into underserved regions. Beyond the immediate impact of increasing revenues at added airports, expansion to new destinations could serve to stimulate local economies through the following impacts:

- **Direct impacts** create new jobs and spending at airports due to the additional air service activity, which includes contributions from expansion in airlines, retail and in-airport services, food and beverage, airport security and passenger screening, and maintenance, repair, and overhaul (MRO) providers.
- **Indirect impacts** create jobs and spending for off-airport firms that support on-premise airport activities such as downstream food and catering wholesalers that deliver to airports, electricity generation for chargers and grid access, professional services firms (e.g., accounting, legal counsel, analytics, and consulting) that deliver to on-premise airlines and MRO providers, and tourism and travel-booking activity.
- **Induced impacts** create business stemming from enplaned passengers spending their incomes at local businesses (e.g., health care, restaurants, hotels, auto rental, and local taxi services).

In addition to affecting local businesses, expanded air service connectivity could enable affordable air commuting and regional air mobility options and, at some point, attract new residents who work in major metropolitan areas but wish to reside elsewhere. For example, a regional airport such as Willard Airport in Urbana-Champaign, Illinois, could expand commuter aircraft service to five major cities within 250 miles (Figure 17).

5.3 Case Study: Washington Electric Aircraft Feasibility Study (Economic Impact)

The Washington State Department of Transportation (WSDOT) put together an electric aircraft feasibility study that addressed the economic impact of electric aircraft on the state of Washington. The study provided a framework for quantifying economic impacts that can be adjusted as data become available. The framework indicated that the total economic impact is the sum of direct and indirect incomes that are expressed in terms of job, labor income, value-added, and business revenues with the aid of multipliers that are generated to quantify how different economic measures flow. Figure 18 shows the connection between the direct/indirect impact, multiplier, and economic measures.

Including these multiplier effects, airports (excluding Seattle-Tacoma International Airport) generate over 255,000 jobs in Washington state, $19 billion in labor income, and nearly $85 billion in business revenue. The multipliers in the study can also be used to calculate the

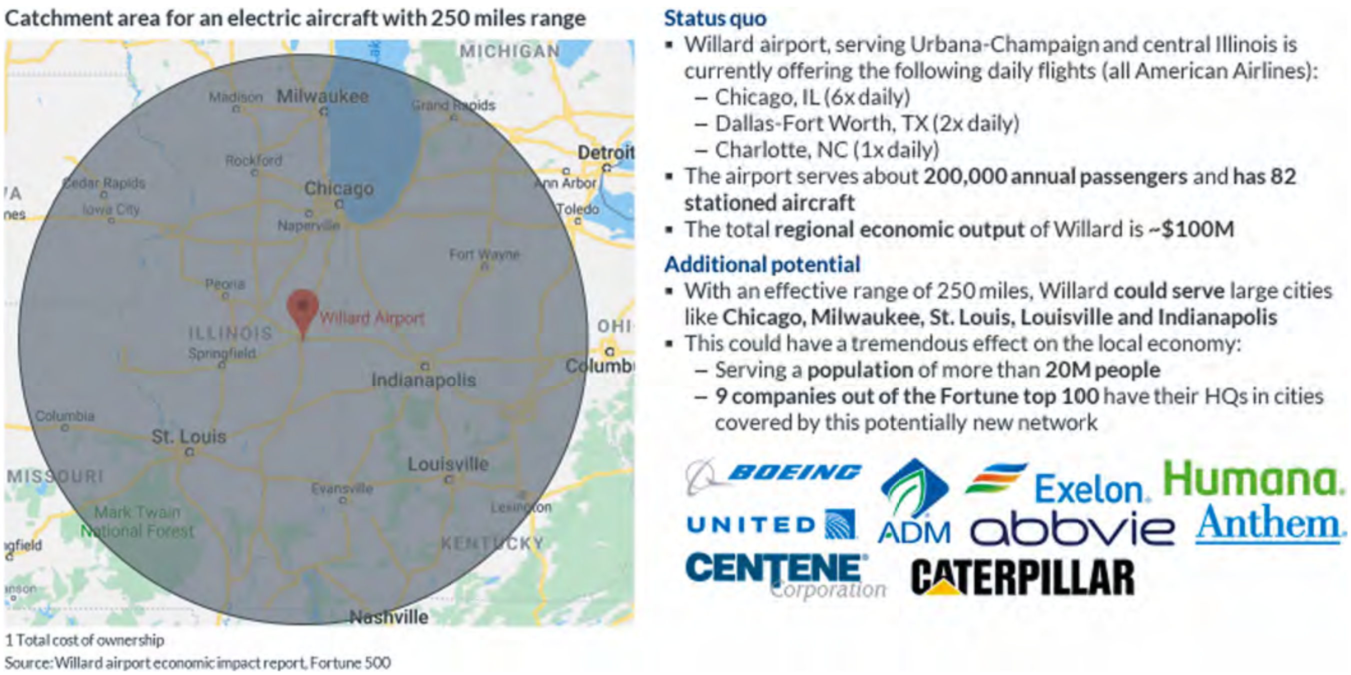
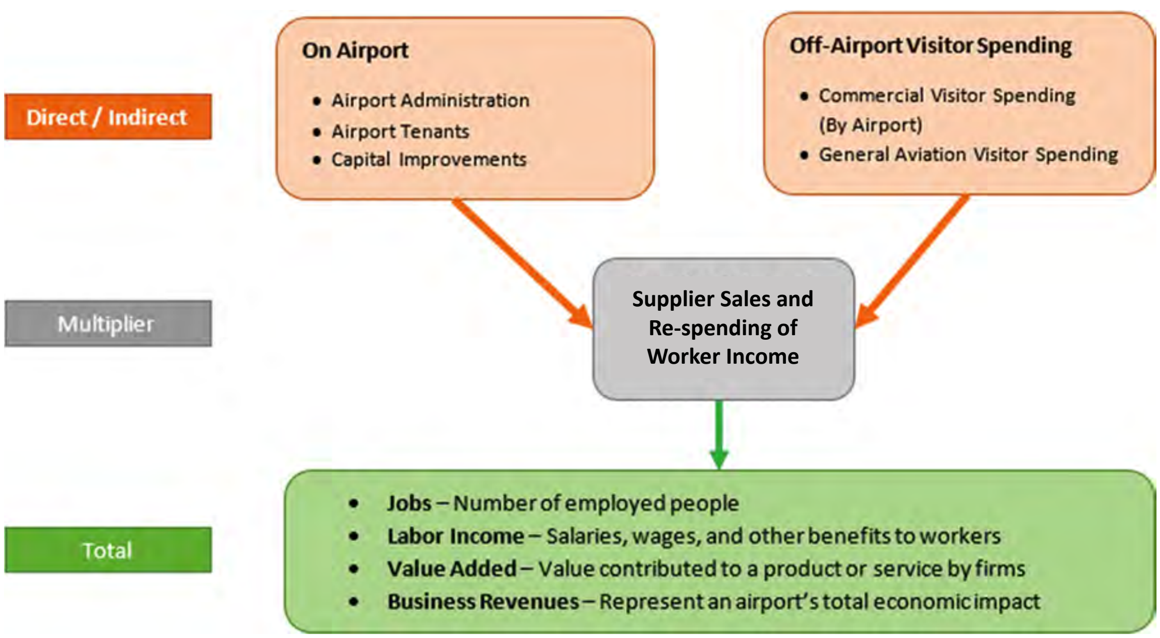


Figure 17. For regional airports, electric aircraft could increase net revenue through opening new routes. Example of Willard Airport in Urbana-Champaign is shown (Champaign County Economic Development Corporation).



Source: EBP US, 2020, Kimley-Horn AIES 2020.

Figure 18. Economic impact and measures.

downstream effects on the economy as money related to aviation cycles through the economy due to growth created by electric aircraft.

According to the study, electric aircraft have the potential to significantly increase flight activity and encourage growth on and off airports that will support jobs and create business revenues as well for the state of Washington in the following ways:

- Reduction in time and costs for people and goods to travel, particularly over short and congested routes, would aid in the creation of more business activities and jobs.
- Reduction in travel cost would also enable the connection between the rural areas in the state and the employment centers along the I-5 corridor.
- Also, while the operation and maintenance of electric and hybrid-electric would require many of the same labor and skills needed to operate and maintain conventional aircraft, the aviation industry workforce will witness some variation in employment and skills needed to operate and maintain electric aircraft, and more jobs would be created.

CHAPTER 6

Perspectives on Federal and State Policies

6.1 Federal Airport Policies

Federal Aviation Administration

The FAA is the federal agency responsible for civil aviation regulations and controls in the United States. The agency is under the authority of the U.S. Department of Transportation (DOT). Officially created in 1958, the FAA regulate all aspects of civil aviation, including aircraft manufacturers, airlines, airport operators, ground handlers, etc.

Electric aircraft will impact major federal policies and missions carried out by the FAA:

- **Certification**: The FAA is empowered to deliver certification of new aircraft, equipment, airline, pilots, and airports. All regulations are defined in Title 14 CFR Chapter 1.
- **Airport Planning and Funding**: The FAA regulates and approves airport planning projects through documents called the Airport Master Plan and the Airport Layout Plan (ALP). In addition, the FAA funds major airport projects through programs, such as the AIP or the PFC.
- **Safety and Design**: The FAA regulates airport safety, inspections, and standards for airport design, construction, and operation, and it takes part in the international harmonization of airport standards.
- **Environment**: The FAA is responsible for establishing programs to control aircraft noise and other environmental effects of civil aviation.

Aircraft Certification

There are three aircraft types of certifications delivered by the FAA: **Type Certificate (TC), Supplemental Type Certificate (STC)**, and **Experimental Category**. These three certifications are defined in Table 7. In addition, variants of existing aircraft have been retrofitted with electrified propulsion systems and have provided a growing number of demonstration flights under the Experimental Category.

Note: In 2020, the Pipistrel Velis Electro was the first fully electric aircraft to receive a TC, which was delivered by EASA in the European Union.

Because several aircraft manufacturers announced their business models on converting and adapting existing airframes to electric aircraft, the definition of major alteration should be understood by the stakeholders. Per 14 CFR Part 43 Appendix A: it is an alteration not listed in the aircraft, aircraft engine, or propeller specifications that might appreciably affect weight, balance, structural strength, performance, powerplant operation, flight characteristics, or other

Table 7. Types of certifications delivered by the FAA.

	Definition	Title 14 Code of Federal Regulations
Type Certificate (TC)	Type certification is the approval of the design of the aircraft and all component parts (including propellers, engines, control stations, etc.). It signifies the design is in compliance with applicable airworthiness, noise, fuel venting, and exhaust emissions standards.	14 CFR Part 21 Subpart B
Supplemental Type Certificate (STC)	An STC is a TC issued when an applicant has received FAA approval to modify an aeronautical product from its original design. The STC, which incorporates by reference the related TC, approves not only the modification but also how that modification affects the original design.	14 CFR Part 21 Subpart E
Experimental Category	A special airworthiness certificate in the experimental category is issued to operate an aircraft that does not have a TC or does not conform to its TC and is in a condition for safe operation. Additionally, this certificate is issued to operate a primary category kit-built aircraft that was assembled without the supervision and quality control of the production certificate holder. Special airworthiness certificates may be issued in the experimental category for the following purposes: • Research and development • Showing compliance with regulations • Crew training • Exhibition • Air racing • Market surveys • Operating amateur-built, kit-built, or light-sport aircraft • Special Airworthiness Certificate, Experimental Category for UAS and Optionally Piloted Aircraft	14 CFR Part 21 Subpart H

qualities affecting airworthiness or that is not done according to accepted practices or cannot be done by elementary operations.

Depending on the type of aircraft, the airworthiness authorities, including the FAA, have established different regulations. For airplanes, two distinguished categories are defined by the FAA based on their MTOW:

- **Normal Category Airplane**: MTOW of 12,500 pounds or less.
- **Transport Category Airplane**: MTOW over 12,500 pounds.

Table 8 summarizes the major policies and equivalent standards of the EASA and the ICAO regarding airworthiness standards.

Advisory Circulars

Advisory circulars (ACs) provide procedural guidance for the aviation industry to comply with FAA regulations and grant requirements. Updates to ACs may be required as electric aircraft are introduced across the industry in more significant numbers. Table 9 presents a selection of ACs that planners should consider when integrating future electric aircraft into airports and aviation systems.

Table 8. Policies on airworthiness.

FAA	EASA	ICAO
14 CFR Part 23 – Airworthiness Standards: Normal Category Airplanes	**CS-23** – Normal, Utility, Aerobatic, and Commuter Aeroplanes	**Annex 8 Part V –** Small Aeroplanes: Aeroplanes over 750 kg but not exceeding 5,700 kg for which application for certification was submitted on or after December 13, 2007
14 CFR Part 25 – Airworthiness Standards: Transport Category Airplanes	**CS-25** – Large Aeroplanes	**Annex 8 Part III –** Large Aeroplanes
14 CFR Part 27 – Airworthiness Standards: Normal Category Rotorcraft	**CS-27** – Small Rotorcraft	-
14 CFR Part 29 – Airworthiness Standards: Transport Category Rotorcraft	**CS-29** – Large Rotorcraft	**Annex 8 Part IV –** Helicopters
14 CFR Part 31 – Airworthiness Standards: Manned Free Balloons	**CS-31GB/CS-31HB** – Gas Balloons/Hot Air Balloons	-
14 CFR Part 33 – Airworthiness Standards: Engines	**CS-E** – Engines and **SC E-19** on Electric/Hybrid Propulsion System	**Annex 8 Part VI –** Engines
14 CFR Part 35 – Airworthiness Standards: Propellers	**CS-P** – Propellers	**Annex 8 Part VII –** Propellers

Table 9. FAA advisory circulars and electric aircraft impact assessment.

AC Title	Electric Aircraft Considerations
AC 150/5020-1 – *Noise Control and Compatibility Planning for Airports*	Noise control and compatibility planning reduce existing noncompatible land uses and prevent future noncompatible land uses around airports. Federal Aviation Regulation 14 CFR Part 150, "Airport Noise Compatibility Planning," which implements portions of Title I of the Aviation Safety and Noise Abatement Act of 1979 guides noise compatibility planning efforts. 14 CFR Part 150 sets a standard metric for measuring noise exposure, or the day-night average sound level (DNL) and establishes a voluntary program governing the development of airport noise exposure maps and noise compatibility programs. **Electric Aircraft**: At this stage, noise emissions of electric aircraft will be significantly lower than current aircraft. Their contributions to the noise environment should be captured and with NextGen program, new flight paths could be created.
AC 150/5060-5 – *Airport Capacity and Delay*	Airport capacity and aircraft delay depends on fleet mix and air traffic control practices and are specific to each airport. Airport planners and designers calculate airport capacity and aircraft delay based on typical hourly demand expected to occur on a weekly basis. Calculations depend on a variety of inputs, including aircraft mix, number, and type of gates, gate mix, and gate occupancy times, among other inputs. **Electric Aircraft**: The main items that will be impacted by electric aircraft is the fleet mix, which will affect the airport capacity.
AC 150/5070-6B – *Airport Master Plans*	Long-term airport development and planning is governed by individual airport master plans. Master plans are intended to develop airports safely and efficiently by looking toward the future to dictate development and planning needs. Master plan studies include environmental considerations, facility requirements, ALPs, facilities implementation plans, and financial feasibility analyses, among other components. They require an inventory of existing conditions, including utility infrastructure and demands such as power needs, to inform quantification of future utility loads. ALPs are a product of the Master Plan Update process that show existing and future airport facilities, requiring approval by the FAA to receive federal funding. **Electric Aircraft**: The Master Planning Update process should consider future electricity needs associated with electric aircraft, including both aviation facility requirements and aircraft-specific power supply requirements. Updates to airport layout plans may be required to integrate infrastructure changes. As part of this report, an airport electric demand Assessment Tool is provided, and may help planners to develop the facility requirements regarding the number of electric aircraft chargers.

Table 9. (Continued).

AC Title	Electric Aircraft Considerations
AC 150/5070-7 – *The Airport System Planning Process*	Airport system planning assesses the performance and interaction of an aviation system, including the interrelationship of airports within the system. It considers state and regional goals related to transportation, land use, and the environment. Elements of the process intended to identify how the aviation system can meet existing and future demand. **Electric Aircraft**: Integration of electric aviation into airport system planning processes provides an important consideration for future studies to enable effective use of federal and local aviation resources.
AC 150/5300-13A – *Airport Design*	Airport design standards ensure a safe, efficient, and economically sound U.S. airport system. Airports, including both airside and landside infrastructure, should be designed to accommodate the range of size and performance characteristics of aircraft anticipated for use at airports and their fueling/charging needs. **Electric Aircraft**: Given the current trends of electric aircraft, there will not be any major impacts on design standards, but they should be considered in the future, when larger commercial electric aircraft will be in service.
AC 150/5325-4B – *Runway Length Requirements for Airport Design*	Determining recommended runway lengths relies on a five-step process. The first step involves identifying the critical design airplanes that will make regular use of the runway for a planning period of at least five years. Step two requires determining which airplanes need the longest runway length based on certificated maximum takeoff weight (MTOW). Small airplanes with MTOW of 12,500 pounds or less are categorized based on approach speeds and passenger seating. The following three steps result in obtaining a recommended runway length based on the prior inputs. **Electric Aircraft**: According to electric aircraft manufacturers, electric aircraft will be more performant than conventional aircraft, and will required less runway length.
AC 36-1H – *Noise Levels for U.S. Certificated and Foreign Aircraft*	Noise level data for certificated aircraft categorizes aircraft into various “stages.” Noise certification ensures that the latest available noise reduction technology, deemed safe and airworthy, is included in aircraft design to reduce noise impacts on communities. **Electric Aircraft**: Noise level data for future certificated electric aircraft would need to be incorporated into this guidance.

Federal Grant Programs

Several federal grant programs exist to encourage industry-wide implementation of sustainable technologies and measures at airports in the United States:

- The **Airport Improvement Program (AIP)** is the main federal grant for the planning and development of public-use airports that are included in the National Plan of Integrated Airport Systems (NPIAS). Eligibility criteria are defined by the U.S. Congress. Projects eligible to these grants shall include improvements related to enhancing airport safety, capacity, security, and environmental concerns. To date, electric aircraft infrastructure and equipment are not eligible for AIP funding.
- The **Passenger Facility Charge (PFC)** is a federal program allowing commercial airports to tax passengers up to $4.5 per flight segment to fund projects enhancing safety, security, capacity, noise reduction, or air carrier competition. Electric aircraft charging infrastructure could fall under the eligibility of this program.
- The **Airport Zero-Emissions Vehicle and Infrastructure Pilot Program** intends to improve airport air quality and facilitate the implementation of zero-emission vehicles at airports. The program allows airports that are eligible for AIP grants to purchase zero-emissions vehicles and the infrastructure required to operate them.
- The **Voluntary Airport Low Emissions (VALE) Program** improves airport air quality and provides air quality credits for future airport development. Created in 2004, VALE helps

airport sponsors meet their state-related air quality responsibilities under the Clean Air Act (CAA). The program has funded projects such as electric shuttle buses, ground power units (GPUs), and preconditioned air units to support gate electrification, charging stations for eGSE, and solar panels to support airport energy flows. Under this program, airport sponsors can use AIP funds and PFCs to finance low-emission vehicles, refueling and recharging stations, gate electrification, and other airport air quality improvements.

- The **Continuous Lower Energy, Emissions, and Noise (CLEEN) Program** was created by the FAA to accelerate the development of new aircraft and engine technologies in an environmental effort. Because environmental protection is an objective of the NextGen strategy, CLEEN is key element to achieve it.
- The **Green Revolving Funds (GRFs)** are internal investments to finance parties within an organization for implementing energy efficiency, renewable energy, and other sustainability projects that generate cost savings. Well-utilized by institutions such as states and universities, airports can receive funding toward sustainability from grants and subsidies or rebates from utility providers.

It is likely that the introduction of electric aviation would have a growing impact on tax revenues from fuel sales. Those effects that occur would likely stem from the long-term growth of electric and hybrid-electric aviation and the corresponding decrease in fuel consumption and purchases in the very long term (beyond 2040). While most funding for the AATF comes from passenger fees, revenue from aviation fuel taxes made up 4 percent of the AATF's total excise tax revenue in 2018. Reductions in fuel tax, while not significant at the beginning, could affect funding availability for some projects or lead to increases in passenger fees to compensate, which could adversely affect aviation ridership.

Congressional Awareness on Policy Needs

The U.S. Congress has started exploring the policy needs of the new airport and airspace users with hearings gathering industry representatives. On May 8, 2019, the U.S. Senate Committee on Commerce, Science & Transportation convened a hearing titled, "New Entrants in the National Airspace: Policy, Technology, and Security Issues for Congress." The hearing examined the current state of our NAS, the status of integration efforts by the FAA for new entrants into the NAS, and the policy, technology, and security challenges that remain. This hearing was followed by another one held on April 27, 2021, on "The Leading Edge: Innovation in U.S. Aerospace."

Proposals for an Advanced Air Mobility Coordination and Leadership Act (H.R.1339 and S.516—117th Congress) were introduced into Congress in February and March 2021. The purpose of these bills is to establish a working group under the leadership of the U.S. Department of Transportation to "plan for and coordinate efforts related to the physical and digital security, safety, infrastructure, and Federal investment necessary for maturation of the AAM ecosystem in the United States."

The working group would be comprised of representatives of federal departments and agencies including FAA, NASA, Department of Commerce, Department of Defense, Department of Energy, Department of Homeland Security, Department of Agriculture, and Department of Labor. It would engage with aviation stakeholders, including electric utilities, energy providers, and market operators.

Per the S.516 bill, the working group will prepare and submit to Congress a report featuring an AAM National Strategy that includes (1) recommendations regarding the safety, security, infrastructure, air traffic concepts, and other federal investment or actions necessary to support the evolution of early AAM to higher levels of activity and societal benefit, and (2) a comprehensive plan detailing the roles and responsibilities of each federal department and agency necessary to facilitate implementing these recommendations.

6.2 Environmental Issues

Environmental Impacts and Considerations of Electric Aircraft

The aviation industry continues to seek innovative ways to improve sustainability by decreasing the environmental impacts of its operations. Electric aviation provides benefits such as reduced noise and emissions. Although the comparison to conventional aircraft would be preferable to quantify the benefits of electric aircraft, it is difficult at this point to quantify the level of noise and emissions reductions possible when electric aircraft are not yet certified. Since noise and air quality impacts are often viewed as a limiting factor for airport operations growth, these are important considerations when planning for the future of electric aviation, as well as fuel cell battery storage and disposal.

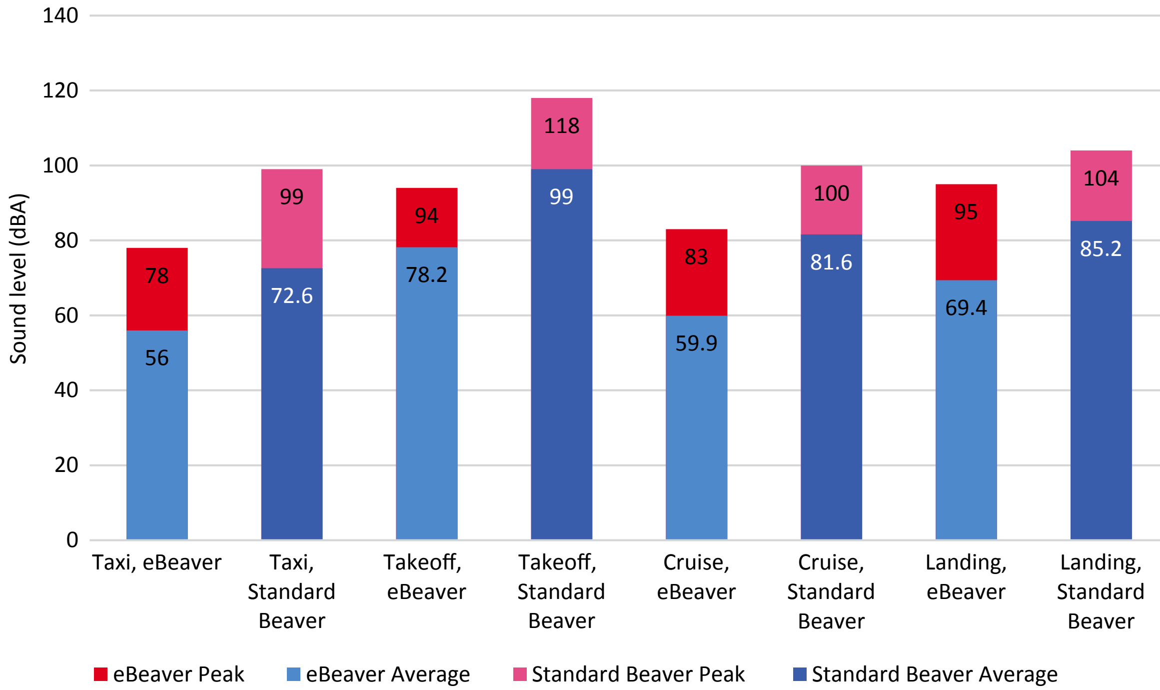
Noise

Aircraft noise has multiple components:

- The aerodynamic noise is generated by the air flowing around the aircraft. This noise component increases with the airspeed and decreases with the aerodynamic performance of the aircraft. During the approach and landing, flaps and landing gear create additional noise when extended. Propellers generate aerodynamic noise as well. This is why the aerodynamic noise of helicopters and open-rotor aircraft (e.g., propfan) can be significant even at low speed due to the rotation of the blades.
- Engines generate noise with the movement of internal parts, combustion of fuel, and—on the turbo and jet engines only—the expulsion of air at high speed. The level of noise generated by the engines can be roughly linked to the thrust. Consequently, at and around airports, takeoff is the phase of the flight where the engine noise is at its highest. Generally speaking, electric engines are quieter compared to combustion fuel engines due to their mechanical characteristics and the absence of the combustion process (with the exception of hybrid propulsion systems).

Some research has attempted to quantify the noise reduction of fully electric aircraft. It is theorized that propulsion noise, the major noise source on takeoff, will be lessened with electric propulsors when compared to turbofans on modern jet aircraft. This would result in a smaller noise footprint near airports as takeoff noise would be reduced. As arrival noise is dominated by noise generated from the airframe rather than propulsion, any reductions in arrival noise would likely be less significant than takeoff noise reductions and would be achieved through other technologies or changes in flight. In addition, the tone and pitch of the noise generated by electric aircraft could change and even reduce. Although the noise is reduced, human perceptions could be more obtrusive and degrade noise comfort. Future studies will have to confirm these potential impacts and should be considered in noise analysis studies, as well as in public education programs. Recent noise measurements performed by magniX on a DHC-2 Beaver retrofitted with an electric powertrain (eBeaver) shows a significant reduction during all phases of the flight (Figure 19).

Through the NAS modernization program named NextGen, the FAA is implementing new Performance-Based Navigation (PBN) routes and procedures. These procedures include Area



Source: magniX.

Figure 19. Noise comparisons between the DHC-2 Beaver and retrofitted magniX eBeaver.

Navigation (RNAV) and Required Navigation Performance to provide for more efficient design of airspace and procedures which collectively result in improved safety, capacity, predictability, and operational efficiency. PBN procedures will increase the accuracy and reliability of lateral and vertical paths, and indirectly reduce the noise footprint on the ground. Moreover, with more accurate flight trajectories, new flight tracks can be designed to avoid noise-sensitive areas. The implementation of such PBN procedures could be facilitated by electric aircraft and will give the airport more option and flexibility to reduce the airport noise footprint without impacting its capacity. Figure 20 shows results from a case study at Hartsfield-Jackson Atlanta International Airport (ATL).

Air Quality Emissions

The transition from conventional thermic-to-electric or hybrid aircraft is expected to significantly reduce direct GHG emissions as fossil fuel combustion is eliminated (i.e., jet fuel and/or aviation gas). In the case of hybrid-electric aircraft, GHG emissions reductions will vary as they depend on the proportion of the flight that is powered by electricity versus fossil fuel turbines. Compared to conventional aircraft, fully electric aircraft emit few or none of the pollutants that adversely affect local air quality. In particular, NOx and fine particulate matter will be greatly reduced due to the reduction in fossil fuel combustion.

Fully electric or hybrid-electric aircraft could significantly reduce the emission of pollutants and GHGs in areas surrounding airports. Aircraft powered by a traditional jet turbine or turboprop engines can produce large amounts of pollutants such as NOx, volatile organic compounds (VOC), sulfur dioxides (SOx), and GHGs. Aircraft powered by piston propeller engines emit larger amounts of CO than jet turbine or turboprop aircraft. To quantify the potential emissions reductions using electric aircraft, the FAA Aviation Environmental Design Tool (AEDT) version 3c was used to estimate potential emission reductions per landing/takeoff cycle of three

Case Study: Hartsfield-Jackson Atlanta International Airport (ATL) PBN Implementation. Since 2010, ATL has implemented RNAV procedures for departures with the following benefits:

- Increase the capacity by 9–12 departures per hour by creating more departure paths and exit points to the enroute airspace.
- Increase the throughput.
- Save annually approximately $30 million.

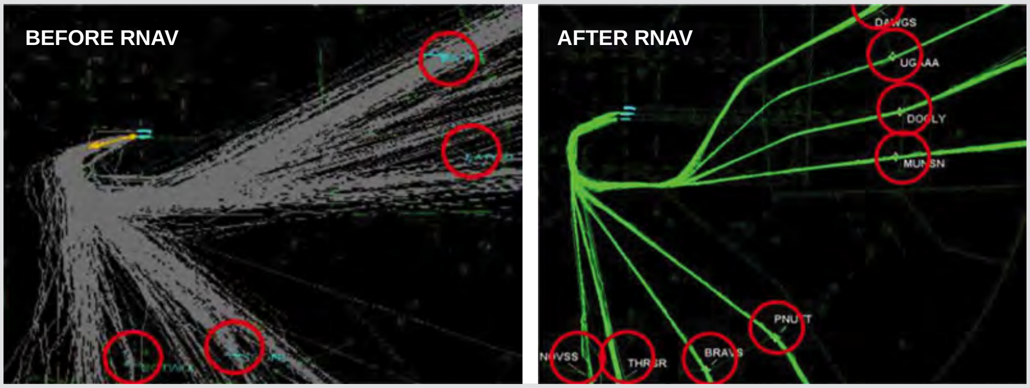


Figure 20. Change in departure trajectories in following PBN implementation at ATL.

representatives of fuel-powered aircraft. The AEDT is a tool developed by the FAA used to model aircraft noise, emissions, and fuel burn and is the current standard model for all civil aviation noise and air quality analyses in the United States. Three representative aircraft were chosen as proxies to experimental electric aircraft currently in development.

To keep the analysis simple, the AEDT run assumes fully electric aircraft potential emissions reductions and does not include a hybrid e-aircraft, which can vary based on the proportion of when fossil fuel and battery chargers would be used. This modeling assumed aircraft used basic straight-in straight-out tracks and AEDT default taxi in and out times at a generic medium-sized hub type airport. Only emissions below a mixing height of 3,000 feet above sea level are considered in this analysis. Potential emissions reductions in pounds per landing/takeoff (simplified as pounds per flight or PPF) are shown in Table 10.

Although in-flight emissions are expected to be reduced, electricity generated and consumed for charging infrastructure represents a likely increase in indirect Scope 2 emissions. Lease agreements may need to include electricity metering so that tenants can properly compensate

Table 10. Potential emissions reductions by aircraft in tons per flight.

Representative Aircraft Type	Fuel Usage (pounds)	NO_x (PPF)	VOC (PPF)	CO (PPF)	PM (PPF)	SO_x (PPF)	CO_2 (PPF)
De Havilland Canada Dash 8	115.3	1.3	0.0	1.0	0.0	0.1	363.9
Cessna 208 Caravan	58.6	0.4	0.0	0.1	0.0	0.1	185.0
Cessna 172	15.8	0.1	0.1	16.5	0.0	0.0	49.7

for the amount of electricity that is used. Scope 2 emissions factors vary based on geography and the electric generation (i.e., utility) fleet mix. In addition, the construction of the charging facilities will also increase direct GHG emissions and must be considered in air quality assessments.

Hazardous Materials

Electric aircraft batteries raise questions regarding their storage and disposal on airport property. Airports and stakeholders should be aware of the risks associated with storing such materials on their property and how to manage them properly. The risk of leakage should also be a concern for airports, and provisions should be made on how to handle such incidents in the Airport Emergency Plan.

Hydrogen fuel cells could also be problematic from an environmental point of view. Currently, there are two ways of transporting gaseous hydrogen:

- By truck in small, pressurized containers or in high-pressure tube trailers.
- By pipeline: conventional pipeline materials have been successfully used for hydrogen up to 1,400 psi, and existing pipelines can be converted to hydrogen service with some limits on stress and pressure.

Either way, the risks of leakage and corrosivity should be a primary concern.

The safety of storing hydrogen at the airport should also be considered. Harvard Environment, Health, and Safety Department developed a hydrogen fact sheet that lists some of the safety precautions to take when storing hydrogen. It states that, to store pressurized hydrogen containers:

- Store the containers with adequate ventilation in a warehouse.
- Temperature of the warehouse should not exceed 125°F (52°C).
- Secure hydrogen containers and tanks to prevent falling or being knocked over.
- Use of flash arrestor on tanks is recommended.
- Store full and empty cylinders separately.
- Building should be equipped with an automatic sprinkler or deluge system in case of fire.

Environmental Regulations and Policies

The following section describes environmental regulations and policies that may have an impact on the integration of electric aircraft at airports and should be considered when planning for the introduction of these aircraft in the future.

National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires federal agencies to evaluate the environmental impacts of their actions and consider alternatives to mitigate potential impacts. For all new projects at airports that require federal action, a NEPA review must be conducted. Airport development projects, ALP changes, and operational changes trigger NEPA review. Federal actions can include the issuance of a federal permit or approval or the granting of federal funds.

FAA Order 1050.1F, "Environmental Impacts: Policies and Procedures," describes the environmental analyses and documentation requirements for complying with NEPA and applicable special purpose laws such as the CAA for aviation projects. The FAA Order 1050.1F Desk Reference gives specific technical direction for environmental analyses, including analyses of potential project air quality, climate, and noise and noise-compatible land-use impacts. In addition, FAA Order 5050.4B, "NEPA Implementing Instructions for Airport Actions," gives added guidance for projects under the scope of the FAA's Office of Airports.

Infrastructure projects required to support the operation of electric aircraft, such as upgrading electrical capacity or adding charging capabilities that require FAA approval of an updated ALP, or use of federal funds, for example, would require a NEPA review. The FAA NEPA orders and accompanying desk references are periodically updated and may include guidance specific to electric aircraft in the future.

Noise

The FAA, in coordination with individual airports and local governments, regulates airport and aircraft noise. The FAA owns and controls national airspace, including the operation of aircraft on the airport and in the air, and regulates maximum noise levels that aircraft can emit through noise certification standards codified in 14 CFR Part 36, "Noise Standards: Aircraft Type and Airworthiness Certification." The FAA, in collaboration with airframe/engine manufacturers, has greatly reduced aircraft noise over time through improvements to aircraft design and technology. As of November 2020, no electric aircraft have received a noise certification.

Additionally, the FAA issues grant funding, ensures compliance with NEPA, and implements 14 CFR Part 150 regulations. As described above, FAA Order 1050.1F, the accompanying Desk Reference, and Order 5050.1B are the FAA NEPA implementing orders. They describe FAA and airport obligations for assessing noise impacts of federal actions, determining projects that required detailed noise analysis for environmental review, and the models and methodologies acceptable for compliance.

To summarize, 14 CFR Part 150 guides airport noise compatibility planning efforts. It sets a standard metric for measuring noise exposure, the DNL. DNL is a cumulative metric that includes a penalty for nighttime noise, representing an average annual day. For purposes of designating compatible and noncompatible land uses, the FAA set a noise level of DNL 65 dB as the threshold of significance for noise exposure.

In addition, 14 CFR Part 150 established a voluntary program governing the development of airport noise exposure maps and noise compatibility programs. Noise exposure maps depict present and future cumulative noise exposure and land use compatibility via noise contours. Noise compatibility programs reduce existing incompatible land use and prevent future incompatible land uses through a combination of measures specific to each airport, intended to mitigate noise. Airports cannot restrict aircraft operations to reduce noise, but they are able to mitigate noise impacts through land use, program management, stakeholder engagement, and operational measures, which the FAA can approve through the Noise Compatibility Program. Part 150 describes procedures and requirements for the development, submission, and approval of noise exposure maps and noise compatibility programs.

In relation to NEPA, FAA Order 1050.1F stipulates that a proposed action would have a significant noise impact if it would cause a noise-sensitive land use in the DNL 65 noise contour to experience an increase in noise of DNL 1.5 dB or more. A significant noise impact would also result if the proposed action exposed a newly noise-sensitive land use to the DNL 65 dB level due to a DNL 1.5 dB or greater increase. Noise analysis guidance defined in FAA Order 1050.1F requires the use of an FAA-approved noise model.

Currently, the FAA's AEDT is used to determine aircraft noise exposure for documentation in environmental analyses. The tool models the noise performances based on the aircraft fleet mix and the number of aircraft operations. With the introduction of electric aircraft into the aviation market, the tool would have to be updated to incorporate in the aircraft fleet mix various electric aircraft, with their noise and emission performances.

Air Quality

At the federal level, the CAA (42 U.S.C. §§ 7401–7671q) gives the EPA authority to specify NAAQS that apply throughout the United States and its territories. Air pollutants subject to the NAAQS are known as criteria pollutants. States that do not meet NAAQS must develop and adhere to State Implementation Plans to reduce air pollution. The FAA *Aviation Emissions and Air Quality Handbook* provides additional guidance, procedures, and methodologies for completing air quality assessments to comply with NEPA and the CAA.

FAA air quality analyses focus on the sources of emissions as in aircraft, auxiliary power units (APUs), GSE, ground access vehicles, construction, etc., as well as the types of emissions that include GHGs and Hazardous Air Pollutants (HAPs). Integrating electric aircraft to the airport operations will automatically impact these air quality analyses: emissions due to combustion engines will be reduced with these new aircraft, but the electric charging equipment and their constructions will generate some emissions. In addition, the upstream energy generations will have to be incorporated in future air quality analyses, unless the electricity used is metered and the airport can clearly account for the electricity used or purchased by third parties.

Hazardous Materials

The generation of hazardous waste during construction, operation, and maintenance of electric aircraft and their charging infrastructure must comply with the Resource Conservation and Recovery Act. Hazardous waste can only be stored on-site temporarily, and special permits may be required. Airports should consider the risks associated with storing additional battery materials on their property and how to manage them properly. They may need to apply for permits to store battery waste over longer periods of time and in larger quantities.

The possibility of soil or groundwater contamination due to spillage or leakage of lithium-ion battery fluids during accidents and incidents is also a risk. Airports will likely need to amend their current emergency planning and reporting structures related to handling battery components under the Emergency Planning and Community Right-to-Know Act. Battery disposal and reuse are other considerations.

General and Transportation Conformity

The CAA requires federal agencies to ensure that their actions conform to the appropriate State Implementation Plan, so that they do not interfere with state air pollution management efforts. Conformity requires that a project or action adheres to the plan's purpose of eliminating or reducing the severity and number of violations of the NAAQS and achieving expeditious attainment of such standards. Federally funded and approved actions at airports are subject to the EPA's General Conformity regulations. The General Conformity rule applies to all federal actions except for certain highway and transit programs, which must comply with the Transportation Conformity Plans (40 CFR Part 93, Subpart A).

The General Conformity rule includes annual emissions thresholds for projects located in EPA-designated nonattainment and maintenance areas that trigger the need for a General Conformity determination and defines projects that are typically excluded from General Conformity requirements. A conformity determination is required if the total direct and indirect pollutant emissions resulting from a project are above *de minimis* emission threshold levels specified in the conformity regulations. A conformity determination is not required if the differences in emissions between the Proposed Action and the No Action alternative are below the applicable *de minimis* emission threshold levels, or if the proposed action is exempt or included in the FAA list of "presumed to conform activities."

Consider a hypothetical example in which an airport proposes to provide electric chargers for charging e-aircraft, which in and of itself would not produce any emissions. Both construction and operational emissions, including reductions from the aircraft (i.e., net benefit) from related activity including any indirect emissions associated with transport or electrical generation (i.e., from the utility) should be compared to appropriate *de minimis* levels as discussed above to evaluate conformity if the project is located in an EPA-designated maintenance and/or nonattainment area. For this comparison, construction emissions associated with any infrastructure related to the electric charging units and operational emissions (i.e., a net benefit of e-aircraft and indirect emissions) should be compared to *de minimis* levels separately. If construction-related emissions or total direct and indirect emissions are above the *de minimis* levels, a General Conformity determination will be required to demonstrate compliance with the NAAQS and CAA. It should be noted that, even if the airport or project is not located in an EPA-designated maintenance and/or nonattainment area, the total construction and direct and indirect emissions should also be reported under NEPA for significance.

Climate

Although no federal standards have been set for GHG emissions, it is well established that GHG emissions can affect climate. Based on guidance from the FAA 1050.1F Desk Reference, state and local policies and programs that address climate change should be discussed in a separate climate section of NEPA documentation.

The FAA has not established a significant threshold for climate and GHG emissions, nor has the FAA identified specific factors to consider in making a significant determination for GHG emissions. No accepted methods of determining significance applicable to aviation or transit projects emissions have been developed, "as such direct linkage is difficult to isolate and to understand." For disclosure purposes, GHGs associated with the alternatives should be calculated in accordance with FAA guidelines and provided in the climate section of the NEPA document.

Airports that develop GHG emissions inventories for NEPA documents, state or local regulatory requirements, or on a voluntary basis should consider how the introduction of electric aircraft may affect that process and how GHGs are categorized. For example, emissions from liquid aircraft fuel are considered Scope 3, or indirect emissions from third parties (airline tenants) under the Greenhouse Gas Protocol and the EPA guidance. Scope 2 emissions are those generated from purchased electricity consumed by an entity, in this case, airports or airlines, depending on how the airport infrastructure and leasing agreements are structured. Unless the electricity used by electric aircraft is metered and the airport can clearly account for the electricity used or purchased by third parties, then the emissions associated with its generation will be attributed to the airport. This is a consideration for airports that have GHG emissions reduction goals and/or participate in formal carbon management programs such as the Airport Carbon Accreditation, which requires that airport members demonstrate emissions reductions over time. Demonstrating progress on GHG emissions reduction goals will be more difficult if the GHGs generated from electricity used by electric aircraft are attributed to the airport.

Storm Water

Construction of electric aircraft infrastructure may require special permits from the EPA to consider the potential discharge of pollutants under the Clean Water Act. New permits may be required specifically for the potential runoff of water contaminated with toxic battery fluids. Airports should verify that EPA permits are applicable for the construction and permanent installation of the anticipated charging infrastructure. Airports should prepare emergency procedures in case battery incidents lead to the discharge of toxic battery fluids.

6.3 Statewide Policies and Plans

State Departments of Transportation

Role of State Departments of Transportation

State DOTs are the core of projects that span across the various travel modes for the respective states. These projects include the planning, design, operations, and maintenance aspects of various transportation modes including highways, rail, and aviation. State DOTs also address a wider range of policy objectives that pertain to planning efforts including, but not limited to, economic development, GHG emissions, and traffic safety. Today, all U.S. states and territories have a division dedicated to aviation and aeronautics or serving the needs of the aviation community. The role of the state DOT aviation division is to assist the respective cities and counties to acquire both federal and state funds to distribute them among the airports in the state. They also have to ensure that all revenues generated from aviation fuel taxes are used on projects that will improve the state's air transportation system. The introduction of electric aircraft may impact some aspects of the state's policies and plans such as the statewide aviation plans, State Block Grant Program, and fuel revenue generation.

Statewide Aviation Plans

States may wish to consider the future introduction of electric aircraft during the statewide aviation system planning process. State aviation system planning is a strategic process to assess all the public-use airports in a given state, determine their and their users' current and future needs, the relationship between the airports, and their ability to meet forecast demands. These plans are also used to evaluate funding priorities and policy or regulatory changes needed to ensure the system's safety and capacity. They often consider the economic impacts and benefits of aviation to a state's economy, how broader industry trends are in turn affecting aviation, and future developments. The planning horizon varies but often includes both short- and long-term analyses. Some considerations for statewide aviation system planners regarding electric aircraft include:

- Electric aircraft manufacturing, maintenance, and associated employment opportunities.
- Impact on FBOs and fuel sales, which are a significant revenue source for general aviation airports.
- Need for additional electrical meters or upgraded electrical supply infrastructure and costs to industry for those upgrades.
- Benefits to flight training including the reduced cost from fuel and maintenance.
- Community engagement opportunities surrounding anticipated lower noise and emissions.

State Block Grant Program

The State Block Grant Program, introduced and authorized by Congress in 1987, is a funding program where the FAA releases AIP funds to each individual state, and in turn, the receiving state takes over the responsibility of prioritizing and distributing the funds to small airports including non-primary commercial airports, reliever, and general aviation airports. There are currently 10 states that participate in the State Block Grant Program. The introduction of electric aircraft, especially smaller ones that may primarily be used in smaller airports, may have an impact in the prioritization and distribution of these funds.

State Fuel Revenue

According to the FAA, state taxes on aviation fuel are considered airport revenues. Fueling revenues—in the form of sales revenue and retained fuel taxes—represent a large portion of airports' non-passenger aeronautical revenues, making up to 18 percent (a total of $418 million) in 2018. These revenues are used for capital and operating costs of the airport or other facilities owned by the airport and are involved significantly in the transportation of passengers to the airport property. As the prevalence of electric aircraft grows, airports, FBOs, and fueling service providers could begin to experience reduced revenue from aircraft fueling operations. The decline in the fuel tax revenues would redirect the state policymakers to assess other means of paying for the transportation infrastructure, such as passenger fees.

Aircraft Registration Fee

As stated above, the introduction of electric aircraft would impact many state's fuel tax revenues. The shift from aviation fuel to other greener power supplies such as electricity would reduce some revenue-generating sources such as fuel revenue as stated above. In some states, with regards to electric vehicles, there is an incentive on the registration fees for electric vehicles to encourage the purchase of more electric vehicles. For other states, a policy being considered is applying a separate registration fee for some hybrid and fully electric vehicles in addition to the standard vehicle registration fees. This additional fee would replace the losses in fuel revenue. Similar to this additional registration fee imposed on hybrid and fully electric vehicles, the introduction of electric aircraft may follow the same policy. However, aircraft do not typically operate within one state only, which will complicate the establishment of such policies if it is not a federal incentive. These measures will probably only concern commercial aircraft to encourage airlines switching to electric aircraft.

Other Electric Aircraft Domains

Electricity Generation, Distribution, and Pricing

The sale of electricity in the United States is guided by various regulations across the federal, state, and local regions. For the sale of electricity and retail transactions when it comes to the electrification of the transport system, for example, electric vehicles, the regulatory jurisdiction usually falls on the state according to the Federal Energy Regulatory Commission. Currently, it is unknown if and how electricity operators should be regulated when it pertains to the use of electric chargers for electric vehicles, which may project to that of electric aircrafts.

Electricity pricing is less volatile than petroleum, which will increase stability in airport financial planning should electrification increase statewide. The price of electricity generation is predicted to decrease, but the requirement of widespread distribution is likely to keep prices level. Research on electricity rates indicates that the cost of electricity varies between cities and providers and is also highly dependent on how electrical energy is drawn from the grid.

Utility Submetering

Several states have laws that regulate "utility submetering," which is defined as the implementation of meter systems that allow the operator or owner of a building or facility to bill tenants for individual utility usage through the installation of additional meters behind a utility meter. Some of these laws could prevent airports and states from charging an additional fee on electricity for aviation purposes. If airports and states decide to establish such taxes, they might have to restrict the use of the revenues to aviation and aeronautical purposes to prevent profit diversion and other conflicts with FAA rules. Submetering laws vary from state to state:

- In some states, the choice of submetering falls on the landlords or facility operators. They usually use a master meter, where the landlord purchases energy from the utilities provider then in turn sub meters it to their tenants.

- In some states, the landlord or facility operator requires approval from the public utility commission for submetering to be provided.
- Other states, rather than submetering, authorize the use of individual metering where each tenant is individually metered directly by the utility company without the landlord or facility operator being a third party.

Figure 21 shows the different electricity submetering laws across some states.

Electricity Surcharges

Surcharges are additional fees added to initially quoted utility, in this case electrical, bills of consumers, usually in the form of an administrative fee. These added fees are usually approved by electricity regulators to make up for costs that would impact the financial health of the individual or group that requests such fees from their customers. An example of a situation that may warrant the surcharge of electric bills could be airports that may be affected by the loss of refuel tax revenue due to the growth of electric aircraft, and thus the additional fees would help offset the difference in revenue acquisition. Figure 22 shows the variation of surcharge laws among some states.

Statewide Electric Aircraft Initiatives: Case Studies

Washington Department of Transportation

The Aviation Division of the WSDOT conducted an electric aircraft feasibility study to aid in the development of a roadmap to ease the introduction and implementation of the electric aircraft industry for relevant stakeholders, including airports, policymakers, industry, and the general public. The Washington state legislature directed the WSDOT

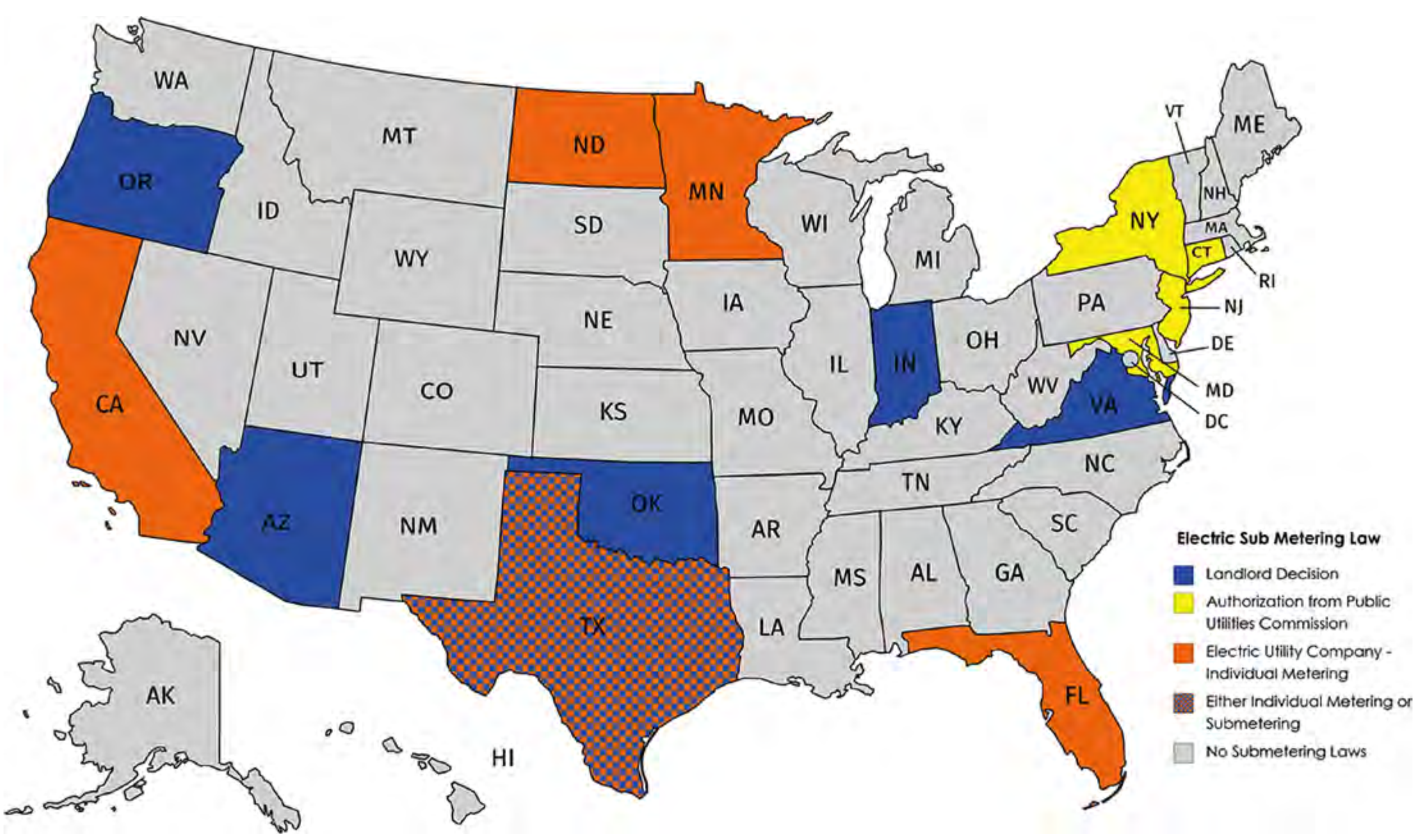


Figure 21. Utility submetering laws among some states.

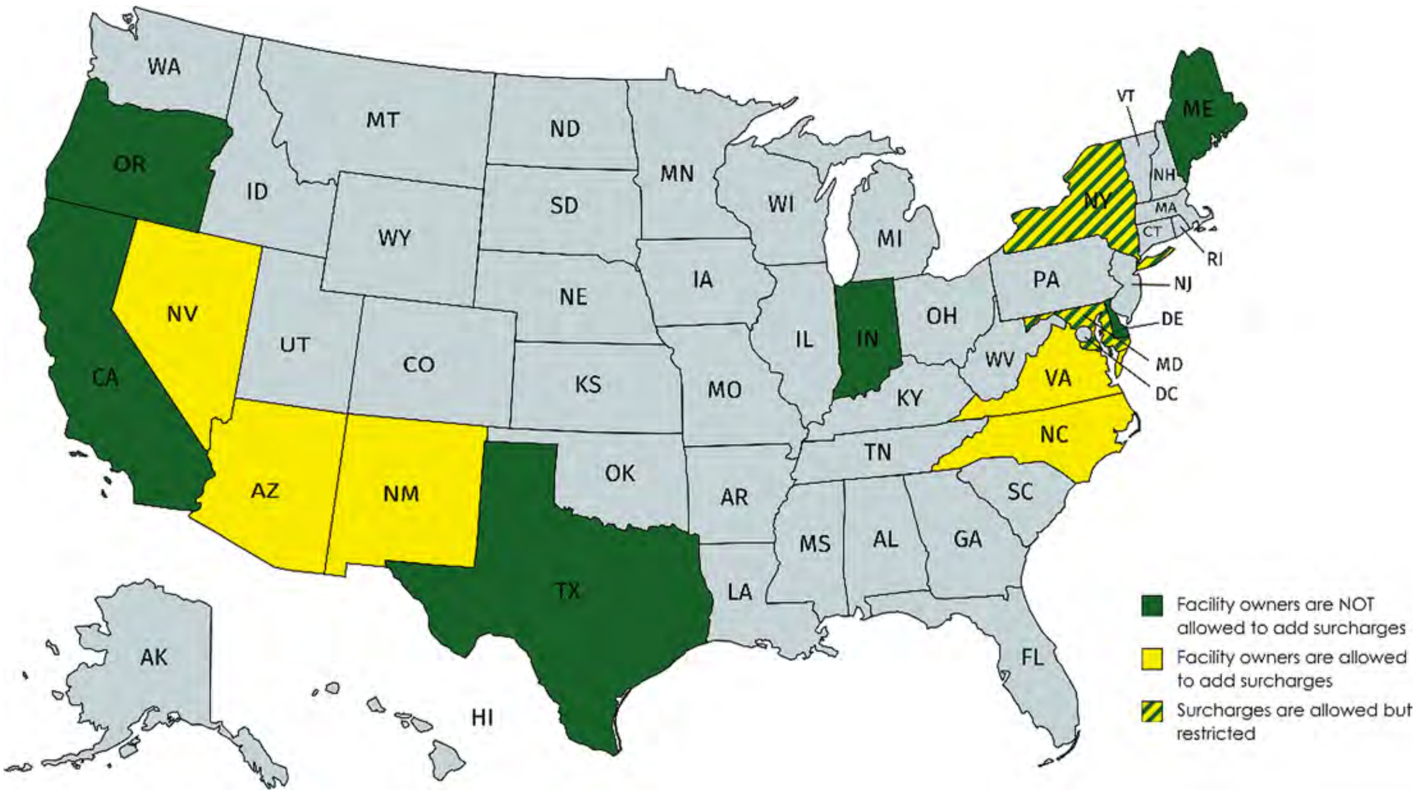


Figure 22. Utility surcharge laws among some states.

aviation division to create an Electric Aircraft Working Group to study electric aircraft service statewide.

The research study, which was carried out over the span of months, looked specifically into five different types of aircraft and their purpose of flight. Each type of aircraft was associated with one scenario as follows:

- Regional commuters that carried fewer than five passengers over a 50-mile range.
- Regional commuters that carry fewer than 15 passengers for scheduled operations.
- General aviation, personal, or business use aircraft that carries between one to six passengers with an average flight time of 43 minutes.
- Light cargo aircraft with a maximum load of 7,500 lbs. and a cruise speed of 200 mph.
- Pilot training aircraft that carry one pilot and one passenger with a cruise speed of 125 mph.

The conclusions from the study are as follows:

- **Infrastructure**: The study determined that the major change in airport infrastructure to accommodate the electric aircraft will be on the airfield. There will be the need for the provision of power and charging capabilities for the electric aircraft because electric aircraft will require the maintenance and charging needs of the aircraft to be met at both the origin and destination airport.
- **Economic Impact**: The assessment of the impact of electric aircraft on the economy of the state was positive and showed:
  - The introduction of electric aircraft will significantly impact passengers and cargo time and cost when traveling, especially over short and congested routes.
  - The reduction of carbon-emission gases attributed to aircraft operations would, in turn, reduce environmental and health costs.

   - One very important but unknown factor for the implementation of electric aircraft into airports is the cost to provide infrastructure and facilities to accommodate electric aircraft at airports. The current state and federal grants can assist in part of the developmental cost, but other areas should be identified and looked into at the local level to support the charging infrastructure and electricity supply needs. Although there are currently no standardized or directly applicable sources of funding, the future may pave the way for funding opportunities if and when public transportation and AAM infrastructure and facilities combine.
- **Demand Assessment**: The study identified different factors that affect or will affect the demand for electric aircraft. These factors include FAA certification, public perception, market availability, available routes, electrical infrastructure, airline adoption, state and federal regulation, cost of traveling, and battery capacity and density.
- **Workforce Development**: The study also identified a number of potential job opportunities for its residents that will come with the development and implementation of the electric aircraft. They recommended that the workforce for electric aircraft can build on the existing workforce to generate new electric aviation-focused training to keep the workforce up to speed.
- **Selection of Beta Testing Sites**: Lastly, the study looked into a few selected airports that were deemed capable of serving as beta testing sites for the demonstration of electric aircraft technology functionality to determine the benefit of electric aircraft across the state of Washington.

Colorado Department of Transportation

The Colorado Department of Transportation is conducting an Airport Electric Charging Infrastructure study for 2021 to develop new statewide incentives as part of its Strategic Plan. Similar to the study conducted by the WSDOT, the purpose of this study is to develop a framework to inform and help the relevant stakeholders, including Colorado airports, flight schools, aircraft manufacturers, and the Colorado Department of Transportation itself with important information to help in the innovative development and implementation of electric aircraft. The primary focus of this project, according to the Colorado Aeronautical Board, is:

- An overview of the existing state of the small electric aircraft industry.
- Analyzing the various types of charging infrastructure and capacity needed by the smaller general aviation aircraft.
- An inventory of the existing electrical service for four selected general aviation training intensive airports (Centennial Airport, Rocky Mountain Metropolitan Airport, Northern Colorado Regional Airport, and Colorado Springs Airport). In addition, an analysis of the capability of said service to support electric aircraft activities will also be made.
- An overall cost estimate for airport electrical service upgrades to accommodate the potential electric aircraft demand and follow-up analysis and evaluation of sources of funds for the upgrades.
- An analysis of potential funding mechanisms that could be implemented by airports, FBOs, and aircraft operators to fund the capital and lifecycle costs of electric aircraft charging infrastructure.

6.4 Electric Aviation Policies Abroad

Norway

Regional air transportation is a lifeline for many communities in Norway that cannot be timely served by road or rail because of the geography and topography of the country. Moreover, aviation is crucial because of its importance for export industries and tourism; it also supports about 60,000 direct aviation jobs.

Norway has committed itself, together with the European Union, to reduce carbon emissions by 40 percent by 2030, and then 80 to 95 percent by 2050, compared with 1990 levels.

The Norwegian Civil Aviation Authority and Avinor, the main airport operator of the country, are working to develop initiatives and roadmaps toward zero-emission and fossil-free aviation by 2050. Fossil-free energy vectors include sustainable aviation fuel, electricity, and hydrogen. These goals do not include emissions from aircraft production and infrastructure construction for aircraft. They consider that electricity from the electric grid in Norway is fossil-free.

In March 2020, the Norwegian Civil Aviation Authority published a report, "Forslag til program for introduksjon av elektrifiserte fly i kommersiell luftfart" (or the Proposed Program for the Introduction of Electric Aircraft in Commercial Aviation), prepared jointly with Avinor. The first electric aircraft will be small fixed-wing aircraft, with a capacity of up to 19 seats and a short-haul range; the report considers these aircraft to be the most relevant for Norwegian conditions. Indeed, the Norwegian air transportation system features short-haul routes connecting airports including several 800-meter-long runways exposed to harsh winter conditions that few aircraft can operate.

To meet the Norwegian climate commitments by 2050, three goals were defined:

- Norway will be a driving force and arena for the development, testing, and early implementation of electrified aircraft.
- By 2030, the first domestic scheduled routes will be operated by electric aircraft.
- By 2040, all civilian domestic flights in Norway will be operated by electric aircraft, to reduce GHG emissions by at least 80 percent compared with 2020.

To achieve these objectives, the report proposed the following recommendations:

- Become a driving force and an arena for the development and implementation of zero- and low-emission aviation technology:
  - Continue the joint multiannual international zero-emissions program developed by the Norwegian and European civil aviation authorities (through CAA Norway and EASA).
  - Prepare a roadmap with a working group consisting of Avinor, airlines, aircraft manufacturers, and public authorities to achieve the goals.
  - Establish an international arena/center for the development, testing, and implementation of zero- and low-emission aviation technology.
  - Define suitable airspace for testing purposes.
  - Coordinate aviation and climate objectives at a national level between government ministries and agencies, state-owned companies, and the state public support system.
  - Prepare an administrative and economic scheme for testing activities in Norway.
  - Take part in the European Union's Horizon Europe/CleanSky research program.
  - Communicate the initiatives and measures that are being launched to the public.
- Establish state policies and incentives to support the transition to electric aircraft:
  - Grant assurances to develop charging infrastructure at Norwegian airports (Enova program).
  - Incentives or government loads for electric aircraft purchases.
  - Possible state guarantee concerning residual value.
  - Taxes exemption for small electric aircraft used for flight schools or private pilots.
- Establish state policies and incentives for aircraft operations:
  - Integrate the requirement of emission-based evaluation criteria for a proposed new route by a public service obligation.
  - Air passenger tax exemptions or reductions for zero or low-emission aircraft until 2040.
  - Value-added tax exemptions or reductions on airline tickets for zero- or low-emission aircraft until 2040.
  - Reduced aviation charges for Avinor, with European Union regulations accordance.
  - Reduction in electricity tax for commercial aircraft.

In summer 2020, a workgroup with industrial Norwegian stakeholders presented a roadmap to the Norwegian Transportation Ministry to achieve the defined goals. Avinor published a report in October 2020, "Bærekraftig og samfunnsnyttig luftfart" (or Sustainable and Socially Beneficial Aviation), to describe this roadmap. Norwegian airlines already expressed its interest to transit to electric aircraft, and committed to strong objectives by 2030:

- SAS: reduction to 50 percent of total CO_2 emissions of 2005.
- Norwegian: reduction by 45 percent per passenger kilometer (km) compared to 2010 through both fleet renewal and the use of sustainable fuel.
- Widerøe: transition to an all-electric short-haul fleet in the period up to 2030–2035.

Avinor has also committed to making its airport operations fossil-free by 2030. Since electrification of aviation also requires new infrastructure at airports, Avinor has promised that electrified small aircraft will receive a tax exemption and free electricity until 2025. Furthermore, Avinor has stated that the company takes responsibility for ensuring that adequate charging infrastructure is in place for charging electrified passenger aircraft when applicable. Avinor and partners are also studying how smart energy management, power production, and optimal use of the power grid can ensure the charging of electric aircraft, ships, and buses without unnecessarily large investments in existing power grids. Finally, Avinor is thinking about using the battery of electric cars parked in its long-term parking for energy storage purposes. This electricity could be released at the peak demand. Car owners would have incentives for "sharing" their battery with the airport (e.g., parking fee reduced or waived).

Nordic Network for Electric Aviation

In 2020, Denmark, Finland, Greenland, Iceland, Norway, and Sweden gathered around the Nordic Network for Electric Aviation. The network is part of Nordic Innovation, an organization under the Nordic Council of Ministers that is the official intergovernmental body for cooperation in the Nordic region.

Sixteen industry stakeholders of these countries, including airlines, airport operators, aircraft manufacturers, and research institutes, worked together with four objectives:

1. Standardize electric air infrastructure in the Nordic countries.
2. Develop business models for regional point-to-point connectivity between Nordic countries.
3. Develop aircraft technology for Nordic weather conditions.
4. Create a platform for European and global collaboration.

United Kingdom

The United Kingdom (UK) government is targeting 2050 to achieve zero GHG emissions by aviation, consistently with the Paris Agreement. In April 2021, the government announced the objective to cut UK emissions by 78 percent by 2035 compared to 1990 levels, which will take the country more than three-quarters to the 2050 goal.

To achieve these objectives, the authorities are funding several projects through two institutes: the Aerospace Technology Institute and the Future Flight Challenge, both administrated by the UK Research and Innovation (UKRI). The latter is under the authority of the British government and directs research and innovation funding. Although the zero GHG emissions objective is the primary goal, several additional objectives were defined to support broader environmental aspects: increasing mobility, improving connectivity, reducing domestic congestion, and increasing manufacturing and service opportunities through new technology development.

The country's geography is conducive to benefit from the advantages of regional aviation transport. Knowing that the first commercial electric aircraft will be relevant to fulfill these missions, the UK government has pushed forward to electrify domestic flights. In this context, the UKRI started to fund several projects:

- In *Scotland*, Highlands and Islands Airports Limited (HIAL) has launched in 2021 a £3.7 million project to develop a sustainable aviation program between remote communities. This part of Scotland is not suitable for the development of conventional, direct ground transportation. The first low-carbon aviation test center will be based at HIAL's Kirkwall Airport in the Orkney Islands. In July 2021, the initiative should start test flights with Ampaire's Electric EEL (6 seats) between Kirkwall and Wick, two small airports 35 miles away from the other (20-min flight time).
- *Hydrogen Electric and Automated Regional Transportation* is a project led by a consortium of nine UK organizations. It aims to develop an automated zero-carbon regional air transportation network, through advanced autonomous controls on Britten-Norman BN-2 Islander aircraft equipped for single-pilot operations, and with a hydrogen-powered aircraft, with a capacity of up to 19 seats and a range up to 500 NM. The project is not only focusing on the aircraft itself, but it will also consider hydrogen production and distribution infrastructure. UKRI funded the project with £3.74 million ($5.14 million).
- *2ZERO (Towards Zero Emissions in Regional Aircraft Operations)* is led by Ampaire and ran by a consortium of different aviation stakeholders, universities, and utility providers, to demonstrate the feasibility of regional electric aviation transport in the southwest of England. This initiative is similar to the HIAL pilot project and will also include Ampaire Electric EEL aircraft in the first phase, and then a 19-seat Eco Otter SX, which is a hybrid-electric conversion of the Twin Otter commuter aircraft. This project is funded by £30 million from the UKRI and aims to model and simulate a point-to-point route system for regional flights.

Other Initiatives

Other technologies for researching and developing electric aircraft technologies include the following:

- *Clean Sky*: In 2008, the European Union created Clean Sky, the largest European research program for aviation research and innovation, to significantly reduce aircraft emission and noise levels. This public-private partnership between the European Commission and the aviation industry was launched as an aeronautical research program to coordinate research and innovation between the industry, research centers, and academic partners. The first phase of the program, Clean Sky 1, had a budget of 1.6 billion EUR and ended in 2017. Started in 2014, Clean Sky 2, the second phase of the program, explored innovative technologies related to aircraft design, but also specific aircraft components, such as engines, airframe, avionic systems, etc. Clean Sky 2 has a 4 billion EUR budget and still runs until 2024. The purpose of this second phase is to respond to the Flightpath 2050 goals set by the ACARE with a 75 percent reduction in CO_2 emissions, 90 percent reduction in NOx, 65 percent noise reduction, and design/manufacture aircraft components with recyclable materials, to mitigate the environmental impact of the lifecycle of aircraft. Clean Sky 2 includes research on the replacement of conventional engines at the 2035 horizon for meeting Airbus A320 requirements: 150 passengers, a Mach 0.78 cruise, and a 1,200 NM (2,200 km) range. Three hybrid-electric propulsion engines were presented in 2019. Hydrogen technologies were also investigated by the program, and a report, "Hydrogen-powered aviation: preparing for takeoff," was delivered in 2020. Clean Sky 3 that was scheduled to begin in 2021 continues these efforts toward greener aviation technologies.
- *Japanese Aerospace Exploration Agency (JAXA) Electrification Challenge for Aircraft (ECLAIR)*: In 2014, JAXA started an electric aircraft program, called Flight Demonstration

of Electric Aircraft Technology for Harmonized Ecological Revolution, to accelerate electric aircraft development in Japan. This project focused on technologies for electric engines, combined with fuel cells, and hybrid propulsion systems. In 2020, the Japanese Prime Minister declared that its country will reduce GHG emissions to zero by 2050. To achieve this objective in aviation, JAXA launched the ECLAIR consortium between industry partners and the Japanese government for the development of innovative electric aircraft technologies. The platform Next Generation Aeronautical Innovation Hub Center was created to facilitate the collaboration between the stakeholders regarding research and development of new technologies.

CHAPTER 7

Impact of Electric Aviation on the Demand

7.1 Perspective on the Aviation Demand

Implementation Timeline

Short-Term Perspectives (2025 Horizon)

In the market assessment, the model forecasts indicate only a modest fleet size, accounting for less than 2 percent of the total fleet mix. It is expected that aircraft operators will be converting or replacing existing airplanes, as presented in *Chapter 4, Market Assessment*, assuming that they can capture operational savings that justify the upfront capital costs, and that the FAA certifies thermic-to-electric retrofitting (via STCs) and new electric aircraft types (via TCs) under the "Airworthiness Standards" of either 14 CFR Part 23 (Normal Category Airplanes) or 14 CFR Part 25 (Transport Category Airplanes).

This effort will begin with smaller aircraft (2 to 12 seats). Small air carriers involved with pilot projects (e.g., Harbour Air Seaplanes) or committed to pioneer electric aviation (e.g., Cape Air) will fly these commuter aircraft as soon as they are certified for commercial service. These air carriers may report a slight increase in passenger demand as a result of emerging electric aircraft if they meet their expectations regarding operating costs. Flight schools and clubs (e.g., Aspen Flying Club, OSM Aviation Academy), as well as private owners will start purchasing electric aircraft as well, as long as the price tag and operating costs are competitive.

The first prototypes of larger regional e-aircraft (20 to 60 seats) may fly by 2025. These prototypes might be existing, commercial retrofitted aircraft with electric powertrains at first. For instance, in 2020, MagniX and Universal Hydrogen announced teaming together for developing retrofitting solutions for Dash 8-300 and ATR 42. Due to the higher electric power demand of this category of aircraft, fuel cells powered by hydrogen might be required to enable adequate payload and range, at least until new generations of batteries with higher power densities are available.

Medium-Term Perspectives (2030 Horizon)

The runup to 2030 is still too early for dramatic shifts in demand to electric flights, so significant changes to the air travel demand induced by electric aviation are not likely in this timeframe. In other words, electric aviation will not be a major driver of passenger demand growth at this horizon. The potential increase in air travel and passenger throughput that could occur as a longer-term impact of electric aviation is still uncertain because electric aviation is still emerging. In addition, the effects of the COVID-19 pandemic and the shape of the recovery could affect and delay the investments of air carriers into new aircraft types and lower their appetite for disruptive technologies due to inherent risk exposure.

However, it is expected that electric aviation will make its case in regional aviation, general aviation, and flight training (Figure 23). If it delivers in terms of lower costs, it can boost regional

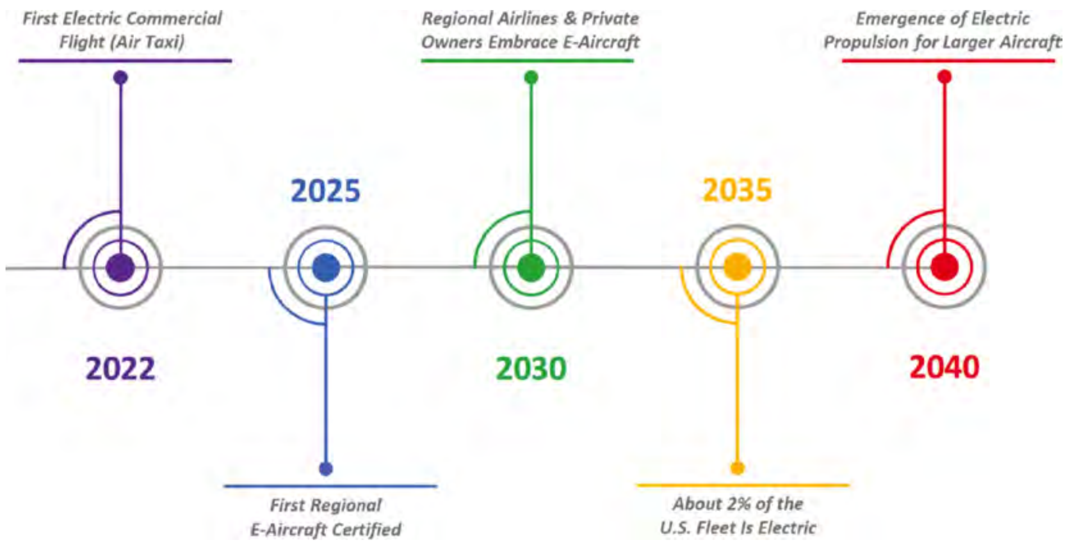


Figure 23. Potential timeline of electric aircraft implementation.

aviation and generate a new type of regional air mobility that connects smaller communities and larger metropolitan areas on short-haul flights. A favorable framework at the state level that addresses the challenges described later in the analysis can enable and promote the emergence of regional leaders in electric aircraft operations. As of today, Colorado and Washington state are exploring options for facilitating the implementation of electric aviation statewide.

Long-Term Perspectives (2040 Horizon and Beyond)

The next step to the electrification of large commercial aircraft (60+ seats) requires a replacement for turbojet engines that has yet to be defined because the technological path to fully electric or hybrid airliners is not yet clear. Growing environmental concerns and social expectations, international and federal policies, and industry practices might push aircraft operators and manufacturers to invest in electric and hybrid options for larger aircraft.

Air carriers are already committing to mitigating their emissions. For instance, JetBlue started to offset the carbon emissions of all its domestic flights in 2020. Robin Hayes, CEO of JetBlue, explains that "reducing and mitigating our GHG emissions is a fundamental aspect of our business plan and our mission to inspire humanity." Delta Air Lines has a 10-year program to mitigate all its emissions. For international aviation, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) is an ICAO-led global carbon-emission mitigation approach that promotes Sustainable Aviation Fuels and carbon offsetting. However, these are only the first steps toward greener aviation.

Electric and hybrid aircraft might be the next step to reduce aviation's contribution to climate change and make the industry less reliant on fossil fuels. Electric aviation, along with hydrogen-powered jet and turboprop engines, can be an evolutionary step toward greener aviation beyond carbon offsetting.

Airport Use Cases

Overview

The objective of this use-case approach is to relate the concept of operations to its environment and the constraints and demands on the supporting airport infrastructure. Metrics of interest associated with these operations follow:

- **Aircraft utilization**: Number of flight hours flown by a single aircraft during a given time period (day, month, or year). A higher aircraft utilization yields lower operating costs because fixed costs are then amortized over a larger number of flight hours. However, the increased amount of flying results in higher energy needs from the supporting airport electric infrastructure.
- **Turnaround time**: Time spent on the ground between subsequent flights. Shorter ground turnaround times enable higher aircraft utilization. This reduces the time available to recharge batteries and requires quicker energy transfer. High-power superchargers can be used to quickly recharge batteries but result in higher power demand from the electric grid and, therefore, higher electricity costs. Swappable batteries can be used to reduce the turnaround time, but this requires a supporting infrastructure to recharge and store additional spare batteries.
- **Operational tempo**: Operational tempo is a measure of the intensity of operations. Short turnaround times define high-tempo operations while extended turnaround times define low-tempo operations.
- **Monthly energy need**: Amount of electric energy needed over the course of one month to recharge the batteries of aircraft operating from an airport.
- **Electric power demand**: Maximum instantaneous power drawn from the supporting electric grid to power battery chargers.

Important: The forecast used in the following airport use cases does not take into consideration the impact of the COVID-19 pandemic that will postpone the occurrence of the level of traffic depicted. A delay of 2 to 5 years might be introduced starting in 2020 to account for the traffic drop and the recovery.

Flight Training

Pilot training is typically divided into ground training and in-flight training. Ground training typically consists of pre-flight instruction and post-flight debriefings. In-flight training usually consists of flights lasting between 45 minutes and 90 minutes, followed by the refueling of the aircraft for subsequent training flights. As a result, missions are quite short and separated by a short turnaround time. Because most flight training missions occur during daylight hours, yearly aircraft utilization is not very high (about 375 hours per year). However, the tempo of operations during the day is higher, and training operations will likely require fast chargers so as not to increase the turnaround time between flights. Flight training is usually done with simple, non-complex aircraft to lower training costs. Using the baseline vehicle presented in Table 11, a flight training aircraft is likely to be similar to the Pipistrel Alpha Electro.

Flight training is usually carried out in smaller and quieter airports because training at larger and busier airports creates inefficiencies given the time spent waiting for flight clearances or avoiding wake turbulence. Four airports were selected to represent the spectrum of airports supporting flight training operations. The first is Paulding Northwest Atlanta Regional Airport (CNI), a non-towered basic airport. The second is McClellan-Palomar Airport (CRQ), a towered airport in a class Delta airspace and home to several flight schools. The third is Prescott Regional Airport (PRC), a towered airport in a class Delta airspace and home to a large flight training school. Finally, the fourth is Grand Fork International Airport (GFK), a larger towered airport in a class Delta airspace and home to a large flight training college. The historical and forecast activity at these four general aviation airports is provided in Figure 24 using data from the FAA.

To estimate energy and power demand, some assumptions are made regarding the state of charge of the batteries, the fraction of aircraft performing flight training missions, the type

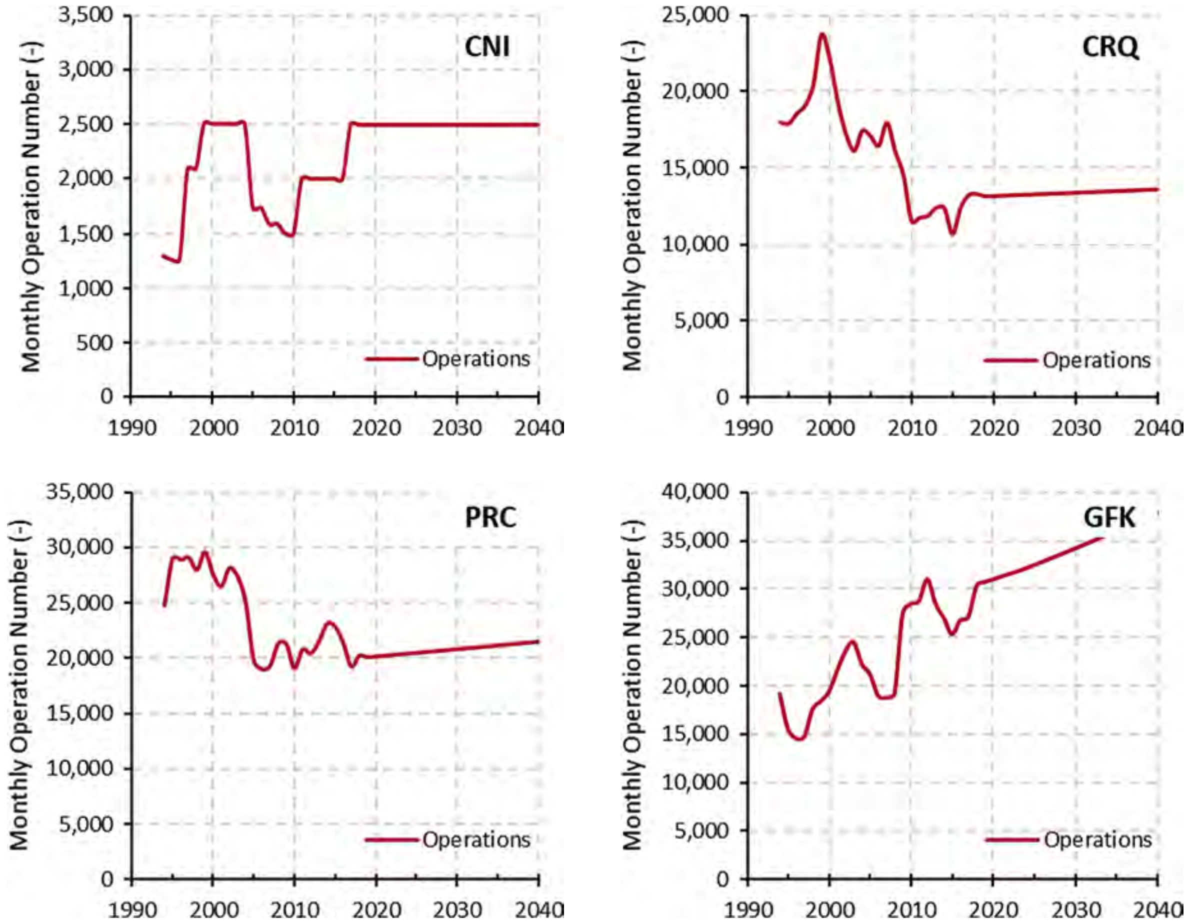


Figure 24. Activity at a selection of airports supporting flight training operations.

of battery chargers used, and the market penetration of electric aircraft. For this use case, the assumptions are documented below:

- The limited range and endurance of electric flight training aircraft and the typical length of flight training missions imply that batteries are depleted upon landing (i.e., down to a 20 percent state of charge) and must be fully recharged (i.e., up to a 90 percent state of charge) for the subsequent departure. Because of the short ground turnaround time of flight training aircraft, the Pipistrel company's fast charger, which is rated at 20 kW, is selected to recharge batteries between flights.
- All but one daily battery recharge occurs between 9 a.m. and 8 p.m. The final recharge takes place at night using lower recharge power.
- Owing to the nature of the airport selected, most of the operations taking place at these airports are assumed to be flight training operations. This is a statistically reasonable assumption, given the high tempo of flight training operations during the day and the lower tempo of other operations at these airports.
- The market penetration is assumed to be between 20 and 100 percent. Many flight schools amortize their aircraft over a long time period, owing to low profit margins of their business. This may lead to a slow introduction of electric aircraft within the fleet of flight schools and, therefore, a low market penetration for electric aircraft. Still, the significant operating cost reductions expected with electrification could provide incentives for flight training schools to renew fleets.

Estimations indicate monthly energy needs between 8 megawatt-hours (MWh) and 40 MWh at CNI, 40 MWh and 220 MWh at CRQ, 60 MWh and 350 MWh at PRC, and 110 MWh and 620 MWh at GFK. A 50 percent market penetration for electric aircraft yields energy needs between 20 MWh at quieter airports and 300 MWh at busier airports to support flight training operations, as indicated in Figure 25.

The power demand corresponding to these energy needs is provided in Figure 26. Power demand is expected between 25 kW and 150 kW at CNI, between 100 kW and 600 kW at CRQ, between 200 kW and 950 kW at PRC, and between 350 kW and 1.8 MW at GFK. A 50 percent market penetration for electric aircraft yields power demand between 75 kW and 900 kW to support flight training operations at these four airports.

Personal Use

Personal-use aircraft have a typical capacity of between two and six passengers. These operations are usually characterized by very low utilization (about 128 hours per year). A leisure vehicle used to reach a weekend house is used twice a week, with extended periods on the ground during which the vehicle can be recharged. These vehicles do not need VTOL capability and will likely be similar to the Bye Aerospace SunFlyer 4/Eflyer 4 aircraft. A work vehicle used to commute every day to and from work is used significantly more but stays on the ground for extended periods of time between flights. VTOL is probably desired, but the extended time on the ground between flights is likely to be incompatible with the limited footprint of vertiports in large cities. Owing to the extensive idle periods on the ground, it is likely that batteries will be recharged directly in the aircraft using low-power chargers. This helps decrease the peak-power demand and thus the cost of electricity.

Personal aircraft can be operated from any type of airport nationwide. Nonetheless, operations are statistically more likely to be operated from busier local or regional airports close to large metropolitan areas. Four airports are again selected to model the wide variety of airports

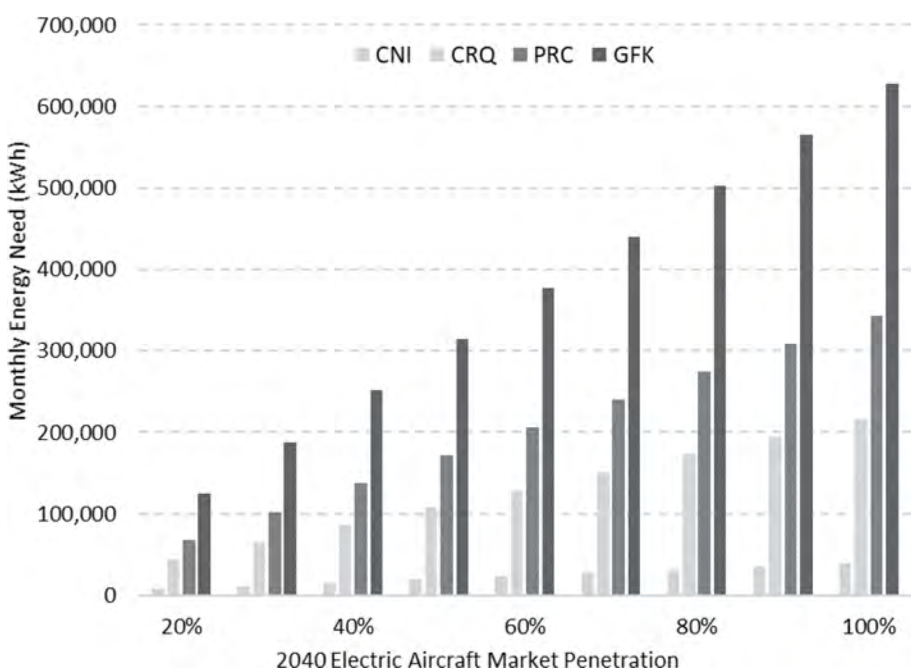


Figure 25. Potential electric energy requirements for different levels of electric aircraft market penetration at airports supporting flight training operations.

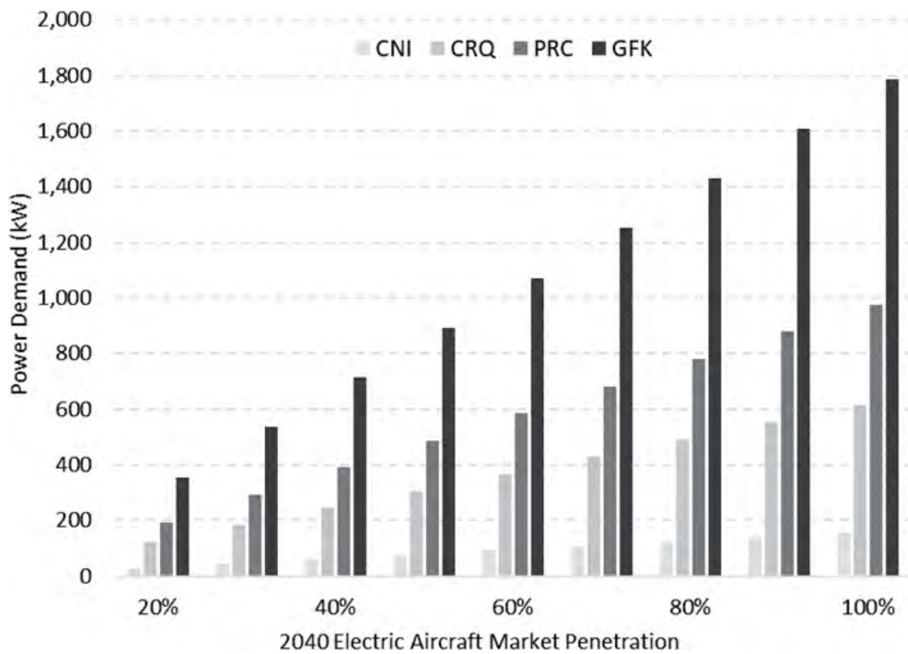


Figure 26. Potential electric power demand for different levels of electric aircraft market penetration at airports supporting flight training operations.

used for personal use. Dekalb-Peachtree Airport (PDK), close to Atlanta, is a towered airport in a class Delta airspace where many personal private planes are based (more than 300 aircraft according to the FAA). Miami Executive Airport (TMB) is another large general aviation airport in a class Delta airspace and serves the southern part of the Miami metropolitan area. Teterboro Airport (TEB) is a towered general aviation relief airport in New Jersey catering mostly to general aviation traffic to and from New York City. Finally, Van Nuys Airport (VNY) is one of the largest general aviation airports in the United States. It is a towered airport in a class Delta airspace serving traffic to the San Fernando Valley section of the City of Los Angeles. The activity at these four airports is provided in Figure 27 in light blue. Non-commercial operations (i.e., non-air carrier, non-air taxi, non-commuter, and non-military) are highlighted in dark red.

To estimate energy and power demand at these airports, some assumptions are made and summarized below:

- The average flight time of single-engine general aviation aircraft in the United States is 43 minutes. Given the 4-hour endurance for these aircraft, it is assumed that 18 percent of the battery is depleted after each flight.
- The slower tempo of operations for personal-use aircraft implies that a slow charge of batteries can be used. For the Bye Aerospace SunFlyer 4/Eflyer 4, a slow charge lasts about 3 hours and 45 minutes to recharge the batteries fully. This means that the recharge for a 43-minute flight will last approximately 40 minutes using a 10-kW charger.
- Non-commercial operations at these airports are carried out exclusively by personal-use aircraft. In reality, some of these operations are also carried out by business jets.
- The market penetration is assumed to be between 20 and 100 percent. Most aircraft owners keep their aircraft for many years owing to the low utilization of personal-use aircraft. Indeed, the average age for single-engine reciprocating engine aircraft is over 35 years in the United States. As a result, electrification of the personal-use aircraft fleet may be slow unless the market is stimulated.

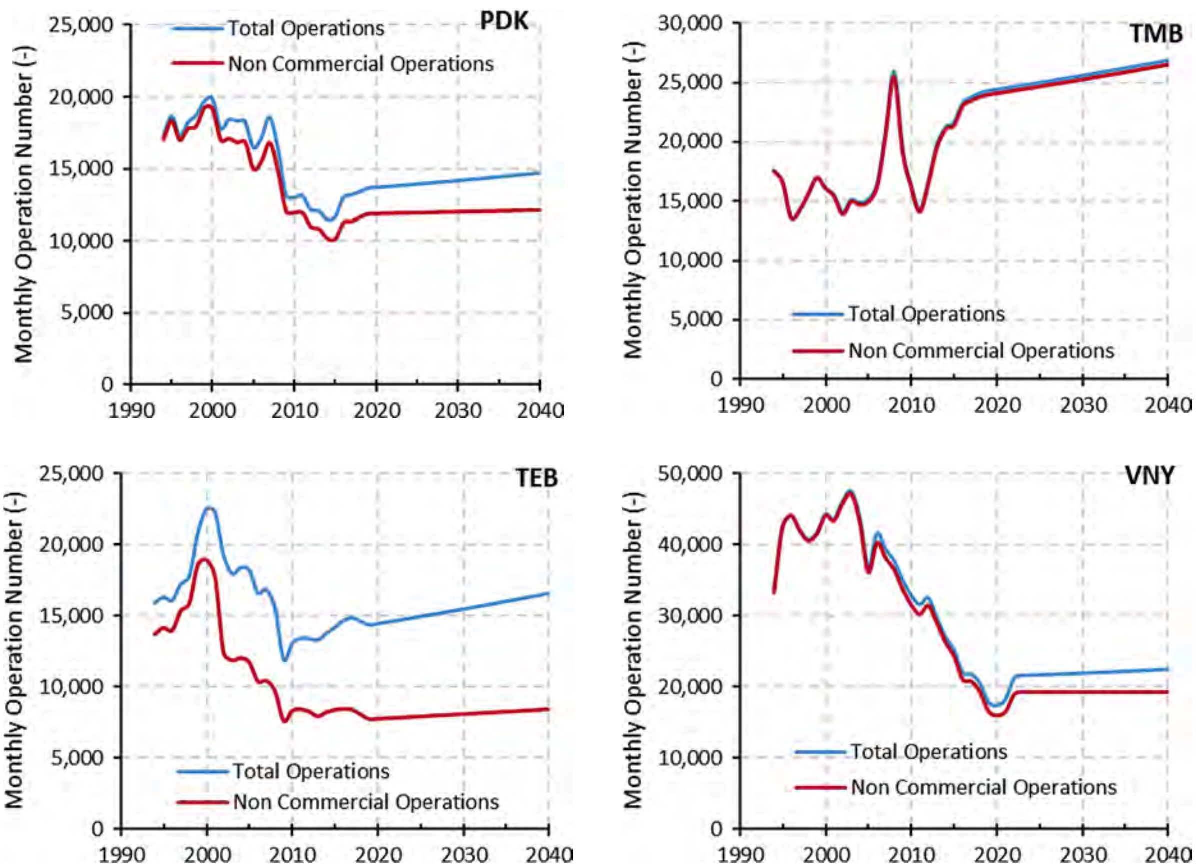


Figure 27. Typical activity at a selection of airports (FAA, 2018).

Estimations based on these assumptions indicate monthly energy needs between 50 MWh and 250 MWh at PDK, between 100 MWh and 600 MWh at TMB, between 35 MWh and 175 MWh at TEB, and finally between 80 MWh and 410 MWh at VNY as indicated in Figure 28.

The corresponding power demand from the electric grid is provided in Figure 29. Power demand is estimated between 150 kW and 800 kW at PDK, between 350 kW and 1,700 kW at TMB, between 100 kW and 550 kW at TEB, and between 250 kW and 1,250 kW at VNY. A 50 percent market penetration for electric aircraft yields a power demand ranging between 250 kW and 800 kW to support personal flight operations at these four airports.

Commuters

Commuter operations aim to connect smaller communities to the rest of the air transportation network by focusing on routes between regional airports and larger hubs. Commuter aircraft are typically low-capacity and low-range aircraft, seating nine passengers and flying routes up to 250 NM. The Eviation Alice and the Ampaire Tailwind concepts are appropriate baseline vehicles for commuter operations. Electric aircraft have already been considered for commuter operations on commercial airlines such as Mokulele Airlines and Cape Air. These aircraft will probably fly alongside and eventually replace Cessna 208 and Cessna 402 on commuter routes. Commuter airlines have high-tempo operations with short turnaround times to maximize aircraft utilization. Average turnaround times between 15 minutes and 25 minutes are frequently observed for these operations.

With a MTOW typically falling between 6,000 pounds to 9,000 pounds and short turnaround times, it is unlikely that batteries can be sufficiently recharged between flights. Instead,

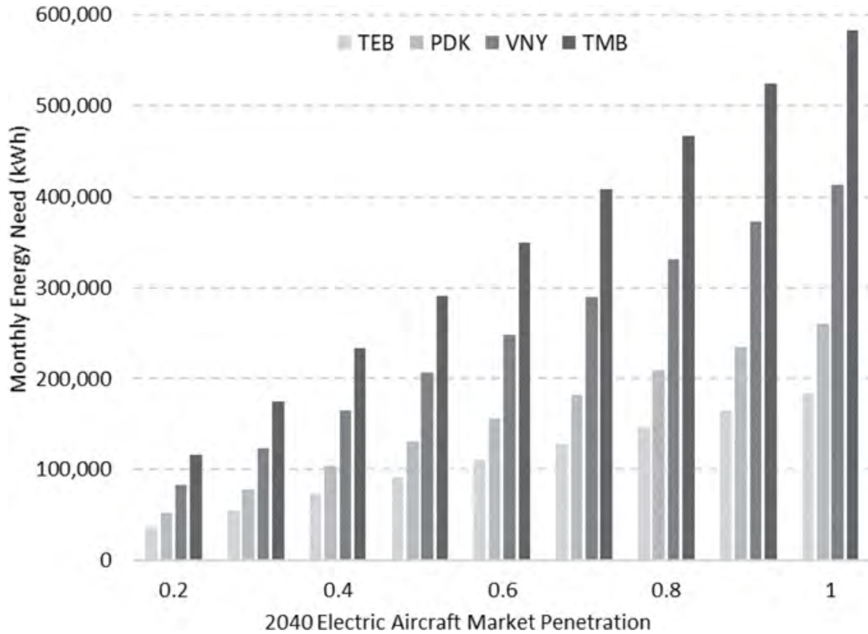


Figure 28. Electric energy demand for different levels of electric aircraft market penetration at a selection of airports for personal use operations.

batteries will be swapped during the ground turnaround time with fully charged spare batteries. Because spare batteries are not tied to an aircraft, charging can be made at a slower pace, which will shave peaks of power demand and thus decrease the cost of electricity for the operator. Because commuter operators typically fly out of quiet regional airports to larger hubs, several airports are selected to model the diverse spectrum of airports that will support commuters. The first is Middle Georgia Regional Airport (MCN), a towered regional airport

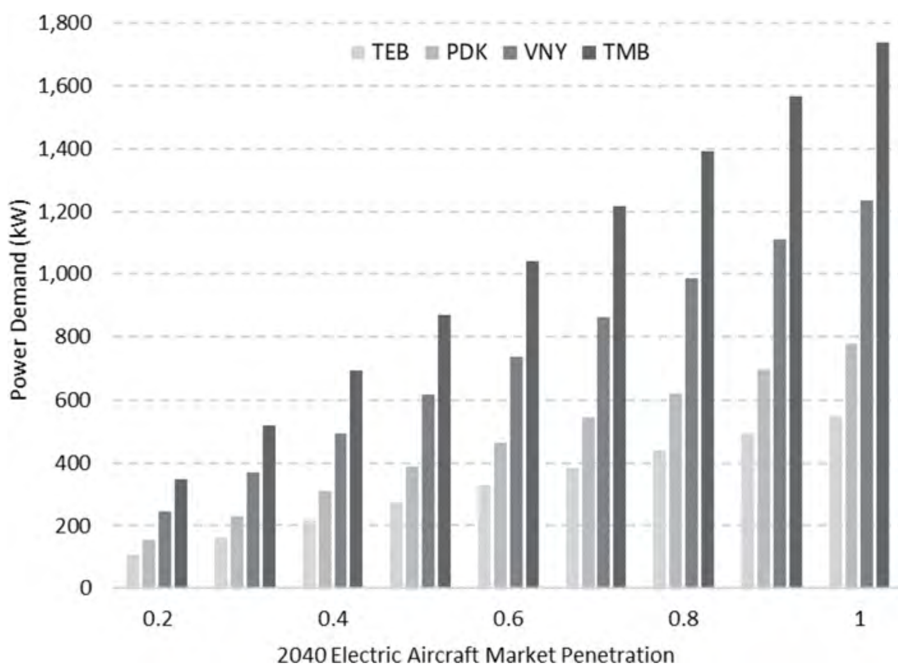


Figure 29. Electric power demand for different levels of electric aircraft market penetration at a selection of airports for personal use operations.

in a class Delta airspace that is eligible to receive Essential Air Services subsidies. The second is Molokai Hoolehua Airport (MKK), a towered airport in a class Delta airspace that receives substantial traffic from commuter operators. The third is Hyannis Barnstable Airport (HYA), a towered airport in a class Delta airspace also served by commuters. Finally, the fourth airport is Boise Air Terminal (BOI), a slightly larger airport in a class Charlie airspace that typically supports commuter and regional air services. Current and forecast activity at these airports is highlighted in Figure 30.

The following assumptions were made to estimate energy and power demand:

- The typical duration of commuter flights is between 45 minutes and 90 minutes.
- Using 400 kW fast chargers, the battery needs between 30 minutes and 45 minutes to be recharged between flights. This is unsuitable for high-tempo commuter operations.
- Battery swaps are performed to enable fast turnaround times, and batteries are recharged using 60 kW chargers throughout the day.

Based on these activity forecasts, estimations indicate monthly energy needs between 500 kWh and 3 MWh at MCN, between 12 MWh and 60 MWh at MKK, between 14 MWh and 71 MWh at HYA, and finally between 3 MWh and 15 MWh at BOI (see Figure 31).

The corresponding power demand from the electric grid is provided in Figure 32. Power demand is estimated between 175 kW and 200 kW at MCN, between 550 kW and 2.5 MW at MKK, between 550 kW and 3 MW at HYA, and between 175 kW and 750 kW at BOI. A 50 percent market penetration for electric aircraft yields a power demand ranging between 125 kW and 1.5 MW to support personal flight operations at these four airports.

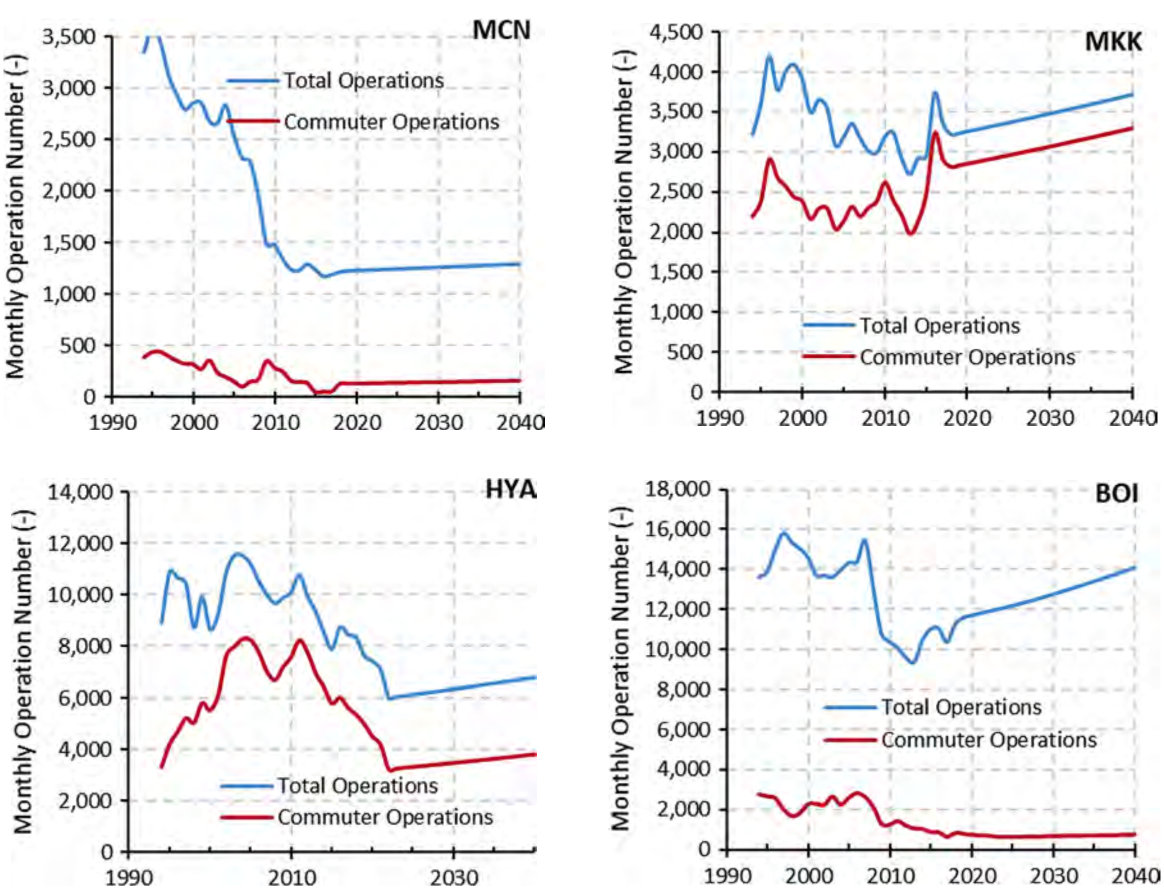


Figure 30. Activity at several regional general aviation airports (FAA, 2018).

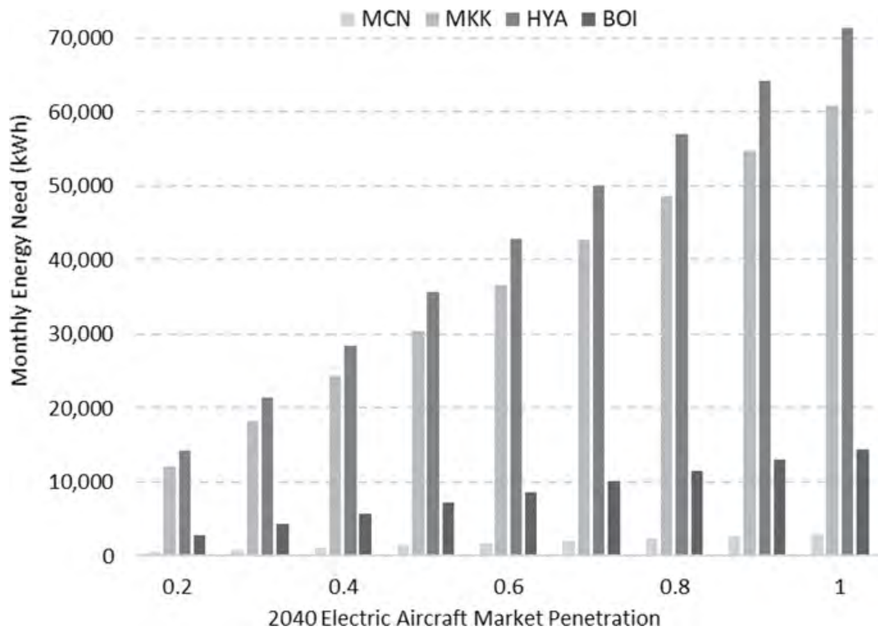


Figure 31. Electric energy demand for different levels of electric aircraft market penetration at a selection of airports for commuter operations.

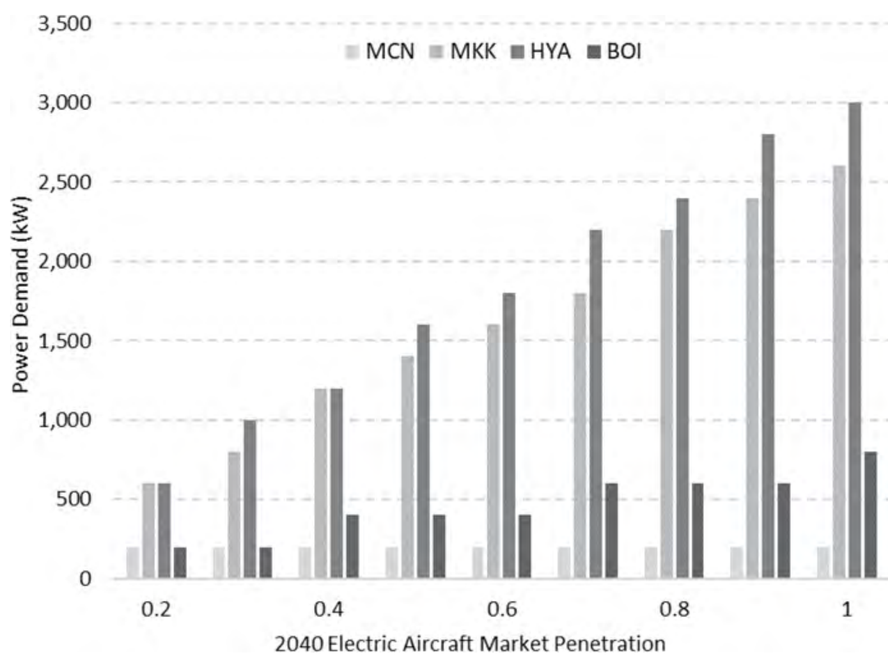


Figure 32. Electric power demand for different levels of electric aircraft market penetration at airports for commuter operations.

Regional Air Cargo

Regional air cargo operations are similar to commuter operations in terms of aircraft size and average mission length. One difference is their slower tempo of operations, resulting in long ground turnaround times and reduced daily utilization. Regional cargo aircraft typically fly just a few times per day, either retrieving packages from quieter regional outstations in the late afternoon to bring them to a sorting or consolidation facility at a larger airport or bringing packages from these facilities to the outstations in the early morning. Cargo versions of the Eviation Alice and Ampaire Tailwind aircraft concepts are therefore appropriate baseline vehicles to model energy needs for regional air cargo operations. Representative airports would then be the same airports as modeled in the commuter use case, namely MCN, MKK, HYA, and finally BOI. The current and forecast activity at these four airports is provided in Figure 30.

The following assumptions are made to estimate energy and power demand, as indicated below:

- The typical duration of air cargo flights is between 45 minutes and 90 minutes.
- Using 400 kW fast chargers, the battery can be recharged in 30 minutes to 45 minutes between flights, which is likely to be faster than needed for low-tempo operations.
- A slower charger charging at 200 kW is sufficient to recharge batteries within 3 hours, which is likely to be sufficient for slow-tempo operations. This will provide at least 2 hours of flight time.

Based on these activity forecasts, estimations indicate monthly energy needs between 500 kWh and 3 MWh at MCN, between 12 MWh and 60 MWh at MKK, between 14 MWh and 71 MWh at HYA, and finally between 3 MWh and 15 MWh at BOI (see Figure 33).

The corresponding power demand from the electric grid is provided in Figure 34. Power demand is estimated at 200 kW at MCN. The low level of activity at MCN airport means that a single 200 kW charger is sufficient whether 20 or 80 percent of the cargo fleet is electrified.

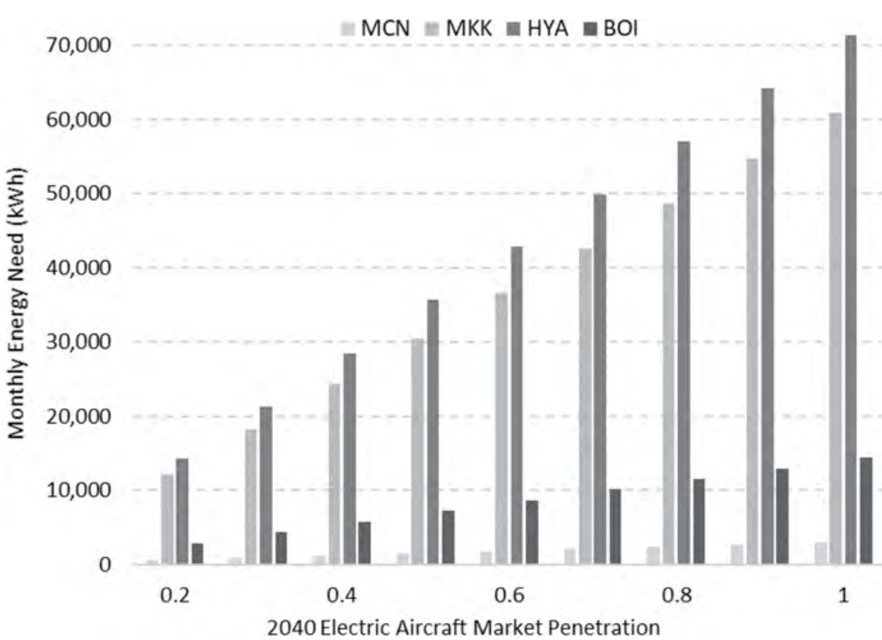


Figure 33. Electric energy demand for different levels of electric aircraft market penetration at a selection of airports for cargo operations.

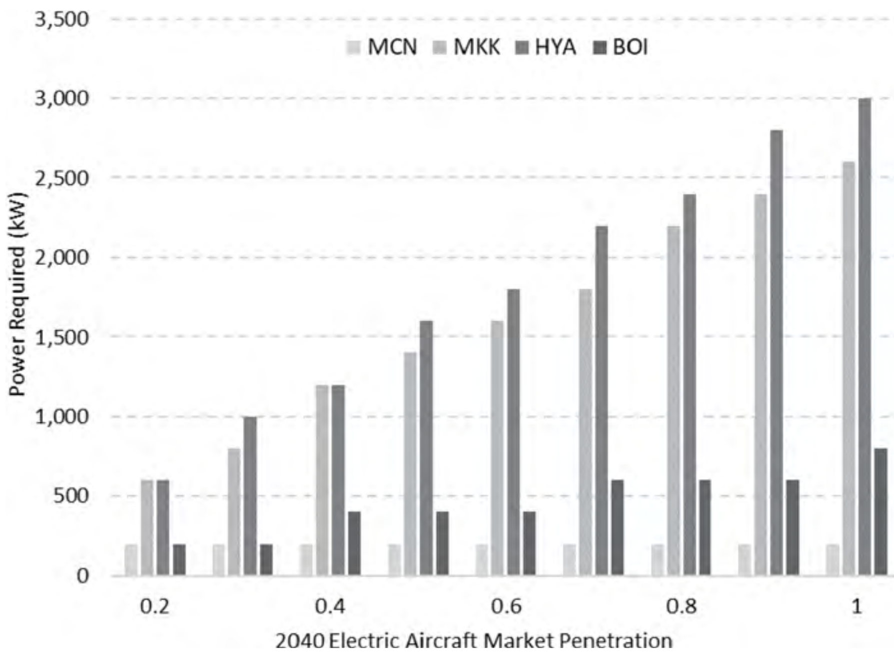


Figure 34. Electric power demand for different levels of electric aircraft market penetration at a selection of airports for cargo operations.

Power demand is estimated between 175 kW and 200 kW at MCN, between 550 kW and 2.5 MW at MKK, between 550 kW and 3 MW at HYA, and between 175 kW and 750 kW at BOI. A 50 percent market penetration for electric aircraft yields a power demand ranging between 200 kW and 1.6 MW to support regional air cargo operations at these four airports.

Regional Airlines

Regional airlines aim to connect regional airports to large national and international hubs. Regional aircraft typically seat between 35 passengers and 75 passengers and fly between 100 and 500 miles. Because of this, regional aircraft are significantly larger than commuter aircraft, and a fully electric regional aircraft is not expected to be feasible in the short term. Hybrid-electric propulsion is more likely, for which a representative aircraft for regional operations would be the UTC Project 804 Concept. The UTC Project 804 Concept features one parallel-hybrid-electric motor but a more realistic aircraft configuration would feature two identical powerplants and thus two parallel-hybrid-electric motors. Regional airlines typically fly from towered regional airports to national hubs. Four large hubs are selected to model the diverse spectrum of airports served by regional airlines. The first is Cincinnati Northern Kentucky International Airport (CVG). CVG is the least busy large-hub airport in a class Bravo airspace. It used to support significant regional airline services. The second is San Francisco International Airport (SFO), another large-size hub in a class Bravo airspace. The third is Dallas-Fort Worth International Airport (DFW), one of the busiest airports in a class Bravo airspace. The fourth airport is ATL, the busiest airport in the world. Current and forecast operations from these four airports are provided in Figure 35.

These assumptions were made to estimate energy and power demand:

- The typical duration of a regional flight is estimated to be 1 hour. During the takeoff and climb segments (which corresponds to the first 20 minutes of the flight), the

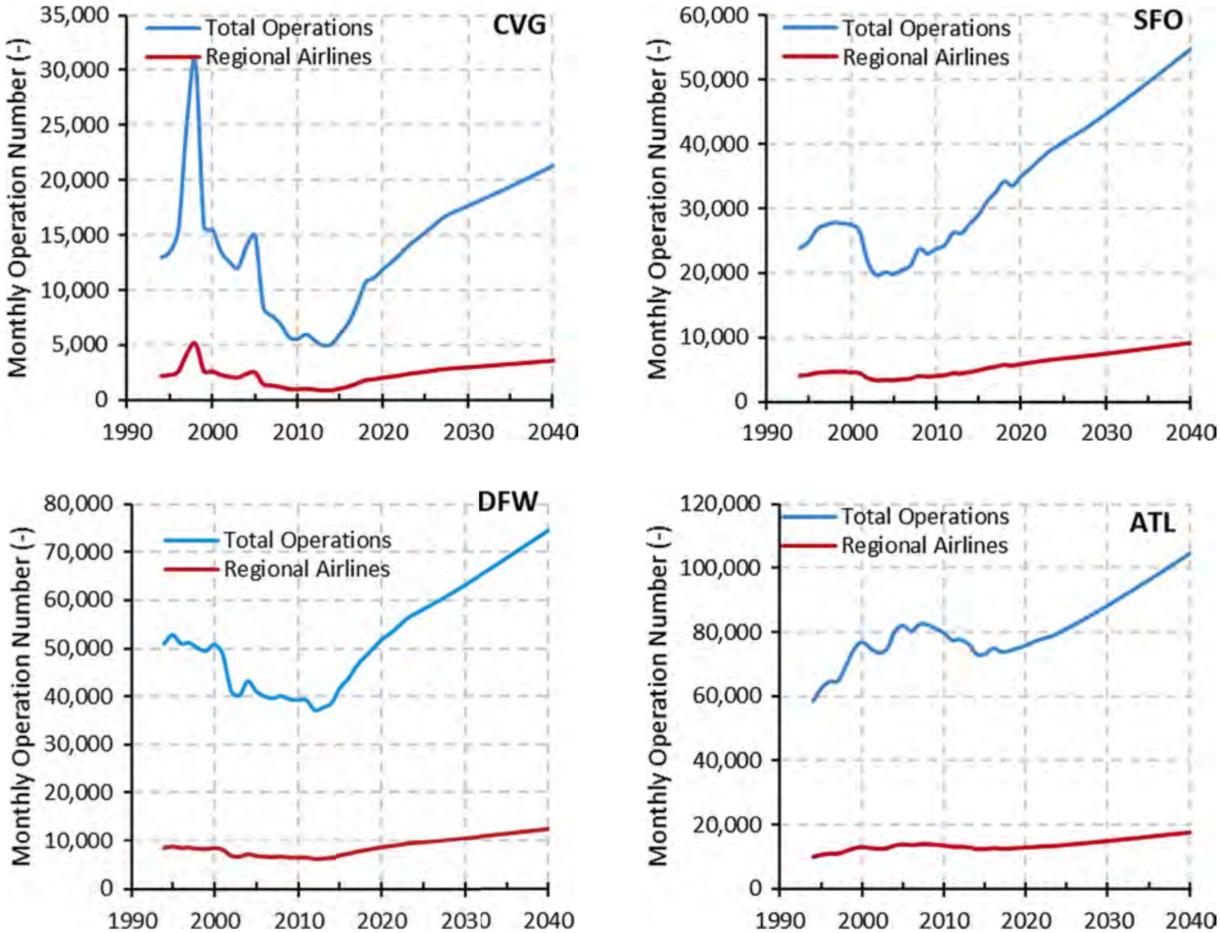


Figure 35. Typical activity at large international hub airports.

batteries and electric motors will provide half of the required power (4 MW), which is about 2 MW.

- The high-tempo operations prevent the batteries from being recharged during the short ground turnaround time. The batteries will be swapped on the ground and replaced with fully charged batteries.
- Given the battery size and a large number of regional flights at large hubs, batteries are recharged using high-power fast chargers (600 kW) to be used several times per day. This limits the inventory of expensive batteries that would be otherwise required.

Based on these assumptions and activity forecasts, estimations indicate monthly energy needs between 200 MWh and 1 GWh at CVG, between 500 MWh and 2.5 GWh at SFO, between 750 MWh and 3.5 GWh at DFW, and finally between 1 GWh and 5 GWh at ATL. See Figure 36.

The corresponding power demand from the electric grid is provided in Figure 37. Power demand is estimated between 550 kW and 1.75 MW at CVG, between 1.2 MW and 4.2 MW at SFO, between 1.2 MW and 5.3 MW at DFW, and between 1.8 MW and 7.2 MW at ATL. A 50 percent market penetration for electric aircraft yields a power demand ranging between 1 MW and 3.0 MW to support regional air cargo operations at these four airports. Meanwhile, Table 11 provides a summary of airport use cases.

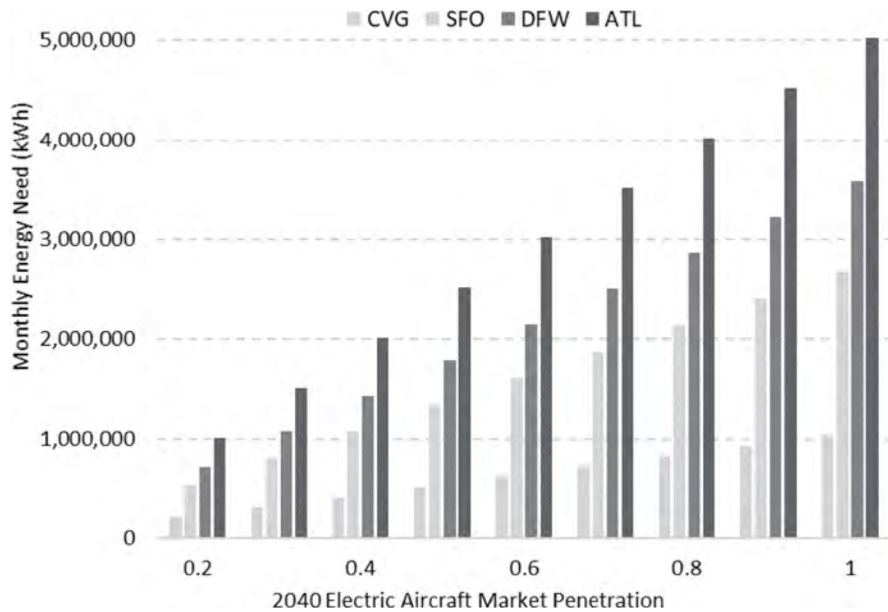


Figure 36. Electric energy demand for different levels of electric aircraft market penetration at a selection of major hub airports supporting regional aircraft operations.

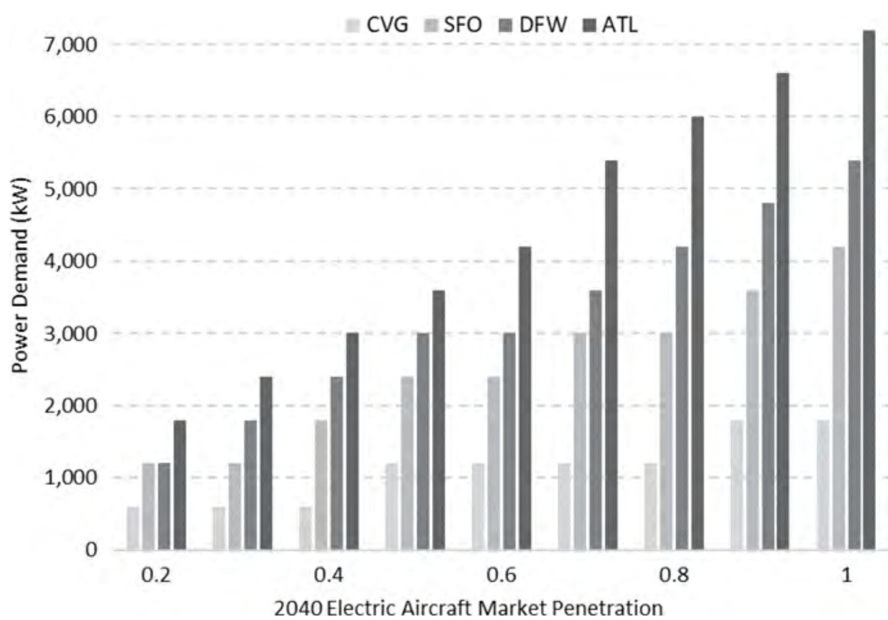


Figure 37. Electric power demand for different levels of electric aircraft market penetration at a selection of major hub airports supporting regional aircraft operations.

Table 11. Use case summary.

Use Case	Example	Operation Tempo	Vehicle Power Requirement	Charging Infrastructure	Airport Power Requirement	Airport Energy Requirement
Flight Training	Pipistrel Alpha Electro	High	~60 kW	Charger @ 20 kW	25 – 1,800 kW	8 – 620 MWh
Personal Use	Bye Aerospace SunFlyer 4 / Eflyer 4	Low	~105 kW	Charger @ 10 kW	100 – 1,700 kW	50 – 600 MWh
Air Taxi	Bye Aerospace SunFlyer 4 / Eflyer 4	Very High	~105 kW	Super-Fast Charger @ 600 kW	100 – 1,700 kW	35 – 600 MWh
Commuter	Eviation Alice	Very High	~260 kW	Battery Swaps & Charger @ 60 kW	50 – 3,000 kW	0.5 – 70 MWh
Air Cargo	Eviation Alice	Low	~260 kW	Fast Charger @ 200 kW	200 – 3,000 kW	0.5 – 70 MWh
Regional Airline	UTC Project 804	High	~4 MW ~2 MW electric (50%)	Battery Swaps & Super-Fast Charger @ 600 kW	550 – 7,200 kW	200 – 5,000 MWh

7.2 Passenger Terminal Facilities

With the emergence of electric aircraft, airports must prepare and plan on how to integrate these new aircraft into airport facilities. Although these aircraft's shape or size will not fundamentally impact existing infrastructure, they might change some airlines' flight business model and the aviation demand, which will indirectly impact passenger terminals. U.S. airports and their passenger terminals could experience consequences similar to those experienced after the airline deregulation in the 1970s. This similarity stems from the potential significant rise in passenger traffic at airport terminals when more electric aircraft, especially for air taxis, are introduced requiring the terminal facilities to accommodate such traffic.

Passenger Traffic

The market assessment forecast projects small electric fleet sizes during the 2020–2030 period. Thus, any increase in passenger traffic during this time will likely not be directly attributable to electric aviation. However, longer-term impacts are expected with electric aviation's anticipated maturation and proliferation beyond 2030. Driven by lower operating costs and increasingly eco-minded aviation industry, widespread use of electrified aircraft could allow carriers to offer lower priced flight services by passing operational savings to the customer if these lower operating costs are confirmed.

This savings has the long-term potential to trigger an uptick in airport passenger throughput as ridership increases, especially on metropolitan UAM and point-to-point regional flights (regional air mobility), which could be the first to be operated with electric aircraft. Electric aviation could facilitate new regional air mobility with smaller aircraft (2 to 20 seaters) being used for rapid connectivity between small communities as well as from these communities to larger metropolitan areas—not without analogies with the Small Aircraft Transportation System (SATS) vision of the FAA in the 1990s.

1978 Airline Deregulation Act Impacts on Passenger Terminal Facilities

The Airline Deregulation Act of 1978 saw the removal of the U.S. government control over the airline market, resulting in the lifted restrictions on where airlines could fly and changing airlines strategies, with the emergence of hub airports. Passenger terminals were immediately impacted by this Act:

- The deregulation kept more aircraft flying, which resulted in increased passenger loads.
- One issue was for airlines to determine if they could obtain an adequate or sufficient passenger terminal facility at airports because of limited airport access.
- There was a significant concern for allocation and terminal expansion of airport passenger terminal facilities.
- The airports tried to efficiently allocate the fixed amount of terminal space.
- Some airports, to accommodate new entrants, constructed additional terminal facilities.
- One airport that the Airline Deregulation Act affected was Newark Airport (EWR).
  - According to the United States General Accounting Office Airline Deregulation Report, EWR saw a 140 percent increase in total departures after the Deregulation Act was established.
  - EWR, underutilized in the 1970s, underwent a significant expansion in the 1980s and 1990s including the construction of Terminal C, to accommodate and keep up with the increase in passengers and flight travel.

(Re)emergence of Regional Airports

An increase in the regional flight demand at some airports at the 2030 horizon would require adapting the passenger terminal facilities to accommodate such demand. This trend could be comparable to the boom of regional aviation at the end of the 20th century that triggered the development of simplified facilities dedicated to short-haul domestic flights. These regional terminals have been often redeveloped to accommodate larger aircraft types due to the industry's transition from turboprops (e.g., ATR72 and Dash-8) and small regional jet aircraft (e.g., CRJ 200 and ERJ 145) to small medium-size airliners (e.g., A220 and E190).

Most early electric aircraft are expected to seat up to a dozen passengers. Cape Air, a regional airline, provides a good example of how air carriers could use these early electric aircraft to provide regional mobility. Cape Air operates mainly Cessna 402s and is transitioning to the Tecnam P2012 Traveler, which are both nine-passenger piston-engine planes. Cape Air operates Essential Air Services routes and other short-haul commercial flights (e.g., to Cape Cod, Nantucket, and Martha's Vineyard, Massachusetts), and it has various interline and codeshare agreements with larger air carriers. At BOS, Cape Air operates 20 to 30 flights per day from JetBlue's Terminal C. Passengers board and deplane onto the apron without a jet bridge. A similar process exists at other hub airports Cape Air serves, such as STL.

Accommodating this additional traffic calls for specific discussions at the planning level. A renewal of smaller point-to-point regional mobility with small commuter aircraft might be accommodated on remote ramps or "non-contact" gates (i.e., without jet bridges). Passengers typically walk to the hold room and then walk to the plane on foot. Most of the time, passengers must take stairs or elevators to descend from the main terminal floor to the ramp level. Some airports have provided canopies from the terminal building to the aircraft stand (e.g., former regional jet gates at JFK Terminal 2), but passengers are often exposed to outside weather conditions.

While such processes are typical at smaller airports, many larger hub airports are getting rid of them because of the inferior passenger experience they provide. The re-emergence of smaller regional aircraft under electrification could prompt the passenger journey to be reimagined. Lessons from the past and abroad include canopies that protect the aircraft and passengers from adverse weather (e.g., former Pan Am Worldport Terminal 3 at JFK), as well as ground-level boarding stairs providing high-end experience (e.g., Infraero's ELO boarding/deplaning connector in Brazil). Some of these developments might be achieved through cost and risk sharing with fellow regional operators. In particular, smaller airports might need these partnerships to fund new terminal capacities and to develop additional services for passengers.

Regional Air Mobility

Current trends show that smaller airports will be the first ones to integrate electric aircraft. Often underutilized today, they should be seen as community resources and can become real assets with the emergence of urban and regional air mobility with electric aviation.

Indeed, with globalization and industrialization, societies are growing and expanding to facilitate the connectivity of their territory with the rest of the world for the movement of goods and people. The transportation network is one of the keys to this connectivity, and electric aircraft would become a new mode of transportation. With all the variety of transportation, from ground to air, communities are not only looking for new routes but also to connect all these transport modes. As explained previously, the earliest electric aircraft will have a small capacity and will be more adapted to regional mobility. In addition, these aircraft would provide more flexibility to connect and transit to other transportation modes, such as transportation network companies (TNCs) or UAM. Smaller airports might become local multimodal transportation and cargo hubs with interconnection to all these transportation modes. The existing infrastructure already exists and will prevent overinvesting in new capacities that would pass along the cost to users ultimately.

7.3 Lessons Learned from the Small Aircraft Transportation System

In the early 2000s, NASA's Office of Aerospace Technology initiated SATS, a 5-year research program created to enhance intercity, intra-regional connectivity of communities, by relieving congestion issues of existing transportation systems. The SATS concept aimed to attract users who make transportation choices based mostly on time considerations and targeted regional transportation markets.

Funded with $69 million from 2001 to 2006, NASA's SATS research program was conceived to:

- Increase the safety and utility of operations at small airports lacking traffic control towers, radar surveillance, or other conventional ground-based means of monitoring and safely separating aircraft traffic in the terminal airspace and on runways and taxiways.
- Allow more dependable use of small airports lacking instrument landing systems or other ground-based navigation systems that are now required for many night-time and low-visibility landings.

- Improve the ability of single-piloted aircraft to operate safely in complex airspace (that is, at airports and in airways with many and diverse operators).

This bold vision of a new transportation system was based on the concept of operations of on-demand and point-to-point routes, and the use of advanced, small fixed-wing aircraft—of a size common in general aviation (4 to 10 passengers)—for personal or business transportation between small communities. The new generation of small aircraft was intended to provide "jet-taxi services," and to operate on small regional, reliever, and general aviation airports, or even other landing facilities, including heliports.

To support SATS, NASA developed new technologies for travel planning and scheduling and selected a variety of airports in Virginia to conduct flight research and demonstrations. The goal of the project was to deploy SATS operating capabilities within the NAS, ultimately over 18,000 landing facilities in the United States.

The main limitations of the concept were that it excluded urban areas and urban transportation, and the majority of the U.S. population and business is located in metropolitan areas, which are most likely to travel by air, due to higher-income households. Moreover, the main competitor of SATS was the automobile, which is part of a transportation mode that was already well implemented and more accessible for most users. Lastly, the costs of traveling were a major obstacle to SATS expansion, even though SATS targeted users valuing the time saved with air mobility.

In 2002, the TRB published a special report on the SATS program: *Special Report 236: Future Flight: A Review of the Small Aircraft Transportation System Concept*. The document identified potential obstacles that could compromise the realization of SATS:

- Lack of evidence that SATS aircraft would have been affordable for use by the general public.
- Lack of attractiveness for users if the concept was not deployed in the nation's major metropolitan areas.
- Potential high costs, that would exclude users that are price-sensitive, and who make most intercity trips.
- Potential obstacles for SATS deployment due to infrastructure limitations and environmental concerns at small airports.
- Success of SATS relied mainly upon the development and deployment of new technologies, which would take time.
- Potential undesirable outcomes, such as environmental issues, impacts to natural resources in the vicinity of airports, etc.

SATS can be seen as a first tentative conceptualization of regional air mobility. This program brought to light meaningful lessons for advanced air mobility, and 20 years after the TRB report on SATS, AAM might be developing the capacity to remove these obstacles by resolving the technological and environmental concerns that the initial SATS concept raised. Prospective operators are targeting both major cities with UAM and networks of interconnected communities with regional air mobility. AAM will have to deliver its promise of lower operating costs and fares. Last but not least, aircraft/airport compatibility issues must be addressed proactively in the field, ahead of effective implementation of these mobility services.

CHAPTER 8

Airside Requirements

8.1 Introduction

The total number of active electric aircraft is expected to remain low until at least 2030. During this period, impacts on airside facilities will likely center on the initial infrastructure necessary to support early electric aircraft operations. Beyond 2030, investment and utilization into electric aircraft among flight operators should increase. Although this shift is expected to occur gradually—likely taking over a decade to manifest starting no earlier than 2030—it will have a meaningful impact on the airside.

Suitable aircraft stands and gate facilities enable aircraft servicing and the movement of passengers and freight in and out of the plane. The primary impact of electric aviation on gate facilities will be the ability to supply aircraft with electricity and hydrogen with minimum impact on the turnaround time.

Different energy vectors and technical solutions are being explored by the electric aircraft industry to deliver power to the electric powertrain (Figures 38–43). The two main options for storing and delivering electrical power to the engine are (1) electrochemical batteries that deliver electricity to the engine, and (2) fuel cells that convert hydrogen (and air) into electricity (and water). The following recharging/refueling solutions are being considered for these two energy storage and delivery options:

Electric charging of high-capacity batteries:

- Recharge by fixed ground chargers, also known as charging stations.
- Recharge by the mobile supercharger on batteries (truck or trailer).
- Battery swap at the gate (batteries are recharged separately).

Hydrogen, or H_2, refueling for powering fuel cells:

- Refuel H_2 from a hydrant system.
- Refuel H_2 from a tanker (truck).
- Swap H_2 containers.

Table 12 summarizes the different energy vector combinations applicable depending on the propulsion system and the technology (batteries or fuel cells). Table 13 presents recharge and refueling technologies.

8.2 Electric Charging Infrastructure

To replenish electric and hybrid-electric aircraft batteries, electric charging infrastructure will be a core infrastructure requirement for any airport seeking to support electric aircraft operations. Airport planners must consider the power requirement, location, funding, and ownership of these charging facilities.

Figure 38. Electric aircraft charging via fixed charging stations.

Figure 39. Electric aircraft charging via a mobile supercharger.

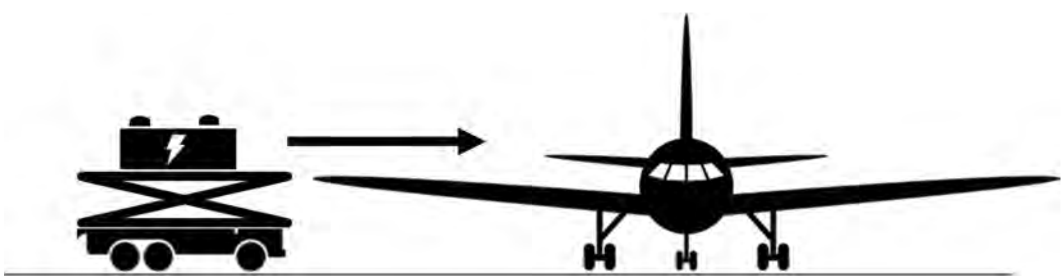


Figure 40. Electric aircraft battery swap.

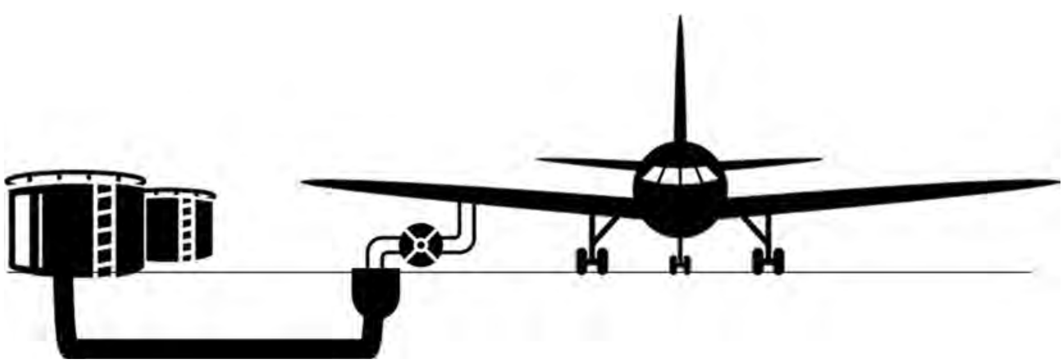


Figure 41. Aircraft refueling from a hydrant system.

Figure 42. Aircraft refueling by fueling truck.

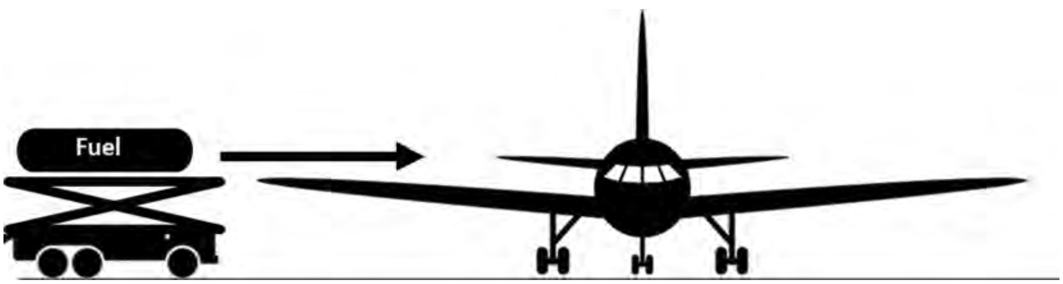


Figure 43. Aircraft H_2 container swap.

Table 12. Energy vectors by propulsion system and energy storage technology.

Propulsion System	All-Electric	Turboelectric	Series Hybrid	Parallel Hybrid	Series/Parallel Hybrid
Batteries	Electricity	Electricity & Aviation Fuel	Electricity & Aviation Fuel	Electricity & Aviation Fuel	Electricity & Aviation Fuel
Fuel Cells	Hydrogen	Hydrogen & Aviation Fuel	Hydrogen & Aviation Fuel	Hydrogen & Aviation Fuel	Hydrogen & Aviation Fuel

Note: Aviation fuels can be Jet A or gaseous hydrogen.

Table 13. Recharge and refueling technologies.

Ramp Integration	Batteries	Fuel Cells
Fixed Airport Units	Electric Chargers	Hydrant System
Mobile Airport Units	Superchargers on Truck or Trailer	Tanker (Truck)
Swap of Energy Containers	Battery Swap	Container Swap

Fixed or Mobile Chargers

Many airports already supply electric power to aircraft at the gate. In particular, commercial service airports provide fixed 400 Hertz (Hz) power units connected to the grid, or air carriers and their ground handlers operate mobile GPUs. These GPUs were previously diesel-powered, but units with power packs are now available on the market. Occasionally, at small airports, aircraft may still use their APUs because the other two options may not be available. The typical GPU power recommended is 90 kW for narrow-body aircraft and 180 to 360 kW for wide-body aircraft.

Aircraft battery chargers for small commuter aircraft and hybrid regional aircraft might be provided at the gate in a similar way. With these requirements in mind, it is likely that current gate facilities for conventionally powered aircraft of similar size will be suitable with minimal modification—namely, the installation of additional electric power capacity for charging aircraft batteries. Conventional aircraft will share the same gate facilities and GSE as their electric counterparts. General aviation facilities could elect to equip part of their aircraft stand with chargers. High-density tie-down parking layouts could be supplied with, for instance, built-in or low-clearance pop-up chargers that can fit between existing tie-down positions. Airport-owned hangars could be equipped as well. Coordination might be required with tenants to anticipate the growth of the electric demand.

Commercial aircraft operations—including commuter, light air cargo, and regional airliner-sized aircraft—will require the installation of more powerful charging systems. Maintaining the current pace of ground operations after the introduction of electric aircraft will be a necessity. Any significant increase in the turnaround time will reduce the financial advantage of electric aviation for flight operators and negatively affect gate capacity.

While general aviation, commuter, and regional aircraft might not need to recharge their batteries entirely at each stop due to the nature of their operations (short-haul flights), a quick turnaround could be achieved by using high-powered fast chargers. Current charging technology is limited to about 600 kW, which is on the lower end of the estimated requirements for commercial airliners expected in the longer term (hybrid regional aircraft), which range from 600 kW to 7 MW.

Battery Swap

Changing batteries at the gate or stand might address the adverse impact of battery charging cycles on the turnaround time. Battery swap operations at individual airports require the following:

- Equipment and trained personnel to load and unload batteries from the aircraft;
- An inventory of batteries that is compatible with the aviation activity and aircraft fleet;
- An infrastructure to store and charge batteries.

Battery swap can help de-peak electric demand at the aviation peak hour as long as the ground handlers and FBOs have an adequate inventory of fully charged batteries. Under these conditions, batteries can share the power supply with other resources and be charged when these other needs are low through smart power management.

Note: The future of battery swap as a way to provide fully charged batteries to an aircraft during regular operations will depend on FAA approval. If the FAA does not consider this as a minor alteration per 14 CFR 21.93, the battery swap might have to be performed by licensed mechanics instead of trained ground handlers, which may impact the operational viability and business model of this solution.

8.3 Hydrogen Infrastructure

Emergence of Hydrogen as an Aviation Fuel

Hydrogen is another promising energy vector for electric aviation, especially for larger aircraft. The advantage of H_2 is its high-energy density or the electrical energy potential of hydrogen processed by fuel cells compared to its weight. In comparison, the energy found in 1 kg of hydrogen equates to that found in 3 kg of jet fuel (kerosene).

However, no adequate infrastructure today delivers large quantities of hydrogen from the production sites to the aircraft. In the short term, the gas could be loaded into aircraft with fueling trucks or in special containers. For instance, Universal Hydrogen is developing an aviation-specific offer where it would play the role of broker between hydrogen producers and aviation users and organize the logistics using special containers that can be safely transported by road and loaded into aircraft.

At the very long-term horizon, hydrogen pipelines could emerge at hub airports, and perhaps hydrogen hydrant systems on the airside at large-hub airports, especially if hydrogen becomes a popular energy vector for other transportation modes.

Table 14 shows some of the properties of hydrogen that makes it hazardous.

Current Hydrogen Aircraft Developments

Currently, the aviation industry is moving toward a greener environment. Some companies have engineered aircraft that use hydrogen fuel cells, and more prototypes are being developed. Table 15 provides a list of existing and prototype hydrogen fuel-based aircraft (including non-electric aircraft concepts burning hydrogen as a fuel in hydrogen jet engines yet to be developed).

Table 14. Chemical and physical properties.

Hazard Type	Description
Physical properties leading to safety concerns	• Lighter than air • Highly diffusive • Flow-induced static charge generation • Low viscosity (leaks easily) • Odorless, colorless gas
Pressure	• High-pressure storage, a 2,000 pound per square inch gauge (psig), or 138 bar, and above, can result in pressure rupture, flying debris • Pipe whip concern with leak events • Oxygen displacement in confined spaces • Gas jet impingement damage is possible • Gas jet impingement on personnel is also a hazard; high pressure can cut bare skin
Chemical	• Flammable, with nonluminous flame, no toxic combustion products • Explosive, 4% to 74% by volume, candeflagrate (typically only a modest overpressure, a few psi in open areas), can also detonate (high overpressure shock wave, several atmospheres) • Low ignition energy, 0.02 to 1 megajoule spark to ignite a deflagration • Modest autoignition temperature, 574°C (1,065.2°F)
Temperature	• Could be stored at room temperature, not an issue
Materials issues	• Embrittlement of metal • Embrittlement of plastics
Toxicological	• Asphyxiation in confined spaces • No other toxic concerns

Source: Safety Issues with Hydrogen as a Vehicle Fuel, Idaho National Engineering and Environmental Laboratory (INEEL), 1999.

Table 15. Current hydrogen aircraft developments.

Aircraft	Year	Power	Description	Storage System	Range (km)	Status
HY4	2015	Hydrogen Fuel Cells and Electric Batteries	Four-seat fixed-wing aircraft, single propeller, twin fuselage	Gas	1,000	Flown
HES Element One	2018	Hydrogen Fuel Cells	Four-seat fixed-wing aircraft, 14 propellers	Gas / Liquid	500–5,000	Under Development
Alaka'I Skai	2019	Hydrogen Fuel Cells	Five-seat futuristic "air taxi" rotorcraft, six rotors	Liquid	640	
Apusi i-2	2019	Hydrogen Fuel Cells	Four-seat fixed-wing aircraft, two propellers	Gas	1,000	
NASA CHEETA	2019	Hydrogen Fuel Cells	Blended wing-body large commercial aircraft	Liquid	n/a	
Pipistrel E-STOL	2019	Hydrogen Fuel Cells	19 seats, fixed-wing aircraft	n/a	n/a	
ZeroAvia	2019	Hydrogen Fuel Cells	10–20 seats fixed-wing aircraft, two propellers	Gas	800	
Airbus Cryoplane	2003	Hydrogen Combustion	Large commercial aircraft	Liquid	n/a	Feasibility Study or Aircraft Concept Only
NASA Concept B	2004	Hydrogen Fuel Cells	Blended wing-body large commercial aircraft	Liquid	6,500	
Airbus ZEROe	2020	Hydrogen Combustion	Large commercial aircraft	Liquid	n/a	

Source: Roland Berger, Hydrogen, A Future Fuel for Aviation, 2020.

Hydrogen Production

Hydrogen can be produced from different energy resources such as solar, wind, and nuclear, using raw materials such as water, natural, gas, and coal. Table 16 shows different hydrogen production processes with their corresponding energy source, feed stock, and cost of production.

The on-site production of aviation hydrogen might be relevant in some cases, including at small and remote airports. In the Netherlands, Groningen Airport Eelde has built a 21.9 MW solar farm with the plan to produce hydrogen by electrolysis for landside and airside applications.

Hydrogen Transportation

There are two main ways to transport hydrogen, via truck and pipelines.

Hydrogen Transportation via Trucks

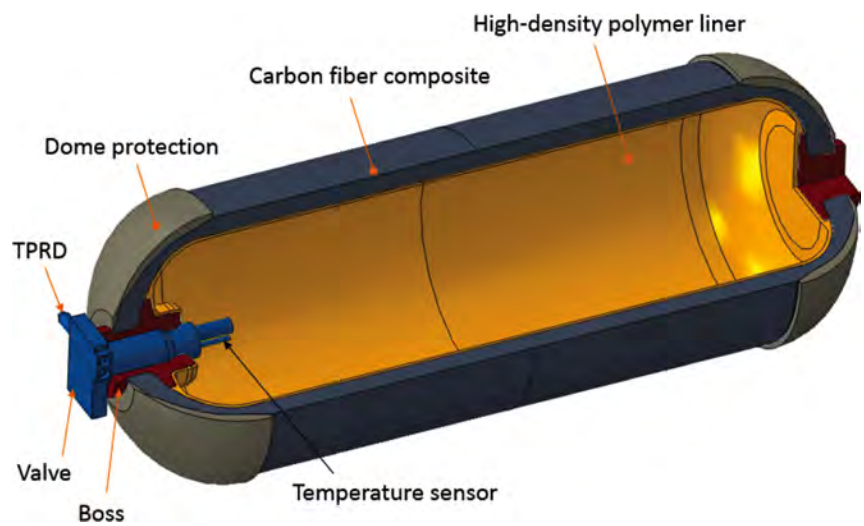
Because gaseous hydrogen is usually produced at low pressures (between 20–30 bars), for it to be transported, the gas must be further compressed and stored in a tank or small containers (Figure 44). The usual method is by stacking filled high-pressure cylinders in tube trailers to be hauled by trucks. There are four main types of high-pressure gaseous storage containers or cylinders:

- **Type I**: All-metal cylinder.
- **Type II**: Load-bearing metal liner hoop wrapped with resin-impregnated continuous filament.
- **Type III**: Non-load-bearing metal liner axial and hoop wrapped with resin-impregnated continuous filament.
- **Type IV**: Non-load bearing, non-metal liner axial and hoop wrapped with resin-impregnated continuous filament.

Table 16. Existing and emerging hydrogen production methods.

Process	Energy Source	Feed Stock	Capital Cost ($ million)[a]	Hydrogen Cost ($/kg)
Steam methane reforming (SMR) with Combined Charging System (CCS)	Standard fossil fuels	Natural gas	226.4	2.27
SMR without CCS	Standard fossil fuels	Natural gas	180.7	2.08
CC with CCS	Standard fossil fuels	Coal	545.6	1.63
CG without CCS	Standard fossil fuels	Coal	435.9	1.34
Autothermal reforming (ATR) of methane with CCS	Standard fossil fuels	Natural gas	183.8	1.48
Methane pyrolysis	Internally generated steam	Natural gas	–	1.59–1.70
Biomass pyrolysis	Internally generated steam	Woody biomass	53.4–3.1	1.25–2.20
Biomass gasification	Internally generated steam	Woody biomass	149.3–6.4	1.77–2.05
Direct bio-photolysis	Solar	Water + algae	50 $/m^2$	2.13
Indirect bio-photolysis	Solar	Water + algae	135 $/m^2$	1.42
Dark fermentation	–	Organic biomass	–	2.57
Photo-fermentation	Solar	Organic biomass	–	2.83
Solar photovoltaic (PV) electrolysis	Solar	Water	12–54.5	5.78–23.27
Solar thermal electrolysis	Solar	Water	421–22.1	5.10–10.49
Wind electrolysis	Wind	Water	504.8–499.6	5.89–6.03
Nuclear electrolysis	Nuclear	Water	–	4.15–7.00
Nuclear thermolysis	Nuclear	Water	39.6–2107.6	2.17–2.63
Solar thermolysis	Solar	Water	5.7–16	7.98–8.40
Photo-electrolysis	Solar	Water	–	10.36

[a] Capital costs are the expenses used to purchase and maintain fixed assets such as buildings where the hydrogen will be produced and associated equipment.



Note: TPRD = thermal pressure relief device.
Source: U.S. Department of Energy, 2020.

Figure 44. High pressure hydrogen container.

The Type I containers are the most common, whereas the Type III and IV are more expensive. Transporting compressed hydrogen gas in high-pressure tube trailers is expensive and used primarily for distances of 200 miles (322 km) or less.

Hydrogen Pipelines

Transporting hydrogen through pipelines is similar to how natural gas is transported currently. In the United States, there are approximately 1,600 miles of pipelines for hydrogen distribution. Transporting or distributing gaseous hydrogen through pipelines is common for long distance and high-volume transport because it is less costly compared to transportation via truck. According to the U.S. Department of Energy, some of the concerns with hydrogen pipeline distribution are:

- The potential for hydrogen to embrittle the pipeline materials.
- The need to control hydrogen permeation and leaks.
- The need for lower cost, more reliable, and more durable hydrogen compression technology.

On-Airport Hydrogen Storage

Hydrogen can be distributed to airports in different ways, including (1) delivery of special containers for direct loading into aircraft, (2) delivery via trucks or pipeline to large tank to refill empty special containers, or (3) fueling trucks. Figure 45 shows the ways in which hydrogen can be delivered.

Harvard Environment, Health, and Safety Department developed a hydrogen fact sheet that lists some of the safety precautions to take when storing hydrogen. It states that, to store pressurized hydrogen containers:

- Store the containers with adequate ventilation in warehouse.
- Maintain temperature of the warehouse that does not exceed 125°F (52°C).
- Secure hydrogen containers and tanks to prevent falling or being knocked over.
- Use flash arrestor on tanks.
- Store full and empty cylinders separately.
- Equip building with an automatic sprinkler or deluge system in case of fire.

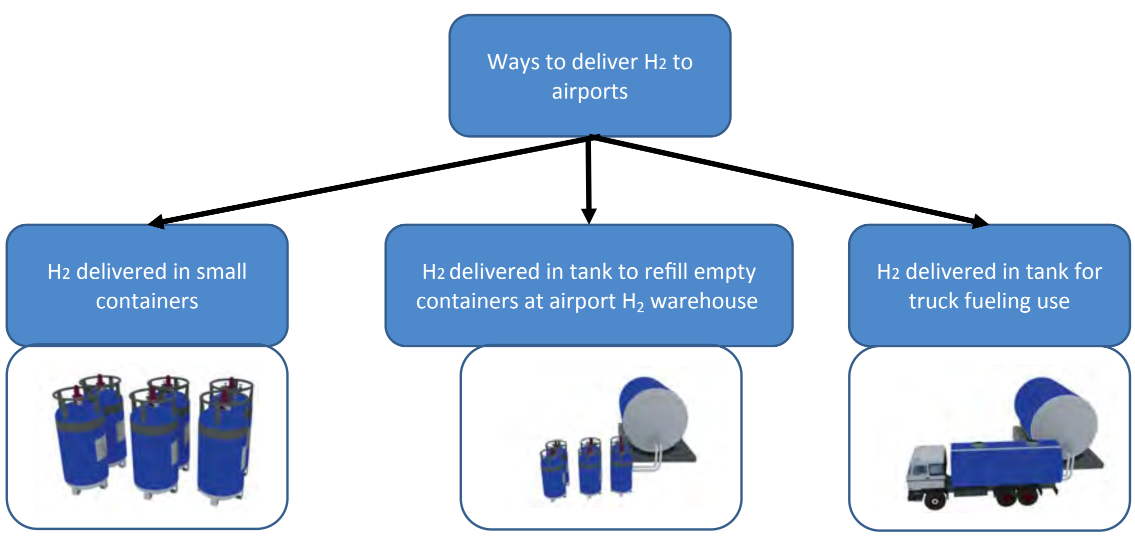


Figure 45. Hydrogen delivery.

Hydrogen Delivery to Aircraft

Because of the preliminary stage of the development of hydrogen-fueled aircraft, understanding of the amount of hydrogen needed to fuel different aircraft sizes, fuel tank capacities, and methods of fueling are not definite. Taking hydrogen fueling methods into consideration, hydrogen aircraft can be fueled three ways:

- **Container Swapping**: Empty containers in aircraft are taken out and replaced by filled containers.
- **Fueling Trucks**: Similar to current aircraft fueling methods, a fueling truck filled with hydrogen refills the empty tanks in the aircraft through a fueling port.
- **Hydrant System**: This method is similar to that of current aircraft fueling through an aviation fuel hydrant system situated underneath the apron. A hydrogen hydrant system is currently not pertinent because the concept of hydrogen-fueled aircraft is in its early stages. Further hydrogen implementation, as part of a broader hydrogen economy and/or in the context of the introduction of larger hydrogen-powered aircraft, could make such infrastructure interesting for the busiest airports.

Note: The future of hydrogen container swap as a way to provide fully loaded containers to an aircraft during regular operations will depend on FAA approval. If the FAA does not consider this as a minor alteration per 14 CFR 21.93, the container swap might have to be performed by licensed mechanics instead of trained ground handlers, which may impact the operational viability and business model of this solution.

8.4 Developing Airside Requirements

General Approach

Airport planners will have to determine the given planning period's design level of demand, which is the maximum number of aircraft that should be provided with charging or refueling equipment at the same time. Figures 46 and 47 detail the processes to charge and swap batteries. Figures 48 and 49 detail the swap and refill H_2 processes. The following parameters should be determined for airport planning purposes for each milestone of the planning period (typically 5 years, 10 years, and 20 years for a master plan):

- Estimate or project the stimulated demand due to electric aircraft.
- Expected percentage of electric or hybrid aircraft as part of aircraft fleet.
- Design aircraft for electric demand. There might be more than one design aircraft, depending on the fleet mix and specialization of aviation facilities (e.g., regional terminal or ramp).
- Design demand levels per category of users.
- Expected number of based general aviation aircraft to be charged in hangars.
- Maximum number of transient general aviation aircraft to be charged on stands.
- Peak gate or stand demands for commuter and larger electric aircraft accommodated on a remote stand or "non-contact" gates.
- Number of aircraft gates or stands and hangars to be equipped with chargers or serviced by charging or refueling equipment.
- Requirements will vary across time with the variation of the aircraft traffic, but first and foremost, with the growth of electric planes among the overall aircraft fleet.

Impact on the Airport Electric Demand

Specific considerations on airport power infrastructure will greatly vary between airports based on size, current power capabilities, and the density of the expected electric aircraft traffic.

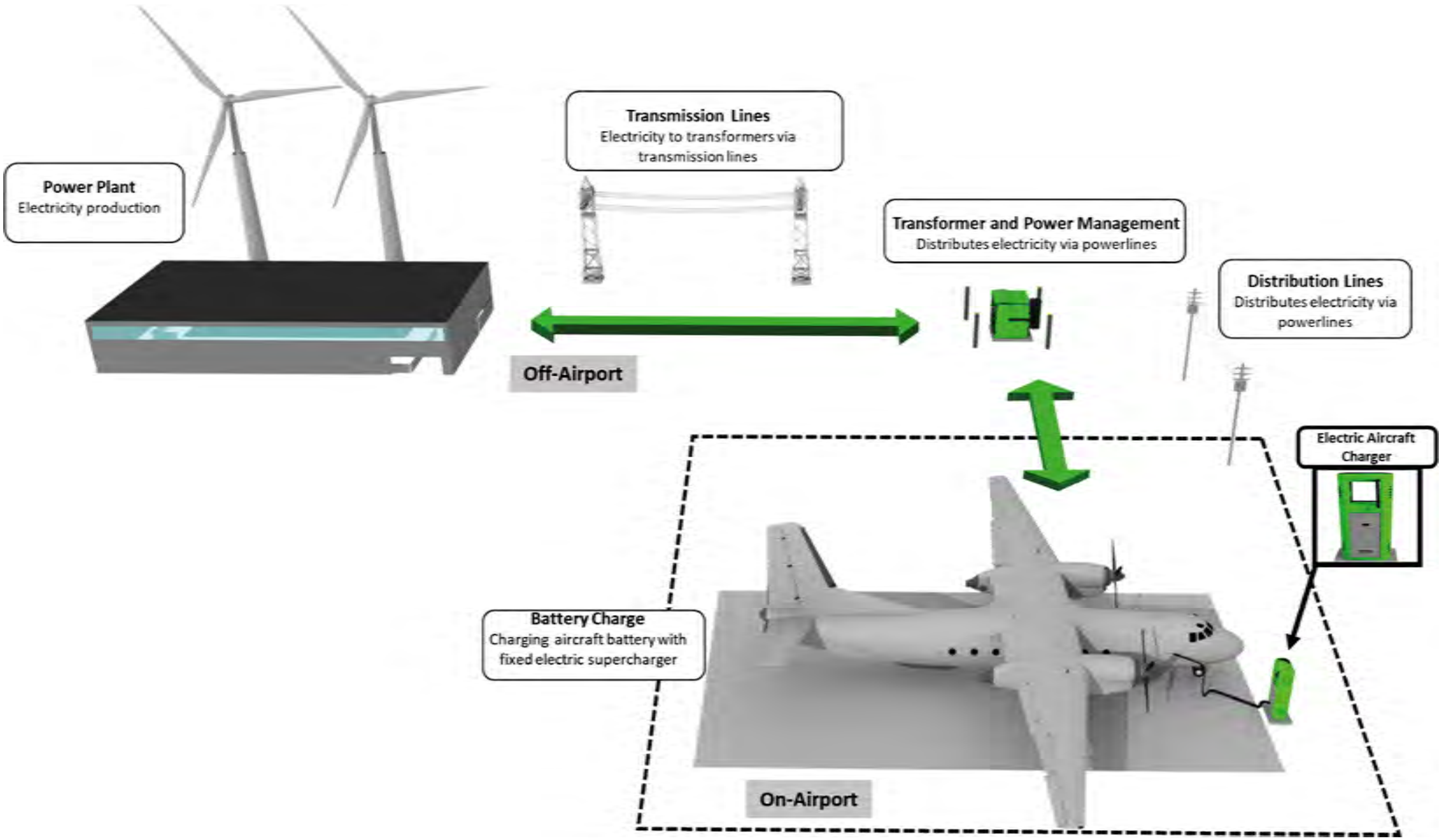


Figure 46. Fixed electric aircraft charger electricity supply.

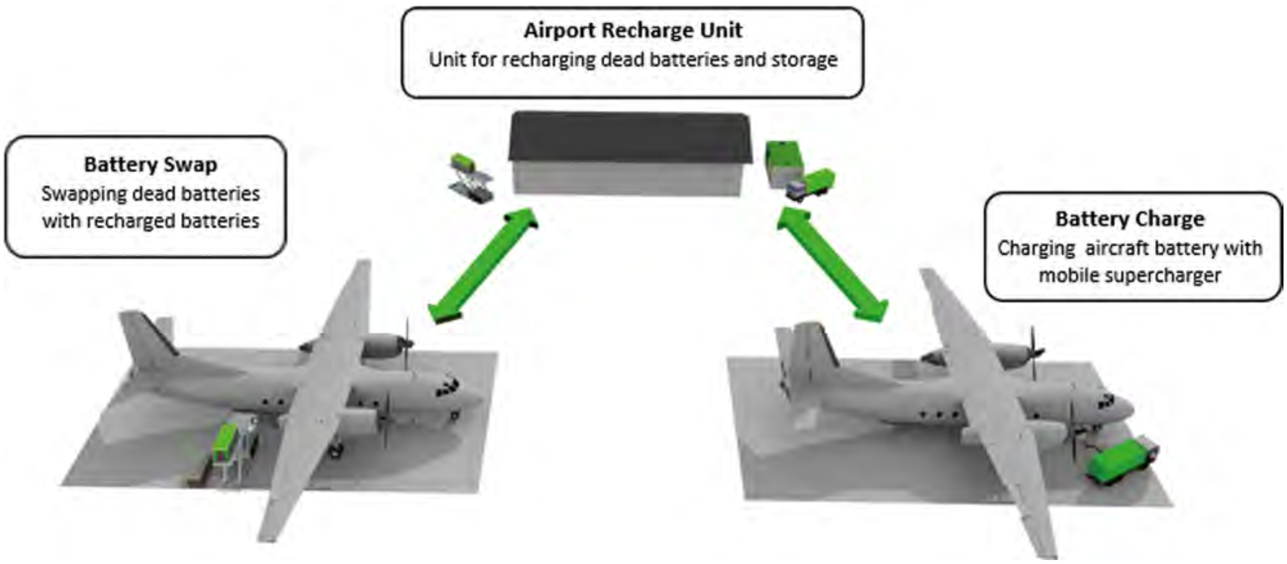


Figure 47. Battery swap and mobile supercharging process.

When planning for electric aircraft, airport planners should consider the effects on power for both current airport operations and long-term airport master plans. For the individual airport, the primary impact will stem from the increased electrical demand necessary to charge electric aircraft. The effects and necessary considerations will vary between airports of various sizes based on the type and density of traffic.

During the planning process, along with the aviation facility requirements, aircraft-specific power supply requirements should be developed. Based on individual charging requirements, and assuming that future chargers will take 45 minutes for a full-charging cycle, the demand could grow to several megawatts even at small airports.

Smaller all-electric general aviation aircraft can be charged in about 45 minutes with 40 to 60 kW chargers. Twenty of those aircraft charging simultaneously would have an electric demand of about 1 MW (800 to 1,200 kW).

Small commuter aircraft demand an additional order of magnitude. An individual aircraft might need 400 to 600 kW for ensuring charging times compatible with the typical aircraft turnaround time. At busy regional airports, power requirements might reach about 10 MW.

Larger commercial aircraft able to fly medium-haul routes with all-electric or hybrid systems might demand 1 to 10 MW chargers. While such estimates are still speculative, we can reasonably predict a power consumption of 10 to 100 MW at commercial service airports specifically for charging aircraft—assuming that 100 percent of the fleet becomes electric.

Currently, terminals consume 60 percent of the electricity at a typical airport, and airfields consume the remaining 40 percent. This balance could be significantly shifted with the emergence of electric aircraft, especially beyond the 2030 horizon. A hub airport like Pittsburgh International Airport has a peak-power demand of 14 MW. In 2019, the airport became one of the first hub airports to have a microgrid, a system that combines a natural-gas generator and solar panels and can deliver 22.5 MW.

The electric demand from aircraft charging their batteries or remote battery chargers (for battery swap) would become significant very quickly, especially when commuter and regional aircraft start flying. This aircraft-specific demand should be considered by planners in the context of

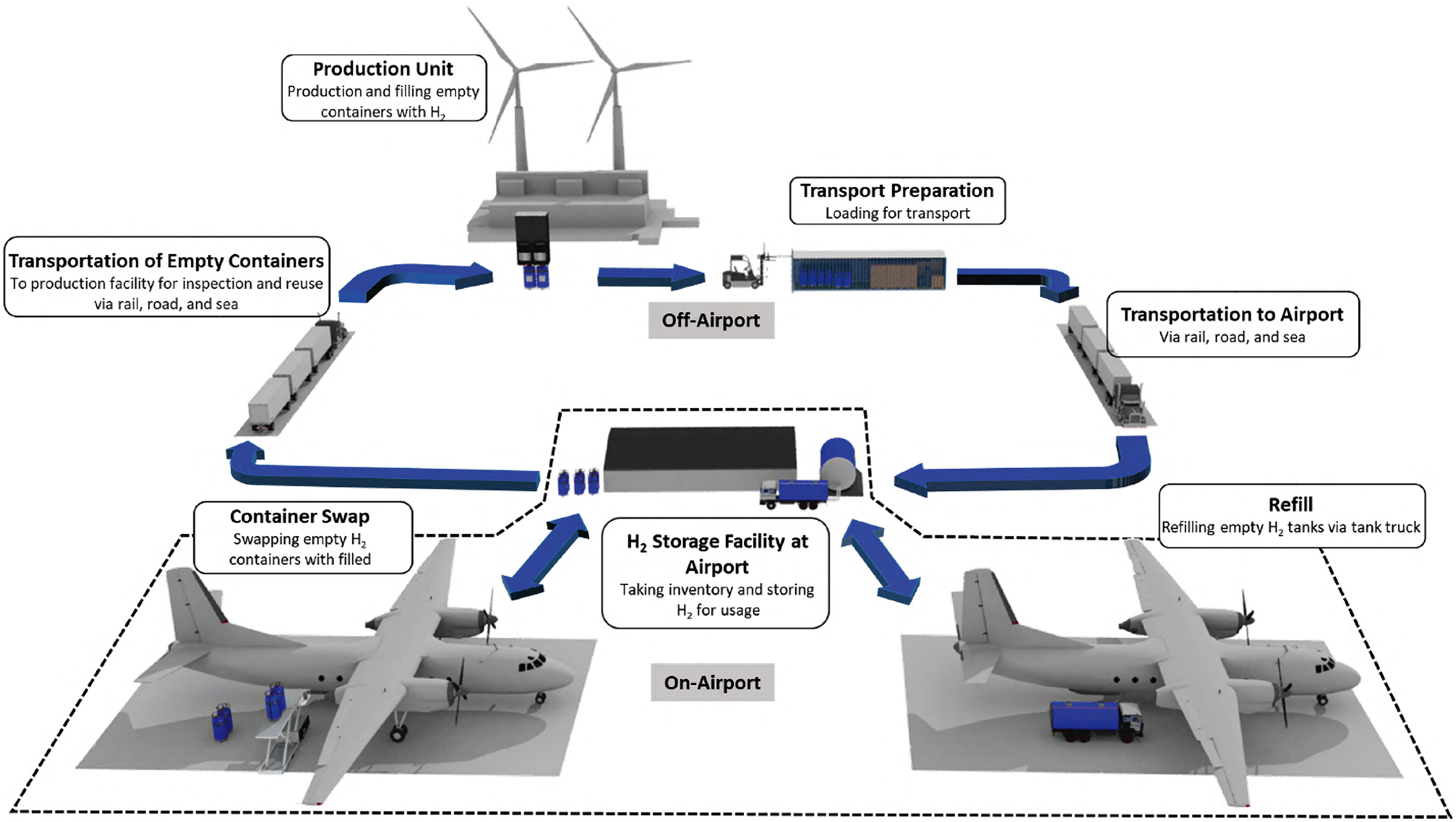


Figure 48. H_2 container swap and tank refilling process from off-airport production unit.

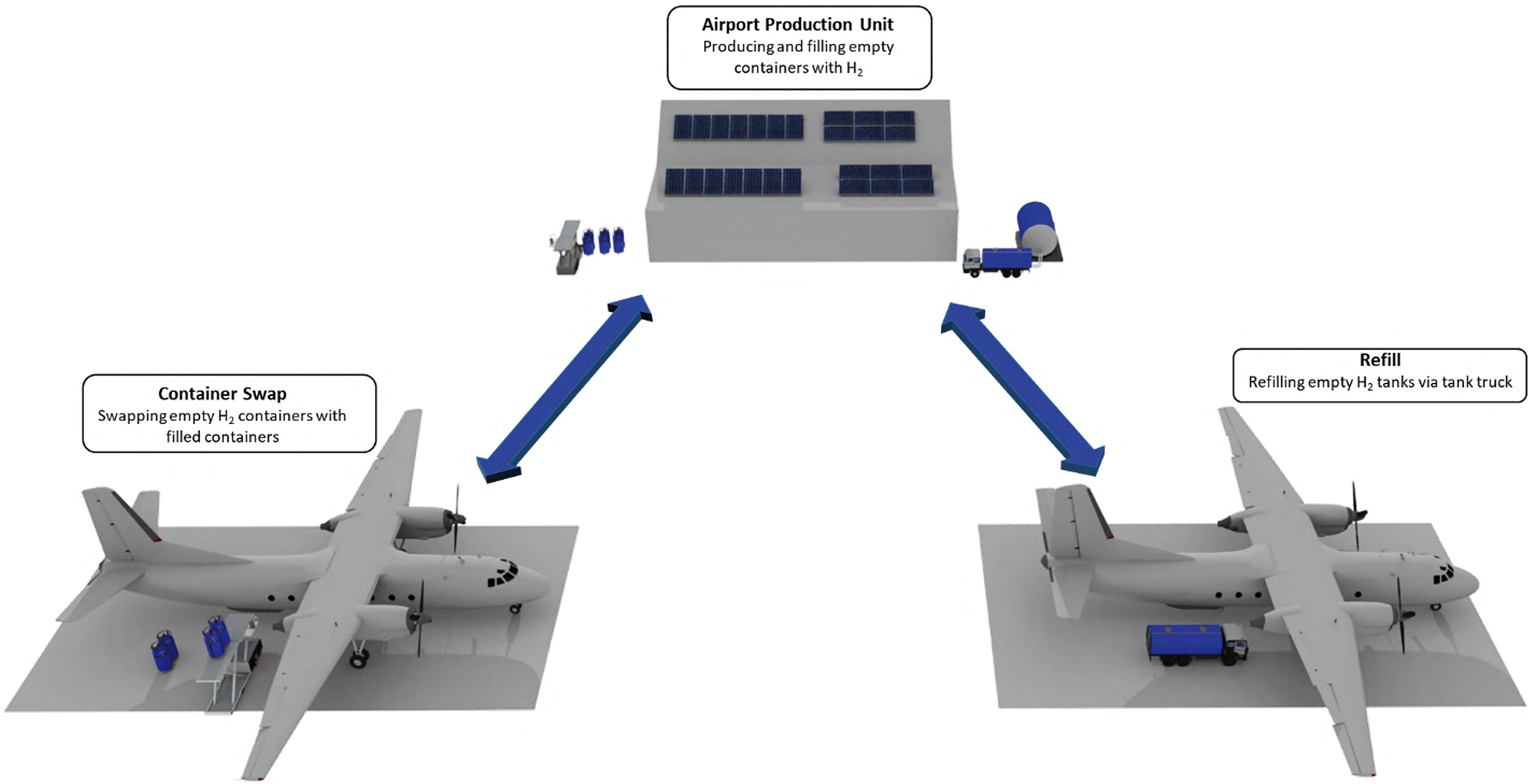


Figure 49. H_2 container swap and tank refilling process from on-airport production unit.

overall growth in electric demand at airports (see Table 17). For instance, as electric cars grow in popularity, airports could seek to expand their on-site charging capabilities, further increasing power demand. The implementation of new parking technologies—such as the deployment of robotic valets at airports—would be an additional power consideration for garage and parking facilities. Trends toward reducing operational emissions have led many airports to install ground-power systems that connect directly to the airport power grid, replacing diesel-powered GPUs and aircraft APUs. Additionally, airports have centralized electrically powered preconditioned air units, which further reduces the need for aircraft to generate power onboard. This growth in gate facility electrification, compounded with the introduction of aircraft charging, could strain existing airport electrical infrastructure.

Airport electric infrastructure is likely to be affected by the integration of electric aviation into existing airport ecosystems. Increasing electrification across airport technology and infrastructure, coupled with the introduction of high-power fast charging for electric aircraft, could place a significant strain on existing airport power grids. Two basic scenarios are likely to arise as airports seek to integrate electric aircraft into their operations:

- In the first scenario, adding necessary airside equipment to support electric aircraft would not require the airport to upgrade its main electrical connection to the greater power grid. In this scenario, infrastructure modifications would require installation of charging stations and associated power distribution and management systems.
- In the second scenario, the airport's electrical supply would be insufficient to support the added equipment necessary to support electric aircraft operations. The following options would address this situation:
  - Smart power management at the airport to share the available capacity with other resources, which would include sharing existing power supply with other airside equipment (e.g., jet bridges) and defining prioritization rules.
  - Working with energy providers to upgrade their electrical power supply.
  - Developing local electric production at the airport, which could include a microgrid strategy to increase resiliency.

Table 17. Power requirements per number of aircraft charging simultaneously.

Configuration	Mission	Baseline Aircraft	Capacity	Power Requirements (Assuming 45 Minutes Recharge)				
				1	5	10	20	50
Small All-Electric Tube & Wing	Flight Training, Private, Recreational	Pipistrel Alpha Electro	1 pilot + 1 passenger	20 kW	100 kW	200 kW	400 kW	1 MW
Small All-Electric Tube & Wing	Very Short Range (420 miles)	Short Range (700 miles)	1 pilot + 3 passengers	60 kW	300 kW	600 kW	1.2 MW	3 MW
All-Electric Tube & Wing Commuter	Short Range (650 miles)	Eviation Alice	2 pilots + 9 passengers	400 kW	2 MW	4 MW	8 MW	20 MW
Hybrid-Electric Tube & Wing Regional	Short Range (700 miles)	UTC Project 804	2 pilots + 39 passengers	600 kW	3 MW	6 MW	12 MW	30 MW

Note: These figures are for aircraft charging at the aircraft gate or stand. Required power might be lower for remote charging for battery swap.

Solar power presents a viable option for airports because they can provide significant amount of space needed for large-scale solar power generation. Several U.S. airports (e.g., Indianapolis International Airport and the Denver International Airport) have leased land to developers to install solar farms on airport property, while some smaller airports (e.g., Chattanooga Metropolitan Airport) have identified solar power as an avenue to electrical self-sufficiency. Installation of solar panels could present a planning challenge for some airports because they must be situated in such a way that ensures installations do not create glint or glare conditions. Additionally, they could be unsuitable in areas that experience heavy cloud cover for much of the year.

Many airports are taking a second approach to on-site power generation by installing microgrid infrastructure. These self-sufficient energy systems can allow an airport to operate independently of the main grid. Additionally, if one microgrid goes down, others can provide backup power to maintain airport operations. Many major airports have installed or are planning to install microgrid systems in an effort to prevent occurrences such as the 11-hour power outage at ATL in 2017. These systems typically leverage natural gas generators as the primary power source, with some utilizing supplemental solar panels.

Each of these avenues to increasing airport power supplies presents benefits and drawbacks, and airport planners must assess the impacts against the needs of their individual airport. Upgrading existing grid connections could present a more affordable short-term solution for smaller airports. However, electric aviation will further increase an airport's reliance on electricity supplies, increasing the impact of power outages. Installing on-site power generation could greatly increase the resiliency of airport power infrastructure; however, these projects would likely have higher upfront costs and longer realization of return on investment and could strain relations with existing local energy partners. Whichever path airport planners deem best for their facilities, energy providers must be involved early in the planning process.

8.5 Applicable Technical Standards and Guidance

Table 18 provides a selection of technical standards applicable to electric aircraft airside facility planning and design that should be taken into consideration when developing airside requirements and alternatives. Because the electric aviation is still emerging, these publications do not address specifically e-aircraft. However, they provide standards that might apply to or be considered for electric aircraft facilities.

Table 18. Main technical standards applicable to electric aircraft airside facility planning and design.

Institution	Standard	Comments
FAA	AC 150/5300-13A and -13B (Draft) – Airport Design	This document features the FAA airfield design standards. Draft AC 150/5300-13B introduces significant changes to the standards. The final version -13B might be released in 2021.
NFPA	NFPA 2 – Hydrogen Technologies Code	This code provides fundamental safeguards for the generation, installation, storage, piping, use, and handling of hydrogen in compressed gas (gaseous hydrogen, or GH_2) form or cryogenic liquid (liquid hydrogen, or LH_2) form.
	NFPA 55 – Compressed Gases and Cryogenic Fluids Code	NFPA 55 facilitates protection from physiological, over-pressurization, explosive, and flammability hazards associated with compressed gases and cryogenic fluids. It includes standards from the former NFPA 50A and 50B standards on hydrogen systems at consumer sites.
	NFPA 407 – Standard for Aircraft Fuel Servicing	This standard outlines vital safety provisions for procedures, equipment, and installations to protect people, aircraft, and other property during ground fuel servicing of aircraft using liquid petroleum fuels.
	NFPA 440 – Guide for Aircraft Rescue and Firefighting Operations and Airport/Community Emergency Planning	As of March 2021, NFPA 440 is a proposed standard that is in a custom cycle due to the Emergency Response and Responder Safety Document Consolidation Plan as approved by the NFPA Standards Council. As part of the consolidation plan, NFPA 440 is combining NFPA 402 and NFPA 424 standards.
	NFPA 460 – Standard for Aircraft Rescue and Firefighting Services at Airports, Recurring Proficiency of Airport Fire Fighters, and Evaluating Aircraft Rescue and Firefighting Foam Equipment	As of March 2021, NFPA 460 is a proposed standard that is in a custom cycle due to the Emergency Response and Responder Safety Document Consolidation Plan as approved by the NFPA Standards Council. As part of the consolidation plan, NFPA 460 is combining NFPA 403, NFPA 405, and NFPA 412 standards.
SAE International	AIR7765 – Considerations for Hydrogen Fuel Cells in Airborne Applications	The scope of this joint European Organization for Civil Aviation Equipment (EUROCAE)/SAE International report is to compile the considerations relating to airborne application of hydrogen fuel cells. This document provides a comprehensive analysis of the use of hydrogen as a fuel by describing its existing applications and the experience gained by exploiting fuel cells in sectors other than aviation.

CHAPTER 9

Developing Alternatives

9.1 Alternatives Development

Developing alternatives is a crucial part of all planning processes. It is the next step after determining additional facilities that will be needed to fulfill or accommodate an airport's future needs and demands, also known as facility requirements. Facilities vary across an airport's functional elements, which include the airside (e.g., runway, taxiways, and hangar complexes), terminals, and landside (e.g., parking lots and ground transportation access). The alternatives development usually draws together various aspects of a planning process to identify and develop options to satisfy an airport's needs and then further assess or evaluate the alternatives to narrow down to the preferred option.

Alternatives development is a thorough and extensive process where all aspects regarding the elements of the study must be considered. Different steps and procedures should be followed to achieve the desired results in an alternatives-development process because it is usually not a "one-size-fits-all" process. It varies from one airport to the other, and its level of complexity differs from study to study. However, there are some general process steps that can be applied and adapted to fit all individual airports.

Airport Master Planning Alternatives Development Process

According to the FAA AC 150/5070-6B on Airport Master Plans, alternatives development includes the following 13 main steps:

- **Step 1**: Determine the Primary and Secondary Elements. This step involves deducing and separating the specific functional elements (e.g., cargo, airside) that should be included in the initial analysis and the secondary analysis, and those that must be left out.
- **Step 2**: Identify Preliminary Primary Element Alternatives. After identifying the primary and secondary elements, the primary elements are focused on, and alternatives for selected elements are identified and developed.
- **Steps 3 and 4**: Screen Alternatives for Immediate List of Primary Element Alternatives. The alternatives identified and selected in Step 2 are screened and sorted out using qualitative methods. This step may rule out and/or introduce some of the primary alternatives.
- **Steps 5 and 6**: Quantitative Analysis for Short List of Primary Element Alternatives. These steps, though similar to Steps 3 and 4, take the primary alternatives further through meticulous analysis to obtain a shortlist of the alternatives for each element being considered.
- **Steps 7 and 8**: Combine and Analyze Primary Element Alternatives. The shortlisted alternatives for each primary element are combined with that of other elements to produce a logical combination. The combinations are further analyzed.

- **Step 9**: Select Preferred Primary Element Alternative. This step selects and documents the preferred primary element alternative.
- **Step 10**: Identify Alternatives for the Secondary Elements. The secondary elements are focused on, and alternatives for the selected elements are identified and developed.
- **Steps 11 and 12**: Evaluate and Select Recommended Alternatives for Secondary Elements. The alternatives identified and selected in the previous step are assessed and evaluated using subjective and qualitative methods to determine and choose suitable alternatives.
- **Step 13**: Prepare Refined Recommended Alternative. The final step involves combining both primary and secondary element recommended alternatives to obtain the refined recommended alternatives.

9.2 Integrating Electric Aircraft into Alternatives Development

Facility Requirements

Market assessment forecasts indicate that about 2 percent of the U.S. aircraft fleet could be electric by 2030. The first available aircraft will probably be a small aircraft, as suggested by existing electric aircraft projects under development. Although likely that the number of electric aircraft will initially be low and concentrated at airports with air carriers willing to pioneer this technology or in states that could provide financial incentives to private owners to acquire or convert their aircraft, airports will plan and prepare to integrate these new aircraft into their master plan. The uncertainty of the future electric aviation demand should not be an obstacle to developing facility requirements and can be estimated at a local level.

Airports should initiate discussions with their main stakeholders, especially airlines, in order to understand if they are planning to integrate electric aircraft in their fleet in the short or medium terms and the implications on their airport operations. A good, recent example is Cape Air, a regional airline based in the Northeast mainly operating Cessna 402s and Tecnam P2012 Travelers. In 2020, the airline signed a purchase option for 92 Eviation Alice aircraft. It is anticipated that other regional airlines may integrate electric aircraft in the next years, and airports should not wait to discuss their vision of electric aircraft with their local stakeholders.

Developments for Electric Aircraft

Electric aircraft will require new infrastructure investments on the following airside, terminal, and landside operations of an airport:

- **Airside**: The initial impacts will center on the charging infrastructure and power capabilities. Three types of charging equipment were identified in this study:
  - *Fixed Chargers*: With this type of equipment, an electric aircraft will have to move to this location to recharge/refuel. The development of alternatives must address two problems: the location and the number of chargers. For commercial aircraft, these charging infrastructure—such as fixed 400 Hz power units—will most likely be implemented at the gate, which could be the most efficient placement. Overnight charging could require airports to equip their existing remote overnight parking or expand available aircraft parking spaces. For smaller aircraft, FBOs would provide charging stations similar to fuel charging stations. At larger airports, a platform could be created that is dedicated to electric aircraft charging any type of aircraft. However, during this process, airports should coordinate and work with their stakeholders to find the most suitable solution.
  - *Mobile Chargers*: Trucks with a supercharger-like device could be charged off-ramp and brought to the aircraft for charging. During the alternatives development process, airport

planners should identify and assess potential locations where the trucks could be charged within the airport property and where these trucks could park after their operations. Charging these supercharger-like devices could be done on an off-airport property, and the airport and stakeholders should coordinate on the entrance of these trucks to the apron.
   - *Battery Swapping*: Assuming that changing batteries can be performed at the gate or stand, airport planners should identify and assess potential locations of infrastructure to store and charge batteries.
- **Passenger Terminal**: Electric aircraft will not directly affect the design of this infrastructure due to its shape and size, but the operational process of airlines will most likely change, especially at regional airports. The operational model of these airlines will drive any terminal modification, and airports will have to become multimodal platforms between all future transportation modes. However, since the terminal building design will not be driven by the aircraft fleet mix but more by the airline operational strategies, the alternatives development process will not differ from the current FAA standards of the AC 150/5070-6B on Airport Master Plans.
- **Landside**: The emergence of electric aircraft will most likely not affect landside infrastructure directly. However, because airline operational and business models might change, airports—especially small and regional ones—will benefit the most from these aircraft. Local communities are searching to gain more connectivity with the outside world, and these airports will be crucial to avoid encroachment. Airports will transition to multimodal transportation platforms, which should be considered during the alternatives development phase.

CHAPTER 10

Electric Industry Trends

10.1 Background

Airports get their power from a large patchwork of different private and public entities. There are approximately 3,300 utilities in the United States. The 200 largest utilities serve most customers and are mainly private, regulated entities. However, public utilities are more likely to serve large public airports. The largest public power providers include the Los Angeles Department of Water & Power, Salt River Project (Arizona), Puerto Rico Electric Power Authority, New York Power Authority, and Sacramento Municipal Utility District.

Both public and private utilities usually have very prescriptive ways of planning for future loads, which are constantly changing. Electric loads have been flat or decreasing for most utilities since the Great Recession in 2008. Besides the slow recovery, the main driver of decreasing loads is energy efficiency, including laptops replacing desktop computers and light-emitting diode (LED) lights replacing less efficient lighting. Because utilities were used to planning for increased future loads, this was a major shift to their business. In the late 1990s, the last round of major regulatory battles occurred when many states went through "deregulation," which broke up vertically integrated monopolies in many states and introduced other aspects of market competition to wholesale power sales. In the 2010s, the most progressive states set out to reform the way utilities sell electricity services, with mixed results. However, the following technological changes will continue to reshape the power markets.

10.2 Renewables and Battery Technology

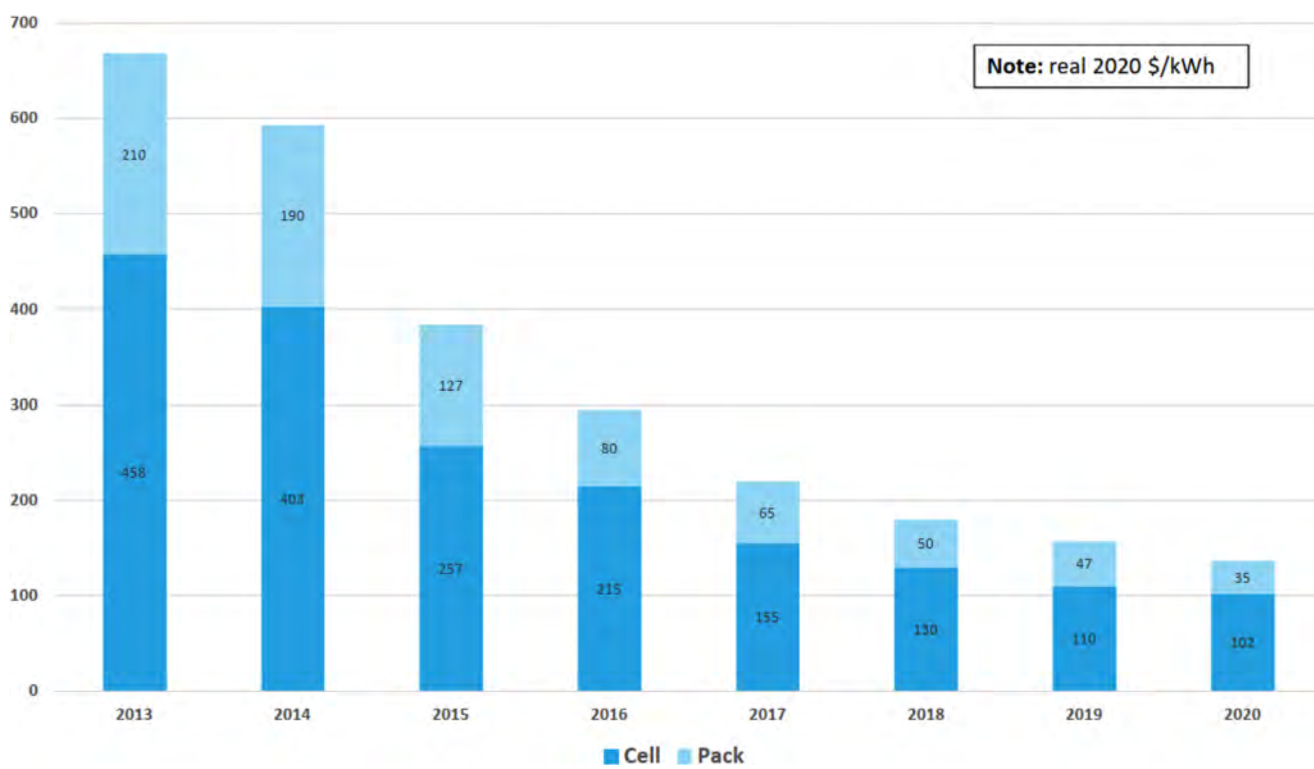
Utilities have been steadily increasing the amount of renewable energy provided due to a cycle in which public policies have driven adoption, which has led to decreases in costs, which has led to more adoption. Within the United States, California has led the way in installing solar power, and the prices have dropped more than 90 percent in the past decade. Meanwhile, West Texas has led the country on wind deployments, which have also seen very significant price declines. Today, most utilities and independent power producers are investing in wind and solar due to the low prices that allow them to undercut coal, natural gas, and nuclear power. The biggest federal policy drivers have been the Investment Tax Credit for solar and the Production Tax Credit for wind. During this period, wholesale power prices have declined steadily due to increasing penetration of wind and solar, as well as low natural gas prices.

However, wind and solar are variable and intermittent power sources, so they cannot be dispatched at exactly the moments when power is needed, which turns the traditional power management equation on its head. Power has been traditionally conceived as end uses and loads that were variable, intermittent, and difficult to predict, while power plants were assumed to be steady and dispatchable assets. Now, end uses are becoming more controllable using smart sensors and innovative demand response contracts, while the power supplies are constantly varying.

The third major disruptive technology that is remaking how utilities and policymakers think about electricity is large-scale batteries that store electricity. Battery quality and reliability have been scaled up from laptops and portable devices, all the way up to cars. The large-scale manufacturing process has also led to significant price declines (Figure 50). Cost declines have led to their use as grid resources.

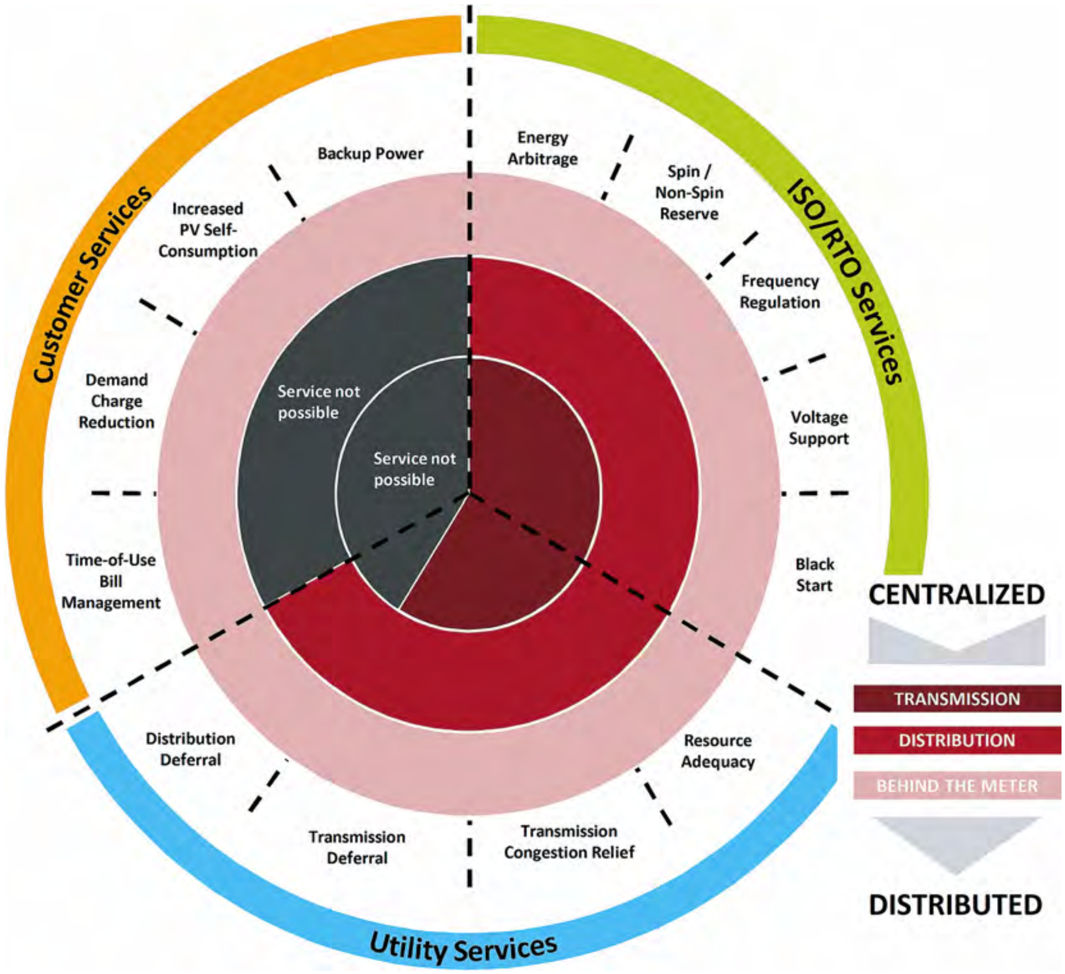
Batteries are sometimes referred to as the "Swiss Army Knife" of the grid since they can perform so many different functions. At their most basic, they absorb electricity from the grid when price/demand is low, and export back to the grid when prices are high, which alleviates congestion on transmission or distribution wires. Rocky Mountain Institute estimates that batteries can provide 13 different services to customers (including airports), distribution utilities, regional transmission organizations (RTOs), and independent system operators (ISOs). See Figure 51.

For airports, solar and batteries will affect operations more than wind power, which is usually best when built in rural areas. Although solar is subjected to FAA regulations on glare at airports, it has already been successfully installed at hundreds of airports. Solar power helps reduce energy bills for airports and can play an important role in an airport microgrid. Battery technology will help improve the economics of solar power by allowing airports to capture more solar energy and to use it when it is most advantageous, through time-of-use bill management or demand-charge reductions. One of the most critical uses of batteries at airports will be to enable DC fast charging of electric aircraft and other electric vehicles with limited distribution upgrades. The stationary batteries will be slow charged over time, and that power will then be



Source: BloombergNEF.

Figure 50. Volume-weighted average pack and cell price split.



Note: PV = photovoltaic.
Source: Rocky Mountain Institute.

Figure 51. Services provided by batteries

rapidly transferred to the electric aircraft battery to enable a quick turnaround. Finally, batteries will provide critical fast-acting backup power in support of an airport microgrid.

Solar Power

As the use of solar power continues to expand, it has become an important energy source at some airports. SFO has solar panels installed throughout airport grounds in locations such as the roofs of auxiliary airport buildings. Many airports are situated on large campuses with auxiliary buildings and land for support facilities, which ideally positions them to generate additional energy and associated cost savings from a solar installation. Support facilities—such as parking lot canopies, consolidated rental car centers, and office buildings—offer ample surface area to locate solar panels (see example in Figure 52).

Specific FAA guidelines exist to ensure that solar installations at airports do not conflict with flight operations. Glare and glint studies are conducted to ensure the solar installations will not negatively hamper pilots' lines of sight. Solar photovoltaic (PV) cells have little to no impact on operations due to their low profile and can convert 14 percent of solar energy that strikes them to be used as electricity.

Figure 52. Solar amphitheater doubling as a parking canopy at Tucson International Airport in Arizona.

Solar power also offers opportunities for airports to advance their environmental and social governance priorities. In a new solar installation at JFK, the Port Authority of New York and New Jersey and the New York Power Authority installed a 5 MW plant for airport consumption and another 5 MW plant that will sell electricity at a discount to nearby low-income neighborhoods.

While many airports need a significant amount of electricity to operate throughout the night, precluding them from relying entirely upon solar power, several airports now operate entirely upon solar power. India's Cochin International Airport became the first to do so in 2015 and has since been joined by South Africa's George Airport, Seymour Airport in the Galapagos, and Chattanooga Airport in Tennessee. Several other U.S. airports, including Denver and Indianapolis, have built large solar farms that are powering a significant portion of their operation.

Some airport solar installations are financed, owned, and operated by a third party, often a utility provider, which requires little capital outlay because the utility provider can sell the energy beyond the airport's demand to the grid. Other installations are funded by federal grants: Chattanooga Airport's 2.64 MW solar farm was funded through the FAA's VALE and Energy Efficiency programs, as was 95 percent of the system cost at Manchester-Boston Regional Airport in New Hampshire.

10.3 Related Transportation Trends

Electric technology has been developed and launched on various sides of the mobility space, including electric vehicles, bicycles, and scooters. The policy disruption and integration concerns that have arisen from these new technologies can serve as examples for future logistical integration and popular acceptance of electric aircraft.

Electric Vehicles

Electric vehicles, as one of the earliest industry-wide adopters of electric technology, offer an ideal case study for the aviation industry to draw upon for successful and unsuccessful elements of their transition.

While electric and hybrid vehicles are more efficient than internal combustion engines in a unit-to-unit (British thermal unit) comparison, the perception that they are "always cleaner" than gas-powered cars is not always true. This depends on the source of the state's power grid.

(For example, an electric vehicle would have a much higher impact in a state that relies heavily on coal than in a state that primarily uses hydroelectric or wind power.)

Electric vehicles are experiencing integration challenges with existing planning, mobility, and policy framework as the sector continues to innovate and expand. The concerns and debates that occur and the results that electric-vehicle stakeholders achieve will be an excellent litmus test for electric aircraft's eventual integration.

Shared Mobility

As with electric vehicles, dockless shared mobility vehicles (particularly electric scooters and bicycles) have posed a significant disruption to urban mobility's policy and operational spheres. Cities worldwide have had varying policy responses to the deployment of these vehicles on their street, ranging from inaction to strictly defined regulations, vehicle caps, and outright bans. Factors underpinning these policy responses include these vehicles' market disruption to public transportation, like the disruption put forth by TNCs such as Uber and Lyft, safety risks of operating these vehicles on streets, and their occupancy of sidewalk space when parked.

Electric aircraft will, in kind, require policy and operational changes in their operating environments. The integration challenges and debates of shared mobility vehicles, while on a smaller scale, provide a similarly valuable experience.

10.4 Conclusions and Next Steps

Airports are constantly going through cycles of rebuilding their infrastructure. The trends toward electric aircraft and "electrifying everything" will promote additional investment in redundant and reliable backup power. New technologies like solar and batteries will become much more common for airports, helping to control energy bills, along with supporting backup power options.

Airports will need to partner with their local electric utility to prepare for load growth in the future for all new electric loads. However, airports must also review energy efficiency and load flexibility options, which will reduce the long-term electric bills but will also save significant capital expenditures required to upgrade peak electric services. As variable renewable production starts to dominate the grid, load flexibility will become more valuable. Airports may be able to capture some of that value with software and on-site energy assets.

CHAPTER 11

Airport Electric Demand

11.1 Introduction

Electric aircraft have emerged as an integral component of the broader electrification of transportation and mobility networks. Electric mobility has been heralded as a step toward reaching climate goals and improving air quality. While the electric mobility movement has been welcomed by many stakeholders in the transportation sphere, indicated by a multitude of innovations in the space, it has yet to be integrated into the broader city planning process and policy framework.

Electric aircraft stakeholders stand to benefit from the achievements and lessons learned by early and parallel adopters of electric mobility, such as electric vehicles. The consideration of electric aircraft in airport planning decisions will pinpoint additional opportunities for airports to integrate energy and resiliency improvements. Recent investments in airport systems, such as microgrids and distributed generation, have brought airports closer to the infrastructure required to power electric aircraft.

Airport Electricity Needs

Airport's electricity needs are measured by demand and consumption. Large-hub airports typically demand 40 to 50 MW for daytime operations and 35 to 36 MW per day for evening operations. Airport electricity use tends to be relatively consistent between daytime and evening operations due to much of an airport's nonessential electrical equipment remaining powered on at night. Smart-charge management systems, which shift charging needs to nighttime where possible, seek to address this. With the advent of electric aircraft, airports will face additional demand for electricity consumption to allow for charging.

Airports have a limited electrical capacity, and while their large capital plans offer opportunities for sizable investments, it can be cost-prohibitive to upgrade electrical systems.

Airports can augment their electrical capacity and revenue streams by installing or retrofitting assets to generate electricity. Electric-vehicle charging stations for public parking, TNC vehicles, and airport fleets are ideal opportunities to generate new revenue on airport grounds.

11.2 Load Growth and Sustainability

Airport electric loads generally increase with size of buildings on the airport campus. There is also some increased energy use per each person who passes through the terminals. One of the key metrics for airport sustainability is reducing the total energy used per enplanement per year, allowing for growth of enplanements and also airport facility size, without reducing the harm from energy use, which includes both pollution and cost of purchasing energy. SFO has done a

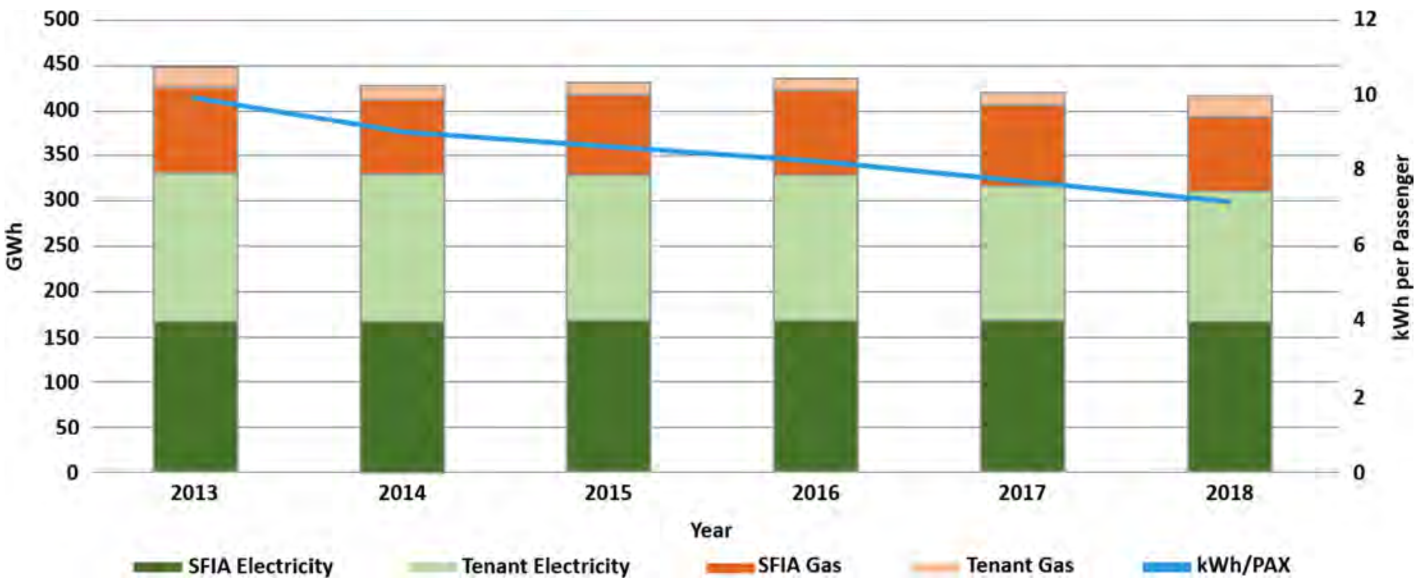


Figure 53. Historical energy consumption and generation at SFO (SFIA = San Francisco International Airport, PAX = passengers).

good job at reducing the energy intensity of serving each customer, as shown in its self-published data (Figure 53). However, the advent of electric aircraft and other electric loads as discussed in this report will strain airport electric distribution systems and lead to increasing electric loads.

Despite the flat/decreasing loads of the last decade, electric utilities are preparing for growth again, due to a number of factors, including the response to climate change. Several high-profile studies over the past year have shown that in significant portions of the United States, GHG emissions can be eliminated through a strategy known colloquially as "electrify everything." This is because electric systems tend to be more efficient than combustion/mechanical systems, and the electric grid is becoming cleaner every year. Therefore, utilities are planning for growth in electric loads from electric cars, heat pumps for heating and cooling, and batteries replacing diesel generators. Within airports, this means that GSE fleets are going electric, and electric aircraft are emerging as a clean alternative, along with other transportation options. Even cooking devices within airport restaurants may eventually switch over to electric options.

Airport Assessment Tool

As part of ACRP Project 03-51, an Assessment Tool was developed for planning purposes to help airport practitioners estimate the electric growth caused by the electric aircraft activity. As part of this tool, the following assumptions were made concerning loads that will convert from fossil fuels to electricity over the next 20 years:

- Heating systems will change to new air- or ground-source heat pumps,
- eGSE will convert to battery electric,
- Shuttle buses will convert to battery electric,
- Rental cars will convert to battery electric,
- Taxis and general public vehicles will convert to battery electric, and
- Electric aircraft will be introduced into the market.

The potential load growth from this equipment may double airport peak electrical loads in the next 20 years. Electric aircraft could be as little as 10 percent of that growth, or could be up to 50 percent of that growth, depending on acceptance of electric aircraft.

Airport managers, electric departments, and sustainability departments at airports must also plan for electric growth. Most large airports have their own medium-voltage electric distribution system on campus. This system acts quite similarly to a small distribution utility. Many airports also already own primary power generators, such as cogeneration plants or solar panels. Solar panels especially have exploded in popularity on rooftops because they are infinitely scalable—from the smallest buildings to the largest parking lots.

11.3 Case Study: JFK, Terminal 5, GSE Electrification

The business case to electrify additional elements of airport operations is strong. Airports' sizes dictate they must remain technology savvy, and their centrally operated structure establishes an opportunity to make sizable investments in electric technology, with comparably sizable returns. Many airport components are positioned to benefit from electrification, especially GSE vehicles that service aircraft, such as baggage tractors, aircraft tugs, forklifts, and belt loaders.

GSEs—which have a short range and rely on low-end torque—frequently need to start and stop, and are ideally situated for conversion to electric power. Electricity pricing is less volatile than petroleum, which will increase stability in airport financial planning if electrification increases industry-wide. Electric power is more efficient for hydraulic lifts, refrigeration, and pumps, and locating charging stations throughout the airport will eliminate "deadhead" refueling travel for GSE. Electric GSEs have been in use since 2001, and about 10 percent of all GSEs were electrified as of 2013. GSE electrification is a common recipient of federal grant funding, such as VALE, the AIP, and the mitigation trust fund for the Volkswagen CAA Settlement. Industry leaders have identified GSE as the "low hanging fruit" of electrification on airport grounds, and if proven to be successful and beneficial to the airport, may encourage airports to explore additional elements of their operation to electrify.

Terminal 5 at JFK in New York City, home to JetBlue and its partner airlines, recently received a $4 million grant from the FAA's VALE Program to support 38 GSE fast-charging stations. This grant will comprise 75 percent of funding for the conversion, and in tandem with an investment from JetBlue and the New York Power Authority grant, will enable JetBlue to electrify all 118 of its baggage tractors and belt loaders, the largest component of its GSE fleet. The airline has been using electric GSE at Long Beach Airport in California and plans to convert a significant component of its GSE fleet at BOS.

This grant receipt aligns with the ongoing Clean Dozen initiative run by the Port Authority of New York and New Jersey, JFK's operator. It is a comprehensive sustainability agenda that responds to the United Nations Sustainable Development Goals and the Paris Agreement. For electrification, it promotes the conversion of airport shuttle buses, light-duty airport vehicles, and fast chargers for TNCs and authority vehicles. The agency continued its thought leadership in airport sustainability by hosting a symposium of industry stakeholders with United Airlines as a component of 2019's Climate Week in New York City.

CHAPTER 12

Electric Aircraft Demand

Electric aircraft are going to significantly change the electric demand profile of airports. The largest aircraft will require large, new power supplies to charge the batteries. The largest impact on power demand is the turnaround time. A faster turnaround time will require faster-charging speeds, or potentially another new technology like battery swapping.

According to the calculations produced using the Assessment Tool, electric aircraft are only a portion of the expected load growth in the next 20 years. The tool has baseline assumptions for electric aircraft adoption that can be changed by the user of the tool. Electric aircraft could be as little as 10 percent of electric load growth, or could be up to 50 percent of that growth, depending on the acceptance of electric aircraft and acceptance and use of other electric transportation, eGSE, and all-electric heating, ventilation, and air conditioning (HVAC) acceptance. As part of this tool, assumptions regarding the battery sizes, charger speeds, and potential gate occupancy times were made based on the market assessment prepared for ACRP Project 03-51 (Table 19).

12.1 Existing Charging Standards

Most U.S. light- and heavy-duty vehicles are gravitating toward the Combined Charging System (CCS) standard, which is a robust standard that can get up to a 400-kW charging rate. Even 1,000 kW+ charging standards are working on making sure that they are backward compatible with the CCS standards to support future-proofing fleets. This means that, even with a new charger, you could still charge an old vehicle using a previous CCS standard, or you could use an old CCS charger to charge a newer standard vehicle, just not at the vehicle's maximum charge rate potential.

Because the CCS combination has already been deployed widely on ground vehicles, the research and development have been done and troubleshooting completed. The one caveat to this is that the charging mechanisms that reside on the aircraft will likely have to go through FAA certification, but this is true for any charging method, be it proprietary, battery swapping, an existing charging standard, or an all-new one. Some industry partners do not believe that the CCS Combi 1 (CCS1) standard will meet their needs due to battery size and mission characteristics.

Another heavy-duty charging standard that is currently restricted to use by buses is the Society of Automotive Engineers (SAE) J3105. This standard uses a hands-free automated coupler to attach to the top of the bus. This can achieve charge speeds up to 600 kW and will increase in the future. No existing electric aircraft manufacturers are using this specifically, but it may act as a template for some manufacturers.

It is recommended that aircraft manufacturers work toward a unified standard, regardless of whether it is a new, e-aircraft-specific standard, or an existing standard such as CCS1.

Table 19. Assumptions of the Assessment Tool.

	Mission	Capacity	Assumed Battery Size (kWh)	Assumed Charger Speed / Output Power (kW)	Gate Occupancy Time (min)
Air Carrier	Short Range (700 miles)	2 pilots + 39 passengers	4,000	600	60
Air Taxi	Very Short Range (420 miles)	1 pilot + 3 passengers	480	60	60
Commuter	Short Range (650 miles)	2 pilots + 9 passengers	900	400	60
General Aviation	Flight Training, Private, Recreational	1 pilot + 1 passenger	42	20	60
Military	Short Range (700 miles)	2 pilots + 39 passengers	4,000	600	60

12.2 Proprietary Charging Standards

Many aircraft manufacturers have implemented custom proprietary charging connectors to meet their specific needs on early prototypes. This is beneficial because it allows the manufacturer to manage the design requirements and charging needs of the specific aircraft rather than cater the aircraft to a specific standard. However, when deployed to scale, if each manufacturer requires its own high voltage DC charger, it could add substantial requirements to how the grid is built and how operations function at the airport. Part of this is due to utility and code requirements that require switchgear and electrical service to be sized for maximum power-draw capacity, even if not all chargers are used at the same time.

Note that existing eGSE use a proprietary charging standard that was developed years ago. The market has been too small to force a need for standardization, but some manufacturers offer plug options for compatibility with other manufacturers.

12.3 Battery Swapping Solutions

One potential technology solution to electric aircraft demand is battery swapping. The aircraft is designed in such a way that the battery is easily removed from the plane when it is on the ground and, rather than charging the battery on the tarmac or at a dock, a new, fully charged battery is swapped into the aircraft, and the depleted battery is then taken to a charging area where it can recharge. The FAA does not fully support this option at this time, but this solution may be re-examined if manufacturers continue to support it.

Several possible benefits to battery swapping include:

1. **The turnaround time on an airplane can be greatly reduced**. Often, commercial planes are on the ground for approximately half an hour before their next flight. This is too small of a window for current charging and battery technology to adequately recharge a battery for the next flight. However, with a battery swap, a fully charged battery could be installed into the aircraft in about 15 minutes. The charging industry is continuing to advance faster-charging standards in its effort to compete with battery swapping, but this is not available today.
2. **Demand on the grid is lower**. Even if the total energy, measured in kilowatt-hours, is the same, being able to charge a battery at a slower rate, measured in kilowatts, helps prevent stress on the grid. To charge at a higher kilowatt rate, infrastructure may need to be upgraded to provide that burst of power to the site. Higher charge rates can also lead to demand charges that hurt the economic feasibility of electric vehicles since the "fueling" cost can become inflated. Battery swapping allows for a much lower kilowatt usage but requires charging the

batteries somewhere on the site, which could take a day to charge. As long as the operator has a fresh bank of batteries available for the next day's flights, additional electrical infrastructure upgrades may not be needed, or at least the needs could be greatly reduced.

3. **A better solution for small seaplanes**. Electrical upgrades to provide high power DC to an aquatic plane can be costly to upgrade, and existing "shore power" technologies do not provide high enough power to fully charge a plane between flights. While in the water, it can be difficult to access battery compartments to do a battery swap on these aircraft. However, the "Beaver" type seaplane can be electrically lifted out of the water to perform a battery swap.

Possible negatives to battery swapping are as follows:

1. **Increased/different maintenance needs.** All charging systems will require maintenance, regardless of whether they are a battery swap setup or stand-alone fast chargers. However, battery swapping adds a mechanical component beyond traditional plug-in charger methods. Any time mechanical components are added, it increases the probability of a point of failure. Battery swapping is especially prone to this, especially if each aircraft has multiple battery swaps per day. In addition to possibly harming the batteries from frequent swaps, the aircraft or battery itself could also be damaged during a battery swap. For seaplanes, it would also increase the number of times the lifts are used every day, which also could increase lift maintenance requirements.
2. **Infrastructure differences.** Battery swapping could require more space or more overall energy, even if the peak kilowatts needed are not as high. Instead of charging one or two batteries at a time at a high rate, the facility must have the space and power to slowly charge multiple batteries overnight to make sure there is enough battery capacity for next-day operations. While this does shift demand from on-peak hours to off-peak hours, it presents a set of operational challenges. In addition, airports that the aircraft may fly to would also need the same battery swapping technologies, and that can be trickier as far as who owns the actual batteries; with fast charging, there is no change in ownership.

One potential alternative to battery swapping technology is stationary batteries integrated into DC fast chargers. This technology could use a lower peak input of electricity, then a much higher peak electric output to the electric aircraft batteries. Several companies are working on this technology.

Table 20 provides a pro/con comparison of e-aircraft demands.

Table 20. Electric aircraft demand conclusions.

Charging Method	Pros	Cons
Battery Swapping	• Currently faster layover times meet a better operational case for aircraft. • Peak power needed could be lower. • Possibly more effective for seaplanes.	• Increased maintenance risks. • Possible damage to aircraft during swapping. • Infrastructure may require more space. • Legal questions on battery ownership when swapping batteries at different airports. • Currently lacks FAA support.
CCS/Standardized Charging	• Known standard already vetted with ground electrical vehicles. • Equipment more readily available and cost effective. • Backward compatible with future technologies.	• Limited by standards to <400 kW charging speeds. • High power charging may have tougher impact on the grid. • Depends on acceptance of this standard by manufacturers and use case.
Proprietary Charging Standard	• Customized per aircraft to suit specific needs. • Could be faster to market or allow for different charging profiles with specific battery technologies.	• Not standardized so different aircraft may not use the same charger. • May cause operational issues as the industry adapts to multiple proprietary methods.

CHAPTER 13

Power Generation and Management

13.1 Power Management

The advent of low-cost computing has helped improve power and building management technologies. However, according to extensive study by James Dice from Nexus, technology in buildings is decades behind other industries. This report will attempt to tease out ways for airports to apply the best available technologies to maximize the efficiency and use of their existing electrical assets and reduce energy bills.

Why Power Management?

The real price to produce electricity can swing wildly throughout the day and across different seasons. Not all of these cost differences are always passed along to customers. However, utilities are allowed to charge differential prices in several different ways:

- **Demand Charges**: The utility measures the peak electric use over any 15-minute period during the month and charges a specific cost per kilowatt of demand.
- **Time-of-Use Rates**: These rates are usually voluntary, sometimes mandatory for large customers. As implied by the name, the cost of electricity varies throughout the day.
- **Demand Response**: This program rewards customers for shifting their energy use away from times of high electricity demand (traditionally hot summer afternoons).
- **Global Adjustment**: Some utilities measure the demand on a single peak hour, or several peak hours throughout the year and charge additional costs per kilowatt.

Generally, variable prices are lower because the customer is taking on some of the risk from the utility. When prices spike, airports must manage their energy use to avoid very high bills.

Emerging Power Management Technologies

New hardware and software tools can help airports manage their electricity use and control bills. This technology will become more important as airport demands increase. One key to enabling large-scale advances in electric transportation use is to defer distribution system upgrades by shifting loads to lower-use times.

Advanced metering and management combine hardware and software that can measure real-time power flows, display them for action by operators, and control circuit breakers for some advanced users. The costs of metering hardware have decreased in recent decades, and there are more options for monitoring smaller loads in real time. Some providers suggest monitoring down at the smallest branch circuit levels. Other providers suggest focusing on bigger loads and controllable loads that can be scheduled for different times of the day.

Building management systems have been traditionally used to control HVAC loads within buildings. These systems are getting more sophisticated by using digital twins, fault detection and diagnostics, machine learning, data lakes, and cloud computing. Load management for demand response/grid interactivity, which has not been a traditional use of building management systems, is a new trend.

Charge management systems have been built specifically for managing the electricity used to charge electric vehicles. The largest current use case is to manage energy costs for electric-vehicle fleets, which are quite price-sensitive. There are not many options yet for large public parking facilities, such as airport short- and long-term parking lots. New options will likely emerge for airport-specific use cases in the next few years.

Battery energy storage technology was introduced in *Chapter 10, Electric Industry Trends*. These systems can help shift loads from times when power is expensive to times when power is cheap. In addition, there are other benefits to the utility and to the transmission system that can produce additional revenue streams to the airport. Rocky Mountain Institute estimates that there are 13 different services to customers (including airports), distribution utilities, and regional transmission organizations.

Distributed energy resources refer to a wide variety of technologies that could be controlled by a utility to manage the grid. For example, if an airport has a microgrid, the utility could send a request for the airport to export power to the grid or to cease all exports. Utilities are investing in distributed energy resources management systems that allow them to communicate in robust ways with more end customers and loads.

Future Energy Delivery Roadmap

As part of integrating electric aircraft with airport operations, the industry should develop a roadmap on energy delivery for any future fuels. The National Renewable Energy Laboratory has been assisting the move toward electric Class 8 heavy trucks to identify gaps and timing concerns with the standardization of protocols and electrical capacity. Similar roadmaps will ideally be prepared for the future electric loads in the United States.

Several countries have looked into this subject, especially Norway, one of the pioneer countries. Avinor, Norway's main airport operator, carried out a study that indicates that it will be able to accommodate charging a capacity of 2 MW at its smallest airports, up to 10 MW at larger airports, and up to 30 MW at Oslo Airport given a planning horizon of 5 years.

13.2 Power Generation and Backup

Overview

This section of the report discusses the need for backup power generation for the airport industry, given the possibility of electric aircraft emerging as a technology option. The rationale for emergency backup power and a high-level evaluation of three backup power technologies—diesel, natural gas, and hydrogen—were conducted as part of this report.

Not all air service can be replaced by electrically powered aircraft, because batteries are heavy and significantly less energy-dense compared with conventional aviation fuels, and electric aircraft may have different flight characteristics; however, in certain applications (e.g., short-haul and cargo service), electric power may be more efficient than jet engines that use fossil fuel. Implementation of some electrically powered aircraft is considered for this report. Documenting the risks associated with a part-electric fleet will enable certain informed decisions to be made on vital infrastructure and holistic planning for new and emergent technologies.

Rationale for Grid Resiliency

Utility power outages that effect an airport for just a few hours can cause thousands of flight delays and cost millions of dollars. Airports have already invested billions of dollars in both redundant sources of utility power and backup power systems that are expected to perform in rare, but impactful outage situations. Table 21 highlights the impact of power outages at various U.S. airports over the past few years.

Table 21. Recent airport power outages.

Date	Airport Name	3-Letter FAA Code	Country	Duration	Operational Impacts
02/21/2021	Dallas-Fort Worth Intl.	DFW	USA	Several hours	A severe winter storm hit North Texas, causing a power grid failure. Approximately 4.4 million Texans lost power for several days, as well as DFW for a few hours. DFW said it was experiencing delays and cancellations until the next day.
8/2/2019	John Wayne	SNA	USA	About 12 hours	An issue in an electrical transformer in Irvine, CA, caused an overnight power outage causing the cancellation of all flights until the next morning.
9/8/2018	Orlando Intl.	MCO	USA	About 12 hours	Some flights were delayed because the jet bridges temporarily lost power after a local outage. The airport used its backup generators to restore power and maintain operations until power was restored.
8/15/2018	Washington–Ronald Reagan Natl.	DCA	USA	1 hour	Minor impact on flight operations but difficulties for passengers to recover their bags and move around in the terminal because it was plunged into darkness.
3/6/2018	Hamburg	HAM	Germany	Several hours	Airport suspended flight operations due to a power outage.
12/17/2017	Hartsfield-Jackson Atlanta Intl.	ATL	USA	11 hours	A fire in a substation of the energy provider resulted in a power outage, causing about 1,200 flight cancellations and an estimated loss of up to $50 million for Delta Air Lines.
8/18/2016	Barranquilla –Ernesto Cortissoz Intl.	BAQ	Colombia	Unknown	One flight in short final approach made a go around because the runway lighting stopped due to a power outage. These lights are supported by an emergency generator, but it took about 10 seconds for the system to start.
3/27/2015	Amsterdam Schiphol	AMS	Netherlands	90 minutes	Significant flight delays due to a regional power outage.

(continued on next page)

Table 21. (Continued).

Date	Airport Name	3-Letter FAA Code	Country	Duration	Operational Impacts
2/26/2014	São Paulo–Guarulhos Intl.	GRU	Brazil	20 minutes	The airport went out of power after a failed electric test at a substation. 12 flights were delayed and 1 inbound flight diverted.
10/13/2013	O.R. Tambo International Airport	JNB	South Africa	Several hours	Power cables were stolen nearby the airport, creating a power outage that affected the pumps of the hydrant system. Several flights were delayed because they were unable to refuel.
3/25/2013	Pointe-à-Pitre	PTP	France	2 days	Multiple flight cancellations.
3/3/2013	Brasília Intl.	BSB	Brazil	2 hours	Of all the flights scheduled on that day, 55% were significantly delayed and 6% were cancelled.
12/26/2012	Rio de Janeiro–Galeão Intl.	GIG	Brazil	1 hour	Unknown.
12/7/2012	Budapest Ferenc Liszt Intl.	BUD	Hungary	Unknown	Airport temporarily closed due to a power outage affecting the air traffic control tower.
7/30/2012	Delhi Indira Gandhi Intl.	DEL	India	Several hours	Despite a multistate outage due to a massive failure of the northern grid of the country, 95% of the airport activity was preserved. Airport used its backup system to maintain essential services.
2/8/2012	São Paulo–Guarulhos Intl.	GRU	Brazil	13 minutes	The airport was able to run on its own generator during the whole power outage.
9/28/2011	Mexico–Benito Juarez Intl.	MEX	Mexico	Overnight	Diversions to Veracruz, Guadalajara, and Monterrey.
8/8/2011	Delhi Indira Gandhi Intl.	DEL	India	5 hours	Unknown.

When transitioning to electric aircraft, it is also important to consider scenarios in the event of a sustained power outage, such as climate-related or natural disaster emergencies. Although reliability has improved in recent years, many types of natural disasters are expected to increase as the climate continues to change. Airports may have new responsibilities to provide services even during a power outage. The following section highlights the impact of natural disasters as well as the role of emergency preparedness.

Natural Disasters

The airport industry has experienced different disasters over past years, including numerous earthquakes, floods, wildfires, energy shortages, landslides, and severe storms. However, increased frequency and intensity of weather events will continue to adversely affect aviation, causing route changes, increased flight times, disruption to ground transport access, and loss of utility power supply.

Looking specifically at the future security of utility supplies:

- Heat waves can increase load requirements that can lead to equipment failure.
- Rising temperatures could lead to decreasing thermal efficiencies, meaning that more fuel will be required to generate the same amount of power.

- Storms can damage electric distribution facilities and electric generation facilities.
- Droughts and high winds across the West, especially in California, are increasing the wildfire risk, which has led to pre-emptive Public Safety Power Shutoff events.

Although some airports have already conducted climate change vulnerability assessments and resiliency studies, moving forward, it is imperative that the airport industry continue to ensure planned-response efforts in the event of a large-scale natural disaster. Financial firms and the U.S. government are now focusing more on "climate risk disclosure," which helps asset owners understand their vulnerabilities.

13.3 Utility Power Reliability

Reliability Indices

Power reliability is a vital factor when considering the transition to increased electrification. Without an understanding of existing reliability, it will be difficult to properly understand the value of resiliency and the costs of mitigation.

Utility companies generally monitor reliability for regulated, investor-owned utilities around a state to ensure that performance is upheld. Table 22 contains the four major reliability indices that are measured and tracked by regulators throughout the United States.

Reliability metrics oscillate from year to year based on large, but infrequent power outage events. Therefore, a 10-year rolling average is generally used to show improvements over time.

Reliability is the average performance as measured by the four reliability indices. For all four metrics, lower numbers indicate more reliability. For example, if a customer average interruption duration is experienced, the number represents the number of minutes of the outage, so an outage of only 10 minutes shows a more robust system than an average outage of 45 minutes.

Regulations mandating strict performance requirements and technological changes have improved overall reliability over the past 20 years across most utilities.

13.4 Backup Power Options

The following section outlines potential emergency backup power technologies that could provide airports with adequate supply in the event of an extended disruption or disaster. Options are discussed with a primary focus on potential feasibility.

Table 22. Electric power distribution reliability indices.

Index	Measure	Units
System Average Interruption Duration Index	Average outage duration per customer	Minutes per outage (per customer)
System Average Interruption Frequency Index	How often a customer can expect to experience an outage	Number of outages a year (average)
Customer Average Interruption Duration Index	Average outage duration if an outage is experienced, or average restoration time	Minutes per year (per customer)
Momentary Average Interruption Frequency Index	The frequency of momentary interruptions	Number of instantaneous outages per year (average)

Source: Electric Power Research Institute.

Roughly 95 percent of generators used today by commercial buildings and critical facilities are powered by either diesel or natural gas. Apart from differences in costs, an important distinction between the two fuels is that diesel is supplied by truck deliveries and stored on-site, while natural gas is supplied by pipeline. As storage is generally not an option for natural gas, any event that disrupts the natural gas supply will disrupt the operation of a natural gas-fueled generator. Natural gas generators are further constrained to locations with access to natural gas pipelines. On the other hand, diesel generators require fuel resupply to continue operating, which can prove difficult in the event of a long outage. Natural gas generators face the risk of a loss of gas pressure, while diesel generators face the risk of running out of fuel. Both risks are greatest for large, long outages.

Emerging technologies could disrupt these established industries in favor of alternative fueling sources, such as hydrogen fuel-cell backup power generation and on-site battery storage. Those technologies in their current nascence are defined in the following sections.

Diesel Fuel Generators

Diesel generators convert fuel energy (diesel or biodiesel) into mechanical energy by using an internal combustion engine and then converting it into electric power by using an electric generator. Diesel generators are the most common electricity generator used in building-integrated microgrids because of their size, initial cost, simplicity, and ease of buying the fuel. A diesel generator is composed mainly of an internal combustion engine, an electric generator, mechanical coupling, an automatic voltage regulator, a speed regulator, a support chassis, a battery for starting the motor that permits the diesel generator start-up, a fuel tank, and a command panel.

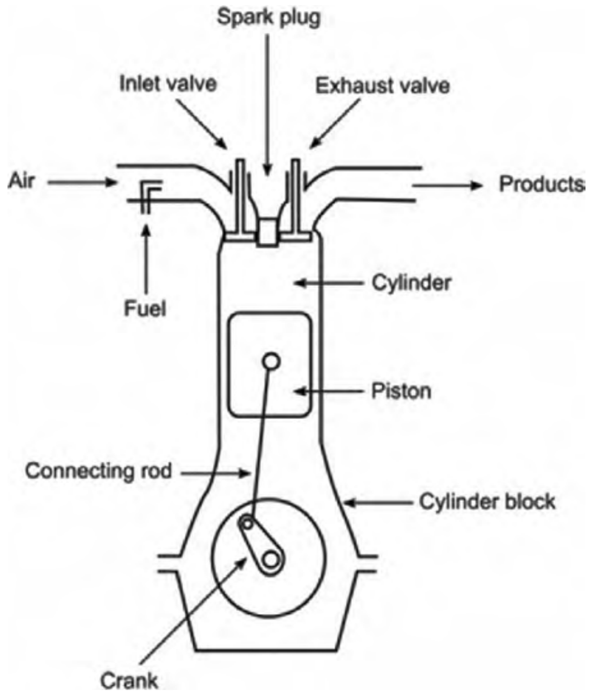
Diesel generators are classified as compression-ignition engines because the air that flows into the compressor is compressed to a temperature sufficiently high for autoignition. The combustion chamber then mixes the heated air with fuel and burns it. Diesel generators convert some of the chemical energy contained by the diesel fuel to mechanical energy through combustion. This mechanical energy then rotates a crank to produce electricity. Electric charges are induced in the wire by moving the latter through a magnetic field. In an electric generator application, two polarized magnets usually produce the magnetic field. A wire is wound around the crankshaft of the diesel generator that is placed between the magnets in the magnetic field. When the diesel engine rotates the crankshaft, the wires are then moved throughout the magnetic field, which can induce electric charges in the circuit.

Natural Gas Generator

Unlike diesel engines that only use the heat from compression and the injection of fuel to start the combustion process, natural gas engines will need an external spark to begin the process and are classified as spark-ignition engines. In a spark-ignition engine, the fuel is mixed with air and then inducted into the cylinder during the intake process. Whereas in a diesel engine, only air is admitted at this stage. In the simplest case, this spark plug is located at the top of the cylinder and directly ignites the mixture within the cylinder (Figure 54). After the piston compresses the fuel-air mixture, the spark ignites it, causing combustion. The expansion of the combustion gases pushes the piston during the power stroke.

Stationary Battery Storage

Stationary batteries are not an alternative energy source but are merely a mechanism to store electrical energy. They can store power when loads are low and power is cheap, such as



Source: Martinez et al. (2017).

Figure 54. Spark-ignition engine.

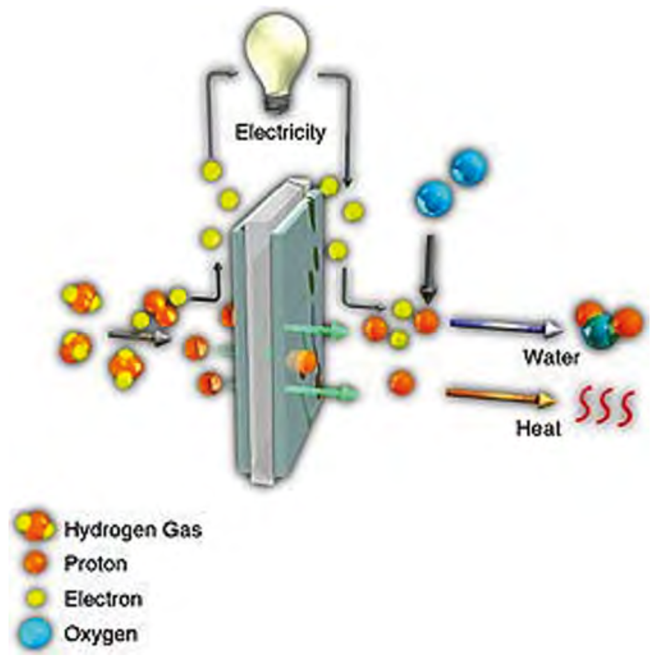
nighttime, and release that energy when power is expensive. Unlike generators, batteries have a limited time duration and get more expensive the longer they are required. Batteries can be integrated with a solar photovoltaic system and used as a source of emergency backup power. Batteries also play a key buffering role in a microgrid to help stabilize the loads seen by the primary generator.

Hydrogen Fuel-Cell Generator

There is increasing interest and research into using hydrogen for power generation to achieve a completely carbon-free energy ecosystem. Hydrogen is a clean-burning fuel that does not produce any carbon emissions because it does not include any carbon molecules. In a complete and balanced reaction, hydrogen would mix with oxygen in the air to produce only water and thus would not emit hazardous air pollutants or GHG.

When used in a generator, hydrogen produces power by using fuel-cell technology, which is a chemical reaction and does not contain any combustion. A fuel cell is constructed much like a typical battery with an anode, a cathode, and an electrolyte membrane. A fuel cell works by passing hydrogen through the anode (negative charge) of a fuel cell and oxygen through the cathode (positive charge). At the anode side, the hydrogen molecules have the electron separated, leaving the hydrogen molecule with a positive charge. The positively charged hydrogen ion passes through the electrolyte membrane, while the electrons are forced through an electrical circuit, generating an electric current and excess heat. At the cathode, the hydrogen ions, electrons, and oxygen combine to produce water (Figure 55). Fuel cells are more efficient than combustion technology.

Note that most fuel cells in use today use natural gas instead of hydrogen in the fuel cell. The process is the same, but the additional carbon molecules also end up producing CO_2 as a



Source: Sciencescene.

Figure 55. Electricity generation in fuel cell.

by-product. However, unlike a natural gas combustion generator, a natural gas fuel-cell generator avoids the production of NOx and particulate matter air pollutants. The major fuel-cell manufacturers are moving toward offering hydrogen, and the following section describes the options for a full hydrogen fuel-cell system.

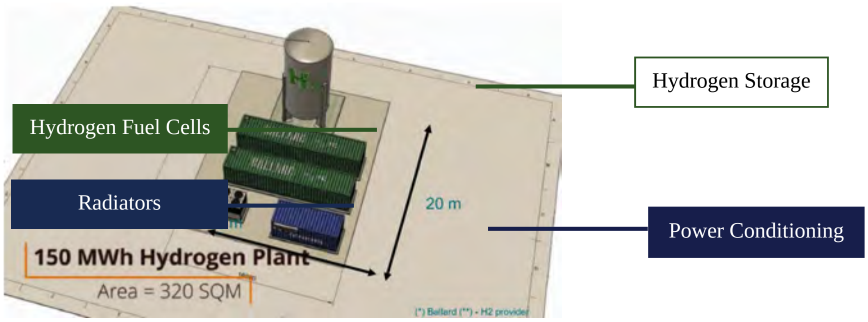
There are some drawbacks to fuel-cell generators. The immediate concerns are the fuel source and the space required to store the fuel and fuel cells. There are four general choices for how hydrogen can be sourced:

- Hydrogen gas delivery via a high-pressure tube trailer or mobile refueler.
- Liquified hydrogen delivery via a tanker.
- Pipeline delivery of hydrogen gas.
- On-site production via steam methane reforming (SMR) or electrolysis.

Access to inexpensive hydrogen fuel remains a significant challenge, although many companies are trying to crack this challenge across the globe. Therefore, long-term costs for hydrogen sourcing should be considered carefully. In addition, contingency and redundancy should be considered for all technologies in case of equipment failure.

Despite the source, all hydrogen (whether gaseous or cryogenically liquified), must have adequate and safe on-site storage. Hydrogen has a lower energy content per volume compared to compressed natural gas, requiring larger storage containers to deliver the same energy. Figure 56 depicts the layout example for fuel cells that can give 3-MW power for 48 hours by using 10,000 kilograms of liquid hydrogen.

An additional concern that must be considered when using hydrogen fuel is the overall safety of the facility. Hydrogen flame has high heat and low luminosity and therefore is hard to see. A flame detection system specifically configured for hydrogen flames must be installed on the maintenance facility. Adjustments to the maintenance facility's safety code and safety zones might also be needed in the case of a hydrogen leak, because hydrogen is more flammable and more prone to seepage compared to natural gas.



Source: Ballard

Figure 56. Hydrogen generator layout example.

Microgrids and Other Options

Microgrids are an emerging solution set that may help airports save on operating costs while still providing the backup power discussed in this report. Microgrids consist of on-site power generation sources that can run during blue-sky operations, but also run in full “island mode” during power outages (i.e., serving as the sole source of power for the local user). They often feature more than one type of power generation source, with one of the most common configurations as solar, battery, and a natural gas generator. This provides some flexibility in operations. Usually. the natural gas generator is clean enough to run regularly. This combination of assets can have a good return on investment, and some companies specialize in financing and operating these assets to improve returns.

When considering solar power, reflection from the solar photovoltaic arrays is a big concern for airport stakeholders. Solar installations must comply with FAA glare policy and standards.

Traditional backup power options are not able to be used for revenue or energy bill management. However, cleaner sources of power could be run to reduce costs or provide revenue. For example, due to their clean nature, fuel cells (both hydrogen and natural gas) can be run 24/7 and may produce a strong payback.

Natural gas generators could be built that can help airports meet fast-ramping markets in the evening hours when power prices are highest. This could be a reliable source of revenue in certain markets, especially California currently.

Battery energy storage systems can participate in wholesale markets and earning revenue from the operator of the transmission system. One additional benefit from batteries could be reduced interconnection costs from the utility company.

Costs

Among the considerations for determining the best-fit backup power strategy to support operations are lifecycle costs. This analysis focuses on the following primary costs associated with each backup power strategy to support in evaluating the cost-benefit of each option: (1) power unit costs, (2) fuel storage costs, (3) installation costs, (4) maintenance costs, and (5) energy costs. Table 23 summarizes the anticipated costs for each backup power option. Battery energy storage system costs are not calculated here because they operate in a fundamentally different way (no fuel input). In addition, battery configurations can vary quite widely and do not lend themselves to a cost per kilowatt calculation.

Table 23. Estimated capital costs per kilowatt of power.

Fuel Type	Diesel	Natural Gas	Hydrogen
Generator	$580	$725	$1,500
On-Site Fuel Storage	$2		$4
Installation	$150	$160	$333

Capital Costs

Included in the considerations for determining the capital cost of each backup power strategy are the costs associated with procuring the unit itself, fuel storage costs, and installation costs. In this analysis, each item cost is broken down by cost per kilowatt to provide a standard metric of evaluation. Costs used in this analysis were sourced from several references, including direct manufacturer quotes, past purchase agreements, and scholarly reports.

As the most mature technology option, at $580 per kilowatt, the diesel component costs are lower than the natural gas and hydrogen fuel cell. This cost assumes the diesel generator includes any additional equipment required to meet the EPA's most stringent air quality standards, classified as Tier 4. The installation costs associated with diesel generators are also the lowest at approximately $150 per kilowatt. Component costs and installation costs for natural gas generators are comparable to diesel at $725 and $160 per kilowatt, respectively. The most expensive option (albeit cleanest), with the highest component and installation costs as well as an additional consideration for fuel storage, is the hydrogen fuel-cell option, requiring an investment of $1,500 per kilowatt for the components and an additional $337 per kilowatt for installation and on-site fuel storage. The on-site hydrogen fuel storage costs assume a direct procurement of the liquid hydrogen tank; alternatively, airports may elect to lease out, which would also alleviate responsibility to maintain the equipment.

The capital costs for natural gas exclude the cost of upgrading pipeline infrastructure at each site, which could be substantial and would need to be discussed with the utility.

Operating Costs

Costs associated with operating backup power units include fuel costs for a full day of service and ongoing maintenance costs. Fuel costs (Table 24) were estimated per kilowatt-hour by multiplying current regional fuel costs by the fuel consumption per hour of the associated technology. A 2,000-kW diesel generator operating at full load has an approximate fuel consumption of 141 gallons per hour. At the current regional price of diesel ($3.40 as reported by the U.S. Energy Administration), the anticipated diesel fuel cost is $0.24 kWh. A typical commercial gas rate is approximately $1.17 per term, resulting in an estimated cost of $0.12 kWh. The cost of delivered hydrogen fuel can vary depending on supplier location and local supply; however, current rates average around $9 per kilogram, resulting in an estimated cost of $0.20 kWh.

Beyond the cost of fuel, the ongoing operating costs for maintaining backup power include periodic tests and repairs to the unit. If the unit primarily serves emergency situations with

Table 24. Estimated fuel costs.

Fuel Type	Fuel Cost	Fuel Cost
Diesel	$3.40/gallon	$0.24 kWh
Natural Gas	$1.17/term	$0.12 kWh
Hydrogen	$9.00/kilogram	$0.20 kWh

Table 25. Estimated yearly maintenance costs.

Item	Diesel	Natural Gas	Hydrogen
1-Year Maintenance Costs (Per MW)	$35,000	$35,000	$36,750

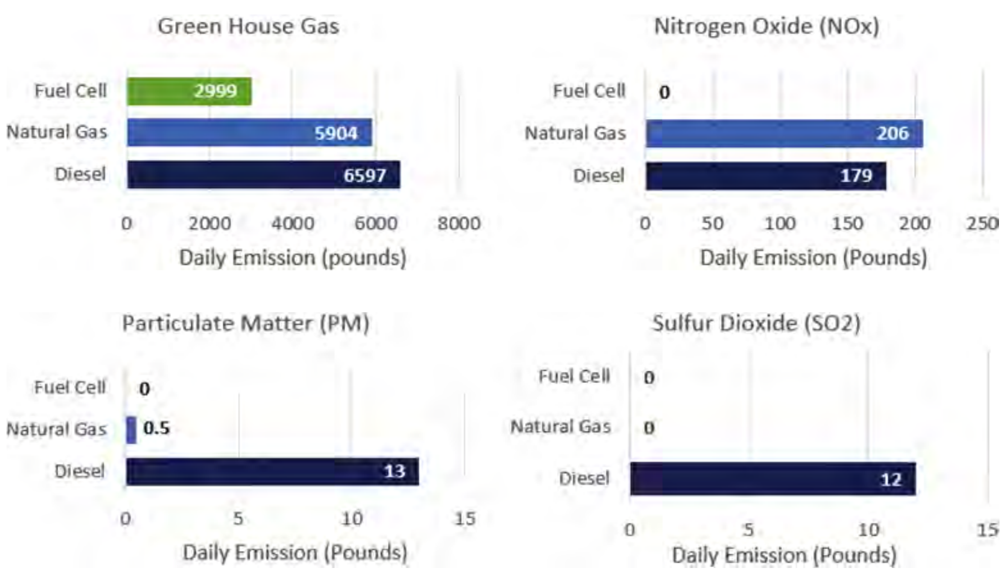
low operational hours, it can be assumed that the majority of the maintenance performed will be scheduled maintenance and testing. The maintenance costs (Table 25) used in this analysis were sourced from the National Renewable Energy Laboratory and are applied equally to all backup power options. The operating costs included in this analysis do not explicitly account for permitting.

Emissions

Emergency and non-emergency generators using common combustion sources can have a significant impact on air quality and public health. If located in a metropolitan or urban area, generators increase the risk of exposing communities to dangerous air pollutants and GHGs. Particulate matter, SOx, and NOx are the major air pollutants that can cause serious health risks. Particulate matter is a complex mixture of microscopic particles and liquid droplets that get into the air. Once inhaled, these particles can affect the heart and lungs and cause serious health effects. SOx and NOx contribute to acid rain, and if inhaled, can harm the heart, irritate airways, and aggravate respiratory diseases. Particulate matter and NOx are the leading causes of reduced visibility (haze) in parts of the United States.

GHGs retain heat in the atmosphere, thus increasing global temperature, altering the climate, and changing weather patterns at the global and regional levels. The main GHGs are water vapor, CO_2, methane, ozone, nitrous oxide (N_2O), and chlorofluorocarbons.

Emissions levels vary dramatically by generator configuration and fuel type. Figure 57 illustrates the different levels of significant air pollutant emissions released on-site based on a natural gas fuel cell, natural gas generator, and diesel generator. The emission calculations do not account for the extraction of natural gas and diesel. Based on the figure, fuel-cell-powered



Note: The daily emission calculation was assumed for a 150 kW-rated generator and 24-hour operation.
Source: Minnesota Pollution Control Agency.

Figure 57. Air pollutants and GHG daily emission based on generator fuel type.

generators emit the least pollutants in total. In contrast, the operation of diesel generators has the highest daily total emission for GHGs, SOx, and particulate matter, while natural gas generators emit the most NOx daily.

While current diesel generators pollute significantly less than older models, they still present potential health risks. To anticipate these risks, the EPA implements a tier system for diesel generators based on the engine's power and year. Based on this regulation, all new diesel generators must comply with the strictest standard of allowed emissions (Tier 4). For backup generators that are used only during grid outages, Tier 3- and Tier 2-compliant engines are permitted.

The engine particulate matter emission rate will also affect the allowed operating hours for reliability-related activities, such as hours used for testing and maintenance. Per Airborne Toxic Control Measures (ATCM) standard, diesel engines with less than 0.15 grams per brake horsepower-hour (g/bhp-hour) particulate matter emission rate can operate for a maximum of 50 hours for reliability-related activities. Meanwhile, engines with less than 0.01 g/bhp-hour particulate matter emission rate can operate for a maximum of 100 hours for reliability-related activities.

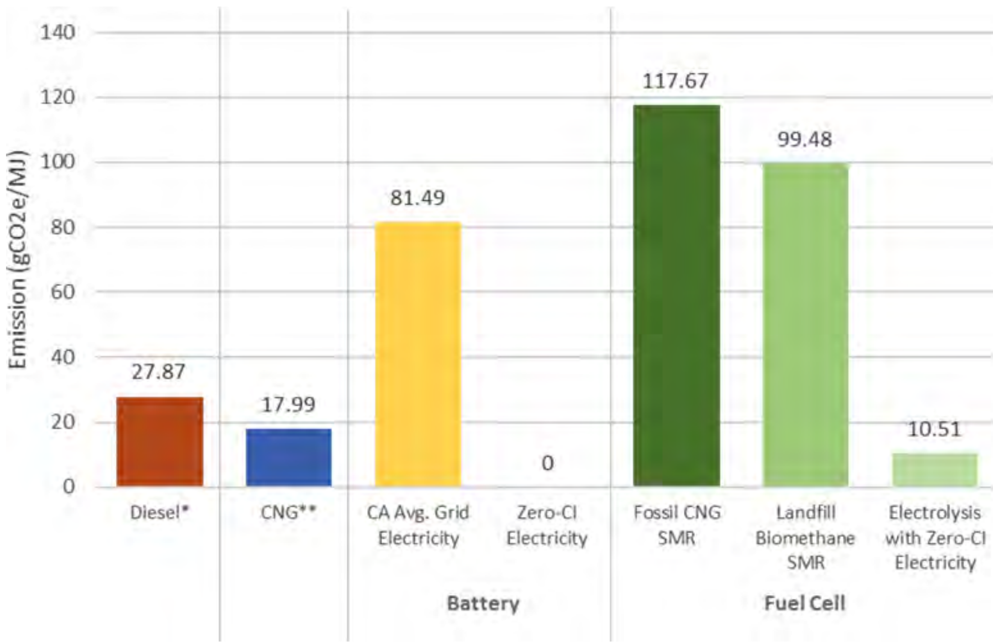
Emissions from natural gas engines are less than those from Tier 2 diesel generators and mostly on par with those of the Tier 4 diesel system. Based on EPA Stationary Combustion Emission Factors, natural gas engines emit approximately 28 percent less CO_2, 67 percent less methane, and 83 percent less nitrous oxide compared to diesel-fueled engines. Because natural gas engines emit significantly fewer emissions than comparable diesel engines, they can meet air quality requirements easier, which results in a more straightforward permitting process. Natural gas and liquified petroleum gas generators do not have an ATCM or trigger Health Risk Assessment requirements.

However, some jurisdictions (e.g., those within California) are implementing or evaluating natural gas bans. It is possible that some of the current natural gas supply could be replaced with renewable natural gas. However, there is not currently a large supply of renewable natural gas, and it is more expensive compared to traditional natural gas.

Due to the nascency of fuel-cell-powered engines, no significant regulations directly pertain to hydrogen generators. However, considering that it emits even fewer pollutants than natural gas-powered generators, it likely will be easier to meet the permitting requirements related to air quality standards.

Although hydrogen-powered generators produce the least emissions on-site, there are still concerns with the emissions resulting from the production of hydrogen and hydrogen leakage. Figure 58 illustrates the amount of emissions produced during the production, processing, and delivery of each fuel (well-to-tank emissions). Hydrogen generation from fossil compressed natural gas SMR produces the most carbon dioxide equivalent emissions compared to other fuel production. Hydrogen production through the electrolysis of water, on the other hand, produces only hydrogen and water as by-products. However, it requires a large amount of energy and water and is still not commonly used by commercial hydrogen suppliers due to the nascency of the technology.

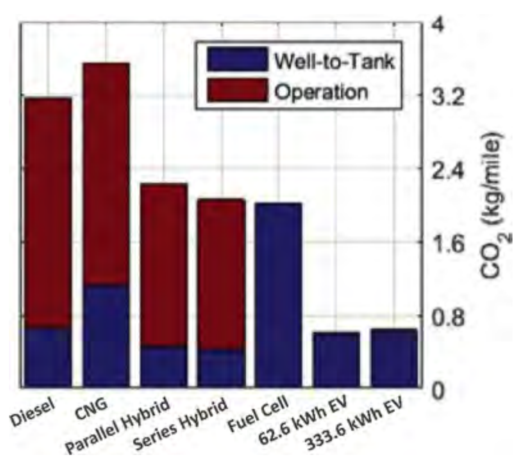
Solutions have been considered to achieve greener hydrogen production, such as using renewable natural gas or carbon capture and sequestration technologies for SMR, and the use of renewable energy sources for electrolysis. The numbers show, using landfill biomethane SMR can reduce GHG emissions. Moreover, using zero-carbon intensity electricity sources, such as solar, wind, or wave panels, to produce hydrogen through electrolysis will reduce emissions even further.



Sources: NREL. (2015). Natural gas for cars. https://www.nrel.gov/docs/fy16osti/64267.pdf and Lajunen, A. & Lipman, T. (2016). Lifecycle cost assessment and carbon dioxide emissions of diesel, natural gas, hybrid electric, fuel cell hybrid and electric transit buses. Energy. 106: 329-342. https://doi.org/10.1016/j.energy.2016.03.075.

Figure 58. Maximum potential well-to-tank emission for different types of fuel.

Even though the hydrogen generation through SMR produces more emissions compared to the production of other fuels, the operation of the fuel-cell engine itself will generate zero emissions. Hydrogen is a clean-burning fuel that does not include any carbon in its balanced combustion reaction and only produces water as a by-product. From Figure 59, it can be concluded that fuel-cell vehicles produce the most emissions from well-to-tank hydrogen production, but ends up with a lower total emission compared to diesel, compressed natural gas, or diesel-compressed natural gas hybrid vehicles. Generators are assumed to have comparable emission proportions with the internal combustion engines used in vehicles.



Note: EV stands for electric vehicles
Source: Lajunen and Lipman, 2016.

Figure 59. CO_2 emissions for vehicles with different fuel types.

Research also shows that significant hydrogen leakage could have negative effects on the atmosphere, such as increasing the lifetime of methane, increasing climate effects, and causing some depletion of the ozone layer. The research found that overall air quality in the lower atmosphere will still improve if hydrogen is introduced to the future mix of energy sources due to the reduction of fossil fuel use. However, hydrogen could also potentially act as a GHG itself under high levels of leakage. Therefore, safety measures to prevent leakage must be put in place and are essential to achieve a green hydrogen use.

Another sustainable option for backup power is using battery energy storage systems. Much like fuel-cell generators, battery energy storage systems only generate emissions during electricity production. Therefore, the level of emissions will vary based on the source of electricity.

13.5 Future Planning

As electric aircraft and "electrifying everything" become more common, airports will need to continue to invest in electric reliability, redundancy, and backup power.

Comparing the various fuel sources, costs, and availability (in 2020 dollars), diesel-fueled power generation has the fewest barriers to entry from a capital and operating costs perspective. However, diesel has significant negative externalities. It has the highest emissions due to fossil fuel combustion and is already the target of increased government regulation and cannot be run during blue-sky events to control energy costs.

Natural gas generators are seen as more reliable than diesel generators, although these conclusions are based on estimates from small data sets and significant assumptions. Thus, natural gas provides the largest reliability premium compared to diesel for regions that face high risks of long outages. Natural gas is a viable solution in the medium term when located adjacent to a pipeline and has significantly lower emissions than diesel.

Hydrogen fuel-cell backup power generation is currently significantly more expensive than established technologies. However, informed decisions based on airport strategic goals will support the overall transition to zero-emission operations. It is therefore recommended to continue researching technological possibilities in terms of backup power generation. For example, fuel cells can run on natural gas today easily and then can be converted to hydrogen when it makes sense to do so. Due to the nascence of emergent technologies, such as hydrogen fuel-cell technology, it is suggested to observe industry trends, disruptions, and advancements that appear on the horizon over the next decade. Vested interests, existing infrastructure, and political support continue to enable fossil fuel technologies' costs to remain artificially low. However, what is feasible in the years ahead will be drastically different than the solutions presented in this 2020 study.

Specifically, in the realm of zero-emission operations, a "tipping point" is forecast to occur in the coming 5 to 7 years, when technological advances in terms of batteries and alternative and renewable fuel sources will be financially competitive in the marketplace. Systemic disruption allows for economies of scale to emerge for these new systems and technological opportunity to emerge.

CHAPTER 14

Infrastructure Upgrades

14.1 Introduction

As described in the previous chapters, the total number of active electric aircraft is expected to reach approximately 2 percent of the entire U.S. aircraft fleet in 2030. The first electric aircraft will be small capacity aircraft, suitable for missions conducted by flight school or private pilots, as well as commuter aircraft. Current trends show that regional flights will be the first routes to be performed by electric aircraft, operated by air taxi companies and regional air carriers, such as Harbour Air in the Puget Sound. Regional electric aircraft above 10 to 12 passengers might be available at the 2025 horizon. Larger electric aircraft are not expected to be introduced in the market until at least 2040. Figure 60 summarizes this projected timeline of electric aircraft integration.

Smaller airports are community resources, and many might be underutilized today. With the emergence of urban and regional air mobility with electric aircraft, these aviation facilities could provide point-to-point connections between communities and with larger urban centers. Some may become local multimodal transportation and cargo hubs with interconnection to buses, TNCs, and other modes. Regional electric aviation will extend to larger commercial airports as well. For instance, Cape Air, which has signed a purchase option for Eviation Alice electric aircraft, has operations at BOS and STL.

14.2 Aircraft Charging Infrastructure

For electric charging of high-capacity batteries, three types of recharging solutions are feasible:

- Recharge by fixed ground chargers, also known as charging stations.
- Recharge by mobile superchargers on batteries mounted on a truck or trailer.
- Battery swap at the gate (batteries are recharged separately).

Many commercial service airports already supply electric power at the gate with fixed 400 Hz power units connected to the grid, or air carriers and their ground handlers operate mobile GPUs. However, general aviation facilities might be the first to see electric planes because small aircraft will be the first to be electrified. Coordination with FBOs and tenants will be necessary to assess the needs and define a strategy to provide adequate charging or hydrogen refueling solutions and define their business model.

14.3 Electricity Infrastructure

Because the implementation of aircraft charging stations will increase the electricity loads at an airport, the electric infrastructure has also been assessed to any upgrade. Additional infrastructure may be required to match the future demand for electric aircraft depending on the

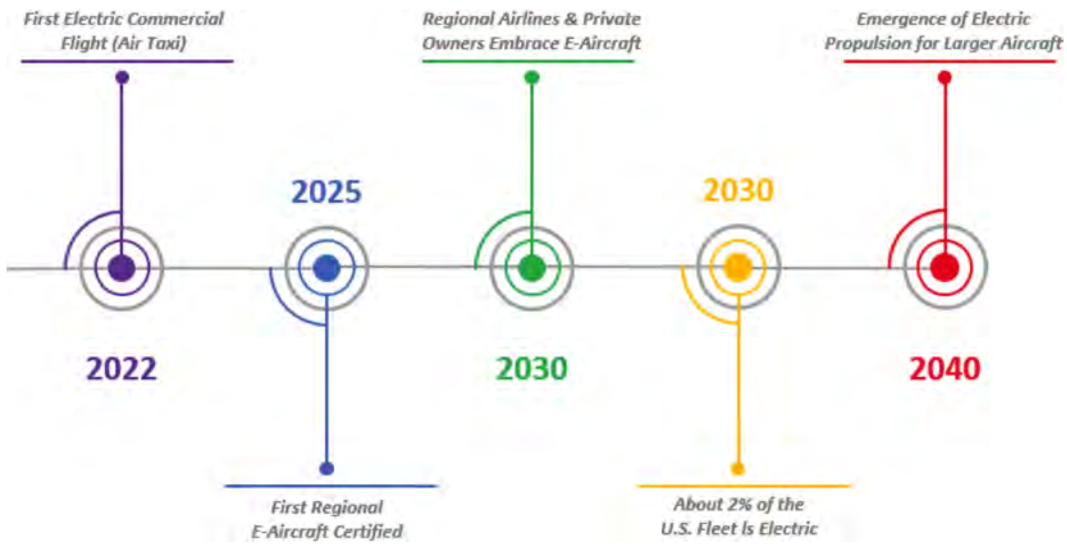


Figure 60. Realistic timeline for the implementation of electric aviation in the United States.

Assessment Tool: Electric Aircraft Chargers

To help airports and practitioners, the Assessment Tool prepared as part of ACRP Project 03-51 provides an estimate of the number of electric aircraft chargers required based on the aviation traffic forecast. The tool recognizes five categories of aircraft and flights: Air Carrier, Air Taxi, Commuter, General Aviation, and Military. For each category, practitioners will be able to determine the typical number of charging equipment required as well as an estimate of the impact on the electric loads. All the rationales are detailed in *Chapter 16, Airport Scenario Planning*, of this report.

6 CHARGERS

	Year of Reference	2025			2030			2040	
		Downside	Baseline	Upside	Downside	Baseline	Upside	Downside	Baselin
Electric Aircraft									
Air Carrier	-	-	-	-	-	-	-	-	
Additional from Year of Reference		-	-	-	-	-	-	-	
Air Taxi	-	-	-	-	-	-	-	-	
Additional from Year of Reference		-	-	-	-	-	-	-	
Commuter	-	-	-	-	-	-	-	-	
Additional from Year of Reference		-	-	-	-	-	-	-	
General Aviation	-	-	-	-	-	-	-	-	
Additional from Year of Reference		-	-	-	-	-	-	-	
Military	-	-	-	-	-	-	-	-	
Additional from Year of Reference		-	-	-	-	-	-	-	
Total	-	-	-	-	-	-	-	-	

existing facilities and will vary from airport to airport. The potential needs for upgrading the airport electricity infrastructure to support the future demand and ensure adequate resiliency must be planned in close collaboration with the electricity companies. In addition, on-site power generation infrastructure can be considered as an opportunity for supporting the electric aircraft demand. This solution provides more autonomy from the grid to airports.

In either case, anticipating these future electric loads is essential, and airports must incorporate energy providers to discuss their ability and capacity to supply electric power, to develop contingency for potential power outages, and to enhance the overall resilience of power supply. To coordinate with local utility providers, airports can use the process illustrated in Figure 61.

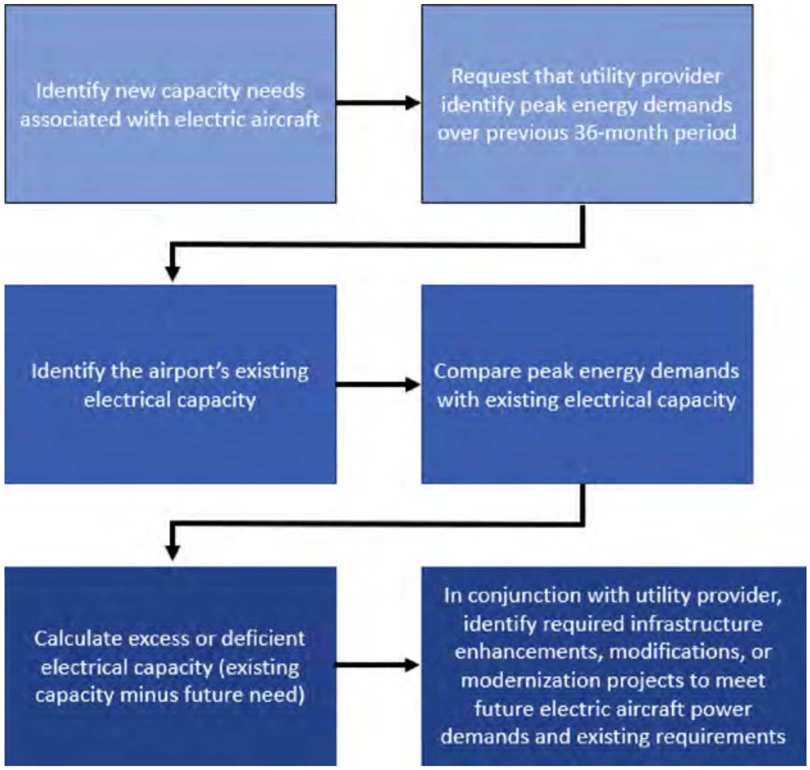


Figure 61. Utility coordination process.

The Assessment Tool provides airports and their stakeholders with an estimate of the future power requirements of electric aircraft and the overall electrification of airports.

14.4 Hydrogen Infrastructure

Hydrogen will power some electric aircraft through fuel cells. Fuel cells might be best suited for regional and larger aircraft. However, this technology has been implemented on some experimental smaller aircraft types as well—including motor gliders and two-seaters. The main limitation is the availability of hydrogen at airports. Three types of refueling solutions are being considered:

- Aircraft refueling by fueling truck (tanker).
- Aircraft hydrogen container swap.
- Aircraft refueling from a hydrant system.

Although hydrogen and Jet-A have different physical and chemical properties, the overall process of supplying, storing, and fueling gaseous hydrogen at the airport will be relatively similar to existing aviation fuel supply chains. There is no adequate infrastructure today to deliver large quantities of hydrogen to aircraft. In the short term, it is very likely that aircraft will be refueled with hydrogen through fueling trucks or special containers or pods. Hydrogen pipelines and hydrant systems could emerge at some large hub airports in the future, especially if this gas becomes a popular energy vector for other transportation modes and applications.

CHAPTER 15

Financial Planning

Full implementation of any project must include an extensive look into a project's financial aspects required to develop, operate, and maintain the associated infrastructure and labor. Airports should develop or obtain a feasible or realistically attainable financial plan to help implement projects such as electric aircraft.

A financial plan comprehensively evaluates an airport's current financial structure, future financial situations, and funding sources to achieve the growth of the airport. The level of detail and complexity of a financial plan vary from one airport to another and reflect significant factors such as the size of the airport. The three main factors of financial planning (per the FAA AC 150/5070-6B on Airport Planning) are funding sources, financial feasibility, and revenue enhancement.

15.1 Funding Sources

Airport Improvement Program

A primary source of federal grant funding for airport infrastructure planning and development projects is the FAA's AIP, funding for which is allocated annually from the AATF. The U.S. national airport system includes about 3,300 airports that are eligible for AIP funding for projects intended to improve airport safety and infrastructure. AIP grant assurances ensure that airport revenue can only be used to support the capital or operating costs of the airport. AIP recipient airport sponsors typically contribute a matching percentage of project costs. AIP grants prioritize safety improvements and thus often represent airfield projects. Currently, electric aircraft projects (including charging stations) are not eligible for funding through the AIP.

Passenger Facility Charges

PFCs are local user fees collected by commercial airports regulated by public agencies. They can be used for infrastructure repairs and improvements at airports, typically supporting airside and terminal projects and, under special conditions, ground transportation projects. PFCs have remained capped at $4.50 per flight segment for the past 20 years. PFCs are not likely to be affected by the integration of electric aviation into airport infrastructure and operations.

Voluntary Airport Low Emissions Program

In 2004, the VALE Program was created to help airports comply with state air quality requirements under the CAA. It is specific to commercial service airports that are in areas where air quality is compromised according to EPA standards, and about 125 U.S. airports are eligible for this program.

The VALE Program funds projects that reduce on-airport emissions but that have historically focused on gate electrification and eGSE. Between 2015 and 2018, the program funded projects for electric shuttle buses, GPUs, and preconditioned air units to support gate electrification, charging stations and ports for eGSE, and solar panels to support airport energy flows. The Vision-100 measure requires the EPA to assign airport emission reduction credits for VALE Program projects.

Making electric aircraft charging infrastructure projects eligible for VALE Program funding would require a change of policy. It is not clear if there is a case for the VALE Program under current rules, since the funding would require justifying that these electric chargers would significantly reduce emissions directly attributed to airport activity.

Green Revolving Funds

Sustainability investments can complicate airport financial planning because they are one-time investments (rather than recurring investments) and can have unknown cost efficiency and revenue enhancement impacts. In addition to capital budgeting, airports can receive funding toward sustainability from grants and subsidies or rebates from utility providers. GRFs have been introduced to create a dedicated funding stream for sustainability improvements.

GRFs—which are used by states and universities—monitor cost reductions and savings that result from sustainability implementations and then transfer these savings to a dedicated fund for sustainability projects. This allows projects to become self-funded and facilitates repayment of loans and initial investments in projects.

By collecting data on investment in and returns from sustainability measures, GRFs force airports to improve their performance tracking. GRFs are a proven mechanism to coordinate with airlines. Increased data sharing incentivizes airlines and other tenants to collaborate on sustainability initiatives and investments, with the knowledge that they have a recurring, independent funding source that is not volatile to fluctuations in other funding streams. The GRF, as a commitment to sustainability, enhances an airport's ability to promote a sustainable culture.

GRFs are ideal at airports that can commit resources 6 to 18 months in the future and that require airport stakeholders to be educated on the fund's mechanics. They work best at airports that use a compensatory rate model, where airports determine the rates and charges issued to airlines and retain the financial risk of operating the airport. This leaves the airport with greater flexibility to designate savings to the GRF, as opposed to the residual rate model, where airlines bear the responsibility of covering the airport's operating costs. The GRF also needs a sufficient scale to provide a high return upon starting and can be ineffective for airports whose annual utility cost is under $200,000. ATL was the first airport to adopt a GRF, which began in 2016 (ACRP Report 205). Smaller airports that would not be positioned to start a GRF can participate in collective GRFs (such as Virginia's Airports Revolving Funds) from which they can obtain attractive financing and financial education.

Other U.S. Department of Transportation Programs

The U.S. DOT is supervising the selection of grant programs or credit assistance to support an efficient and economical national transportation system. Although these programs are not specific to aviation and concern the enhancement of regional transportation systems, they could include funding the integration of electric aircraft at this regional infrastructure:

- The **Better Utilizing Investments to Leverage Development Transportation Discretionary Grant** program was created in 2009 as an incentive to enhance environmental problems and reduce the U.S. dependence on energy. Between 2009 and 2017, the program provided $5.1 billion to 421 projects across the United States.
- The **Infrastructure for Rebuilding America** grant program is another discretionary grant program to fund major strategic infrastructure projects, such as highways, ports, bridges, and railroads. For 2021, the U.S. DOT is seeking projects that address climate change and environmental justice. The funding available is up to $889 million this year.
- Created in 1998, the **Transportation Infrastructure Finance and Innovation Act** program provides credit assistance for qualified transportation projects of regional and national significance, such as highway, transit, railroad, intermodal freight, and port access projects. The benefits of this credit are to offer low interest rates, with a flexible amortization of up to a payment period of 35 years. Over $31 billion in loans have been delivered since the program's creation.
- The **Congestion Mitigation and Air Quality Improvement** program provides funding to states for transportation projects designed to reduce traffic congestion and improve air quality, particularly in areas of the country that do not attain national air quality standards. Over $8.1 billion has been provided since 1991.

State Funding Programs

In the United States, most states have various programs that are regulated or managed by state agencies to aid in airport capital development in the form of, but not limited to, grant funding, loans, and tax incentives. These funds are usually provided to cover the non-federal parts of FAA-supported projects that are in the state airport or aviation system plan. The management of these funds varies from state to state.

For example, the WSDOT, in its electric aircraft feasibility study, says that the state of Washington purposely provides the following three grant programs for regional infrastructure project funding that could affect projects associated with introducing electric aircraft at the state's airports:

- **Airport Aid Grants Program** supports projects on safety, pavement, maintenance, operations, and planning capabilities. This grant program could cover the installation of electric charging stations, acquiring electronic components, and other related electric aircraft airport planning activities.
- **Regional Mobility Grants** assist with improving the connection between state counties and populated areas to reduce transportation delays. Since the use of electric aircraft would improve the regional connectivity of people and also cargo, electric aircraft operations may qualify under this grant funding.
- **Green Capital Opportunity Grant Program** primarily focuses on capital projects that aim to mitigate or minimize the carbon emissions in Washington state. Most electrification projects, including, but not limited to, electrification of vehicles, electric transmission upgrades, and charging station construction, qualify for this grant funding.

Private Sector

The private sector usually involves the funding support of third parties for incentivized projects. Electric aircraft projects—which could include some research and development that covers the introduction, development, and implementation of electric aircraft and its components such as battery pack development—are considered incentivized projects because they support current efforts for a greener environment.

WSDOT's electric aircraft feasibility study points to the Seattle-Tacoma International Airport as becoming one of the first potential airports to provide biofuels to its customers. This project is supported by Boeing and Alaska Airlines, which partnered with the Port of Seattle to help the state in reducing transportation emissions to have a greener community.

In addition to the different funding or credit programs, local and state governments can issue a tax-exempt private activity bond (PAB) to attract private investment in transportation infrastructure by offering special financial benefits. In 2020, approximately $13.27 billion in PABs have been issued to several U.S. transportation infrastructure projects, including Maryland's Purple Line light rail system. Electric aircraft integration could be eligible for these PABs.

15.2 Financial Feasibility

Financial feasibility involves identifying and assessing the level to which the potential project wanting to be developed is financially viable, practical, and desirable. According to the FAA AC 150/5070-6B on Airport Planning, the following two actions are involved with an airport financial feasibility study.

Review the Airport's Financial Structure

Reviewing the airport's financial structure involves identifying and establishing the structure and makeup of all the airport's finances to be able to determine its effect on the airport's cash flow. Per the FAA AC 150/5070-6B on Airport Planning, the parts of the airport that are known as the revenue-producing areas that form the financial structure include airfield movement areas, aprons, terminals, ground transportation, parking, maintenance facilities, cargo buildings, and other leased areas of the airport. The incorporation of electric aircraft could pave the way for additional revenue-generating areas for the airport over time.

Prepare a Capital Improvement Program Funding Plan

The capital improvement program funding plan, according to the FAA, "serves as the primary planning tool for identifying and prioritizing critical airport development and associated capital needs for the National Airspace System." The funding plan should spell out the proposed projects and the phases of the project development. In addition, a corresponding source of funding should be identified for each phase of the project development.

The project in this case—which is the development, operation, and maintenance of electric aircraft facilities—would not happen all at once. The market assessment forecast shows less than 2 percent of the total fleet mix going electrical over the short-term horizon with projected small fleet sizes. The takeaway from this assessment is that the full implementation of a higher percentage of the electrical aircraft fleet would be over a long-term horizon; thus, a phasing for an electric aircraft facilities project would be necessary.

15.3 Revenue Enhancement

Airports are expected to have a reasonable user cost. To be able to achieve that reasonable cost, their finances and revenues must be constantly improved in order not to face significant losses. Airports are recommended to explore all other options as far as practicable to achieve an increase in revenues. Some of these airport revenue-generating sources include concessions, parking fees, fueling operations, airlines' landing fees, etc.

Although the main impacts with the introduction and growth of electric aircraft are expected in the long term beyond 2030, airports—as well as FBOs and fueling service providers—could begin to experience reduced revenue from aircraft fueling operations. The costs that come with placing and installing electric charging equipment at specific locations also could be a potential revenue dip.

To counter the potential significant decrease in revenues with regards to fuel operations, FBOs could provide aircraft charging services to airlines and private owners and pass a portion of the revenue to the host airport. The airport could also gain potential fee-charging revenue opportunities for airports that could pay for the chargers.

Additionally, cleaner sources of power could reduce costs or provide revenue. For example, due to their clean nature, fuel cells (both hydrogen and natural gas) could be run 24/7 and could produce a strong payback. Natural-gas generators could be built that would help airports meet fast-ramping markets in the evening hours when power prices are highest. This could be a reliable revenue source in certain markets, especially California, currently.

CHAPTER 16

Airport Scenario Planning

16.1 Introduction

Neither the FAA's Terminal Area Forecast nor its Aerospace Forecast feature projections for electric aviation; however, the latter has provisions on UAS. Consequently, individual airports should discuss and collaborate with their local stakeholders and governments to understand their vision and potential interests regarding these new technologies.

Although the planning scenarios differ from airport to airport depending on size, current power capabilities, and expected electric aircraft traffic density, electric aircraft are expected to mainly impact the airport electric demand, due to charging needs. It will be essential in the future to integrate electric demands into the airport planning process, providing new opportunities for airports to integrate energy and resiliency improvement. Airport electric demand will become a design criterion for airport planners to evaluate the power infrastructure needs to support future electric loads. Assessment of electric demand will have to consider not only electric aircraft operations, but also the growth of electric power needs from other elements of the airside, terminal, and landside operations.

16.2 Existing Electric Demand

The airport should estimate its current electric consumption as a basis for assessment. On average, large hub airports demand 40 to 50 MW during daytime and 35 to 36 MW during nighttime. However, this consumption varies significantly from an airport to another, based on the number and type of airside operations, number and size of buildings, the landside, etc.

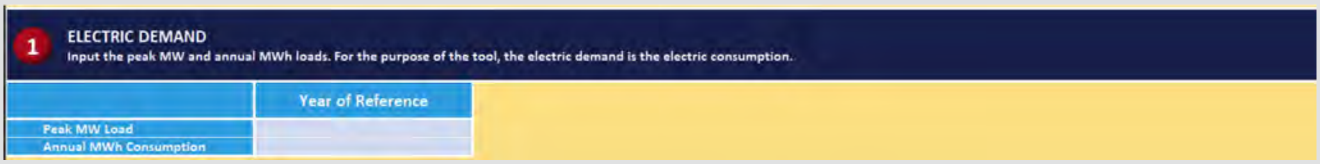
The electric consumption and future needs of the airport should be evaluated as a peak load in MW, and as an annual consumption in MWh. For planning purposes, the peak MW load for the entire airport, without any diversity factor, must be calculated, even if the actual peak coincident loads will be significantly lower. Understanding the true diversity of loads and the true peak coincident demand can be very difficult. To estimate these numbers, the airport should directly contact its local electric utility provider, who will consider its own internal best practices during new load applications.

16.3 Electric Aircraft Requirements

For each airport, the primary impact will stem from the increased electrical demand necessary to charge electric aircraft. The effects and necessary considerations will vary between airports of various sizes based on the type and density of traffic. Therefore, airport planners should develop aircraft-specific power supply requirements that can be evaluated in terms of electric

Assessment Tool: Electric Demand

To assist airports and their stakeholders, ACRP Project 03-51 developed an Assessment Tool to help the industry plan for the potential impacts of electric aircraft to their operations and electric demand. This tool estimates the electric growth caused by future electric aircraft activity for planning purposes at an airport, but also by other airport elements, such as passenger terminals, electric vehicles, etc. As an input, the tool requires the user to provide the peak load in MW and the annual consumption in MWh for the base year, which can be provided by the local electric utility provider directly.



demand loads and types of charging solutions. As explained in *Chapter 8, Airside Requirements*, three types of recharging solutions are feasible:

- Recharge by fixed ground chargers, also known as charging stations.
- Recharge by mobile superchargers on batteries mounted on a truck or trailer.
- Battery swap at the gate (batteries are recharged separately).

Default Scenario

To develop future planning scenarios, the airport must develop its electric aircraft forecasts. For this project, *default scenarios* were developed using electric aircraft forecasts in the United States, based on the market assessment available in this report and discussions with industry leaders; this should be used only for information and comparison purposes. To reflect the future conditions at an airport, the airport operator should work with local stakeholders to identify any future possibilities of electric aircraft operation.

According to the market assessment, 3,500 electric aircraft are predicted to operate from U.S. airports in 2030, which will represent approximately 2 percent of the entire U.S. aircraft fleet. Current trends on electric aircraft reveal that the first electric aircraft in service will be small aircraft and UAS/UAM. The UTC Project 804 and the conversion of Dash 8 by magniX and Universal Hydrogen are the largest electric aircraft in development. These regional aircraft could accommodate between 35 and 75 passengers and fly between 100 and 500 miles. No OEMs have announced working on projects with larger commercial electric aircraft.

Therefore, for five aircraft categories defined by the FAA—air carrier, air taxi (including UAS/UAM), commuter, general aviation, and military—the following three scenarios were developed (Figure 62):

- *Downside Scenario*
  - *Air Carrier and Military*: Given the current trends for electric aircraft, this scenario assumes that no electric aircraft will be available in the next 30 years.
  - *Air Taxi, Commuter, and General Aviation*: This scenario assumes that electric aircraft will slowly enter the market and will increase in a linear trend.
- *Baseline Scenario*
  - *Air Carrier and Military*: Because there is no project on electrifying large commercial aircraft, the scenario assumes that zero percent of the aircraft will convert to electric in

Estimated Share of Electric Aircraft									
	2030			2040			2050		
	Downside	Baseline	Upside	Downside	Baseline	Upside	Downside	Baseline	Upside
Air Carrier	0%	0%	1%	0%	1%	2%	0%	2%	3%
Air Taxi	1%	2%	4%	2%	4%	10%	3%	6%	25%
Commuter	1%	2%	4%	2%	4%	10%	3%	6%	25%
General Aviation	1%	2%	4%	2%	4%	10%	3%	6%	25%
Military	0%	0%	1%	0%	1%	2%	0%	2%	3%

Figure 62. Electric aircraft demand scenarios.

2030. It is more realistic that the first large electric aircraft will be in service at least in 2040. Therefore, this scenario assumes a linear trend starting in 2040.
  - *Air Taxi, Commuter, and General Aviation*: Based on the market assessment, 2 percent of the U.S. aircraft fleet will convert to electric for each aircraft category. A linear trend was assumed for the next 30 years.
- *Upside Scenario*
  - *Air Carrier and Military*: This scenario assumes that in 10 years, 1 percent of the U.S. fleet will convert to electric. A linear trend will follow.
  - *Air Taxi, Commuter, and General Aviation*: This scenario assumes a higher conversion to electric aircraft in the U.S. fleet in the next years and an exponential trend. In 2050, the scenario forecasts that 25 percent of the U.S. fleet will be electric aircraft.

Charging Requirements

With the electric aircraft forecasts, airport planners can develop aircraft-specific power supply requirements. While the first electric aircraft will most likely recharge with fixed ground chargers, mobile superchargers and battery swaps should also be considered. Because electric aircraft operations will not exceed 5 percent of the total airport operations in the next 10 years, the power infrastructure requirements can be directly discussed with the relevant stakeholders to determine the number of charging stations, mobile superchargers, specific areas for mobile supercharger parking, and specific hangar areas for battery swapping. Thus, per these infrastructure requirements, airport planners can evaluate the growth of electric demand load.

16.4 Other Airside Requirements

In addition to the electric aircraft requirements, other airside elements should be estimated in the power supply requirements by airport planners:

- *Electric power for aircraft*: Although not electric, existing commercial aircraft are equipped with technologies powered by electricity. Many airports already supply electric power to these aircraft at the gate, via fixed 400 Hz power units connected to the grid, or via mobile GPUs operated by air carriers and their ground handlers. The typical GPU power recommended is 90 kW for narrow-body aircraft and 180 to 360 kW for wide-body aircraft.
- *Airfield visual aids and navigational aid equipment*: Airports, especially large ones, are equipped with visual aids and navigational aid equipment to provide information and guidance to pilots maneuvering. The FAA has established policies regarding the configuration of electrical power for visual aids with facilities in the NAS, which are defined in the FAA Order 6030.20G, Electrical Power Policy. Power supply requirements will not change due to electric aircraft

Assessment Tool: Electric Aircraft

With the ACRP 03-51 Assessment Tool, airport planners can evaluate the growth of electric demand, in-peak MW load and annual MWh load, and the number of required charging stations. As a conservative assumption, all electric aircraft are charged with fixed chargers. Based on the literature review and market assessment for Project ACRP 03-51, individual charging requirements were developed for each FAA aircraft category. The tool assumes use-case scenarios with the following characteristics for each category:

- *Air Carrier/Military*: a typical mission of 700 miles (short range) with an average capacity of 2 pilots and 39 passengers.
- *Air Taxi*: a typical mission of 420 miles (very short range) with an average capacity of 1 pilot and 3 passengers.
- *Commuter*: a typical mission of 650 miles (short range) with an average capacity of 2 pilots and 9 passengers.
- *General Aviation*: a typical mission for flight training, private, and recreational purposes with an average capacity of 1 pilot and 1 passenger.

For each aircraft category, an assumed battery size (kWh) and assumed charger speed/output power (kW) were set as default values based on the literature review and market assessment. In addition, an average gate occupancy time (min) is set at 60 minutes, which is the current trend. This parameter will be used to determine the number of chargers. All these parameters can be modified by the user, to match local conditions.

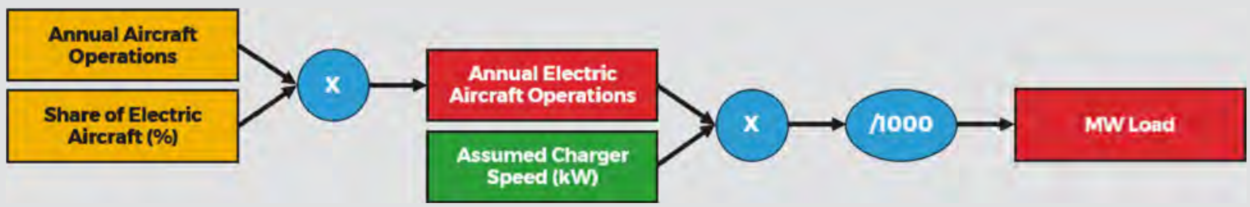
	Mission	Capacity	Assumed Battery Size (kWh)	Assumed Charger Speed (kW)*	Average Gate Occupancy Time (min)
Air Carrier	Short Range (700 miles)	2 pilots + 39 passengers	4,000	600	60
Air Taxi	Very Short Range (420 miles)	1 pilot + 3 passengers	480	60	60
Commuter	Short Range (650 miles)	2 pilots + 9 passengers	900	400	60
General Aviation	Flight Training, Private, Recreational	1 pilot + 1 passenger	42	20	60
Military	Short Range (700 miles)	2 pilots + 39 passengers	4,000	600	60

Calculations

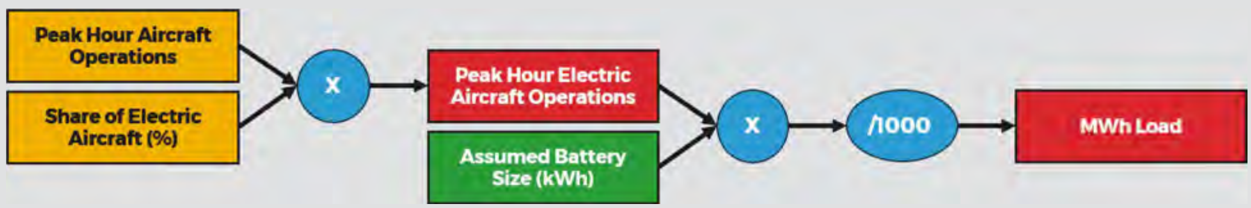
The Assessment Tool will provide three types of requirements for each electric aircraft category: the number of chargers, the peak MW load, and the annual MWh load.

- *Number of chargers*: To estimate the number of chargers, the peak hour of electric aircraft operations is the design parameter, since it is at the same "scale" as the charging time of an aircraft. The gate occupancy time will determine the ratio of aircraft per charger within the peak hour. By multiplying the peak-hour electric aircraft operations by the gate occupancy time in an hour, the tool estimates the number of chargers.

- *MW Load (peak hour demand)*: To estimate the MW load due to electric aircraft, the tool multiplies the annual electric aircraft operations by the assumed charger speed/output power in kW. The tool then divides the result by 1,000 to convert to MW.



- *MWh Load (annual demand)*: To estimate the MWh load due to electric aircraft, the tool multiplies the peak hour electric aircraft operations by the assumed battery size in kWh. The tool assumes that each aircraft needs a full battery charge. The tool then divides the result by 1,000 to convert to MWh.



but should be considered for any airfield improvements requiring the installation of visual aids or navigational aid equipment.

- *eGSE vehicles*: Many airports are electrifying their GSE vehicles, which are ideally suited for conversion, due to their short range, and their frequent need to start and stop. The next paragraph will describe the *default scenarios* elaborated on the forecasts of eGSE vehicles in the United States.

Default Scenario for eGSE Vehicles

In 2013, *Ground Support Worldwide Magazine* prepared a survey that estimated about 10 percent of all U.S. GSE vehicles were electric. Since then, multiple airlines and airports have announced plans to convert their fleets to electric powered. For example, JetBlue announced in 2019 that it will convert 40 percent of its GSE fleet at JFK. This transition to electric vehicles is enabled through special funding programs, such as the FAA's VALE Program. This program helps airport sponsors finance the GSE electrification.

The following three scenarios were developed (shown in Figure 63):

- *Downside Scenario*
  - This scenario assumes a linear trend based on a slower transition to electric vehicles. In 2030, 20 percent of the fleet will be electric.
- *Baseline Scenario*
  - This scenario assumes a linear trend, and that in 2030, 30 percent of the U.S. GSE fleet will be electric.
- *Upside Scenario*
  - This scenario translates a more "aggressive" conversion, thanks to special funding programs like VALE. An exponential trend was assumed to illustrate the continuity of current

Estimated Share of Electrification									
	2030			2040			2050		
	Downside	Baseline	Upside	Downside	Baseline	Upside	Downside	Baseline	Upside
eGSE Vehicle	20%	30%	40%	30%	50%	75%	40%	70%	99%

Figure 63. Demand scenarios for eGSE vehicles.

trends for airports and airlines to transition to electric vehicles. By 2050, this scenario assumes that all the U.S. GSE fleet will be converted to electric.

Charging Requirements for eGSE Vehicles

Similar to electric aircraft, airport planners can develop eGSE power supply requirements. Although no FAA standards exist regarding eGSE charging requirements, numerous airports have already installed such equipment. Airports can discuss directly with airlines or ground handling companies to plan their electrification of GSE vehicles, to define future electric needs. Typical existing charging equipment has a power rating varying from 10 kW up to 80 kW.

Assessment Tool: eGSE Vehicles

With the ACRP 03-51 Assessment Tool, airport planners can evaluate the growth of electric demand for eGSE vehicles, and the number of required charging stations. To estimate electric growth due to eGSE vehicles, the tool has default values for the following parameters for charging stations:

- *Assumed charger speed/output power (kW)*: based on the current trend. This can be modified if the charging equipment has different characteristics at the airport.
- *Assumed battery size (kWh)*: based on a benchmark of 19 existing eGSE vehicles on the market, from tow tractor to towbarless tractor. The user can modify as well if the eGSE vehicles have different characteristics at the airport.
- *Assumed daily number of chargers*: average battery endurance of 6 hours of operations, according to eGSE charging stations feasibility studies at LaGuardia and JFK. The user can modify if the ground operations at the airport are different.
- *Assumed charger-vehicle ratio*: this ratio represents the number of eGSE vehicles charging simultaneously per station. Typically, in the existing market, charging stations are dual-port chargers. The tool sets this parameter considering dual-port chargers. The user can modify if the charging equipment has different characteristics at the airport.

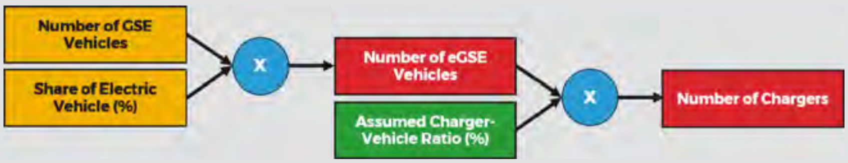
Charging Type	Charging Standard	Rated Voltage	Assumed Charger Speed (kW)*	Plug Type	Vehicle Compatibility
Fast	eGSE Charger	250-1000 V	60		eGSE

Assumed Battery Size (kWh)	Assumed Daily Number of Charges	Assumed Charger-Vehicle Ratio
33	2	50%

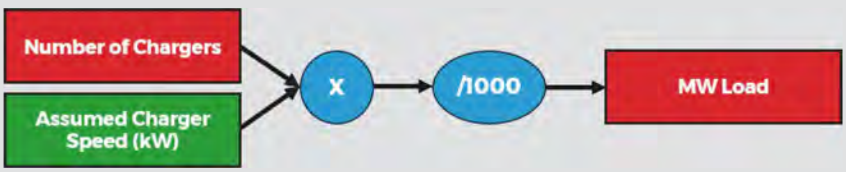
Calculations

The Assessment Tool will provide three types of electric requirements: the number of chargers, the peak MW load, and the annual MWh load.

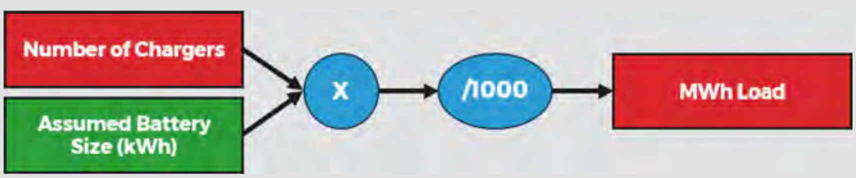
- *Number of chargers*: To estimate the number of chargers, the tool assumes a charger-vehicle ratio. With this ratio and the number of eGSE vehicles, the number of chargers can be determined.



- *MW Load (peak hour demand)*: To estimate the MW load due to eGSE vehicles, the tool multiplies the number of chargers by the assumed charger speed/output power in kW. The tool then divides the result by 1,000 to convert it to MW.



- *MWh Load (annual demand)*: To estimate the MWh load due to eGSE vehicles, the tool multiplies the number of chargers by the assumed battery size in kWh. The tool assumes that each vehicle needs a full battery charge. The tool then divides the result by 1,000 to convert it to MWh.



16.5 Passenger Terminal Requirements

Airport planners should assess passenger terminal power supply requirements. Passengers on electric aircraft will not directly impact the electric loads, but the number of enplanements will. Airport electric loads generally increase with the size of buildings on the airport campus. There is also some increased energy use per person passing through the terminals. Over the past decade, airports seek to improve their sustainability by reducing the total energy used per enplanement per year. A good example is SFO, which was able, through measures and on-site solar power equipment, to reduce by 9 percent from 2019 to 2020. Additionally, as airports move toward strategic electrification, the principal piece of equipment that will significantly affect the airport electric loads is the HVAC system. Therefore, airport planners should consider all these different aspects when developing passenger terminal power supply requirements.

Assessment Tool: Passenger Terminal

With the ACRP 03-51 Assessment Tool, airport planners can estimate the growth of electric demand for passenger terminal buildings. Assessing these demands can be very challenging for airports, depending on their sizes and their HVAC system configurations. For this planning tool, the following conservative assumptions were made:

- The peak MW load is calculated for the full set of equipment installed, without any diversity factor, even if the actual peak coincident loads will be significantly lower.
- The tool considers the possibility of switching the main source of heating, from a fuel fossil or electric fuel pump to an electric heat pump. It assumes only the principal HVAC system, and that the source of heating will convert to electricity at once.

Different parameters can be defined by the user to illustrate this electrification: the year of electric conversion of the HVAC system, the conversion efficiency, and the electric coefficient of performance (COP) to an electric heat pump. The tool assumes default parameters based on current market value.

	Values
Fossil Fuel Conversion Efficiency	70%
Electric COP (Efficiency)	200%
Electric Resistance Efficiency	99%
Electric COP (Efficiency)	200%
Year when Source of Heating Convert - Fossil Fuel to Electric Heat Pump	2029
Year when Source of Heating Convert - Electric Resistance to Electric Heat Pump	2024

Calculations for Passenger Terminal

To compute the MW and the MWh loads of the passenger terminal, the Assessment Tool assumes that the electricity consumption will increase at the same rate as the number of annual enplanements. Therefore, the tool computes the rate of increase between the year of reference and each planning period (+5 years, +10 years, and +20 years).

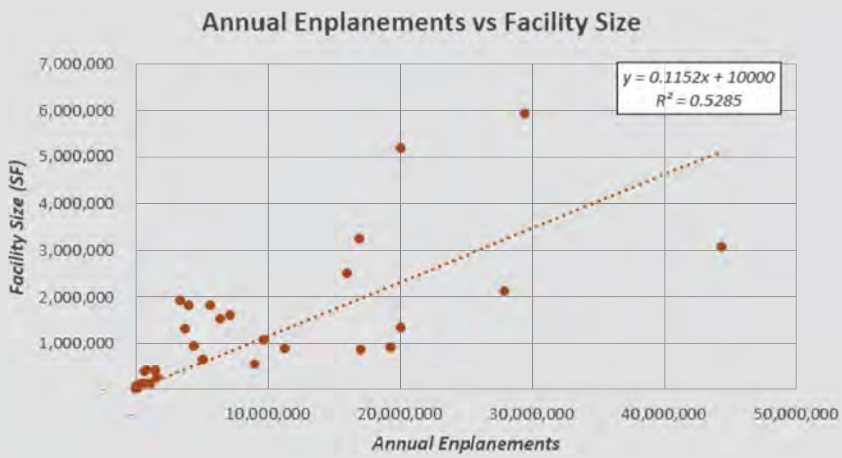
Calculations for HVAC System Conversion

The Assessment Tool considers the possibility of switching the main source of heating from a fossil fuel or electric resistance pump to an electric heat pump. Two assumptions were made:

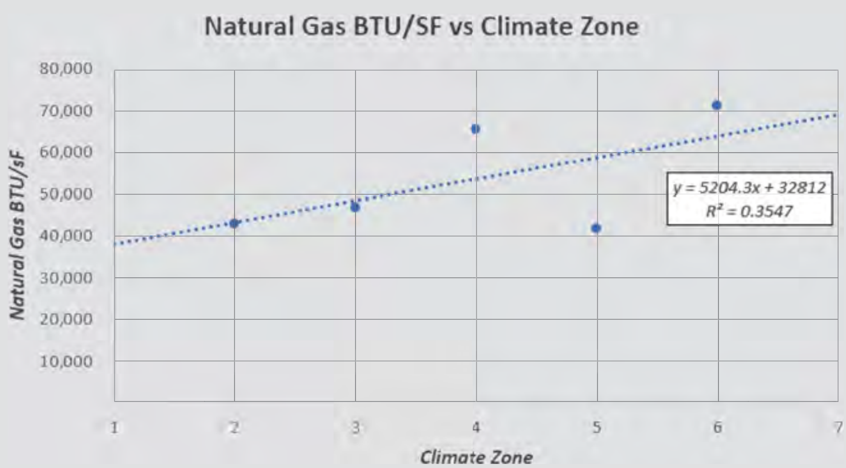
- **Switching from a fossil fuel pump to an electric heat pump** will increase the electric load as there is an energy transition to electric.
- **Switching from an electric resistance pump to an electric heat pump** will reduce the electric load, since the new pump is assumed more efficient by the tool.

The potential impacts of switching HVAC source were based on data compiled by a study published in 2020 by Sang-Chul Kim, Hyun-Ik Shin and Jonghoon Ahn, named *energy performance analysis of airport terminal buildings by use of architectural, operational information and benchmark by metrics*, and by a survey conducted for ACRP 03-51 in 2021 on Passenger Terminal Building Energy Consumption. These two sets of data compiled the annual enplanements, the passenger terminal footprint, the annual natural gas usage measured in British thermal units (BTU) per square foot (SF), and the climate zone of each airports. Two equations were established:

1. **Annual Enplanements vs. Passenger Terminal Footprint (SF):**
   - y = 0.1152x + 10,000, with a $R^2 = 0.5285$



2. **Natural Gas (BTU/SF) vs. Climate Zone:**
   - y = 5204.3x + 32,812 with a $R^2 = 0.3547$



Based on equation (2), the tool established an estimated natural gas usage as a measure of BTU/SF for each climate zone.

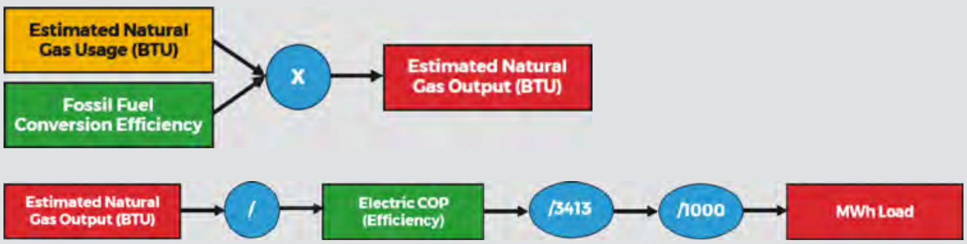
Climate Zone	Natural Gas BTU/SF
1	38,016
2	43,221
3	48,425
4	53,629
5	58,834
6	64,038
7	69,242

(continued on next page)

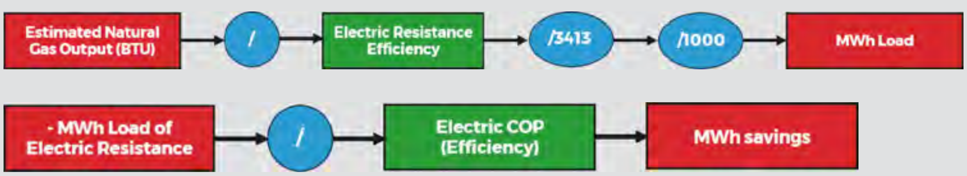
The correlation factors of these equations are pretty low, due to the small sample size of airports (less than 40 airports). The correlation factor is even smaller for equation (2) because only one or two airports from Climate Zones 1 and 7 provided relevant values to the study. For this tool, only the annual electric load growth caused by switching HVAC systems is estimated due to the low number of airports with relevant data.

To estimate the MWh load growth due to the HVAC system, the tool computes the approximate size of the passenger terminal based on the annual enplanements with equation (1), and depending on the climate zone of the airport, computes the estimate natural gas usage (as BTU).

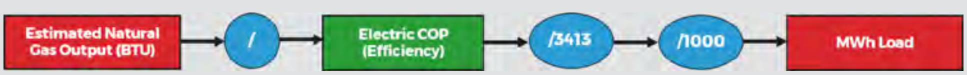
- **Switching from a fuel fossil pump to an electric heat pump**: the MWh load growth is equal to the equivalent of natural gas usage (as BTU) in MWh.



- **Switching from an electric resistance pump to an electric heat pump:** Since the tool assumes that an electric heat pump is more efficient than an electric resistance pump, the airport will be more able to reduce its MWh loads. Therefore, based on the electric resistance efficiency, the tool estimates the MWh savings and reduces the total passenger terminal MWh load growth by the savings.



If the source of heating is already an electric heat pump, then the tool computes the MWh load growth as equal to the equivalent of natural gas usage (as BTU) in MWh.



16.6 Landside Requirements

Airport planners should consider the potential impacts of landside infrastructure on the power supply requirements, especially the following transportation modes:

- Shuttle/Bus,
- On-Site Rental Car,
- Taxi/TNC, and
- Short-/Long-Term Parking.

Estimated Share of Electrification									
	2030			2040			2050		
	Downside	Baseline	Upside	Downside	Baseline	Upside	Downside	Baseline	Upside
Shuttle/Bus	45%	49%	75%	60%	68%	99%	75%	87%	99%
On-Site Rental Car	5%	10%	15%	15%	31%	45%	25%	50%	80%
Taxis & TNC	5%	10%	15%	15%	31%	45%	25%	50%	80%
Short-Term Parking Spots	5%	10%	15%	15%	31%	45%	25%	50%	80%
Long-Term Parking Spots	5%	10%	15%	15%	31%	45%	25%	50%	80%

Figure 64. Landside transportation demand scenarios.

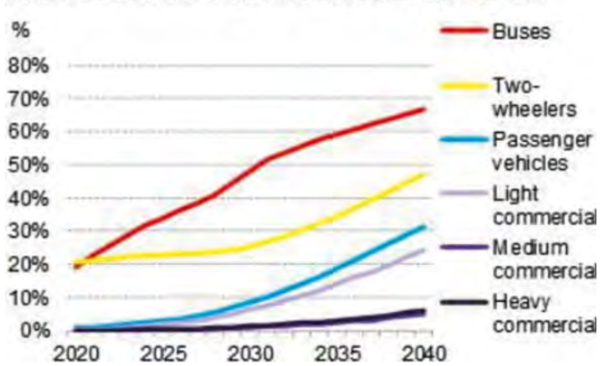
Electric vehicles already exist in the U.S. market, and over the years, the number of these vehicles has increased. The airport should include these vehicles when estimating their electric demand. Some airports are already integrating electric vehicles into their planning process, and existing documentation could help airport planners to estimate the number of chargers and electric demand.

Default Demand Scenario

To assist airport practitioners, *default demand scenarios* (Figure 64) were developed for each identified electric vehicle using the Electric Vehicle Outlook 2020, published by BloombergNEF (Figure 65). These scenarios were developed for information and comparison purposes:

- *Downside Scenario*
  - *Shuttle/Bus*: This scenario assumes a slower trend for electrification.
  - *On-Site Rental Car, Taxis & TNC, Short-/Long-Term Parking*: These scenarios assume half of the baseline scenario values.
- *Baseline Scenario*
  - *Shuttle/Bus*: This scenario was based on the "buses" forecasts of the BloombergNEF figure.
  - *On-Site Rental Car, Taxis & TNC, Short-/Long-Term Parking*: These scenarios were based on the "passenger vehicles" forecasts of the BloombergNEF figure.

Figure 16: EV share of global vehicle fleet by segment



Source: Electric Vehicle Outlook 2020, BloombergNEF.

Figure 65. Electric vehicle share of global vehicle fleet by segment.

- *Upside Scenario*
  - *Shuttle/Bus*: This scenario assumes that, by 2040, all airport shuttles/buses will be electric. These vehicles typically cover short distances (less than 20 miles) and could be funded under the VALE Program.
  - *On-Site Rental Car, Taxis & TNC, Short-/Long-Term Parking*: These scenarios assume a more "aggressive" transition to electric vehicles. They follow more exponential trends.

Charging Requirements

Based on the electric vehicle forecasts, airport planners can develop landside-specific power supply requirements. Given the complexity of each vehicle category, planners should develop electric demand requirements in coordination with the relevant stakeholders, to capture their needs based on current industry practices. *ACRP Synthesis 54*: *Electric Vehicle Charging Stations at Airport Parking Facilities* (Richard, 2014), provides planning requirements for implementing electric vehicle charging stations at airports. Moreover, standards for charging stations already exist, which will allow airport planners to determine future electric needs.

Assessment Tool: Landside Transportation

With the ACRP 03-51 Assessment Tool, airport planners can estimate the growth of electric demand for landside transportation, and the number of required charging stations. To estimate this electric growth, the tool assumes four types of chargers currently used in the market. For each charger type, an assumed charger speed/output power was set as a default value, based on current equipment available in the market. The user can modify the output power if the airport equipment is different.

Charging Type	Charging Standard	Rated Voltage	Assumed Charger Speed (kW)*	Plug Type	Vehicle Compatibility
Slow	Level 1 AC	120V AC	2	SAEJ1772	All Light Duty US vehicles
	Level 2 AC	240V AC	7.5	SAEJ1772 or CCS	All Light Duty US vehicles
Fast	Level 3 AC	480 VAC	50	CCS1	All Light Duty US vehicles
	Level 4 DC	250-1000 VDC	60	CCS1	Buses

The Assessment Tool considers five categories of landside transportation:

- **Shuttle/Bus**: This category includes airport buses that transport passengers from their gate to the aircraft. Hotel shuttles/buses are not considered.
- **On-Site Rental Car**: This category includes only rental car campuses within the airport property.
- **Taxi/TNC.**
- **Short-Term Parking**: Short-term is considered as less than 4 hours.
- **Long-Term Parking**: Long-term is considered more than 4 hours.

Each transport category will not use the same standard charging equipment and may use a mix. Thus, the tool offers the possibility for the user to define a percentage of each load equipment for each category. The default values have been set according to current practices:

- **Shuttle/Bus**: One type of charger is compatible for buses; therefore, the tool assumes that it will be the only type of charger.

- **Rental Car**: The tool assumes that rental cars will need to be charged faster to be operational as soon as possible for the next client; therefore, slow and fast chargers are set as default values.
- **Taxi/TNC**: Taxis/TNCs usually just pick up passengers and do not stay at the airport; therefore, the tool assumes that fast chargers will be used for these vehicles.
- **Short-Term Parking**: The tool assumes both slow and fast chargers because the duration of short-term parking is usually less than 4 hours.
- **Long-Term Parking**: Because long-term parking is usually over 4 hours, the tool assumes only slow chargers for these parking spots.

	Level 1 AC	Level 2 AC	Level 3 AC	Level 4 DC
Shuttles/Buses	0%	0%	0%	100%
Rental Cars	90%	0%	10%	0%
Taxi/TNC	0%	0%	100%	0%
Short-Term Parking	0%	90%	10%	0%
Long-Term Parking	100%	0%	0%	0%

To estimate the number of required charging stations, based on current market trends, the tool assumes one charging station per vehicle. However, for taxis/TNCs, because the data entered by the user are annual pickups—and because not all vehicles will stop for charging—the default ratio is one charging station for 20 pickups. The user can modify these default values.

Each transportation category does not have the same mission and does not involve the same electric needs. To reflect these differences, different parameters were defined for each transportation category and were set based on current trends. The user can modify each default value.

- **Shuttle/Bus and Rental Cars:**
  - *Assumed Daily Number of Charges:* The tool assumes that each vehicle will charge once per day, based on the current operational practices.
  - *Assumed Battery Size (kWh):* Based on current equipment available on the market, the tool assumes specific battery sizes.
- **Taxis/TNCs:**
  - *Assumed Percentage of Vehicle Stopping for Charging:* Not all the taxis/TNCs will stop for charging at each pickup; therefore, the tool assumes that half of the vehicles will stop for charging.
  - *Assumed Average Charging Time (min):* Taxis/TNCs need to charge as quick as possible; therefore, the tool assumes that these vehicles will stop charging after 20 minutes on average.
- **Short-/Long-Term Parking:**
  - *Assumed Utilization Factor:* For parking, a utilization factor of electric charging equipment is used in the industry to estimate the electricity consumption. As default values, the tool assumes a 50 percent utilization factor for short-term parking spots and 20 percent for long-term parking spots.

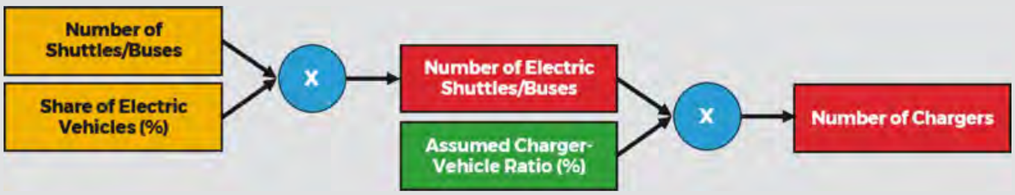
	Shuttles/Buses	Rental Cars	Taxi/TNC	Short-Term Parking	Long-Term Parking
Assumed Charger-Vehicle Ratio	100%	100%	5%	100%	100%
Assumed Charger Speed (kW)	60	6.8	50	11.75	2
Assumed Daily Number of Charges - *Shuttles/Buses/Rental Cars*	1	1	N/A	N/A	N/A
Assumed Battery Size (kWh) - *Shuttles/Buses/Rental Cars*	220	100	N/A	N/A	N/A
Assumed Percentage of Vehicle Stopping for Charging - *Taxi/TNC*	N/A	N/A	50%	N/A	N/A
Assumed Average Charging Time (min) - *Taxi/TNC*	N/A	N/A	20	N/A	N/A
Assumed Utilization Factor - *Short/Long-Term Parking*	N/A	N/A	N/A	50%	20%

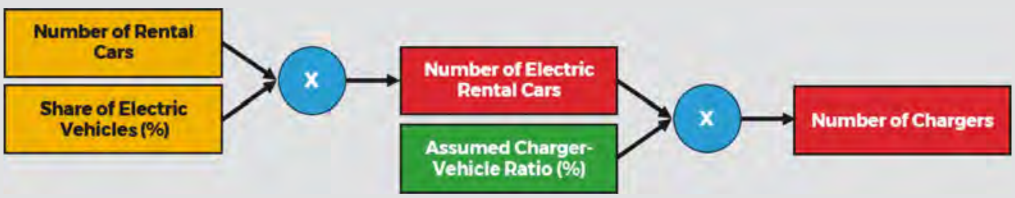
(continued on next page)

Calculations for Shuttle/Bus and Rental Car

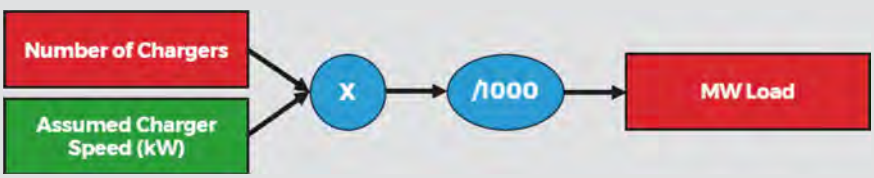
The Assessment Tool will provide three types of requirements: the number of chargers, the peak MW load and the annual MWh load.

- **Number of chargers**: To estimate the number of chargers, the tool assumes a charger-vehicle ratio that can be modified by the user. With this ratio and the number of vehicles, the number of chargers can be determined.

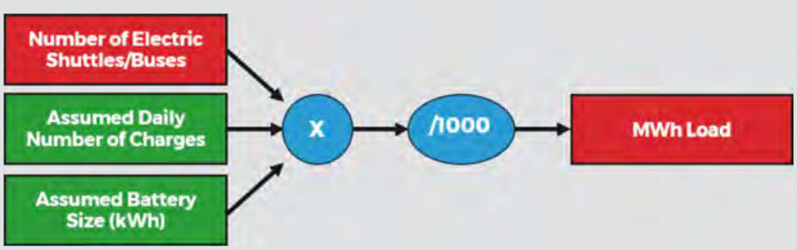


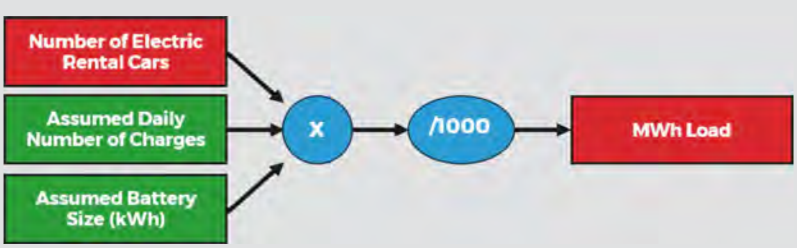


- **MW Load (peak hour demand)**: To estimate the MW load due to shuttle/bus and rental car vehicles, the tool multiplies the number of chargers by the assumed charger speed/output power in kW. The tool then divides the result by 1,000 to convert it to MW.



- **MWh Load (annual demand)**: To estimate the MWh load due to shuttle/bus and rental car vehicles, the tool multiplies the number of vehicles by the number of daily charges and by the assumed battery size in kWh. The tool assumes that each vehicle needs a full battery charge. The tool then divides the result by 1,000 to convert to MWh.



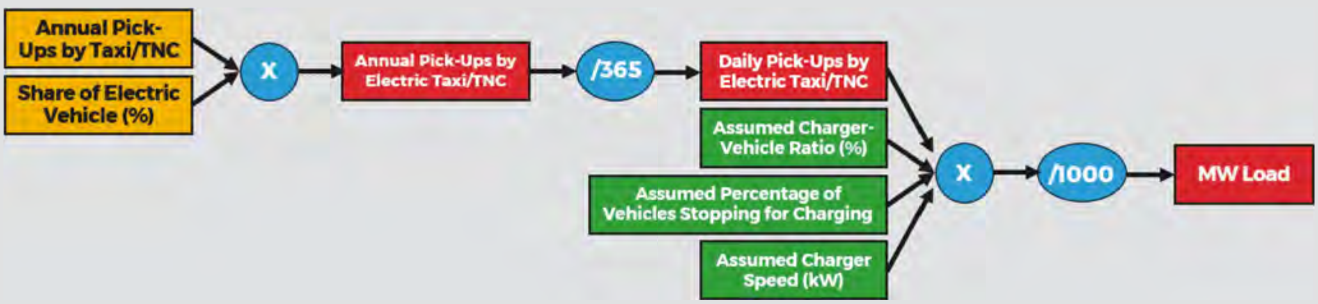


Calculations for Taxi/TNC

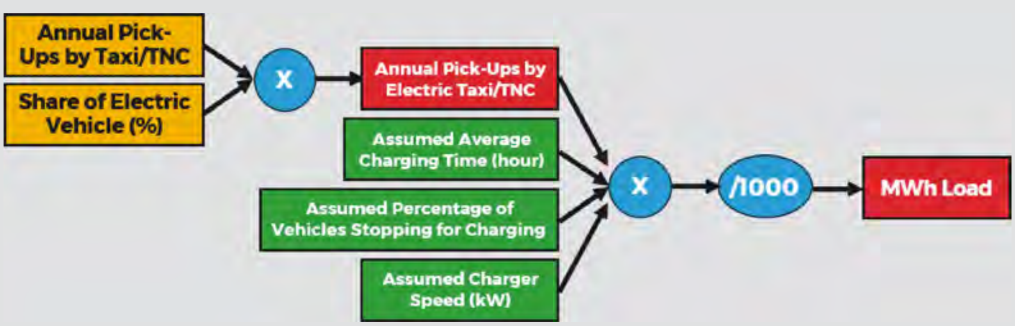
The Assessment Tool will provide three types of requirements: the number of chargers, the peak MW load, and the annual MWh load.

- **Number of chargers**: To estimate the number of chargers, the tool divides the MW load by the assumed charger speed/output power in kW, then multiplies it by 1,000.

- **MW Load (peak hour demand)**: To estimate the MW load due to taxi/TNC vehicles, the tool uses the daily pickups by electric vehicles and multiplies it by the ratio charger-vehicle, by the percentage of vehicle stopping for charging, and then by the assumed charger speed in kW. The tool then divides the result by 1,000 to convert to MW.



- **MWh Load (annual demand)**: To estimate the MWh load due to taxi/TNC vehicles, the tool multiplies the annual pickups by electric vehicles, by the charging time by the percentage of vehicle stopping for charging, and by the assumed charger speed/output power in kW. The tool assumes that each vehicle needs a full battery charge. The tool then divides the result by 1,000 to convert it to MWh.



CHAPTER 17

Accounting for Electric Aircraft into Long-Term Planning Documents

17.1 Integration in Master Plans

The Airport Master Planning Process

Long-term airport development and planning are governed by individual airport master plans. Master plans are intended to develop airports safely and efficiently by looking toward the future to dictate development and planning needs. The master planning process establishes capital development initiatives for an airport and a long-term plan for incremental and flexible development. Master plan studies include environmental considerations, facility requirements, ALPs, facility implementation plan, and financial feasibility analysis, among other components.

FAA AC 150/5070-6B – *Airport Master Plans* provides guidance to prepare a master plan. According to the advisory circular, the master plan provides the framework needed to guide future airport development that will cost-effectively satisfy aviation demand, while considering potential environmental and socioeconomic impacts. The master plan is a comprehensive study of the airport that describes short-, medium-, and long-term plans for airport development. The following elements should be included in a master plan:

1. **Pre-planning**: Determine the needs, request for proposal and consultant selection, development of study design, negotiation of consultant contract, and application for study funding.
2. **Public Involvement**: Establish a program to involve as early as possible the public in airport planning projects.
3. **Existing Conditions**: Inventory pertinent data on the existing conditions of each part of the airport, from the airside to the landside, and the surrounding airport community.
4. **Aviation Forecasts**: Develop forecasts of aeronautical demand for short-, medium-, and long-term timeframes.
5. **Facility Requirements**: Based on the forecasts, assess the future airport needs of each element of the airport environment to support the forecast demand and estimate the requirements of new infrastructure that may be required to meet the future demand.
6. **Alternatives Development and Assessment**: For each requirement identified in the facility requirements stage, identify multiple alternatives to meet these future requirements. Assess each alternative with a wide range of evaluation criteria, especially operational, environmental, and financial impacts. Recommend a preferred alternative at the end of this process and refine it subsequently.
7. **Airport Layout Plans**: Prepare a set of drawings that provides graphic representations of the long-term development plan for an airport.
8. **Facilities Implementation Plan**: Provide a summary description and a schedule of the recommended alternative and the associated costs.
9. **Financial Feasibility Analysis:** Present the financial plan for future airport developments and their funding.

Airport master plans are eligible for FAA funding. The FAA typically reviews and approves the aviation forecast and the ALP.

Planning for Electric Aircraft

With the emergence of electric aircraft in the coming years, master plans must consider these new airside and airspace users. The following section identifies and discusses for each element of a master plan the potential impacts of electric aircraft and how to address them:

1. **Pre-planning:** During the pre-planning process, the planning needs should be identified based on future potential shortcomings, which could be triggered by a capacity reached, the introduction of new aircraft types, or the emergence of a critical environmental problem. Airport stakeholders can also identify future needs and inform the airport. Typically, airlines can announce their intentions to open new routes with a new aircraft type. The type of study should be therefore determined, to answer the needs, if a full airport master plan is required or a simple technical report. The airport sponsor then hires a consultant to prepare the master plan after a bidding process. The two actors must agree on specific topics before beginning the planning study: discuss the goals and objectives of the study, identify the data available, determine the forecast horizons, identify the level of environmental documentation, fix a schedule of the deliverables, and agree on a budget.
   - *Electric Aircraft*: The pre-planning process will not be fundamentally impacted by electric aviation. The introduction of new electric aircraft types should be considered because it might warrant a specific planning effort to address facility requirements. It should be included in the scope of work, if applicable, that electric aircraft should be considered throughout the master planning process.
2. **Public Involvement:** A public involvement program should be created in the earliest stages of master plan development. This program is intended to share information about the planning study and to collaborate among the airport sponsor, users and tenants, resource agencies, elected and appointed public officials, residents, travelers, and the general public. It is important to involve them with an early opportunity before any major decisions are made to consider their comments and educate them on future potential airport development.
   - *Electric Aircraft*: Electric aviation should not significantly impact existing practices for public involvement at existing airports because of its significant benefits to the airport environment and noise exposure. However, the creation of whole new services such as the conversion of smaller facilities into community service airports acting as a local mobility hub or into commercial STOLports, and the introduction of new UAM routes, will require specific public involvement efforts.
3. **Existing Conditions:** Master plans require an inventory of existing conditions for both physical attributes and operational and performance characteristics of the airport and related facilities and infrastructure. They include the airside, passenger terminal, and landside facilities. The regional setting of an airport and the land-use patterns around should be examined, and an environmental overview should be included.
   - *Electric Aircraft*: The inventory of existing conditions includes documenting the utility infrastructure. It also includes the identification of commercial service and general aviation facilities and planned improvements, which may include existing plans for electricity and hydrogen storage and distribution facilities, if applicable.
4. **Aviation Forecast:** Aviation activity forecasting completed during the master planning process informs future facility requirements and the timeline for airport development and improvements. An appropriate forecast methodology must be selected according to the level of effort required by the master plan. This step is crucial in a master plan development

and must be submitted to the FAA for review and approval, before being used as a basis for the facility requirements.

– *Electric Aircraft*: Aircraft fleet mix projections are a component of the master planning process that also must consider electric aircraft in the future as private owners, training centers, and air carriers are able to integrate them into their fleets. Identifying the share of electric aircraft among future aircraft operations will help planning for their accommodation. Forecasting also considers gate utilization and turnaround times for aircraft; depending on electric aircraft charging requirements and time required for charging, this could impact the turnaround times and gate utilization. Potential changes in service patterns resulting from the introduction of electric aircraft or the emergence of new services with the advent of AAM that could impact the aviation activity should be considered when air carriers and other flight operators and air mobility providers have specific plans for electric aviation.

  Note: The FAA does not have provisions for electric aviation in the Terminal Area Forecast. The FAA Aerospace Forecast features analyses on UAS, but not on AAM and electric aviation. Although the Aerospace Forecast is not suitable for aviation activity forecast at individual airports, it does provide useful national trends.

5. **Facility Requirements:** After the approval of aviation forecasts, the next step is to determine the adequacy of the existing airport facilities to accommodate future demand and identify if any additional facilities will be required. These requirements are driven by circumstances of each airport, which includes capacity shortfalls, enhanced security requirements mandated by the Transportation Security Administration, new or updated design standards, airport sponsor and the stakeholder's strategic vision for the airport, and outdated facilities.
   – *Electric Aircraft*: Electric aircraft trigger three specific facility requirements:
      i. An aircraft charging infrastructure to supply electric power to aircraft through chargers or battery swap;
      ii. An airport electricity infrastructure to support and enable the aircraft charging infrastructure; and
      iii. A hydrogen infrastructure for supplying gaseous hydrogen to aircraft with fuel cells.

   With the introduction of new aviation fuels, and among them electricity and hydrogen for electric aircraft, specific projections derived from the aviation forecast will be needed to develop these requirements. Airport sponsors should discuss with their aviation stakeholders to determine their needs for charging infrastructure and hydrogen infrastructure.

   The Assessment Tool available in the Toolkit was developed to help airports and planners to estimate the electricity demand growth due to electric aircraft. This tool estimates the potential electrical loads for electric aircraft based on the aviation forecast. Also, it provides an estimate of the number of charging stations required for five different activities: air carrier, air taxi, commuter, general aviation, and military.

   Note 1: The Assessment Tool assumes that all electric aircraft are powered by batteries recharged by chargers at the gate. The use of alternative charging means—such as mobile superchargers and battery swap—should be discussed with flight operators, ground handlers, and FBOs. In this case, electric chargers computed with the tool can be substituted with alternative means.

   Note 2: The Assessment Tool does not consider electric aircraft powered by fuel cells. These aircraft need hydrogen that is processed by fuel cells to provide electricity, instead of relying solely on batteries. These hydrogen-electric aircraft should be excluded from the electric aircraft forecast entered into the Assessment Tool. Their hydrogen demand should be evaluated separately based on methodologies used for conventional aviation fuels. Facility requirements should be developed with the stakeholders as the delivery and supply methods might be airline- and FBO-specific (e.g., hydrogen pods or hydrogen fueling trucks).

6. **Alternatives Development and Assessment:** Based on the facility requirements, the alternatives development process is to identify alternative ways to address previously identified facility requirements; to evaluate the alternatives, individually and collectively; to gain a thorough understanding of the strengths, weaknesses, and other implications of each; and, finally, to select a recommended alternative.
   – *Electric Aircraft*: With the facility requirements that were centered on charging infrastructure and power capabilities, three types of charging equipment have been identified: fixed chargers, mobile chargers, or battery swapping. During this stage, airport sponsors and planers would benefit from exploring preferred charging locations, tie-in options, and identifying any other necessary electrical system upgrades. The evaluation of each alternative must include specific criteria regarding electric aircraft, such as the impacts of the location of the charging infrastructure, the environmental impacts of these chargers, and the financial feasibility.
7. **Airport Layout Plans:** The drawing sets of the ALP must include a cover sheet, the ALP depicting existing and future airport facilities, data sheet, facilities layout plan, terminal area plan, airport airspace drawing, inner portion of the approach surface for each runway, on-airport land use drawing, off-airport land use drawing, airport property map, runway departure surface drawing for each runway, utility drawing, and airport access plans. ALPs are also subject to approval by the FAA to receive federal funding.
   – *Electric Aircraft*: The electric aircraft infrastructure (airside electricity power supply infrastructure, electric chargers, alternative charging means, hydrogen infrastructure) may be depicted in the ALP drawing set.
8. **Facilities Implementation Plan:** This plan is the framework on how to implement the findings and recommendations of the planning effort. It will differ depending on the complexity of a project and vary from airport to airport. Local conditions will significantly influence the schedule, costs, and any special regulations.
   – *Electric Aircraft*: The implementation of the electric aircraft infrastructure should be considered. Electricity and utility connections providers should be involved in this plan if an upgrade of the power supply infrastructure and the connection to the grid is required. Such an approach must consider the future of the overall electricity demand of the airport, as well as plans for decentralized power generation including microgrid.
9. **Financial Feasibility Analysis:** During this analysis, the airport sponsor must demonstrate its capability to fund the projects in the master plan and present the capital improvement program.
   – *Electric Aircraft*: Potential funding sources were identified, and they are discussed in *Chapter 15, Financial Planning*.

Utilities Master Plan

With the growing electrification of airports from the landside to the airside, and the need for more power resilience, aviation facilities may consider a utilities master plan as part of their broader long-range planning effort. Regarding electricity, the utilities master plan can address the long-term trends on the overall airport consumption, the demand of new and future users (including electric aircraft), the federal and local regulations, airport requirements for more power resilience, and the sponsor's vision and policies regarding its resource usage and environmental footprint. A utilities master plan—encompassing electricity—can be developed in parallel with the traditional master planning effort. The utilities master planning process should follow the steps of the broader airport master planning process. The Assessment Tool available in the Toolkit provides useful projections on the overall airport energy demand for utilities master plans.

17.2 Statewide Aviation Plans

State aviation system planning is a strategic process to assess all public-use airports in a given state, determine their and their users' current and future needs, and identify the relationship between the airports and their ability to meet forecast demands. These plans are also used to evaluate funding priorities and policy, or regulatory changes needed to ensure the system's safety and capacity. They often consider the economic impacts and benefits of aviation to a state's economy, how broader industry trends are in turn affecting aviation, and future developments. The planning horizon varies but often includes both short- and long-term analyses—similar to those of the airport master plan.

The statewide aviation plan is the equivalent of an airport master plan at the state level. It encompasses all the airports within the state. It is a technical report that provides information and analysis on the system of airports and has the main goal to provide an efficient airport system, which integrates and participates in the economic development in the state.

A typical process to develop a statewide aviation plan is the following:

1. Aviation System Goals and Objectives.
2. Existing Conditions.
3. Aviation Forecasts.
4. Capacity/Needs Analysis.
5. Alternatives Development.
6. Recommendations.

Electric Aircraft in Statewide Aviation Plans

The following section describes for each element of the typical statewide aviation plan the potential impacts of electric aircraft.

1. **Aviation System Goals and Objectives**: During this first step, the state's vision of its aviation system must be defined and translated to goals and objectives on how to achieve that vision. The state provides markers for tracking progress toward that vision. A specific committee should be appointed and supervise and define the direction for the system plan. This committee should include members with responsibilities and knowledge of airports and aviation.
   - *Electric Aircraft*: The definition of goals and objectives will not be fundamentally impacted by electric aviation. However, these vehicles and the air services they might provide in the future should be considered in the scope of the plan. The state can also elect to evaluate the specific needs of these aircraft and potential funding to make its state aviation system accessible to electric aircraft.
2. **Existing Conditions**: Similar to a master plan, a statewide aviation plan requires an inventory of existing conditions for both physical attributes and operational and performance characteristics of the airport system and related facilities and infrastructure. Air navigation and airspace should also be included.
   - *Electric Aircraft*: The inventory of existing conditions may document the current accessibility of the state aviation system to electric aircraft with a mapping of the existing aircraft charging infrastructure and hydrogen fueling services.
3. **Aviation Forecasts**: The trends and forecasts of aviation activity within the state must be performed and will be used as a basis for the capacity and need analysis.
   - *Electric Aircraft*: Aircraft fleet mix projections must consider electric aircraft as private owners, training centers, and air carriers might start acquiring these vehicles soon. Identifying the share of electric aircraft among future aircraft operations will help planning for the development and funding of e-aircraft services and support facilities. *Note: The FAA does*

not provide to date a specific electric aircraft forecast including in its Terminal Area Forecast and Aerospace Forecast.

4. **Capacity/Needs Analysis**: Based on the aviation forecasts, the capacity of the existing infrastructure must be assessed to evaluate the ability of the regional airport system to accommodate future demand. Following this evaluation, it must be determined if the current infrastructure is sufficient for future aviation demand and if any additional facilities are required.
   – *Electric Aircraft*: Electric aviation is emerging. It is important that the stakeholders of electric aircraft operations are gathered at this stage to understand the needs of this community as well as the ambitions of the economic community and the state regarding electric aviation. Statewide coordination can be achieved through a specific electric aviation working group set up to discuss and determine the needs of the aviation community. The energy industry and state regulators (e.g., state department of energy or energy commission) may also be involved in this process.
5. **Alternatives Development**: During this phase, following the capacity/needs analysis, different alternative actions to meet the goals and objectives of the state vision are identified. Subsequent analysis can be performed to evaluate each airport and the relevant projects to meet the established targets.
   – *Electric Aircraft*: In the continuity of the capacity/needs analysis, electric aircraft must be considered, and special provisions regarding the availability of charging solutions or hydrogen should be developed. Electric aircraft manufacturing, maintenance, associated employment opportunities, and utilities providers should be involved in the development of alternatives.
6. **Recommendations**: The last phase is to recommend the different actions, alternative strategies, airport metrics, and evaluation of system needs through the development of policy recommendations.
   – *Electric Aircraft*: Policy perspectives regarding the integration of electric aircraft at the state level should be developed in this phase. They can include considerations on strategies to incentivize electric aviation, potential state funding or support to increase accessibility to the state aviation system, evaluation of the impact of electric aircraft on fuel revenue, and the evaluation of different scenarios to compensate for this loss.

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Appendices A–F

Appendices A–F are available from the TRB website (TRB.org) by searching for "ACRP Research Report 236."

Appendix A: Market Assessment: Other Segments of Electric Aircraft Value Chain
Appendix B: Market Assessment: Model Assumptions
Appendix C: Electric Aircraft Characteristics for Airport Planning
Appendix D: Electric Aircraft Safety Review
Appendix E: Industry Standards: Applicability and Needs
Appendix F: Summary of Electric Aircraft Workshops

Acronyms and Abbreviations

AAAE	American Association of Airport Executives
AATF	Airport and Airway Trust Fund
AAM	advanced air mobility
AC	advisory circular
ACARE	Advisory Council for Aeronautics Research in Europe
ACC	Airports Consultants Council
ACDM	Airport Collaborative Decision-Making
ACI–NA	Airports Council–North America
ACRP	Airport Cooperative Research Program
AEDT	Aviation Environmental Design Tool
AIP	Airport Improvement Program
ALP	Airport Layout Plan
ALPA	Air Line Pilots Association, International
AOPA	Aircraft Owners and Pilots Association
APU	auxiliary power unit
ARFF	airport rescue and firefighting
ATCM	Airborne Toxic Control Measures
ATL	Hartsfield-Jackson Atlanta International Airport
ATR	autothermal reforming
BOI	Boise Air Terminal
BOS	Boston Logan International Airport
CAA	Clean Air Act
CAGR	compound annual growth rate
CASA	Civil Aviation Safety Authority (Australia)
CCS	Combined Charging System
CFR	Code of Federal Regulation
CLEEN	Continuous Lower Energy, Emissions, and Noise
CNI	Paulding Northwest Atlanta Regional Airport
CO	carbon monoxide
CO_2	carbon dioxide
COP	coefficient of performance
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
CRQ	McClellan-Palomar Airport
CTOL	conventional takeoff and landing
CVG	Cincinnati Northern Kentucky International Airport
DC	direct current
DFW	Dallas-Fort Worth International Airport
DNL	day-night average sound level

DOT	Department of Transportation
EAA	Experimental Aircraft Association
e-aircraft	electric aircraft
EASA	European Union Aviation Safety Agency
ECLAIR	Electrification Challenge for Aircraft
eGSE	electrical ground support equipment
EPA	Environmental Protection Agency
EUROCAE	European Organization for Civil Aviation Equipment
eVTOL	electric vertical takeoff and landing
FAA	Federal Aviation Administration
FBO	fixed-base operator
FSP	flight service provider
GAMA	General Aviation Manufacturer's Association
g/bhp-hour	grams per brake horsepower-hour
GFK	Grand Fork International Airport
GHG	greenhouse gas
GPU	ground power unit
GRF	Green Revolving Funds
GSE	ground support equipment
H_2	hydrogen
HIAL	Highlands and Islands Airports Limited
hp	horsepower
HVAC	heating, ventilation, and air conditioning
HYA	Hyannis Barnstable Airport
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
ISO	independent system operator
JFK	John F. Kennedy International Airport
JAXA	Japanese Aerospace Exploration Agency
kW	kilowatt
kWh	kilowatt-hour
LAA	Light Aircraft Association
LED	light-emitting diode
MCN	Middle Georgia Regional Airport
MKK	Molokai Hoolehua Airport
MRO	maintenance, repair, and overhaul
MTOW	maximum takeoff weight
MW	megawatt
MWh	megawatt-hours
NAAQS	National Ambient Air Quality Standards
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NM	nautical miles
NOx	nitrogen oxide
O&M	operation and maintenance
OEM	original equipment manufacturer
PAB	private activity bond
PBN	Performance-Based Navigation

PDK	Dekalb-Peachtree Airport
PFC	passenger facility charge
PKZ-1	Petróczy-Kármán-Žurovec 1
PPF	pounds per flight
PRC	Prescott Regional Airport
PV	photovoltaic
RAM	Regional Air Mobility
RNAV	Area Navigation
RTO	regional transmission organization
SAE	Society of Automotive Engineers
SATS	Small Aircraft Transportation System
SFO	San Francisco International Airport
SMR	steam methane reforming
SOx	sulfur dioxides
STC	Supplemental Type Certificate
STL	St. Louis Lambert International Airport
STOL	short takeoff and landing
TC	Type Certificate
TEB	Teterboro Airport
TMB	Miami Executive Airport
TNC	transportation network company
TPRD	thermal pressure relief device
TRACON	Terminal Radar Approach Control Facilities
UAM	Urban Air Mobility
UAS	unmanned aerial systems
UK	United Kingdom
UKRI	UK Research and Innovation
UTC	United Technologies Corporation
VALE	Voluntary Airport Low Emissions
VNY	Van Nuys Airport
VOC	Volatile Organic Compounds
VTOL	vertical takeoff and landing
W/kg	Watts per kilogram
Wh/kg	Watt-hours per kilogram
WSDOT	Washington State Department of Transportation

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FAST	Fixing America's Surface Transportation Act (2015)
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
GHSA	Governors Highway Safety Association
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TDC	Transit Development Corporation
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S. DOT	United States Department of Transportation

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