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# Preparing for Take-Off: Urban Air Mobility Infrastructure National Institute of Aerospace (NIA) National Aeronautics and Space Administration (NASA) Study Results

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**Summary**

With the increase in population in metropolitan areas, alternative modes of transportation are becoming more attractive to save the user time and reduce congestion. Alternative fuel sources are also being investigated to propel cities and infrastructures into the zero-emission future. Like the infrastructure required for transit and medium-duty EVs, building infrastructure for Electric Vertical Take-Off & Landing (eVTOL)s can be scaled to meet the demand.[1] This study explores eVTOL sites that consist of an at-grade market location, existing multi-story parking garages, and high-rise buildings. The study provides budgetary estimates for the development of vertiports in a variety of scenarios, highlights the potential co-development of Electric Conventional Take-Off & Landing (eCTOL) infrastructure, and guides planning and future study that will help the electric aviation ecosystem prepare for eVTOLs.

*Keywords: Infrastructure, Energy, Communication, Deployment, Ultra-Fast Charging*

## 1.0 Study Description

In cooperation with the National Institute of Aerospace (NIA) on behalf of National Aeronautics and Space Administration (NASA), Black & Veatch was retained to study the electrical infrastructure emerging market with a focus on energy supply and charging infrastructure. Within the scope of this task, Black & Veatch provided a high-level understanding of the changes to the existing electric grid needed to support electric vertical take-off and landing (eVTOL) operations for an Urban Air Mobility (UAM) transportation system. In addition to grid modifications, the project report estimates the timeframes and costs required to develop infrastructure, including all infrastructure elements from the electricity generation through to the charging of the aircraft at a vertiport. Our subject matter experts (SMEs) collaborated with the NASA Team to inform and advise across the following project tasks:

- Overview of the electrical infrastructure in the United States
- Identification of markets for study
- Development of assumptions and ranges
- Analysis to determine typical infrastructure upgrade requirements for eVTOL

- Evaluation of utility grid infrastructure and sufficiency
- Exploration of on-site energy storage at vertiports and refueling infrastructure estimation.

# 2.0 Utility Grid Infrastructure and Sufficiency

Demand could range from less than 1 MW up to 20 MW or more when integrated with other loads, depending on the number of chargers and power demand of the infrastructure at various vertiport sites. Based on these power requirements, it is anticipated that the utility distribution system may require significant upgrades to mitigate equipment overloads during peak charging periods. Requirements are specific to each project and highly dependent on existing equipment capacity and load of the connected site, circuits, and substation. Black & Veatch evaluated and outlined representative possible scenarios based on historical observation of power delivery upgrades, and estimated cost impacts that may occur at various load sizes. In addition to grid power, onsite generation, using various distributed resources and battery storage, was also evaluated.

Utilities face similar challenges with a significant aging distribution infrastructure that could result in increased investment required to accommodate future large vertiport load. However, utilities have current and future projects to replace aging infrastructure, upgrade priority feeders, install advanced technology, and prepare for overall power system growth. These forward-looking projects support the integration of electric vehicles to the grid. As with ground transportation electrification planning, new aviation loads must be anticipated and included in distribution grid planning forecasts. Market success depends on understanding the unique characteristics and geography of requisite aviation charging networks.

## 2.1 Utility Network Overview

A utility's distribution network supplies electricity from high-power transmission downstream to the end consumer. At the substation, power is converted from high to medium voltage and split among many feeder circuits. Supply taps along the feeders connect customers to the circuit either directly (primary service, higher power) or via a service transformer (secondary service, lower power). Key equipment in power delivery from a distribution substation to a secondary service supply customer is shown in Figure 1.

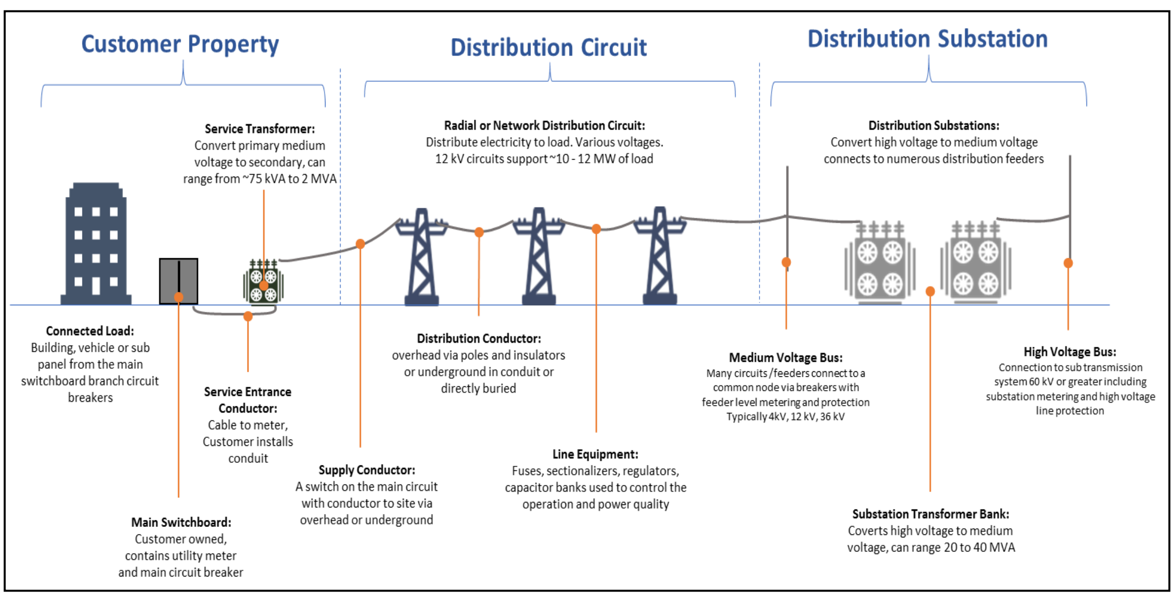



Figure1: Typical Distribution Network to Secondary Service Customer Site.
Icons for the distribution towers and transformers by Freepik.

## 2.2 Power Delivery Overview for High Power EV Charging

The addition of high power EV charging load may require equipment upgrades to either grid elements or building facilities depending on site selection and existing property supply and location on the distribution network. Power levels tend to decrease down the network. Upgrades are more likely to be required as EV load size increases. As additional upgrades are required upstream on the network, the cost and duration of time needed by the utility to get power to the site may also increase.

Generally, utilities install new or upgraded service connections based on customer load requests. Some utilities will prorate this cost, anticipating the revenue they will receive over several years. For this reason, much of the upstream utility cost can be low or free at the initial project installation. Some utilities include a clause in the agreement, whereby if the revenue is not received within a certain number of years, then they will charge the customer the difference.

The approximate capacity at which an upgrade is required depends on site-specific load and equipment capacity characteristics. When installing new equipment, the utility may also size new or upgraded equipment to meet future anticipated load growth in addition to the request. For example, if a 5 MW vertiport causes a new line to bring energy to a specific site or district, then the equipment may be sized to carry three to four times that capacity if it will also serve future load growth or system reliability needs.

## 2.3 Possible Grid Upgrades

Impacts on grid infrastructure may occur as power demand increases to power vertiports. The approximate size at which these impacts may occur is indicated in parenthesis. Grid upgrades may be required, as summarized in Table 1.

Table 1: Grid Upgrade Descriptions

| Grid Upgrade | Description |
|---|---|
| **Service line extension (up to 1 MW):** | The existing utility supply conductor from the main grid to the utility service transformer at the customer site is often sized for maximum service load. As the service transformer size increases, the supply conductor may require replacement. |
| **Conversion to medium voltage service (over 2 MW):** | If the required load exceeds standard service transformer and low voltage switchboard ratings, then the customer may seek or be required to take primary service at medium voltage to allow for multiple service transformers (customer-owned) behind the meter. For this study, we assumed the service voltage to be 12,470V. (Other medium voltage service voltages are used but are not nearly as common.) |
| **Reconductoring (over 1 MW):** | As the load on a circuit increases, the capacity of the distribution line increases. This line would need to be replaced to support the increased ampacity or to replace a worn feeder. The length of reconductor determines the duration of the schedule. |
| **New feeders (over 5 MW):** | New feeders will need to be installed to bring in power from the existing substation to the new electric charging ports. |
| **New substation transformer and capacity increase (over 10 MW):** | With an anticipated load growth, a new or overloaded transformer would be added or replaced with a larger transformer. This equipment requires physical space in the substation and may impact the electrical capacity of connected equipment such as the medium voltage bus and relaying. Some substations may not have the adequate area available to accommodate new transformer banks. Significant equipment lead time may be required. |

| | |
|---|---|
| **New substation (over 20 MW):** | As a last-case option, a new substation would be installed to meet increased ampacity and load growth. Typical equipment includes multiple transformer banks (often rated between 20 and 60 MVA) and the associated bus work, breakers, switches, and protection for high voltage and low voltage yards. Typical high side voltages range from 66 kV to 230 kV for transmission and sub-transmission connected stations. Distribution connected substations range from 33 kV to 44 kV. Low side voltages may range from around 4 kV to 44 kV. |

## 2.4 Interconnection Cost Drivers

Many factors may significantly impact the overall cost of the generic upgrades identified in Section 2.3. Table 2 summarizes the most common location and design-specific cost drivers.

Table 2: Key Cost Drivers

| **Key Cost Drivers** | **Description** |
|---|---|
| Rural/urban areas | Rural projects cost less than urban and suburban due to land availability, limited load growth, and construction impact. Material and labor costs can vary widely depending on location. |
| Existing system/ expected load growth | Present or planned load centers may define the size of new facilities. The existing system configuration will drive connection requirements for the new equipment. |
| Land / environmental constraints | Available right-of-way, alternative land-use constraints, adverse wildlife or environmental impacts, and mitigation requirements may increase design, construction and equipment costs. |
| Location-specific design constraints | Drainage and soil conditions, atmospheric conditions, nearness to existing infrastructure (airports, railroads, highways) can increase design, construction and equipment costs. |
| Public safety or concerns | Proximity to schools or day-care centers, and concerns over appearance, noise, or electrical effects can result in expensive mitigation measures. |

## 2.5 Grid Infrastructure Costs

A high-level review of grid infrastructure costs was performed to demonstrate the potential order of magnitude costs that may be incurred by the electric utility to accommodate higher levels of electric load. Utility infrastructure upgrades required to serve the new charging stations were evaluated by Black & Veatch. The scope of utility upgrades can be very site-specific (depending on upstream network and electrical loading). Similarly, upfront estimated cost allocation for these upgrades can vary; sometimes the utility covers upfront estimated cost, and sometimes the estimated costs are allocated to the project. Table 3 shows common utility upgrade costs that a project may encounter and the charging level at which these upgrades may be required. The cost analysis is based on publicly available data. Available data is limited and mostly available for California.

Table 3: Grid Upgrade Costs and Dependencies

| Grid Upgrade | Cost | Cost Dependencies |
|---|---|---|
| Service Line Extension up to 1 MW (up to 3 chargers) | $75,000 – $100,000 | • Each utility has a different price.<br>• Involves the cost of construction, distance to the location and the cost to bring power to the specific site location. |
| New Feeder/Reconductoring up to 5 MW (up to 8 chargers) | $264,000 - $1,300,000 per mile | • Planning, engineering, design, and construction outage sequencing is required to remove and replace existing equipment.<br>• Geography influences cost. 50$/ft for |

| | | |
|---|---|---|
| | | overhead cable in a rural area up to 250$/ft for the underground circuit in an urban area.<br>• California IOU costs for overhead distribution: Rural 130 $/ft to 258; Urban 180 $/ft. to 258 $/ft. |
| New transformer bank over 10 MW (over 15 chargers) | $3 million to $11 million | • Significant planning, engineering, and construction is required at the substation |
| New Substation over 20 MW (over 30 chargers) | $40 million to $80 million | • Site acquisition, site preparation, design, and construction.<br>• New substations must be integrated into the sub-transmission or transmission network, which requires additional studies and may trigger further upstream upgrades or permitting approval. |

With increased power levels, the scope and location of distribution grid upgrades increase, as do the intensity of land use, right of way and permitting requirements. Existing overhead and underground feeder pathways provide significantly faster approval cycles compared to new pathways. However, existing pathways may be fully subscribed. Similarly, upgrading a substation versus constructing a new substation with requisite transmission lines service will have significantly less impact on costs and schedules.

Utilities will generally not release site-specific power delivery capabilities without expressed intent to develop a location. Therefore, early engagement and utility coordination at an account and engineering level are highly encouraged to fully understand requirements and feasible power delivery schedules.

## 3.0 eVTOL and Conventional Take-Off & Landing (eCTOL) Electrification

Based on the National Plan of Integrated Airport Systems (NPIAS) 2019–2023 data[4], there are over 19,600 landing areas in the United States for aircraft. Including heliports and seaplane facilities, nearly 6000 are available public use, however over 99% of commercial air passenger service was boarded via just 380 "Primary Airports", the designation for facilities that handle over 10,000 commercial passengers annually. These 380 facilities are categorized as Large (30), Medium (31), Small (72) and Nonhub (247) airports. Following NPIAS guidelines, there are 2,941 Non-Primary airports which are designated as National (88), Regional (492), Local (1,278), Basic (840) and another Unclassified (243).

Table 4: NPIAS - Numbers and Types of Existing Airports in the United States (as of May 2018)[4]

| Type of Facility | Total U.S. Facilities | Private-Use Facilities | Public-Use Facilities | Existing NPIAS Facilities |
|---|---|---|---|---|
| Airport | 13,117 | 8,302 | 4,815 | 3,273 |
| Heliport | 5,842 | 5,782 | 60 | 10 |
| Seaplane Base | 507 | 292 | 215 | 38 |
| Ultralight | 112 | 109 | 3 | |
| Gliderport | 35 | 30 | 5 | |
| Balloonport | 14 | 12 | 1 | |
| **Total** | **19,627** | **14,527** | **5,099** | **3,321** |

Due to noise and other community opposition, many of the 5,842 heliports built for private or public use in urban settings such as San Francisco and Los Angeles have restricted use and are not allowed to be used other than by special permit or emergencies. As an example, the busiest public heliport in the country, the Downtown Manhattan Heliport, originates about 58,000 flights annually for business and tours. In 2019, these flights were estimated to be responsible for an annual carbon footprint of over 6,000 tons and had received 1,200 noise and air quality complaints from area residents and workers[5]. eVTOL technologies are being developed as energy-efficient, zero-emission mobility that seamlessly and quietly integrates within communities. Community acceptance hinges on substantially safer vehicle operations, which will be safer due to fully redundant battery and propulsion systems.

Figure 2: Downtown Manhattan Heliport, New York, iStock Photo, demerzel21

Just like fleet managers of New York City's over 5,700 transit buses, eVTOL stakeholders need to plan for the energy required to translate these flights into electric to realize these benefits. Transit buses consume 250KWh or more per day, and eVTOL stakeholders can assume a similar number. Using the 600KW charging for 8-10 minutes as modeled in the NASA study, 160 flights per day would require a minimum of 14.4 Megawatt Hours (MWh) per day of energy:

(600KW/60 minutes * 9-minute charging session *160 flights per day) = 14,400 KWh

Planners sited traditional airports in locations with more airspace, which can safely host both vertical and runway based conventional take-off and landing vehicles. Technology advancements, economics, and the drive for sustainable transportation unlock electric flight, and eVTOL and eCTOL applications will expand rapidly.

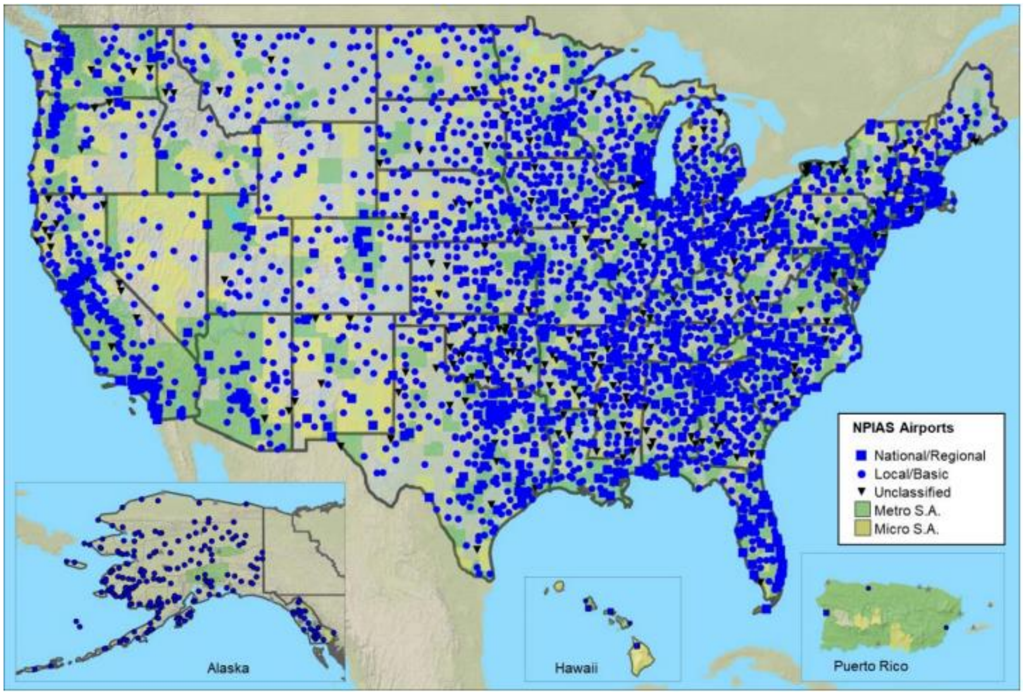



Figure 3: NPIAS - Nonprimary Airports (as of May 2018) [4]

While Primary airports will see significant demand, Non-Primary Airports will also become hubs for Aviation Electrification. They will have charging infrastructure requirements far beyond today's basic lighting and facility operations loads. As illustrated in Figure 3, Non-Primary airports are conveniently distributed throughout North America. It is important to evaluate integrating them into air and ground transportation systems moving forward.

Looking ahead, eVTOLs will function as part of an air ecosystem that will often overlap with eCTOLs and conventional airport locations. A holistic planning view is essential because electric aviation will require power infrastructure investments and planning considerations along with ground transportation.

## 3.1 Communications

The infrastructure needed to integrate the introduction of drones into the airspace with conventional aircraft will also support eVTOLs. The need for robust and expansive communications infrastructure will increase with the number of drones and other vehicles in the airspace.

The Federal Aviation Administration (FAA) acknowledges the need for innovative solutions to evolve and expand current airspace command and control (C2) systems. FAA path to enabling manned/unmanned Urban Air Mobility will require communication Beyond Visual Line of Sight for Drones (BVLOS) for low altitude manned eVTOL and unmanned cargo aircraft. Safe operations may still rely on C2 integrity management.

Multiple jurisdictions will build and test dedicated UAS BVLOS communication networks across regions that include 5G, radio, and satellite to provide continuous coverage.

Additional mission-critical control facilities will also be required. The development of these facilities will require gathering, siting, security, and resilience capabilities for government and third-party network control facilities. Current networks designed to support ground-based operations must expand to facilitate the increased use of the airspace.

## 3.2 Sustainability and Resilience

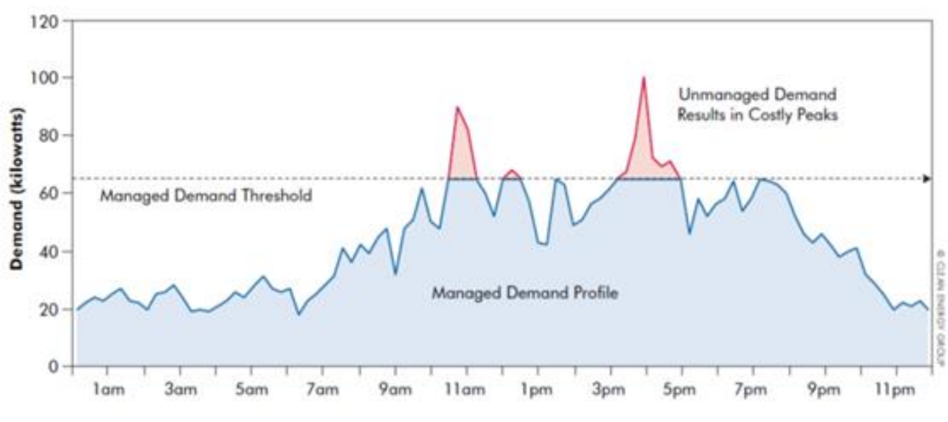
Renewable energy and other distributed generation that is configured as a microgrid at airports to reduce reliance on the grid and increase resiliency at airports will support eVTOLs. Microgrids, small-scale electrical grids with a power system, operate separately from or alongside the electric grid and provide both resilience and sustainability opportunities. Onsite renewable energy and battery storage can help minimize the cost of energy and support grid integration by reducing grid impact and providing power for continued operation during grid outages.

Energy rates typically include two major components: energy charges and demand charges. Energy charges reflect the cost of energy consumed by the site. The cost per unit energy can be fixed or change based on time of day and season. Most utility companies have Time of Use (TOU) rates, when they charge more during the time of day when electricity use is higher, and rates vary during the hours of the day and season. Actual rates and the difference in off-peak price and on-peak price vary across utilities. Demand charges are charges based on the highest demand, during any 15- to 30-minute interval that is measured in a billing period. Demand charges may be a fixed charge per kilowatt, or divided into rate brackets, with the highest charge on the first bracket, and lesser charges on the following brackets.

Energy storage can help reduce energy and demand charges. Demand charge reduction is achieved by reducing the peak consumption and energy arbitrage reduces the energy charges. Energy arbitrage is the practice of purchasing and storing electricity during off-peak times, and then using that stored power during periods when electricity prices are the highest.

The cost savings that can be achieved are dependent on three factors: (1) the utility rate; (2) shape of the local load; and (3) capital cost investment. To determine the optimized solution for a site, the final load based on the charging schedule for each site will need to be evaluated to determine the system size. Properly sized energy storage systems can have a positive return on investment for large "peaky" loads such as the one shown in the figure below. The potential cost savings that can be achieved by deployment of energy storage will vary by vertiport and its charging profile. Batteries as part of a microgrid could provide resiliency. During a grid outage, the battery storage system can help provide power to continue safe operation by charging for excess solar generation during a period of low usage to charge the eVOTLs.

Table 5: Example of Ideal Profile for Demand Charge Reduction with BESS[6]



# 4.0 Recommended Next Steps

This document establishes key infrastructure requirements, feasibility, costs, and stakeholder alignment for successful eVTOL applications. It also sets the framework for follow-on work to identify additional markets, facility profiles, network density scenarios, and equipment specific solutions. To expand the research base and industry knowledge, we recommend that 1) this body of work is replicated other across the country; and 2) key stakeholders investigate cross-domain infrastructure considerations to refine assumptions and operational conditions. Each stakeholder plays an important role.

## 4.1 Original Equipment Manufacturer (OEM) Recommendations

- Continue vehicle development and validation, investigating fuelling, state of charge communications, and interoperability.
- Investigate synergies with conventional take-off vehicles fueling at rural and urban airports
- Pilot site assessments, specific layouts, conceptual design through final design, permitting, construction and commissioning

## 4.2 Government and Policymaker Recommendations

- Develop charging hardware development and interface standards. This includes vehicle connections, safety, sitting considerations, grid signalling, certification, permitting, cybersecurity and optimized layouts.
- Ensure North American requirements are harmonized with international organizations
- Fund research to characterize the airport of the future. Prioritize studies that define national air travel and identify airport facilities that need site reviews and investigations to support power, communications, and logistics planning.
- Conduct air traffic control system and public safety planning to account for energy, weather and security events.
- Evaluate how eVTOLs integrate with drones and commercial airspace.

## 4.3 Electric Utility Recommendations

- Integrate with utility planning processes. This includes power requirements, network density, and grid support.
- Continue to support distributed energy and build resilience.
- Investigate synergies with conventional take-off vehicles fueling at rural urban airports.
- Understand opportunities for power sharing with buildings, other vehicle charging, and the role of energy storage.
- Reduce cost of energy and renewables integration.
- Incorporate lessons learned from other high-power charging applications and this initial study.

## 4.4 Communications and Technology Integrator Recommendations

- Review communications infrastructure, including requirements, of existing networks and implications of upcoming 5G, other emerging technologies, vehicle-to-vehicle and vehicle-to-infrastructure communications.
- Investigate mission critical control facilities, including requirements gathering, siting, security and resilience needs for government and third-party network control facilities.
- Develop roadmaps for network deployments.
- Support load profile development and route analyses.

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