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NIA-NASA Urban Air Mobility Electric Infrastructure Study

BLACK & VEATCH

eVTOL Electrical Infrastructure Study for UAM Aircraft

National Institute of Aerospace

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Glossary of Terms

Table 1 Glossary

ACRONYM	DEFINITION
5G	Fifth generation of cellular mobile communications
B&V	Black & Veatch
BESS	Battery energy storage system
BEV	Battery electric vehicle
CEC	California Energy Commission
Co-op	Electric cooperative
CPUC	California Public Utilities Commission
DER	Distributed energy resources
EV	Electric vehicle
EVs	Electric vehicles
eVTOL	Electric vertical take-off and landing
FAA	Federal Aviation Administration
FERC	Federal energy regulatory commission
High Voltage	Above 35kV, measured phase to phase
IEEE	Institute of electrical and electronics engineers
IOU	Investor owned utility
IPPs	Independent power producers
IRP	Integrated resource plan
LADWP	Los Angeles department of water and power
LCNG	Liquified to compressed natural gas
LNG	Liquified natural gas
LoS	Loss of supply
Low Voltage	600V and below, measured phase to phase
MED	Major event days
Medium Voltage	From 601V to 35kV, measured phase to phase
MWe	Megawatt (electric)
NASA	National Aeronautics and Space Administration

ACRONYM	DEFINITION
NEC	National electric code
NIA	National Institute of Aerospace
O&M	Operations and maintenance
OEM	Original equipment manufacturer
PHEV	Plug-in hybrid electric vehicle
PUC	Public utility commission
PV	Photovoltaic (Solar)
ROE	Return on equity
RPS	Renewable portfolio standard
SAE	Society of Automotive Engineers
SAIDI	System average interruption duration index
SAIFI	System Average interruption frequency index
SCCR	Short circuit current rating
SCE	Southern California Edison
SEPA	Smart electric power alliance
SME	Subject matter expert
SMUD	Sacramento Municipal Utility District
TCO	Total cost of operation
TOU	Time of use
UAM	Urban Air Mobility

1.0 Executive 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 on the roadways. In addition, alternative fuel sources are being investigated to propel cities and infrastructures into the zero-emission future. Like the infrastructure required upon the emergence of transit and medium duty electric vehicles, building infrastructure for electric vehicle take-off and landing (eVTOL) can be scaled to meet the demand as we see in surface electrified transportation.[1,2]

Potential markets for eVTOL sites that have been explored within the report consist of an at-grade market location, existing multi-story parking garages and high-rise buildings. While the estimates to implement an eVTOL infrastructure vary due to existing conditions, estimates can be developed based on a range of assumptions. Assumptions encompass multiple aspects including: available square footage, equipment loading, electrical grid distribution voltages, charger power, electrical grid infrastructure capacity and size along with the performance and unique design characteristics of Urban Air Mobility (UAM) vehicles.

The scope of this report covers budgetary estimates for the development of vertiports in a variety of scenarios. Additional study and facility specific engineered designs will increase the accuracy of these numbers. In the below table, estimates are provided following multiple ranges of assumptions.

Table 2 Budget Estimate Pricing for Chargers

ESTIMATED BUDGET PRICING SUMMARY	DESCRIPTION
$883,000.00	Single charger station incorporated to an existing building landing pad on a five-story building. Pricing does not include utility costs
$1,876,000.00	Three charger station incorporated into an existing roof on a five-level parking garage. Pricing does not include utility costs.
$2,630,000.00	Three charger station installed into a ground based station. Pricing does not include utility costs.
$10,200,000.00	Ten Charger station installed into a ground based station. Pricing does not include utility costs.

Utility infrastructure upgrades required to serve the new charging stations are also discussed within the report. 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 with the utility covering the upfront estimated cost and at other times the estimated cost being allocated to the project. These topics are further described in the report.

1 Priming the U.S. Grid for High-Powered Electric Vehicle Charging - presentation by Black & Veatch https://www.slideshare.net/blackveatch/priming-the-us-grid-for-highpowered-electric-vehicle-charging

2 Priming the U.S. Grid for High-Powered Electric Vehicle Charging – white paper by Black & Veatch https://www.slideshare.net/blackveatch/whitepaper-priming-the-united-states-grid-for-highpowered-electric-vehicle-charging

Below are pricing estimates and descriptions of common utility upgrade costs that a project may encounter and charging level at which these upgrades may be required.

Table 3 Budget Estimate Pricing for Utility Upgrades

ESTIMATED BUDGET PRICING SUMMARY	DESCRIPTION
$100,000	Service supply extension; up to 1 MW (up to 3 chargers)
$264,000 - $1,300,000 per mile	New conductor/ reconductor; up to 5 MW (up to 8 chargers)
$3,000,000 to $11,000,000	New transformer bank; over 10 MW (over 15 chargers)
$40,000,000 to $80,000,000	New substation bank; over 20 MW (over 30 chargers)

2.0 Project Description

2.1 PROJECT SCOPE

In cooperation with National Institute of Aerospace (NIA) on behalf of National Aeronautics and Space Administration (NASA), Black & Veatch has been 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 is providing 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 these needed modifications to the grid, estimates of 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, are included in this report.

Our subject matter experts (SMEs) have collaborated with the NASA team to inform and advise across the following project tasks:

- Overview of the electrical infrastructure in the United States
- Markets for study
- Development of assumptions and ranges of assumptions
- Analysis to determine typical infrastructure upgrade requirements for eVTOL
- Evaluation of utility grid infrastructure and sufficiency
- Exploration of on-site energy storage at vertiports
- Refueling infrastructure estimation

The deliverables for this project include:

- Monthly reporting
- Kick-off meeting and presentation
- Overview presentation of the electrical infrastructure in the United States
- Interim and informal final reports

- Final presentation

2.2 TRANSPORTATION ELECTRIFICATION

Advances in battery capacity, density, power electronics, lightweight materials, multi-motor controls, distributed propulsion, reliability and energy efficiency coupled with exponential computing capabilities are opening new markets and applications to electrification. On the ground, this has translated to a full range of personal vehicles, light-duty trucks and an increasing range of commercial vehicles in successful deployments. As of October 2018, over four million electric vehicles have been sold around the world, with over one million in the United States. [3]

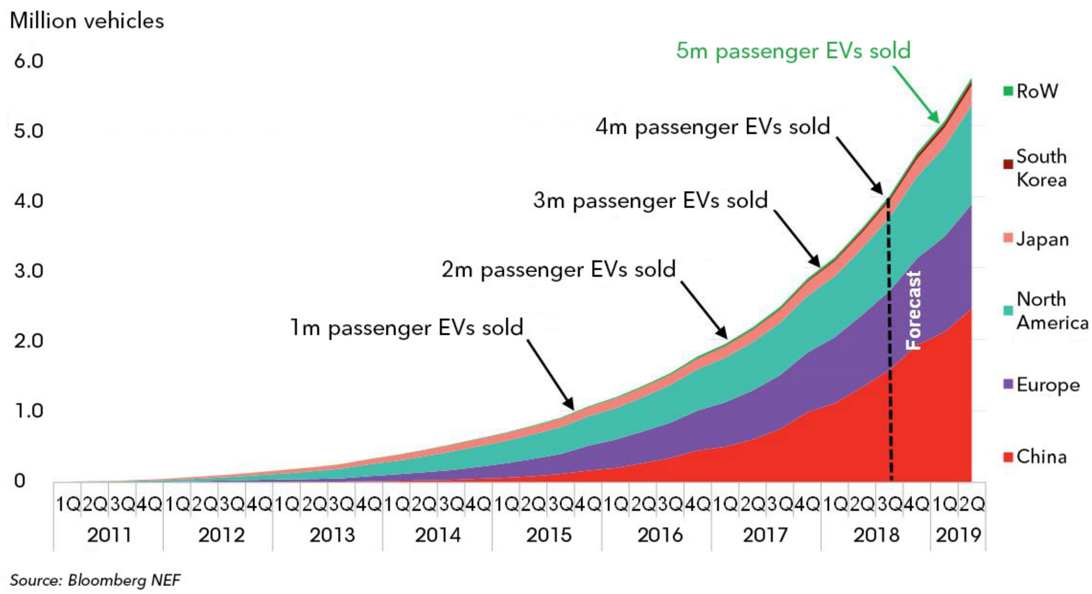

Figure 1 Cumulative global passenger EV sales, current and forecast

As electric vehicles approach initial cost parity with internal combustion vehicles, the overall total cost of operation (TCO), of high utilization fleets have *already* crossed the tipping point in high utilization applications such as rideshare, transit buses and port drayage vehicles.

Just behind these applications are medium and heavy-duty delivery vans, short haul semi-trucks and over road coaches. Each of these vehicle applications will have significantly larger battery capacities that require more substantial charging infrastructure. With many of these vehicles' applications trending towards full battery electric vehicles (BEV), some use cases may employ hybrid drivetrains to leverage the benefits of Electrification along with a conventional engine to address extended duty cycles without re-charging. There are a variety of plug-in hybrid electric

[3] 4 Million Electrified Vehicles Sold Globally, 5 Million Expected In 6 Months https://cleantechnica.com/2018/09/03/4-million-electrified-vehicles-sold-globally-5-million-expected-in-6-months-bnef/

vehicle (PHEV) configurations available that minimize emissions and capitalize regeneration and precise motor controls for autonomous functions.

Beyond lower cost of operation, each of these applications benefit from emissions reductions, instant motor torque, more efficient use of energy, diversity of fuel supply options, vehicle design flexibility, inexpensive multi-motor configurations, energy efficiency and quieter operation that can expand operating hours. These benefits improve safety and the mobility experience for passengers, drivers and communities in which they operate.

In the air, these trends will unlock a new era for aviation that capitalizes on the advantages and unique capabilities of electrified propulsion. This opportunity has led to significant investment to develop eVTOL and conventional take off vehicles. As of October 2018, there are dozens of eVTOL development projects underway that leverage electric propulsion.

Much like their ground-based counter parts, these electric vehicles need considerable energy to serve intended duty cycles and high-power charging infrastructure to keep pace with their fueling requirements.

3.0 Overview of the Electrical Infrastructure in the U.S.

3.1 ELECTRIC GRID

The North American power grid is divided into four distinct power grids or interconnections – Eastern Interconnection, Western Interconnection, Electricity Reliability Council of Texas Interconnection and Quebec Interconnection. Each interconnection consists of multiple utilities that are electrically connected during normal system conditions. Electricity is typically generated at distantly from regions where demand is met, and thereby, electricity is transmitted over large

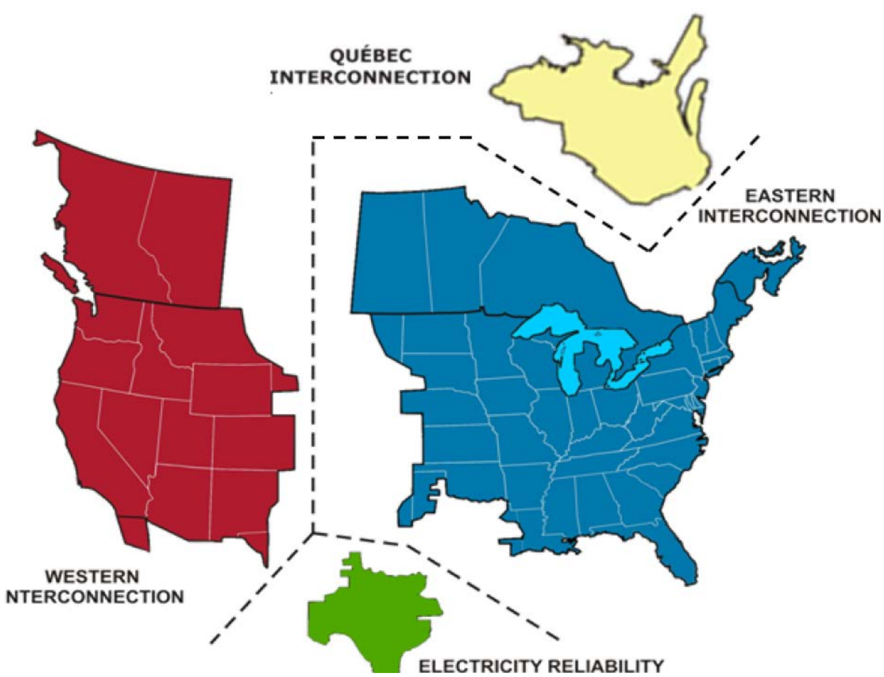

Figure 2 North American Power Grid (Source: Department of Energy)

distances with considerable power losses. Therefore, power is generated, transmitted and distributed at different voltage levels using transformers and substations to minimize power losses.

3.2 ELECTRICITY UTILITIES AND MARKETS

Utilities are typically power companies that generate, transmit and distribute electricity to end-users; however, not all utilities provide all three functions. Utility companies can be broadly divided into five different categories based on the business model and functions:

- **Investor-owned utilities (IOU):** These utilities are for-profit companies that can operate in one or more states and are regulated by state service commissions. IOUs are regulated by public utility commissions (PUC) in each state they operate, and any interstate electricity sales are regulated by Federal Energy Regulatory Commission (FERC).
  - State regulators, the PUCs, review and approve infrastructure investments. These investments can include those needed to integrate renewable energy resources and EVs, if such investments are necessary to meet state goals and mandates (such as Greenhouse Gas reduction).
  - IOUs can earn a profit on the distribution infrastructure they build to serve their customers. The return on equity (ROE) invested ranges from 9-10 percent.
  - Utility rates, approved by the PUC, are set to recover costs and earn the allowed ROE for the investors in return for the risk they bear for investing in new facilities.
- **Public power utilities:** They are non-profit utility companies owned by local cities and counties.
  - Public power utilities are subject to local public control and regulation.
  - They have access to tax-free bonds.
  - Their rates are set to recover costs and earn additional return to maintain bond ratings and invest in new facilities.
- **Cooperatives (Co-ops):** They are non-profit entities owned by members and are generally managed by an elected board of representatives. Co-ops typically serve rural areas that are not served by traditional utility companies.
  - Co-ops are subject to local public control and regulation.
  - They have access to low-interest loans.
  - Their rates are set to recover costs.
- **Federal power programs:** Federal programs are wholesale-only entities providing electric services to other utilities.
- **Independent power producers (IPPs)/non-utility generators:** IPPs are either privately owned or publicly traded companies that own and operate power generation assets that sell power to other utilities or directly to end-users.

The electricity market in which these utilities operate can be broadly classified into both wholesale and retail markets. Wholesale markets involve the sale of electricity among electric utilities before it is eventually sold to consumers. Retail markets involve the sales of electricity directly to the end-user. Both wholesale and retail markets can be regulated or deregulated. Deregulated markets in the United States are administered by two regional entities, regional transmission organizations (RTO) and independent system operators (ISO). Regulated markets are monitored by vertically integrated utilities (utilities that generate, transmit and distribute electricity). There are currently seven different ISOs and four different RTOs in North America. Both ISOs and RTOs have similar functions of managing generation, transmission and distribution of electricity within their respective territory. RTOs also monitor the operation of a region’s transmission network by providing fair transmission access. In addition, there are numerous state public service commissions that regulate electricity rates under its jurisdiction. Commissions adopt and enforce regulations that protect the public's safety and interests, study the economic and environmental impact of utility operations, ensure the safe and reliable service of electricity to customers, and, in some cases, mediate disputes between the utility and its customers.

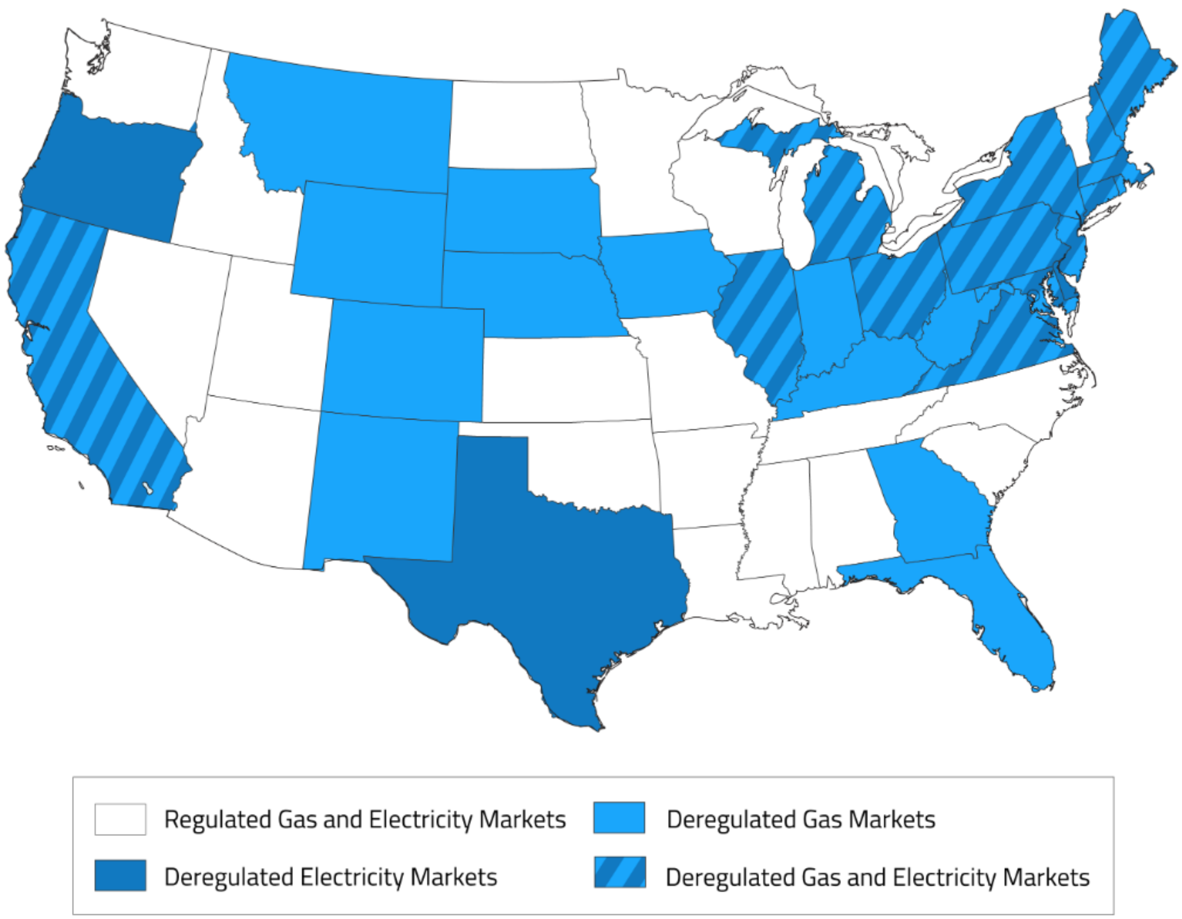

Figure 3 Overview of United States Markets (Source: Electric Choice)[4]

Regulated electric markets include vertically-integrated utilities that own and operate generation assets, transmission lines and distribution system. In these markets customers only have one option, the local utility, for the electrical service. The customer gets one bill that includes charges for the energy and the infrastructure needed to deliver the energy (transmission and distribution grid). The rates/tariffs charged by the utility are regulated by the state's PUC. The regulators also approve infrastructure investments, including infrastructure to support EVs, made by the utility.

[4] https://www.electricchoice.com/map-deregulated-energy-markets/

In deregulated markets, the local utility owns and operates the distribution system, the electric supplier can be one of the third-party retail electric suppliers that sells electricity in the local market. Some utilities in deregulated markets are split into two companies, the regulated potion that owns and operates the physical infrastructure (regulated by the local PUC) and deregulated portion that competes to be the energy supplier, like other third-party retail companies. Large customers can often use competitive bidding from the suppliers to get lower energy rates. Customers in deregulated markets will also get two energy bills, one from the local utility for delivery charges and one from the energy supplier that covers the cost of the energy.

It should be noted that, in both types of markets, the customer must submit an interconnection request (physical connection to get power to the site) to the local utility. Deregulated markets can result in lower cost and contract flexibility because they allow for a choice of suppliers. Third-party energy suppliers can offer different contract structures, such as varying length of contact, fixed price, time-of-use, etc.

The final cost of electricity varies across the United States. Figure 4 below shows the relative differences in residential rates across the country. Commercial rates are lower but follow a similar geographic trend.

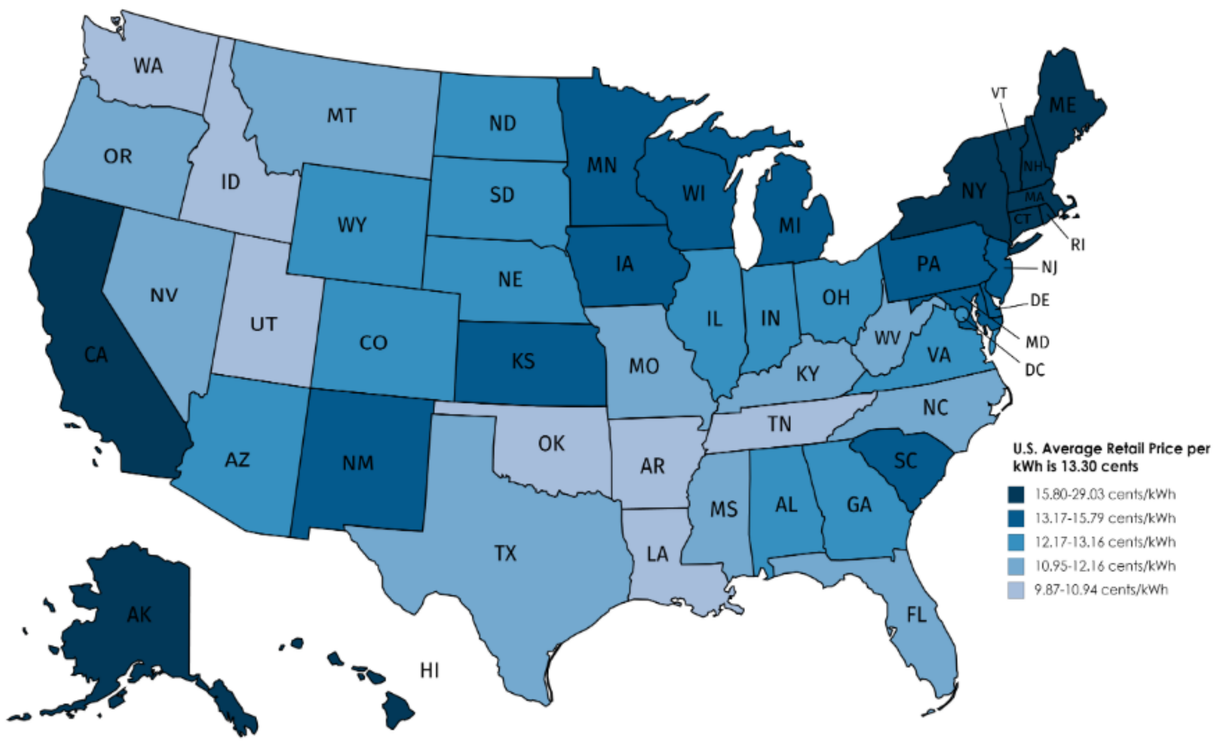

Figure 4 2018 Average Retail Energy Prices per kWh (Source: Choose Energy)[5]

[5] https://www.chooseenergy.com/electricity-rates-by-state/

In addition to the final cost of energy, the type of generation resources also varies across the country. More than half the states have renewable energy targets, as shown in Figure 5 below.

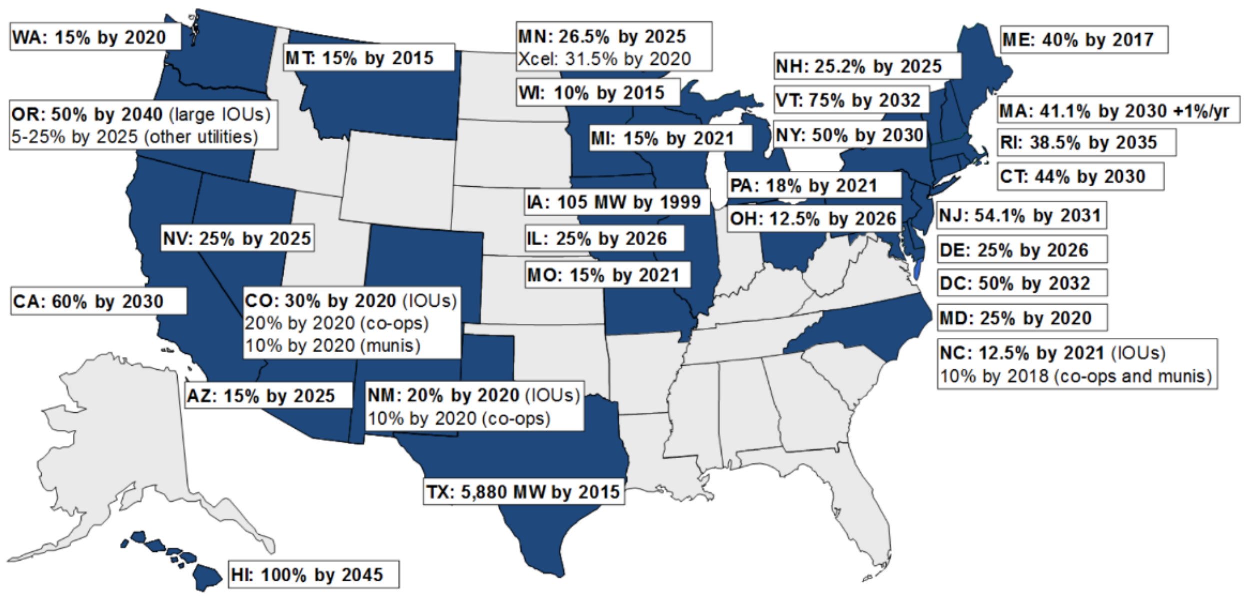

Figure 5 Renewable Energy Procurement Standards (RPS) by State (Source: LBNL Nov 2018)[6]

SB100, a bill signed in 2018 by the California governor, requires that California obtain 100 percent of its energy from renewable resources by 2045. Nevada also approved an increase of their renewable energy targets to 50 percent by 2030 by passing a ballot in November 2018.

Coal and natural gas still provide a significant amount of the energy, but will decline in the future as utilities procure more renewable energy such as solar, wind, biomass and geothermal to serve their customers. The following figures show the portion of the energy generated from natural gas and coal for each state in 2016.

[6] https://emp.lbl.gov/projects/renewables-portfolio

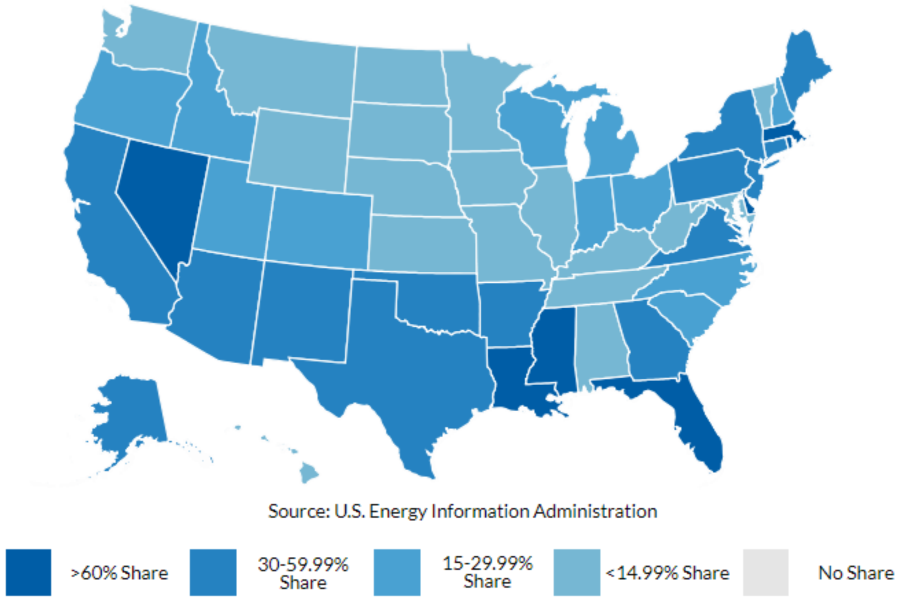

Figure 6 Natural Gas' Share of Electricity Generation, 2016

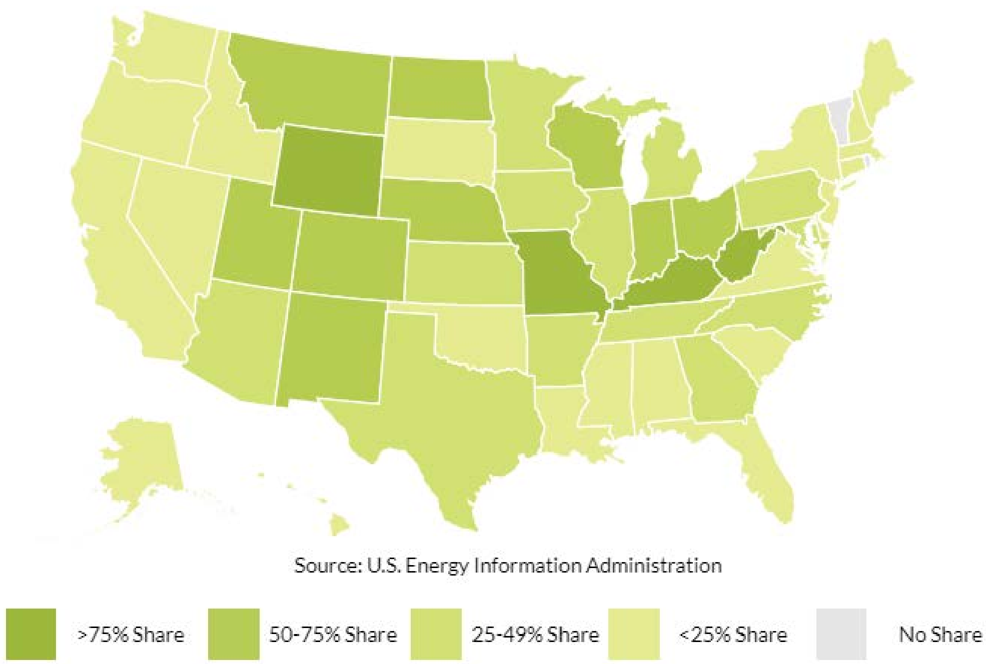

Figure 7 Coal's Share of Electricity Generation, 2016

3.3 UTILITY PLANNING PROCESS

The planning process for utilities includes development of an integrated resource plan (IRP), which outlines resources needed over a 10-to-20-year span, varying in requirements by state. The IRP is reviewed and updated periodically. The IRP also includes future energy demand projections and resources needed to meet the demand in the most cost-effective way. The plan is reviewed and approved by the state PUC for least-cost and stable electric services to the utility customers over the long term. The figure below shows which states require utilities to develop IRPs.

In addition to growth in customer load, most utilities are including the projected demand from electrical vehicles in their future energy demand projects.

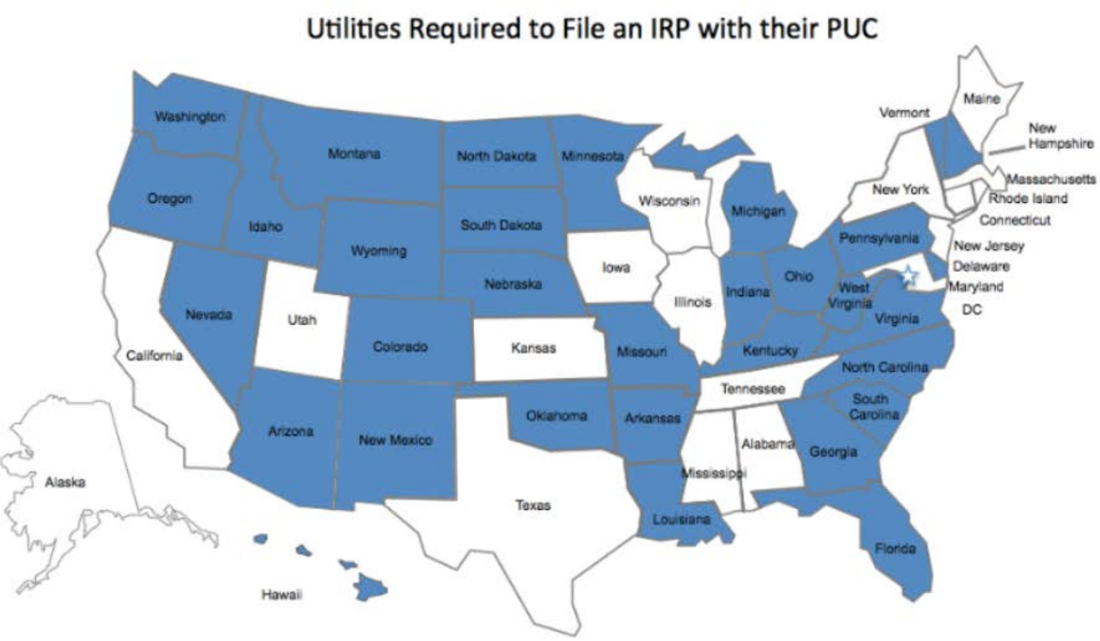

Figure 8 Utilities Required to File an IRP with their PUC

In addition to developing IRPs to identify resources needed to meet future load (including load from future electric transportation), utilities also conduct distribution planning. The typical distribution system planning process is focused on maintaining safety, reliability and cost to support investment decisions. Figure 9 below shows the distribution system planning process. The cost of investments identified in planning process become part of the rates paid by the customers, the rates include the return on equity allowed by the state.

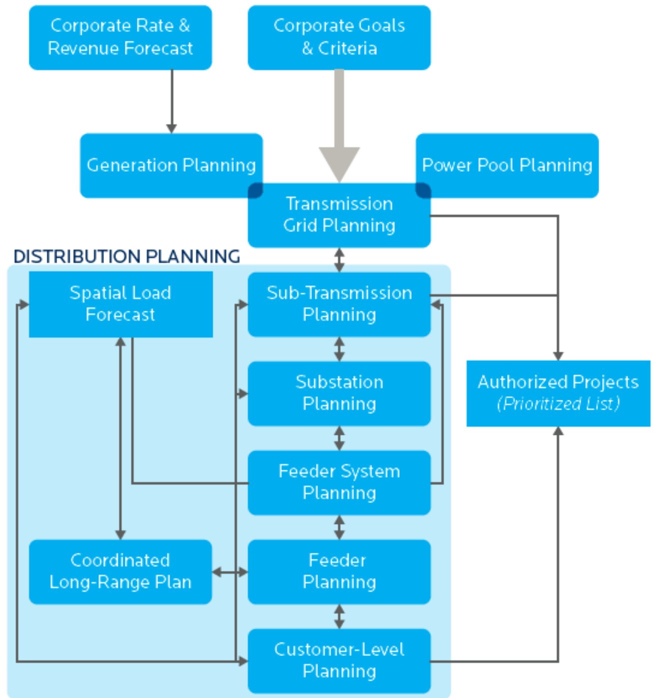

Figure 9 Traditional Utility Distribution System Planning Process (Source: B&V and SEPA)

Some states require utilities to develop and provide public hosting capacity maps. These maps increase public visibility of specific substation/feeder's available capacity and helps determine the feasibility of connecting additional loads and distributed energy resources at the location. These maps can be used to screen sites for ease of interconnection. Currently these maps are available for California, New York, Hawaii and Minnesota.

3.4 ELECTRIC VEHICLES ON GRID

The recent rise in EV adoption will increase load growth and require distribution system upgrades to accommodate higher electricity consumption associated with EVs. For instance, California predicts 4-6 percent load growth in the next decade, with a prediction that 3-4 million EVs on the road by 2030.

National Renewable Energy Laboratory (NREL) released a study titled Electrification Futures Study[7] that explores the impacts of widespread Electrification. The study found that demand growth rates due to Electrification are within historical experiences, but increase from the recent flat growth trends thus availability energy is not a major concern. The study did find that there will be shifts in peak demand timing that could have a significant impact on electric utility planning and grid operations. To reduce the impact on the grid, utilities and other stakeholders across the country are developing strategies to minimize grid impacts that contain options for EVs charging with various business models, including incentivizing consumers by offering time of use (TOU) rates to charge at night.

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[7] https://www.nrel.gov/analysis/electrification-futures.html

3.4.1 Impact of Electric Vehicles Growth on Utility Infrastructure

The effects of charging an EV are dependent on where it is located on the grid and the time of day it is charged. If many EV owners attempt to charge simultaneously, large spikes in electricity demand could cause stress and strain on the grid and affect stability, efficiency and operating costs because the local distribution grid was not built to handle large spikes in the power demand.[8] Charging multiple EVs with the same transformer, known as clustering, results in power quality being degraded because utility equipment could prematurely fail. The grid could potentially be overloaded and could cause damage or a power outage.

Starting in 2012, California Public Utilities Commission required all investor-owned utilities in the state to provide an annual load research report that shows the impact of EVs on the grid. These studies have reported that EV integration has yet to result in a major hurdle on the grid. Reports from utilities also suggest that substantial EV charging can be integrated without significant cost towards system upgrades. In 2016, of the $5 billion that the three California utilities spend annually to maintain their distribution systems, roughly $610,000 was attributed to upgrades required to accommodate EVs – which made up approximately 3.6 percent[9] of the total personal vehicles in 2016. In addition, the reports also show that EV owners charge in ways that minimize harmful impacts on the electric grid when concerning TOU rates. However, increased investment will be required to accommodate future growth in EV penetration. A Smart Electric Power Alliance (SEPA) / Black & Veatch study[10] for Sacramento Municipal Utility District (SMUD) shows that for a high-penetration distributed energy resources (DER) scenario (240,000 EVs) predicts a significant impact in distribution system through 2030. The study also suggests that nearly 26 percent of SMUD's substations would experience voltage violations[11] and 17 percent of the utilities transformers will need to be replaced in the high penetration case (total cost of approximately $89 million - 12,000 transformers at $7,400 each).

3.4.2 Managed Charging Programs

Managed charging is a combination of infrastructure and communication signals sent directly to the electric charging vehicle to control the charging events. A 2017 survey conducted by SEPA indicated that 69 percent of the utility respondents are planning and considering EV managed charging demand response programs. Managed charging can reduce grid stress, maintain stability, improve capacity factors of generation assets during off-peak times, avoid grid upgrades and reduce charging costs to the consumers. Several utilities have pilot managed charging programs to reduce grid impact by offering special rates for EV owners to charge their vehicles during off-peak hours, when supply is abundant and the prices are low.

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[8] https://www.lexingtoninstitute.org/wp-content/uploads/2018/09/9.18.18-How-Electic-Vehicles-Can-Support-the-Grid.pdf

[9] IHS Markit

[10] Planning the Distributed Energy Future, Volume II, https://sepapower.org/resource/beyond-meter-planning-distributed-energy-future-volume-ii/

[11] Example voltage violation boundaries Pacific Gas & Electric https://www.pge.com/includes/docs/pdfs/mybusiness/customerservice/energystatus/powerquality/voltage_tolerance.pdf

Typically, these programs are not mandatory, and they are designed to encourage charging during periods of low cost of demand on the grid thus reducing the burden to integrate. It is possible that the cost of energy for charging outside of the preferred hours by the utility would increase significantly with the increasing penetration of EVs thus increasing the benefits of onsite managed charging programs. Onsite managed charging programs would optimize charging with cost of energy and potentially incorporate onsite energy storage.

3.4.3 Power Delivery Overview for High Power EV Charging

A utility's distribution network issues electricity from high power transmission down 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 10 below.

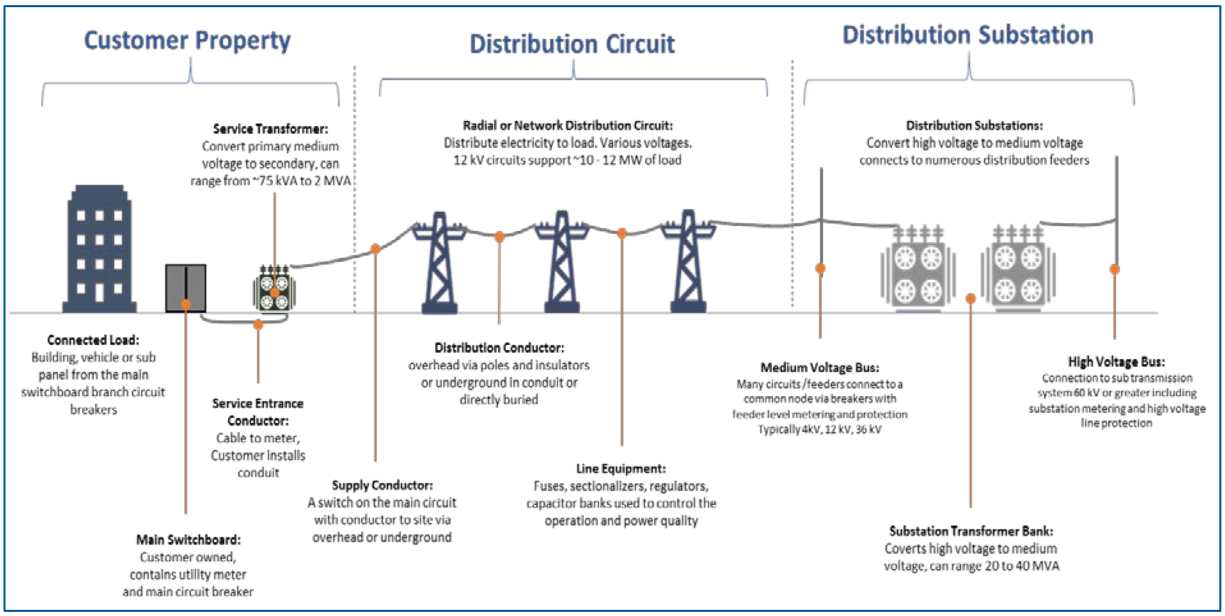

Figure 10. Typical Distribution Network to Secondary Service Customer Site[12]

Depending on the site selection, existing property supply and location on the distribution network, the addition of high power EV charging load may require equipment upgrades to either grid elements or building facilities. 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 site may also increase.

[12] Icons for the distribution towers and transformers made by Freepik from www.flaticon.com.

4.0 Markets for Study

In partnership with NASA's Technical Representative, Black & Veatch considered a variety of study markets across the United States. During the initial phase of this study, the grid and energy infrastructure of each city was researched in detail. Each market was also considered based on other market specific factors including building types and air space characteristics.

The three markets selected were:

- Los Angeles, CA
- Houston, TX
- Baltimore, MD; Washington DC

This section addresses the market selection in three sub-sections as given below:

- Market Study, Grid and Energy Infrastructure
- Market Study, Air Space characteristics
- Market Characteristics

4.1 MARKET STUDY, GRID AND ENERGY INFRASTRUCTURE

From the variety of study markets that were initially considered, three sites were selected. From the grid and energy perspective a few factors were considered. First, the involvement of the utility in moving towards an electrified future and decentralization of the electric grid was considered. Reviews of these programs were used to opine on the possibility of future incentivized vertiport charging options and receptivity to alternative or distributed infrastructure solutions (current investments to support EV integration assumed to be indication of future support of eVTOL). Similarly, the utility distribution planning and load expansion process was considered at a high level to understand differences in publicly available data across locations that could be used for optimal eVTOL siting analysis. Finally, grid reliability of the local distribution network was also considered.

Each of the selected markets are discussed in detail from the grid and energy perspective below.

4.1.1 Los Angeles, CA

The electrical infrastructure in Los Angeles includes both an investor owned utility (IOU) and municipality. The IOU in Los Angeles is Southern California Edison (SCE) and the municipality is Los Angeles Department of Water and Power (LADWP).

The map below, in Figure 11, shows the territory of utilities serving the Los Angeles region.[13] The LADWP service territory is highlighted in light purple and the SCE service territory is the surrounding area shown in yellow. Outside of the Los Angeles city limits, several additional local electric companies and municipalities serve neighboring cities, including Burbank, Anaheim and Riverside. Though these utilities are not explicitly addressed within this study, it is worth noting that a regional expansion of the eVTOL network would require familiarity with the load expansion process, electricity rates and incentive structures offered by the utility in each expanded location.

Figure 11 Territory of Utilities Serving Los Angeles

SCE has a large physical footprint and serves 14 million people throughout the wider Southern California region. SCE has more than 105,000 miles of distribution lines, 1.4 million power poles and more than 725,000 transformers across its service territory.[14] To accommodate load growth, SCE develops transmission and distribution plans every year describing projects required for the expansion of the electric grid over the next 10 years. Recently, SCE has focused on modernizing the distribution planning process, partially through regulatory proceedings mandated by the California Public Utilities Commission (CPUC).[15] As part of this process, electric vehicle adoption is forecasted and included in infrastructure expansion planning to accommodate anticipated load growth.

Furthermore, SCE encourages the use of electric vehicles by introducing various types of electric vehicle rebates, tariffs and electric vehicle plans. The TOU plans and tier (i.e. different rates for different customers based on usage) use plans make using energy efficient and saves the customers' money. SCE has also proposed new electric vehicle rates, which consist of a 5-year introductory period with no demand charges followed by a 5-year phase-in of demand charges.[16]

LADWP is the largest municipal electric utility in the United States, serving approximately 1.5 million electric service connections in Los Angeles county. LADWP has more than 9,000 miles of

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[13] http://www.socalev.org/aboutus/territories.html
[14] https://www.insideedison.com/stories/sce-proposes-investments-to-increase-grid-safety-reliability-and-efficiency
[15] https://www.edison.com/content/dam/eix/documents/newsroom/news-releases/A15-07-XXX_DRP_Application_SCE_Application_and_Distribution_Resources_Plan_and_Appendices_A-J.pdf
[16] https://www.sce.com/NR/sc3/tm2/pdf/3853-E.pdf

distribution lines, 300,000 distribution poles and 125,000 transformers in its territory. LADWP releases an annual Power Infrastructure Plan, which evaluates and prioritizes maintenance and replacement of infrastructure as part of the 5-year capital planning process. Since 2007, LADWP has launched a targeted Power Reliability Program focused on replacing overloaded and aged distribution equipment, which resulted in a 20 percent reduction in outages. Looking forward, LADWP has a long-term goal of replacing 4,000 poles, 10,000 cross arms and 800 transformers annually by 2020.[17]

LADWP offers commercial customers rebates to help deploy EV charging infrastructure at businesses, including workplaces, multi-unit dwellings and public parking lots. The city has a 5-year plan which targets up to 145,000 electric vehicles in the city with up to 10,000 commercial EV chargers by 2021. Innovative solutions are being explored, including direct LADWP install and charger ownership programs as well as simplified EV metering.[18]

Generally, Los Angeles faces the same challenges as the rest of the country with significant aging distribution infrastructure that could result in increased investment required to accommodate future large vertiport loads. This may be further compounded as Los Angeles county continues to lead the country in total number of electric vehicles and has seen similar rapid growth in rooftop and distributed solar photovoltaic (PV) installations. In response to this outlook, increased distribution spending for this region has resulted in year-over-year growth in the annual number of pole and transformer replacements over the past decade. Similarly, grid modernization roadmaps and advanced distribution planning processes are evolving to address vehicle electrification, which may in turn streamline the planning and integration of this load into the electric system in the future.

[17] https://s3-us-west-2.amazonaws.com/ladwp-jtti/wp-content/uploads/sites/3/2018/07/11111628/2018-Power-Infrastructure-Plan1.pdf
[18] http://cmua.org/wpcmua/wp-content/uploads/2018/05/3_Designing-Competitive-Electric-Vehicle-Rates-George-Chen-LADWP.pdf

4.1.2 Houston, TX

The IOU in Houston is CenterPoint Energy – who owns, maintains and operates the distribution infrastructure. CenterPoint Energy covers a 5,000-square-mile electric service territory and serves 2.5 million customers in the Houston metropolitan area. The map below, in Figure 12, shows the various utility territories serving the Texas/Houston region.[19] The CenterPoint Energy service territory is shown in yellow.

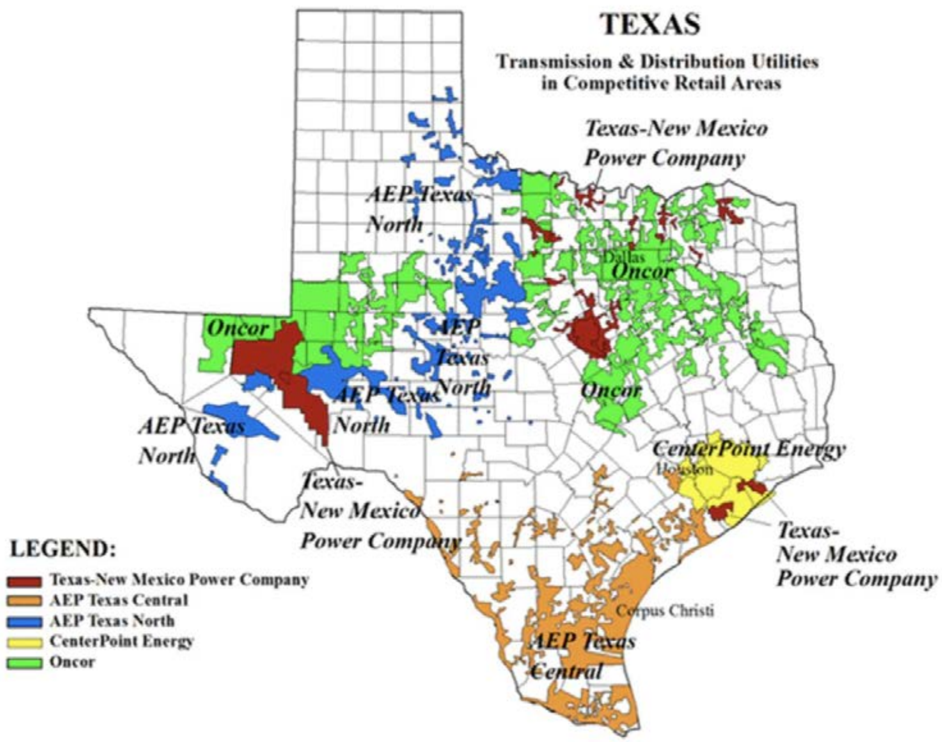

Figure 12 Utility Territories Texas/Houston Region

Houston has a deregulated market where some of the energy suppliers are as follows: First Choice Power, Direct Energy, Txu Energy, TriEagle Energy, Frontier Utilities, Spark Energy. CenterPoint Energy serves as the local distribution company to provide the power delivery service, but the customer has the option of working with any of these energy suppliers and select the one that provides the best rates and contract terms.

Houston is one of the most populous cities in the United States, with many vehicles and large number of commuters driving to work. Houston has more commuting vehicles per worker than New York or Chicago. As one of the largest urban areas, Houston faces congested road conditions. The 2010 Urban Mobility Report rated the Houston area as 4th among the 15 largest United States cities in terms of travel auto commuter delay, and 2nd for excess fuel use by auto commuters as a result of congestion. [20] In addition to these statistics, other important factors that are transforming

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[19] http://www.puc.texas.gov/industry/maps/maps/tdumap.pdf
[20] https://www.houstontx.gov/fleet/ev/longrangeevplan.pdf

the vehicle landscape and resulting in potential electric vehicle growth in Houston are air quality issues and vehicle market size.

A recent, tremendous industrial growth in Houston had led to an increased load growth and this is a forward-looking trend. This load growth has encouraged capital investment in project initiatives to improve reliability and resiliency of the electric grid and technology advancement. In a study conducted by ERCOT (Electric Reliability Council of Texas) in 2014, it was determined that there will be a need for additional electricity import capacity into the Houston region by 2018.[21] As a response to the ERCOT studies, the Houston Import Project was launched – a $590 million project, which involved the construction of a double circuit 345 kV 130-mile transmission line. CenterPoint Energy recently completed their part of this project, called the Brazos Valley Connection: the construction of a 345 kV 60-mile transmission line, which is the southern portion of the Houston Import Project.

eVTOL mobility vertiports impose large loads on the electric grid and further investment will be required to accommodate such loads onto the grid. Utilities in Houston are on the right path with projects as aforementioned that focus on grid infrastructure upgrade and increased electrical capacity planning. Additionally, grid modernization roadmaps and advanced distribution planning processes are evolving to address vehicle Electrification which may in turn streamline the planning and integration of this load into the electric system in the future.

4.1.3 Baltimore, Maryland / Washington DC

The IOUs in Baltimore are Baltimore Gas and Electric Company (BGE) and Potomac Electric Power Company (PEPCO). The map below in Figure 13 shows utility territories for the Maryland/Baltimore region[22]. The regions in green and red show the Baltimore Gas and Electric (BGE) and Potomac Electric Power Company (PEPCO) utility territory respectively. The map also shows surrounding cities and their respective utility territories. Although not covered as part of this study, it is worth noting that a regional expansion of the eVTOL network would require familiarity with the load expansion process, electricity rates and incentive structures offered by the utility in each expanded location.

[22] http://bettercostcontrol.com/wp-content/uploads/2012/04/Maryland-Electric-Distribution.jpg

Since Baltimore has a deregulated market, the customer can choose from a list of independent energy suppliers, including North American Power, Crius Energy and Clearview Energy.

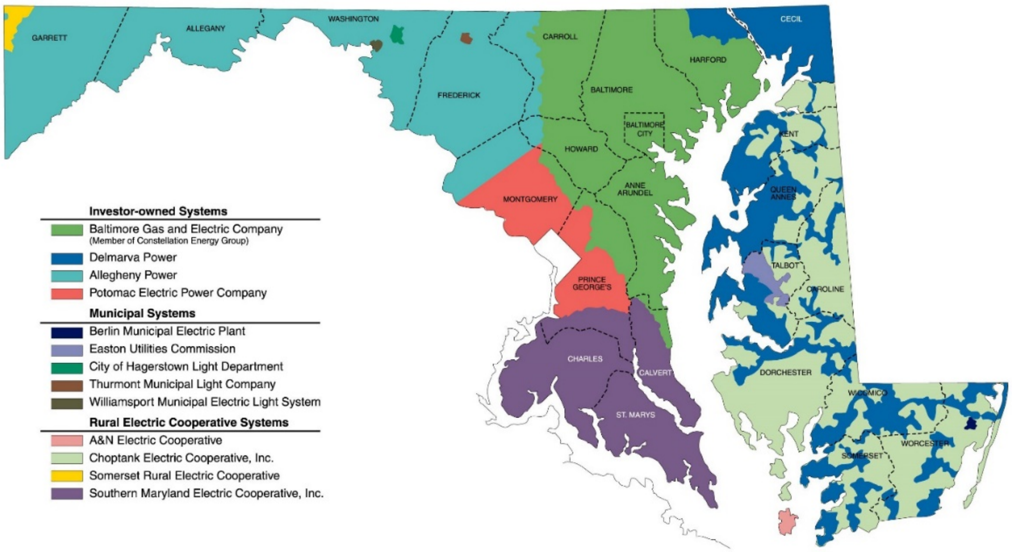

Figure 13 Utility Territories for Maryland/Baltimore Region

Baltimore Gas and Electric (BGE) is Maryland's largest natural gas and electric utility, delivering power to more than 1.25 million electric customers. It has around 243 substations, more than 25,000 circuit miles in distribution power lines and almost 1,300 circuit miles in transmission lines.

As part of the state's ambition to increase its electric vehicle usage, the Maryland Public Services has initiatives set in place with a $104 million program that bring together utilities with the vision of modernization of the grid and necessary infrastructure for the Electrification of mobilization. BGE will spend more than $48 million on its share of the network. Of that, $17 million will be spent on 1,000 public, BGE-owned stations; $7.5 million will subsidize the installation of 15,000 residential charging stations; and $10.8 million will subsidize 2,125 workplace and multi-unit dwelling stations. The utility will spend another $7.1 million on outreach, deployment and other costs. Given the progressive approach to support elective vehicles, Maryland may be open to supporting installation of eVTOL charging infrastructure, if it is shown to be beneficial to their ratepayers.

Furthermore, BGE encourages the use of electric vehicles by introducing various types of electric vehicle rebates, tariffs and electric vehicle plans. The TOU plans and tier use plans make using energy efficient and save the customers money.

PEPCO has a service territory around 640 square miles and serve about 842,000 customers in Maryland and the District of Columbia. There are about 134 substations in its territory.

As a part of Maryland's electric vehicle expansion initiative, PEPCO is seeking approval for a Transportation Electrification Program that is designed to achieve the District of Columbia's goal of becoming carbon neutral and climate resilient by 2050. The proposed program focuses on expanding transportation Electrification in the city. The offerings include various levels of cost sharing between ratepayers, EV owners, the owner of EV charging stations, as well as a variety of different business models. If approved, the next cost to ratepayers will be approximately $9.9 million.

Baltimore/DC faces many of the same challenges as the rest of the country with significant aging distribution infrastructure that could result in increased investment required to accommodate future large vertiport load. However, utilities have current and future projects which address replacement of aging infrastructure, upgrading priority feeders, installing advanced technology and preparing for overall power system growth. It is worthwhile to note that, with such forward-looking projects planned, the integration of electric vehicles to the grid will be capable in the future.

4.1.4 Grid Reliability Metrics, System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI)

With the addition of vertiports to the electric grid, it is critical to measure the performance of the electrical distribution from the utility. A reliable grid means lesser electricity outages that could directly impact the fuel source of eVTOL vehicles and thus the operational capability of the eVTOL network. The reliability of the grid is measured is terms of the SAIDI and SAIFI metrics – detailed below.

SAIDI and SAIFI were created by the Institute of Electrical and Electronics Engineers (IEEE), and utilities use these indicators to measure the reliability of their electrical distribution. SAIDI and SAIFI are important metrics for calculating the reliability and resiliency of the grid because they provide the array of interruptions and the frequency of theses interruptions experienced by the customers of the electric grid. SAIDI and SAIFI give data about the duration and frequency of the interruptions respectively.

- **SAIDI** (System Average Interruption Duration Index) is calculated as the total number of customer outage minutes per year divided by total number of customers served. The units of measurement are in minutes/year.
- **SAIFI** (System Average Interruption Frequency Index) is calculated as the total number of customer interruptions divided by total number of customers served. The units of measurement are in occurrences/year.

Sometimes, utilities report these numbers with and without major event days (MED) and loss of supply (LoS). The inclusion of MED and LoS do not represent the true state of the system. MED is defined by IEEE as “events that are beyond the design and/or operational limits of a utility”. These indicators are involuntary events and affect the distribution system adversely.

The table below demonstrates the SAIDI/SAIFI with and without MED and SAIDI /SAIFI with MED minus LoS. Houston has a greater index than Los Angeles and Baltimore/DC. The difference in the numbers between SAIDI with MED and SAIDI with MED minus LoS is minimal. IOUs and municipalities of the same state have their own SAIDI metrics.

Table 4 Reliability Metrics

Utility Characteristics				IEEE Standard					
Data Year	Area	Utility Name	Ownership	SAIDI With MED	SAIDI Without MED	SAIDI With MED Minus LOS	SAIFI With MED	SAIFI Without MED	SAIFI With MED Minus LOS
2017	Baltimore/DC	The Potomac Edison Co (MD)	Investor Owned	131.957	131.957	121.467	0.980	0.980	0.858
2017	Baltimore/DC	The Potomac Edison Co (WV)	Investor Owned	158.928	138.934	147.600	1.049	1.010	0.939
2017	Baltimore/DC	Baltimore Gas & Electric Co	Investor Owned	96.000	74.000	96.000	0.830	0.720	0.820
2017	Houston	CenterPoint Energy	Investor Owned	454.190	130.610	453.490	1.800	1.260	1.800
2017	Los Angeles	Los Angeles Department of Water & Power	Municipal	220.680	120.910	.	1.230	0.970	.
2017	Los Angeles	Southern California Edison Co	Investor Owned	139.728	91.724	128.742	1.192	0.870	0.985

MED- Major Event Days.
MINUS LOS- Minus Loss of Supply.

Overall, the power in the three regions being considered is reliable with outages occurring once a year and lasting for less than 2.5 hours, outside of major events such as hurricanes and historic storms. Some eVTOL owners and operators may want to have higher service availability, which would be achieved by installation of onsite power generation, storage and/or investing in priority utility service and/or redundant feeders. Traditionally, diesel generators have been used as the source of backup power but energy storage, charged from onsite solar generation or the grid also be implemented with the added benefits of providing value during on normal operating conditions.

4.2 MARKETS STUDY, AIR SPACE CHARACTERISTICS

For the analysis in this section, Black & Veatch used the airport information that is published by United States Department of Transportation, Federal Aviation Administration-Aeronautical Information Services. In this dataset, an airport is defined as an area of land or water intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft / helicopters. The airport information is published every week and the effective date for the dataset used in this analysis is May 24, 2018 to July 19, 2018.

The categorization of the helipad data per service location (hospital, police station etc.) was done by Black & Veatch based on the name of the airport.

Black & Veatch defined the area of interest to be within a 100-mile radius from the city centers for Los Angeles, Washington D.C. and Houston.

4.2.1 Los Angeles

There are 89 aerodromes and 218 helipads that are operational within a 100-mile radius of Los Angeles Financial District. Fifty-five (55) of the helipads are on hospital/medical centers. Fourteen (14) are on police/sheriff facilities.

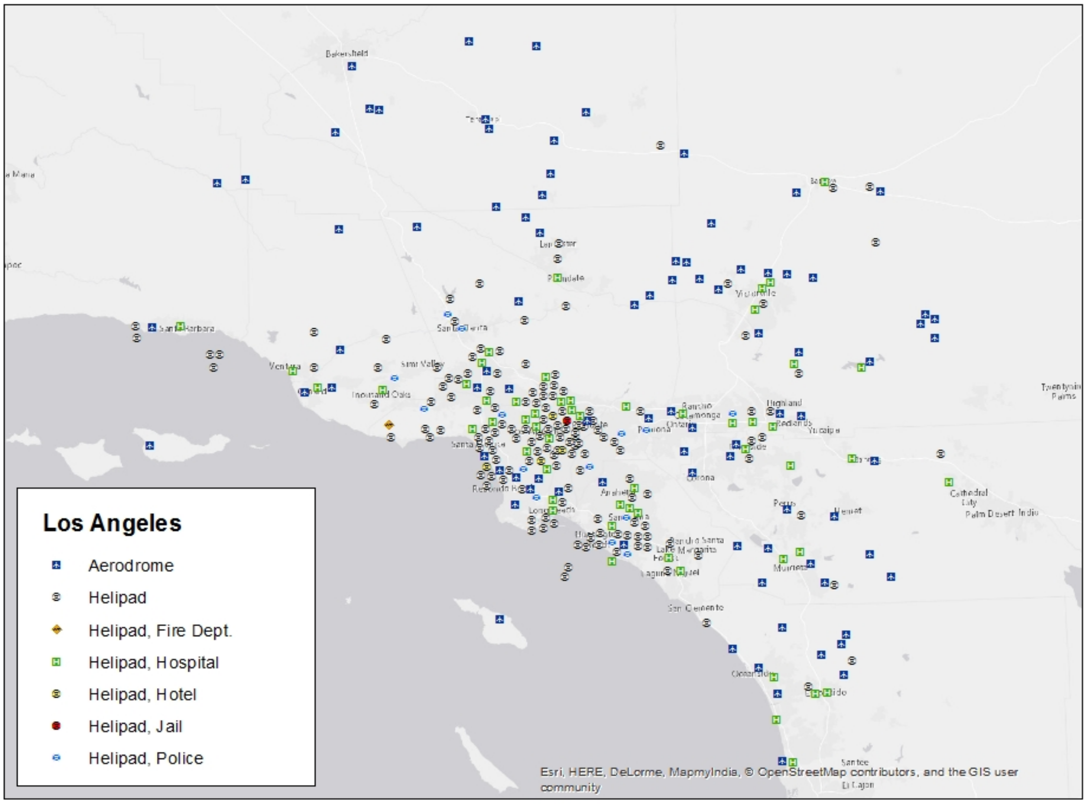

Figure 14: Aerodrome and Helipad locations around Los Angeles

4.2.2 Houston

There are 189 aerodromes and 195 helipads that are operational within a 100-mile radius of Houston's city center. Forty-three (43) of the helipads are on hospital/medical centers. Seven (7) are on police/sheriff facilities.

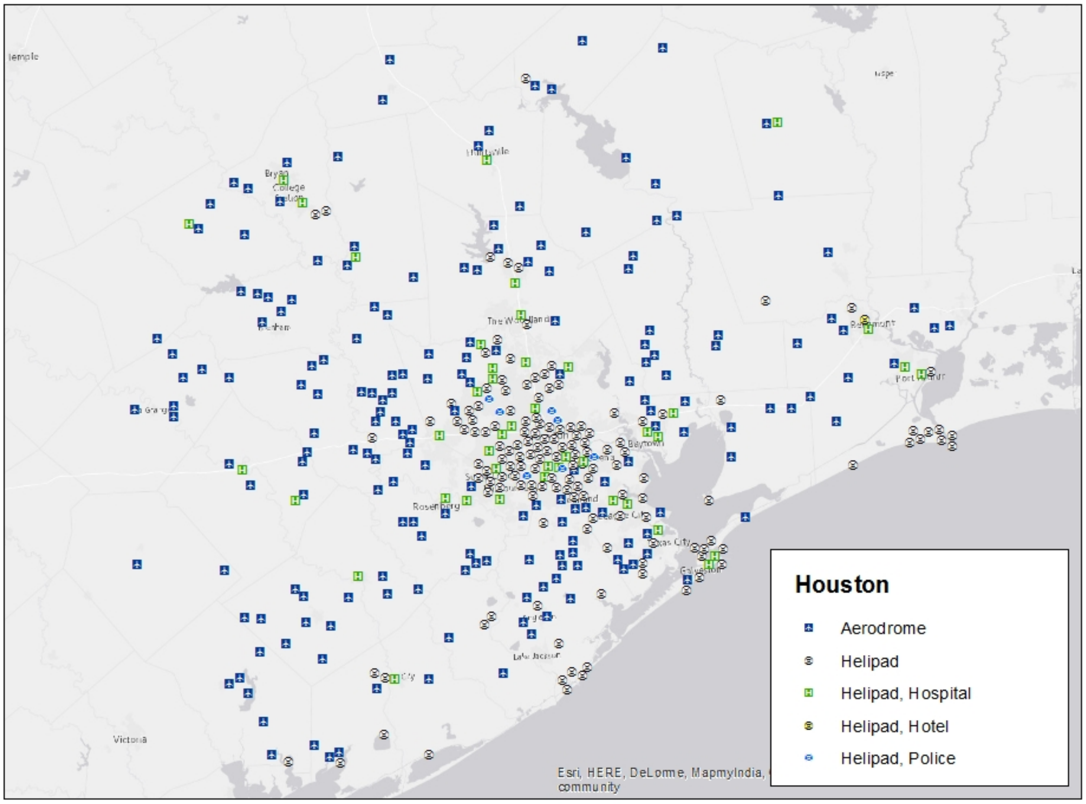

Figure 15: Aerodrome and Helipad locations around Houston

Table 3 in the next section summarizes the number of airports within an approximate 30-mile radius of the city centers of each of the three test regions. These airports have controlled airspace and the potential for high density traffic at many or all times of operation. As the siting and operational routes are developed for each city, it will be important to consider the approach and departure paths of these locations. It will also be important to consider route detours to avoid the approach and departure paths, as well as siting vertiports away from these areas, if possible.

The Federal Aviation Administration (FAA) has established airport categories to better identify an airports purpose and connectivity. Regional, local and basic airports support regional economies and have varying links and support to statewide and intrastate markets, while also being able to provide emergency support. National airports provide access to national and international markets but will have major impacts on airspace that can be utilized by eVTOLs because of the potential for high density air traffic. The Washington D.C./Baltimore region has numerous military/restricted air space that will pose additional challenges that should be considered when selecting potential eVTOL sites.

4.2.3 Baltimore

There are 334 aerodromes and 173 helipads that are operational within a 100-mile radius of Washington D.C. Sixty-six (66) of the helipads are on hospital/medical centers. Seven (7) are on Police/Sheriff facilities.

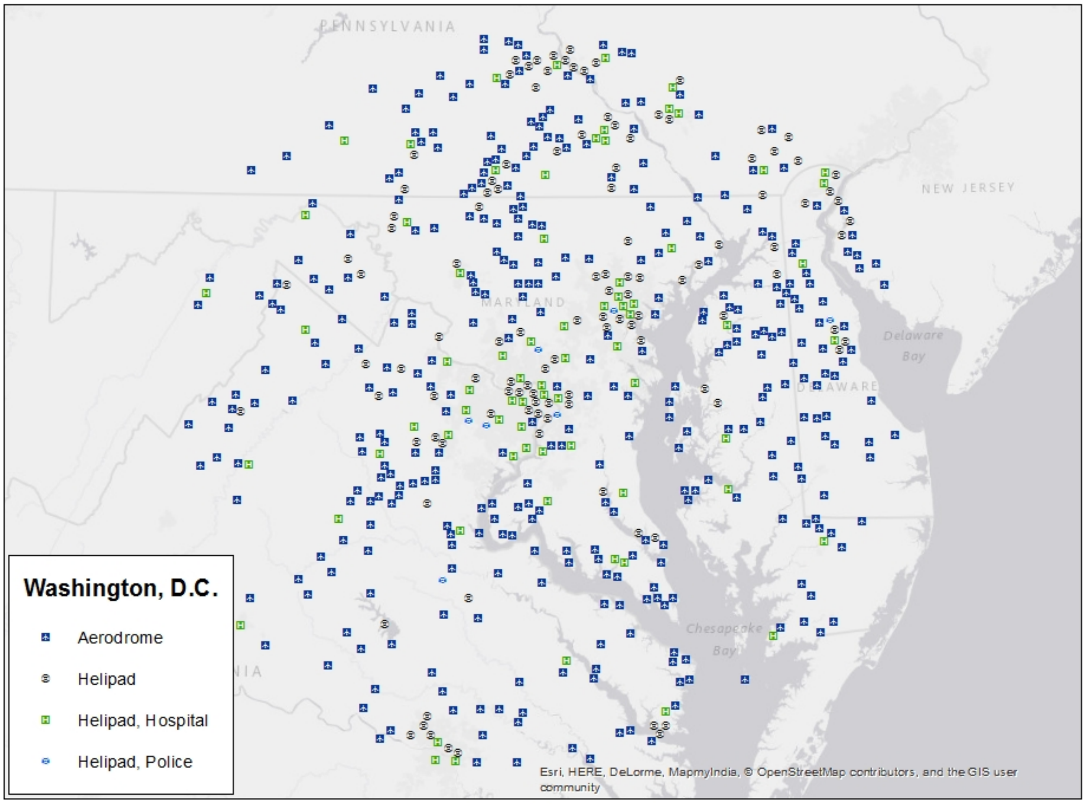

Figure 16: Aerodrome and Helipad locations around Baltimore/Washington D.C.

Table 5 Number of Airports by Region

AIRPORT CATEGORY	LOS ANGELES	HOUSTON	DC/BALTIMORE
Regional/Local/Basic	15	2	26
National	2	2	3

- Los Angeles
  - John Wayne Airport-Orange Country Airport
  - Los Angeles International Airport
- Houston
  - William P Hobby Airport
  - George Bush Intercontinental Houston Airport
- Washington D.C./Baltimore
  - Baltimore/Washington International Thurgood Marshall Airport
  - Ronald Reagan Washington National Airport
  - Dulles International Airport

5.0 Development of Assumptions and Ranges of Assumptions

5.1 ASSUMPTIONS TO GENERALIZE THE STUDY FINDINGS

Potential site locations were identified for this study including site locations at grade, multi-story structures, and high-rise structures all within metropolitan areas. Each potential site location caters to unique layouts for size of vertiports, number of vehicles capable of being charged, and power requirements.

At-grade site locations have potential for greater square footage that can be used when developing the vertiport to accommodate multiple chargers capable of charging a greater number of vehicles at a given time. Greater square footage could also provide the area needed for vehicle taxiing, as well as area needed for additional facilities that support the day-to-day operations of the vertiport (i.e. communication/connectivity center, weather, IT, patron accommodations, etc.). Regional/municipal airports have been identified as existing at-grade potential site locations that may have existing infrastructure to support future vertiports. At-grade vertiports could hold up to eighteen chargers, with multiple vertiports depending upon available square footage. Square footage needed for necessary electric charging equipment is discussed in later sections.

With multi-story and high-rise structures, the size of the vertiport and number of chargers is more restricted when compared to at-grade site locations. Existing parking structures have potential to support multiple vertiports and charging equipment, with the typical open, top floor square footage of a parking structure. Typical parking structures are located in areas where there is high urban density and limited space for automobiles, making them attractive locations for eVTOL vertiports. These locations would be appealing to commuters in efforts to reduce travel time and reducing traffic congestion within the adjacent areas. High-rise structures would provide the most limited space for vertiports, limiting the number of vehicles and chargers but may provide a desired location for metropolitan business districts. High-rise vertiports may compete with existing helicopter traffic, making agreements and coordination a necessary part of high-rise vertiports. While existing helipads may provide helipads meeting FAA regulations, all existing structures would need to undergo structural analysis to ensure additional loading (i.e. vehicles, patrons, additional equipment, etc.) can be supported.

The number of chargers and vertiports would be limited to available area; however, it is safe to assume that for a typical high-rise structure a maximum of two chargers and one vertiport could be supported, pending available structural capacity.

5.2 RANGES OF ASSUMPTIONS

5.2.1 General Design Parameters

Design vehicle dimensions developed on common existing helicopter model dimensions, while maximum take-off weight is in line with the conceptual "lift+cruise electric" vehicle, as shown in the list below. The ability of the design vehicle being capable of taxiing is crucial to site layout and design where charging areas are separate from take-off and landing areas. Vehicle assumptions influenced by FAA regulations on helipad minimum required dimensions established for vehicle operation and safety.

- Design vehicle
  - Height range: 10.5 - 14.0 ft. (3.2 m)
  - Length of helicopter: 43.0 - 63.0 ft. (13.1 - 19.2 m)
  - Rotor diameter: 50.0 ft. (15.24 m) minimum
  - Vehicle able to be taxied
  - Maximum take-off weight: 8,210 lb. (3,724 kg)

5.2.2 At-Grade Take-Off and Landing Areas

At-grade take-off and landing areas (i.e. regional airports) pad mounted equipment would be straight forward with relatively minimal structural analysis compared to installation on an existing structure. Taking advantage of existing infrastructure such as helipads and airspace corridors would help address construction and permitting considerations.

The assumptions listed below are considered when analyzing a potential at-grade site location.

- Property Requirements
  - Zoning and compatibility land use
    - Zoning to limit building/object height
    - Zoning for compatible land use
    - Air space and property easement
  - Clear of objects that may create turbulence (i.e. building, trees, terrain irregularities, etc.) within final approach and take-off area.
  - Approach/departure paths aligned with predominant winds
  - Minimal interference from existing above/below ground utilities
  - Minimum width, length, and diameter of the final approach and take-off area to be at least 1.5 times the overall length of the design helicopter.
  - Adequate lighting (i.e. flood lighting, flight path lights, landing direction lights, taxiway route lighting, etc.)
  - Minimize impact to manned and other commercial aircraft traffic.
  - Electrical demand must account for site lighting in accordance with FAA requirements.
- Pavement
  - Paved or aggregate surface

    - Concrete is preferable at ground level facilities as asphalt may rut over time
    - Adequate sub-grade
  - Surface designed for dynamic loading created by helicopter
- Taxiing and parking design considerations dictated by width of design vehicle
- Type of Trips: commutes
  - Volume of trips dependent on-site specifics (i.e. number of chargers, number of vertiports, etc.)
  - No charging time assumed
- Minimum level of office space, network equipment, weather tracking, radio communications equipment, and some minimal restroom facilities, and payment, staging queuing, etc., existing or developed.

Figure 17 below shows a potential site layout at the Long Beach Airport. The site contains one vertiport with two charging pods capable of supplying 600kW to six different charging stations simultaneously. Vehicles would land in the take-off and landing area and, if needed, taxi to an available charging station. Once charged to the desired power level, and with patrons aboard, the vehicle can taxi to the vertiport for next available take-off. Utilizing equipment capable of supplying 600kW (*see Section 5.1*) now would prevent any upgrades in the future when more advanced vehicle models are capable of handle the available power supply. The size of the vertiport takes into account FAA standards for touch down and lift off, as well as final approach and takeoff dimensions for operation and safety. Charging stations sized for 50 ft. rotor diameter (an FAA minimum). Analyzing the Long Beach Airport reveals ample square footage that could be catered to house different configurations that meet the needs of the property and eVTOL objectives, thus making at-grade site locations advantageous for larger eVTOL site locations.

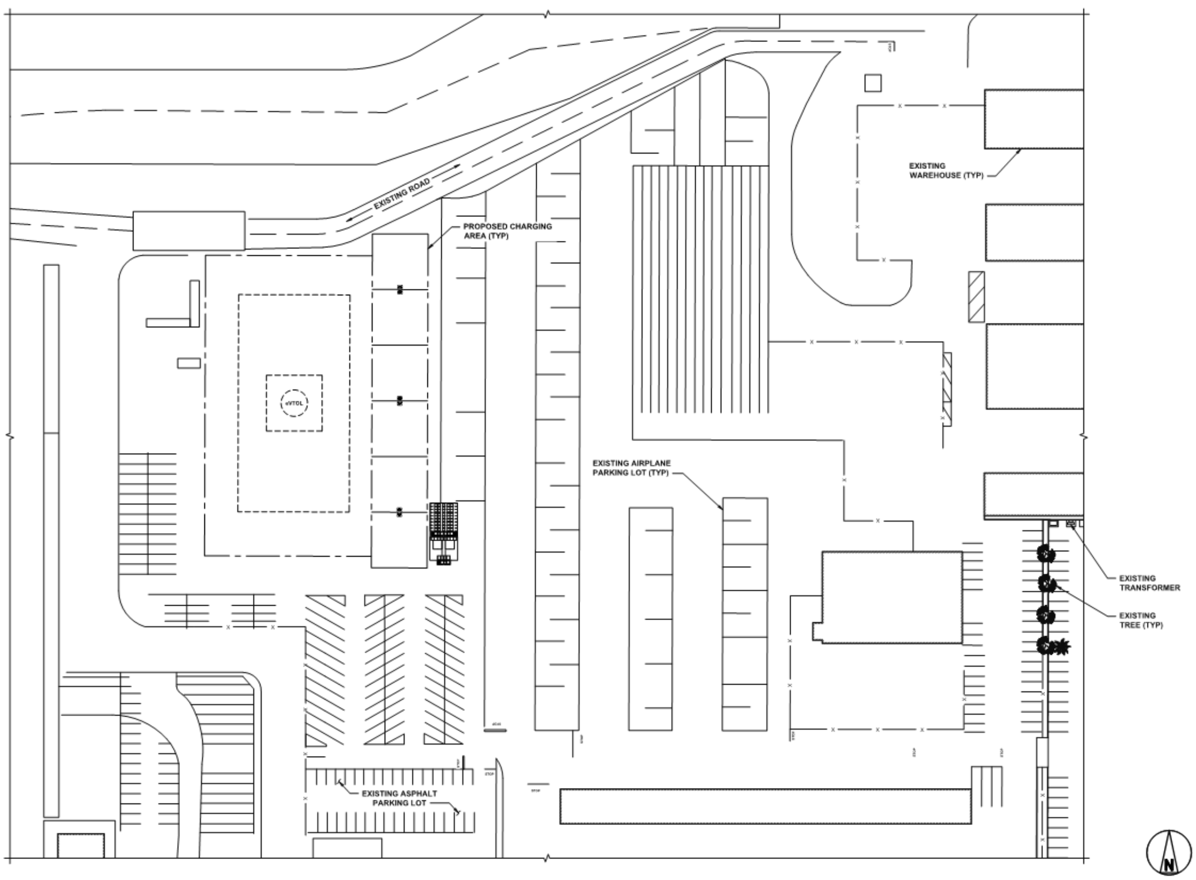

Figure 17 Example layout of (2) pods at Long Beach Airport

5.2.3 Rooftop and Other Elevated Take-Off and Landing Areas

Elevated structures are appealing locations for potential eVTOL site locations. Parking structures provide potential square footage where eVTOL vertiports could be added, as well as charging equipment and supporting infrastructure. High-rise buildings with existing helipads have high potential for the ability to support eVTOL vertiports, as much of the necessary existing infrastructure is already in place. While these are attractive locations, extensive analysis is needed to ensure the additional loading and potential retrofitting of existing infrastructure is possible. The list below identifies assumptions in order to reduce complications for potential elevated take-off and landing areas.

5.2.3.1 Assumptions:

- Property requirements
  - Zoning and compatibility land use
    - Zoning to limit building/object height

        - Zoning for compatible land use
        - Air space and property easement
    - Existing structural drawings provided to confirm design considerations
    - Adequate space for touchdown and lift-off area, taxiing
    - Space considerations for patrons (lobby, queuing, network equipment, weather tracking, radio communications equipment, etc.)
    - Take-off and landing area free of obstacles that may affect safety or eVTOL operation
    - Surface designed for dynamic loading
    - Minimum width, length, and diameter of the final approach and take-off area to be at least 1.5 times the overall length of the design helicopter
    - Adequate lighting (i.e. flood lighting, flight path lights, landing direction lights, taxiway route lighting, etc.)
    - Minimize impact to manned and other commercial aircraft traffic
    - Electrical demand must account for site lighting in accordance with FAA requirements.
- Type of Trips: commutes
    - Volume of trips dependent on-site specifics (i.e. number of chargers, number of vertiports, etc.)
- Taxiing and Parking Design Considerations dictated by width of design vehicle
- Type of Trips: commutes

6.0 Analysis to Determine Typical Infrastructure Upgrade Requirements for eVTOL

6.1 ELECTRIC CHARGER REQUIREMENTS ANALYSIS

600kW class chargers are utilized for infrastructure estimation purposes of this study. This follows an industry wide investigative effort to support future electric vehicle battery characteristics and technologies. While eVTOLs currently in development are estimated to be able to charge at a maximum of 350kW, choosing to utilize 600kW chargers will futureproof the design of the infrastructure required. Renovation of a site to increase its individual charger capacity would effectively require full-site demolition and reconstruction.

Charging systems up to 500kW can utilize a common liquid-cooled *CCS Type 1* connector commonly utilized in the industry for high power DC charging. Systems above 500kW typically utilize a connection method from either the SAE J3105 standard or another listed proprietary connector. One would imagine a new connector standard might be developed to better suit the eVTOL industry and would match the power levels required by the crafts. The chargers selected must have a Short Circuit Current Rating (SCCR) of 50kA higher to be suitable for use in the pods detailed in the below infrastructure analysis. The 600kW charger used in this study is approximately 12,000 lbs. and can be configured to require a pad space of either 13’ x 8’ or 7’ x 16’ including NEC required clearances. Sites with six 600kW chargers containing two pods can have equipment arranged into an area occupying approximately 1,400 sq. ft., including NEC required clearances. See figure 18.

6.2 TYPICAL BUILDING ELECTRICAL INFRASTRUCTURE REQUIREMENT ANALYSIS

6.2.1 Ground Landing Site without charging stations

For a site without any charging ability the following would be installed: waiting area building, fencing and lighting. New landing zone lighting and ground markings will be installed. The existing electrical infrastructure would be used for power to the waiting area and lighting.

The pricing for a three-landing pad site is estimated to be **$350,000.00**, which does not include the charging stations and the major electrical upgrades to support them.

6.2.2 Rooftop Existing Landing Site:

A new medium voltage feeder will be brought to the site by the utility company. The new feeder will be terminated at a transformer provided by the contractor. From the transformer the new electrical feeders will be run underground into the building. Space will be needed for a new switchboard section near the utility feeder entrance. From the new switchboard section electrical feeders will need to be installed to the roof. Since the building will be occupied coordination with the building owner and tenants will be required to determine the conduit pathways. The new conduits will need to have core openings made on each floor and the roof. Since the building has an existing pad structural reinforcement for the eVTOL the assumption is that the roof will not need reinforcement. Space will be needed for the charging system; possible steel reinforcement will need to be determined. They can be mounted on the floor below if space is available, assuming that with the size of the units building elevator access or other access is adequate to allow transit.

The following are the details involved in the installation of a single charger on a five-story building. We have estimated this scope of work at **$883,000.00**. Estimated details are provided in the Appendix.

The anticipated timeframe for implementation; including engineering, permits, construction and commissioning is 9 to 12 months.

- (1) 600kW / 480V / 800A eVTOL charging station. Assuming there is an existing landing pad we would only have room for one vehicle.
- Bring new 1200A service from a new utility feed to a metering and 1200A, 80 percent rated main breaker service switchboard section.
  - Conductors and conduits are usually specified by the Utility. Often the client is only responsible for conduit installation, and conductors are owned and installed by the utility, e.g., PG&E.
  - Metering and 1200A main service disconnect will most likely need to be placed before, or shortly after entering building.
- Primary Power will be brought to the transformer by the utility company typically for no fee up front.
- Feeder conductors and conduits will be run horizontally across the lobby or first floor from 1200A main service breaker to an electrical or mechanical room that is vertically stacked and installed to the roof. Fire proofing and core drilling as needed.
- Penetrate the roof and provide a water tight seal with the conduits.
- Set new 1200A switchboard on roof of building
  - (1) 100 percent rated 1200A main breaker
  - (1) 80 percent rated 1000A 3P branch breaker

  - (1) 80 percent rated 125A 3P branch breaker, feeding internal transformer
  - (1) 75kVA 480-120/208V 3P step down transformer, internal
  - (1) 225A 120/208V panelboard
- Set the new charger on the roof with new roof steel, each charger is about 12,000 lbs. Penetrate roof supports to the floor beams below. Rigging with a crane.
- Assume that all aviation lighting, safety nets, signage, and beacons are existing.

6.2.3 Ground Landing Site

A new medium voltage feeder will be brought to the site by the utility company. The new feeder will be terminated at a transformer provided by the contractor. New ground infrastructure will be installed including concrete pads, charging stations, switchboard, underground feeders to each charging station, waiting area building, fencing and lighting. New landing zone lighting and ground markings will be installed.

The pricing for a three-landing pad site is estimated to be **$2,630,000.00**, that includes the charging stations. The pricing shown in the appendix has been generated in a unit price format based on a three-charging stations minimum. For budgetary purposes, pricing can be multiplied out into any number of charging stations needed, subject to available power.

The anticipated timeframe for implementation; including engineering, permits, construction and commissioning is nine to twelve months.

- New concrete pad 500 feet long by 170 feet wide.
- Use a modular approach of **(1)** pod with **(3)** 600kW eVTOL vehicle chargers.
  - See general pod description below.
- Install new aviation lighting, signage, safety fencing, beacons and weather guide.
- Install a small prefabricated waiting area with lighting, cooling and heating.

6.2.4 Existing Parking Garage

A new medium voltage feeder will be brought to the site by the utility company. The new feeder will be terminated at a transformer provided by the contractor. From the transformer the new electrical feeders will be run underground into the building. Space will be needed for a new switchboard section near the utility feeder entrance. From the new switchboard section electrical feeders will need to be installed to the roof. Since the garage will be occupied coordination with the building owner will be required to determine the conduit pathways. The new conduits will need to have core openings made on each floor. We have assumed that the rooftop structural integrity of the garage will be able to accommodate the eVTOL vehicles. Space will be needed for the charging system; possible steel reinforcement will need to be determined. A waiting area will need to be constructed, new landing lighting will be installed, and barriers installed to prevent any car vehicle traffic. New landing zone lighting and ground markings will be installed.

The pricing for a three-landing pod site is estimated to be **$1,876,000.00**, that includes the charging stations. The pricing shown in the appendix has been generated in a unit price format based on a three-pod minimum, and a five-story building. The pricing can be multiplied out into any number of pods needed, subject to available power.

The anticipated timeframe for implementation; including engineering, permits, construction and commissioning is six to twelve months.

- Assume that the existing structure is adequate
- Use a modular approach of **(1)** pod with **(3)** 600kW eVTOL vehicle chargers.
  - See general pod description below
- Install new aviation lighting, signage, safety fencing, beacons and weather guide
- Install a small prefabricated waiting area with lighting, cooling and heating

6.2.5 Ground Landing Site Central Charging Station Only

A new medium voltage feeder will be brought to the site by the utility company. The new feeder will be terminated at a transformer provided by the contractor. New ground infrastructure will be installed including concrete pads, charging stations, switchgear, underground feeders to each charging station, fencing and lighting. New landing zone lighting and ground markings will be installed.

The pricing for a three-landing pad site is estimated to be **$2,560,000.00**, that includes three charging stations.

The anticipated timeframe for implementation; including engineering, permits, construction and commissioning is nine to twelve months.

- Assume that the existing structure is adequate
- Use a modular approach of **(1)** pod with **(3)** 600kW eVTOL vehicle chargers.
  - See general pod description below
- Install new aviation lighting, signage, safety fencing, beacons and weather guide
- Install a small prefabricated waiting area with lighting, cooling and heating

6.2.6 General Pod Description and Scaling

Below is a list and set of conditional statements to determine the required electrical infrastructure equipment for a site, based on the number of pods to be installed. What a pod consists of varies depending on the number of pods to be installed. The list is hierarchically structured.

- (1) pod is defined to be as follows:
  - (1) 2MVA transformer
    - **If a single pod is to be installed:** Utility typically sizes and provides the transformer
  - Trench the new conduit from transformer(s) to the 2500A switchboard.
    - 2500A of service laterals between 2MVA transformer and 2500A switchboard:
      - **If a single pod is to be installed:** Service conductors and conduits usually specified by the Utility.
      - Often the client is responsible for conduit installation, and conductors are owned and installed by the utility. e.g., PG&E
    - Some jurisdictions will require copper conductors.
  - Set new outdoor 2500 amp 480/277V 3P 4W NEMA 3R switchboard, of which contains:
    - **If a single pod is to be installed:** (1) 2500A specific utility compliant metering equipment
    - (1) 100 percent rated 2500A 3P main breaker with ground fault and maintenance switch
    - (3) 100 percent rated 800A 3P branch breakers
    - (1) 80 percent rated 125A 3P branch breaker, feeding internal transformer
    - (1) 75kVA 480-120/208V 3P step down transformer, internal
    - (1) 225A 120/208V panelboard section, internal

- Set the new 600kW chargers into place
  - Power from 2500A switchboard to each 600kW charger:
    - Some jurisdictions will require copper conductors.

- **If more than (1) pod is to be installed per site:** Medium voltage equipment will most likely be required as the utility is not likely to comply with adding additional 480V services using multiple meters
  - **(2) to (5) pods** would require the following:
    - (1) 600A 12,470V Switchgear with metering, specific utility design for metering required
    - (1) 600A main breaker, utility specific protection specification may be required
    - If required for utility protection specification: Relaying backup and power in the form of battery bank, charger, and separate enclosure if not internal to switchgear
  - **(6) to (10) pods** would require the following:
    - (1) 1200A 12,470V Switchgear with metering, specific utility design for metering required
    - (1) 1200A Main breaker, specific utility design for protection scheme required
    - (2) 600A circuit breakers
    - If required for utility protection specification: Relaying backup and power in the form of battery bank, charger, and separate enclosure if not internal to switchgear
  - Per 600A breaker, conduit and conductors run from 12,470V switchgear to the first pod's 2MVA transformer, then from that pod's transformer to the next pod's transformer, up to (5) total transformers or pods per 600A breaker.
  - For the 10-charger site a new medium voltage feeder will be brought to the site by the utility company. The new feeder will be terminated at a transformer provided by the utility company. New ground infrastructure will be installed including concrete pads, charging stations, switchboard, underground feeders to each charging station, waiting area building, fencing and lighting. New landing zone lighting and ground markings will be installed.
  - The estimated pricing for a 10 charger sites is **$10,200,000.00**, which includes the charging stations
  - The estimated schedule for implementation; including engineering, permits, construction and commissioning is nine to twelve months

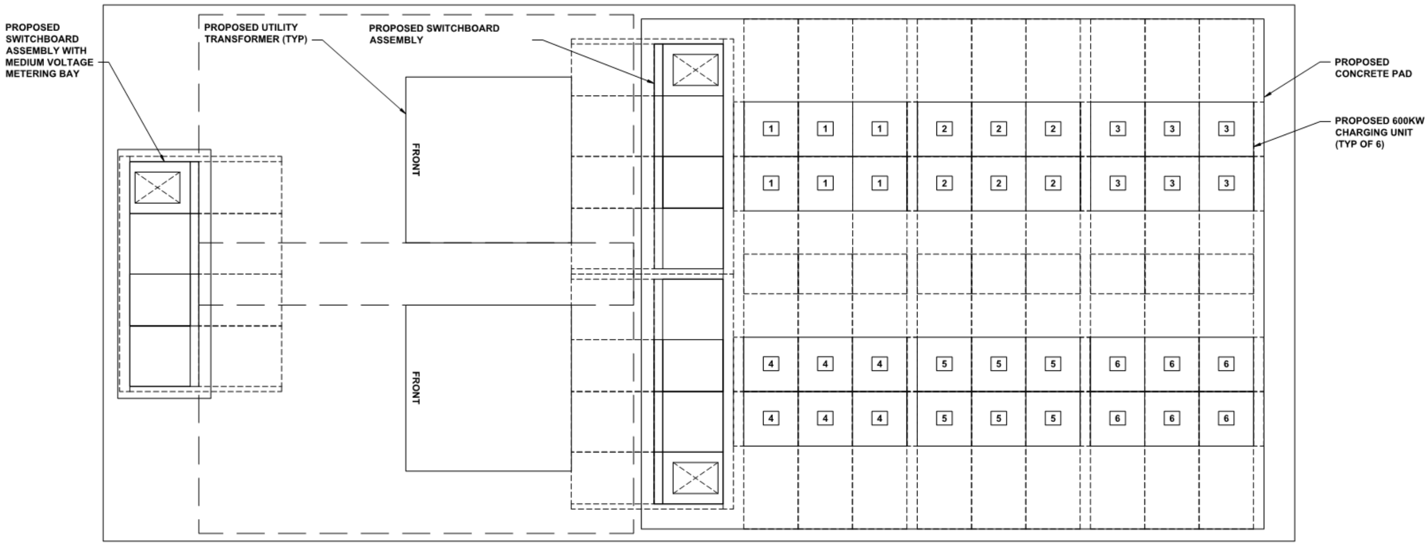

Figure 18 Example (2) pod layout including medium voltage equipment.

6.3 TYPICAL AIRPORT ELECTRICAL INFRASTRUCTURE REQUIREMENT ANALYSIS

For the purposes of this study, a new service is assumed will be provided by the relevant utility. This would most likely circumvent any potential issues related to downtime, maintenance, installation, or any other event that might interfere with the airport's redundancy features and reliability agreements with the utility.

A new medium voltage feeder will be brought to the site by the utility company. The new feeder will be terminated at a transformer provided by the contractor. New ground infrastructure will be installed including concrete pads, charging stations, switchboard, underground feeders to each charging station, waiting area building, fencing and lighting. New landing zone lighting and ground markings will be installed.

The pricing for a 3-landing pod site is estimated to be **$2,630,000.00**, that includes the charging stations. The pricing shown in the appendix has been generated in a unit price format based on a three-pod minimum. The pricing can be multiplied out into any number of pods needed.

The estimated schedule for implementation; including engineering, permits, construction and commissioning is 9 to 12 months.

6.3.1 Ground Landing Site

- New concrete pad 500 feet long by 170 feet wide
- Use a modular approach with **(3)** 600kW eVTOL vehicle chargers per **(1)** pod
  - See general pod description above
- Install new aviation lighting, signage, safety fencing, beacons and weather guide
- Install a small prefabricated waiting area with lighting, cooling and heating

7.0 Evaluation of Utility Grid Infrastructure and Sufficiency

As described in previous sections, depending on the number of chargers and power demand of the infrastructure at various vertiport sites, demand could range from less than 1 MW up to 20 MW.

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. While upgrade requirements of a specific project are highly dependent on existing equipment capacity and load of the connected site, circuits and substation, the following scenarios outline possible experience based on historical observation of possible power delivery upgrades and estimated cost impacts that may occur at various load sizes.

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 will have a clause in the agreement whereby if the revenue is not received within a certain number of years, they will then 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 site, the equipment may be sized to carry three to four times that capacity if it is planned to also serve future load growth or system reliability needs.

Different components of grid infrastructure which may be impacted were identified as a part of this study and have been summarized below. The approximate size at which these impacts may occur are indicated in parenthesis.

Possible grid upgrades for vertiports:

- **Service line extension (up to 1 MW):** Often existing utility supply conductor from the main grid to the utility service transformer at the customer site is sized for maximum service load. As the service transformer size increases there is also a possibility that the supply conductor must be replaced.
- **Conversion to medium voltage service (over 2 MW):** If the load required at a site exceeds standard service transformer and low voltage switchboard ratings 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 the purposes of this study, we assume the service voltage to be 12,470V. Other medium voltage service voltages are used but are not nearly as common.
- **Reconductoring (over 1 MW):** An existing feeder line is replaced with a new feeder either due to higher ampacity requirements or due to existing feeder being worn out due to age.
- **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):** New transformers will be installed, or existing transformers will be replaced to meet the required load growth. Capacity increase refers to installing new transformers or other switchgear in a substation to facilitate the substation capacity increase.

- **New substation (over 20 MW):** To meet increased ampacity and load growth, a new substation would be installed. This would be a last-case scenario, if all other alternatives to increase demand do not work.

There are many factors that may significantly impact the overall cost of the generic upgrades identified above. A summary of the most common location and design specific cost drivers are identified in the following table below:

Table 6 Key Cost Drivers

KEY COST DRIVERS	DESCRIPTION
Rural/urban areas	Rural areas projects cost less than urban and suburban areas due to land availability, limited load growth and construction impact. There can also be major differences in material and labor cost 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 daycares, concerns on appearance, noise or electrical effects can also result in expensive mitigation measures

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. The costs are based on publicly reported project costs.

- Service Line Extension: For a service line extension, each utility has a different price, but this will typically involve cost of construction, distance to the location and the cost to bring power to the specific site location. The total cost of this extension will typically range between $75,000 – $100,000.
- New Feeder/Reconductoring: As the load on a circuit increases, the capacity of the distribution line increases, and this line would need to be replaced to support the increased ampacity. Reconductoring or installing new line equipment will require planning, engineering design and construction outage sequencing to remove and replace existing equipment. Furthermore, the length of reconductor will determine the duration of the schedule. The cost for reconductoring is dependent on the geography of the location. Rural installations of medium voltage overhead and underground cable can range from approximately 50 $/ft. up to over 250 $/ft. for a new underground circuit in a highly congested urban environment. The major IOUs in California have

provided unit cost information and report that the cost for reconductoring in rural areas for an overhead distribution ranges from 130 $/ft. to 258 $/ft. and the cost for reconductoring for urban areas for an overhead distribution ranges from 180 $/ft. to 258 $/ft.23

- New Transformer: With an anticipated load growth, a new transformer would be added, or an overloaded transformer would be replaced with a larger transformer. This equipment requires physical space in the substation and may also impact the electrical capacity of connected equipment such as the medium voltage bus and relaying. Significant planning, engineering and construction is required at the substation and significant equipment lead time may be required for the new transformer. Some substations may not have adequate area available to accommodate new transformer banks. The cost analysis for a new transformer ranges from $3 Million - $11 Million.24
- New Substation: A new substation will require site acquisition, site preparation, design and construction. Typical equipment will include 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 will range from 66 kV to 230 kV for transmission and sub transmission connected stations. Distribution connected substations will range from 33 kV to 44 kV. Low side voltages may range from around 4 kV to 44 kV. New substations are required to be integrated into the sub transmission or transmission network which requires additional studies and may trigger further upstream upgrades or permitting approval.

As per the general rate case prepared by Southern California Edison (SCE), the cost for the new substation is inclusive of adding new transformers, new circuit breakers and new switchgear[25]. Below is an example from the SCE rate case for the different new substation projects planned by SCE and the costs associated with each. The average cost for a new distribution substation in the table below ranges from approximately $40 million to $80 million.

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[23] https://data.nrel.gov/submissions/77, https://data.nrel.gov/files/77/Cost_database_for_release_November_20_2017.xlsx

[24] AVOIDING DISTRIBUTION SYSTEM UPGRADE COSTS USING DISTRIBUTED GENERATION, Pacific Northwest National Laboratory

[25] 2018 General Rate Case, Southern California Edison,http://www3.sce.com/sscc/law/dis/dbattach5e.nsf/0/64C26E22579296A68825802100663852/$FILE/SCE02V03.pdf

Table 7 New Substation Costs for future SCE projects (CPUC-Jurisdictional – Nominal X $1,000)

LINE NO.	SUBSTATION	PROJECT NO.	OPERATING DATE	LOCATION	DRIVER	FORECASTED VIOLATION	PROJECT SCOPE	TOTAL COST
1	Lakeview 115/12	05411	2016	Communities of Nuevo and Lakeview in the city of San Jacinto	Residential developments in communities of Nuevo and Lakeview	Nuevo 33/12 and Model 33/12 capacity will be unable to serve projected development growth	Construct new 115/12 substation Install 2-28 MVA transformers Install 4-12 kV circuits	$37,439
2	Safari 33/12	07516	2017	City of Irvine	Base load growth driven by office buildings, apartment complexes, and housing developments	Santiago 66/12 is projected to reach 107 percent in 2017 under 1-in-10 weather conditions	Construct new 33/12 substation Install 2-28 MVA transformers Install 3-12 kV circuits Construct new 66/33 substation Install 2-56 MVA transformers Install 2-33 kV circuits	$67,458
3	Banducci 66/12	06619	2018	Cummings Valley in Kern County	Base load growth New greenhouse projects	Cummings 66/12 is projected to reach 103 percent in 2016 and 119 percent in 2018 under 1-in-10 weather conditions	Construct new 66/12 substation Install 2-28 MVA transformers Install 3-12 kV circuits	$44,498
4	Falcon Ridge 66/12	05397	2018	City of Rialto	Large residential developments in the city of Rialto and Fontana	Alder 66/12 is projected to reach 101 percent in 2018 and Randall 66/12 is projected to reach 100 percent in 2019 under 1-in-10 weather conditions	Construct new 66/12 substation Install 2-28 MVA transformers Install 4-12 kV circuits	$83,129
5	Yokohl 66/12	06067	2020	Yokohl Ranch are of San Joaquin Valley	Development of approximately 10,000 residential homes over 10 years	Isolated development requiring new facilities	Construct new 66/12 substation Install 2-28 MVA transformers Install 4-12 kV circuits	$74,842

7.1 ASSUMPTIONS AND CLARIFICATIONS

- The cost analysis is based on publicly available data. Available data is limited and mostly available for California.
- With increased power levels, the scope and location of distribution grid upgrades increases, so does the intensity of land use, right of way and permitting requirements. Existing overhead and underground feeder pathways provide significantly faster approval cycles vs. 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 is highly encouraged to fully understand requirements and feasible power delivery schedules.

8.0 Exploration of On-Site Energy Storage at Vertiports

Energy rates typically includes 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 rates (TOU) where 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 difference in “off peak” price and “on peak” price vary from utility to utility. Demand charges are charge based on the highest demand, during any 15 to 30-minute interval that is measured in a billing period. Demand charge may be a fixed charge per kilowatt, or divided into rate brackets: the highest charge on the first bracket, and lesser charges on the following brackets.

Energy storage if deployed without onsite 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 utilizing 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 charging schedule for each site will need to be evaluated to determine the system size. It is important to understand both the onsite load as well as the rates that are applicable to the site to properly size the battery energy storage system (BESS). The larger the storage capacity of the BESS, the more the system costs, so the analysis using hourly load data (sub-hourly if available) is needed to balance the system cost with the additional benefits (bill reductions) the BESS may provide. Properly sized energy storage systems can have a positive return on investment for large “peaky” loads such as the one shown in figure below.

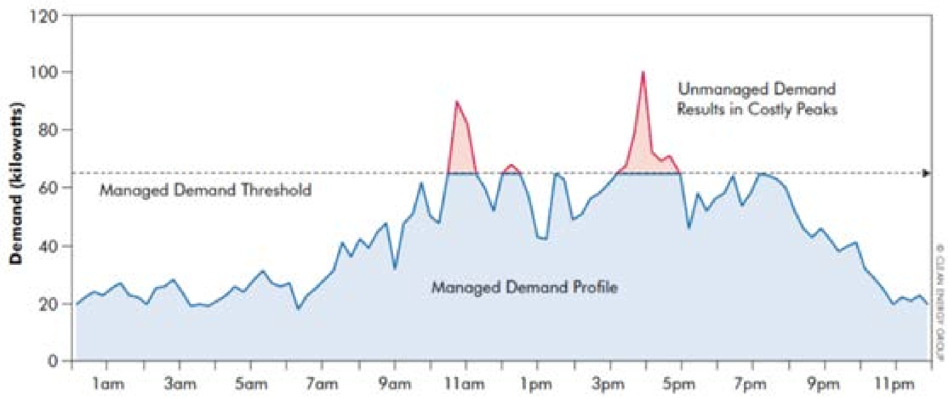

Figure 19 Image Source: Clean Energy Group. Example of Ideal Profile for demand charge reduction with BESS

The potential cost savings that can be achieved by deployment of energy storage will vary by vertiport and its individual charging profile.

The regional model developed for the Houston by NASA Langely Research Center area estimated the number of vehicles charging at each vertiport throughout the day, based on random number information[26]. The resulting charging profile is shown in the following figure. Assuming 600 kW eVTOLs, the Houston vertiport with 8 stations would require approximately 50 MWh of energy per day.

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[26] System-Level Urban Air Mobility Transportation Modeling and Determination of Energy-Related Constraints, 2018

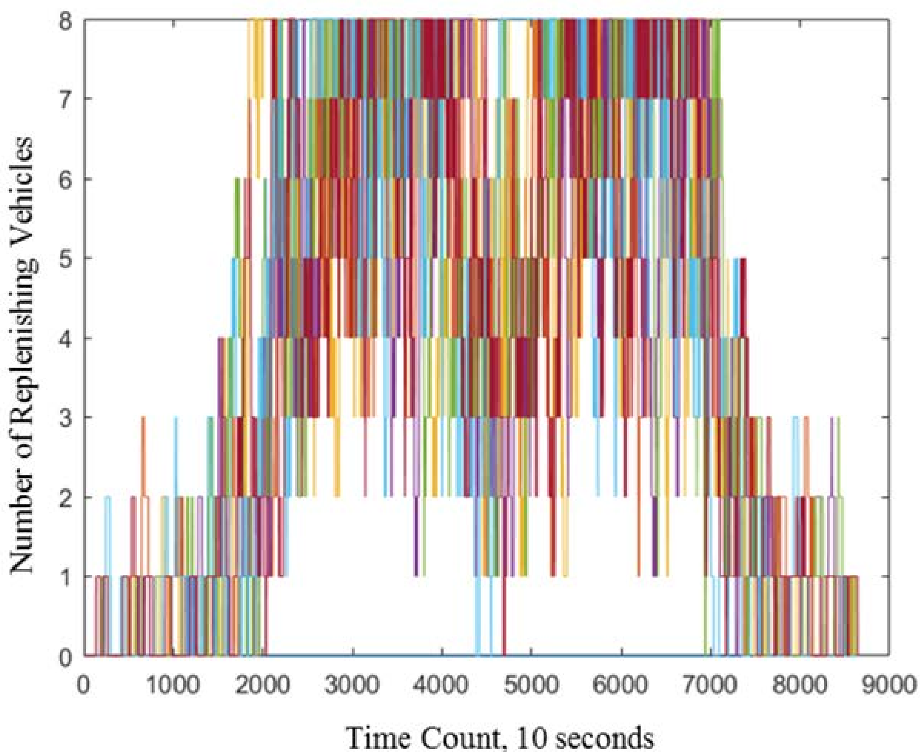
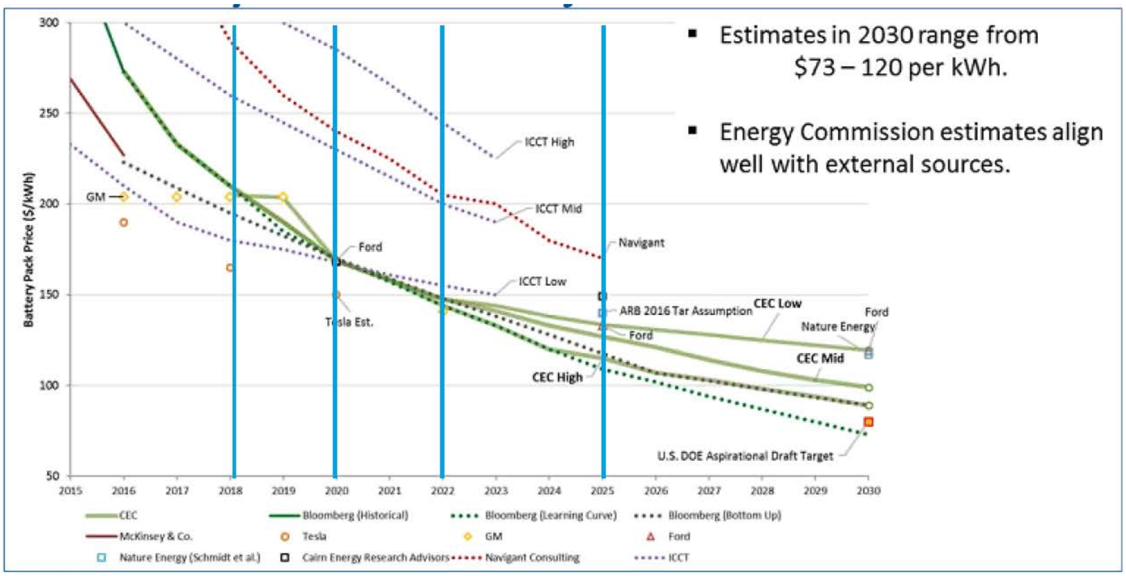


Figure 20 Houston – Number of vehicles in replenish state at each vertiport, colors represent different vertiport (NASA)

Some of the vertiports will have "peaky" profiles similar to the example ideal profile thus they will be good candidates for onsite energy storage, the optimal design for each site would need to be determined using capital cost, site tariff and load shape. It is also important to note that energy storage may not provide economic benefits based on current rates and energy storage prices but both are likely to change in the future. Increased solar penetration will lead to over-generation of power during the day resulting in lower rates during daytime and higher rates during the morning and evening, thus higher cost of energy during peak charging periods at the vertiports. There are several battery chemistries on the market, but lithium-ion is the most prevalent for commercial and industrial behind-the-meter (customer sited) applications. The BESS has two main components, the batteries and inverter. Approximate installed cost of BESS is $500/kWh. Both battery and inverter costs have been dropping precipitously in the last few years and these trends are expected to continue with estimated annual reduction of approximately 10 percent.



Ref: CEC Webinar

Figure 21 Future Energy Storage Cost by California Energy Commission (CEC)

Due to limited space at vertiport location and need to preserve open space to allow for vehicles landing and takeoff, energy storage will have to be charged from the grid. For ground stations with some available space, BESS could be installed with other less land intensive onsite generation.

8.1 NATURAL GAS FUEL CELLS

A fuel cell is a device that uses an electrochemical process to produce electricity and water from hydrogen. Fuel cells consist of two electrodes, a cathode and an anode, separated by an electrolyte. Depending on the types of the electrolyte, fuel can be categorized into proton exchange membrane fuel cell (PEMFC), solid oxide fuel cell (SOFC), molten carbonate fuel cell (MCFC), and phosphoric acid fuel cell (PAFC). PEMFC is a low temperature fuel cell that operates at approximately 100° C and requires pure hydrogen as the fuel for operation; SOFC and MCFC have more fuel flexibility (such as using hydrocarbon fuels or, in this case, natural gas) and operate at higher temperature (more than 600° C). The natural gas with the support of metal-based catalyst and high temperature is converted through methane reforming reaction and water gas shift reaction.

Figure 16 below describes the internal process of SOFC where synthetic gas used as the fuel. Synthetic gas, also known is syngas is a fuel gas mixture that consists of hydrogen, carbon monoxide and some carbon dioxide. A similar process, together with the reforming and shift reaction, is occurring inside the fuel cell when natural gas is used as the fuel.

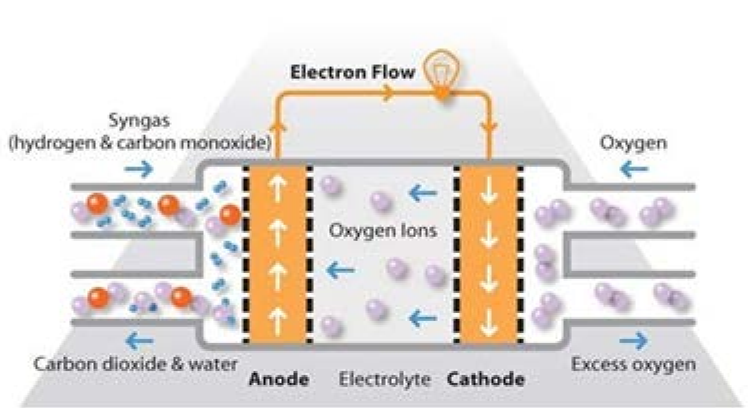


Figure 22 Solid Oxide Fuel Cell. Image source www.fuelcelltoday.com

Fuel cell technologies have a number of operational advantages, including relatively high conversion efficiency (i.e., greater than 40 percent), lower emissions than engines, can be part of a combined heat and power system (CHP), and quiet operation compared to the engine generators. However, fuel cells currently suffer from a number of shortcomings, including high capital cost, short fuel cell stack life of approximately 5 to 10 years (which increases O&M costs), inability to ramp up and down (do not follow load), and corrosion and breakdown of cell components, resulting in power generation degradation over the cell stack life. Natural gas based fuel cells also exhibit long startup times because of the high temperatures required for operation, so this technology generally operates primarily as baseload generation and cannot be dispatched to follow load.

There are three commercial suppliers of natural gas based fuel cells used in continuous power generation.

- Bloom Energy
- Doosan Fuel Cell
- FuelCell Energy

Black & Veatch reviewed Doosan and FuelCell Energy for this application. Both Doosan and FuelCell Energy are established fuel cell OEMs in the market, with hundreds of installations between them. Doosan is a PAFC type fuel cell, while FuelCell Energy is a MCFC type. Both technologies have proven to be effective at producing both power and recoverable heat for a CHP configuration.

FuelCell Energy offers standard plant installations in sizes of 1.4 MW_e, 2.8 MW_e, and 3.7 MW_e. The Doosan units come in configurations of 460 kW_e units, enclosed in a single module. Space availability will determine the total capacity that can be installed. The electrical efficiency of FuelCell Energy units is approximately 47 percent and Doosan is approximately 44 percent.

The cost for the natural gas fuel cell option is approximately $4,700/kW, for an all-in, turnkey price. Part of this cost is due to the complicated nature of the installation, compared to the engine options, and the construction and installation of the natural gas fuel cells would be handled almost exclusively by the OEM. A long-term service agreement would be required, and the price for this was estimated at approximately $0.03/kWh.

Fuel cells are not a ramping resource (they do not increase or decrease production with load) thus they mostly decrease the base load. They will need to be installed with energy storage to reduce the demand charges.

8.2 GENERATOR

Reciprocating internal combustion engines (RICEs) are machines that generate work using the combustion of a fuel inside of a piston cylinder, driving the piston to create work through a shaft. RICEs can be categorized into spark-ignition engines and compression-ignition engines. A natural gas engine is categorized as a spark-ignition engine. Natural gas engines reviewed have the advantages that they produce high electrical output for a given footprint compared to other options, such as a fuel cell, and recover the heat from the engine to improve overall plant efficiencies. Natural gas engines are also an established power generation asset used in the distributed generation and microgrid market. Modern natural gas engines are also relatively efficient machines based on electric generation alone and efficiency can be further improved by use of recovered heat.

There are several natural gas engine OEMs that produce natural gas engines for power generation. With many different engine OEMs and types to choose from, natural gas engines are a well-established technology in the distributed generation and microgrid markets. One of the most established natural gas engine companies in the market is GE Jenbacher, based in Austria, which has more than 80 years of being recognized as a manufacturer in the development and production of gas engines for the efficient generation of power and recoverable heat. The GE Jenbacher gas engine offers a wide variety of combined heat and power (CHP) systems with a power range of 250 kW to 10 MW. Additionally, Jenbacher has the advantages of fuel flexibility to run on natural gas as well as other types of gases.

Another established engine OEM is Wärtsilä, based in Finland, which has supplied more than 11,000 engines in 176 countries. Wärtsilä gas and multi-fuel power plants are designed for optimal performance in a wide variety of decentralized power production applications: baseload, peaking power, and CHP plants. Wärtsilä manufactures engines ranging from 4.2 MW to 18.8 MW and has multiple versions of each model capable of running of different fuels, including a stand-alone natural gas version and a dual fuel version.

The cost for a 4.4 MW to 8.8 MW Jenbacher natural gas engine plant is approximately $2,000/kW. The cost for a 4.2 MW to 8.4 Wärtsilä natural gas engine plant is approximately $3,100/kW. These numbers were derived from a standard equipment price for the genset packages, along with a conservative multiplier for the engineering and construction based on previous experience with natural gas engine plants coupled with heat recovery. The maintenance costs for the natural gas engine is approximately $0.02/kWh.

8.3 SPACE REQUIREMENTS AND OTHER CHALLENGES

Approximate BESS pad footprint requirements including ventilation space and NEC required working clearances:

- ~200kWh – 10’ x 11’
- ~1MWh – 22’ x 11’
- ~2MWh – 37’ x 11’ or 22’ x 21’

Additional fire hazard clearance requirements: Indoor installation of most battery energy systems will require rather high forced airflow for cooling and ventilation purposes.

FuelCell Energy system with 1.4 MW of capacity requires approximately 42 ft. by 58 ft. of space with additional 42 by 30 ft. for maintenance. The 2.8 MW unit requires approximately 86 ft. by 40 ft. for equipment and additional 40 ft. by 20 ft. for maintenance.

The 4.2 MW and 4.4 MW engines is will require approximately 50 ft. by 10 ft.

9.0 Refueling Infrastructure Estimation

While centralized hydrocarbon refueling depots have certain advantages, the option of having chargers and refueling stations at vertiports should be explored as it may help maximize usage of the hybrid-electric UAM Vehicles, as well as person-trips per flight.

Limited studies are available for the cost of diesel fueling facilities. Based on a quote received by a Black & Veatch partner, approximate cost for a new fueling facility with 4 island stations (4 pumps), canopy and 20,000-gallon storage tank is $500,0000. This cost does not include land or support buildings.

The cost to construct Liquefied Natural Gas (LNG) and Liquified to Compressed Natural Gas (LCNG) varies by project thus there are standard cost available. A survey with cost of facilities of varying size was included in a report by Our Energy Policy group called U.S. and Canadian Natural Gas Vehicle Market Analysis: Liquified Natural Gas Infrastructure.[27]

Figure 23 LNG and LCNG fueling station costs (Our Energy Policy Report, U.S. and Canadian Natural Gas Vehicle Market Analysis: Liquified Natural Gas Infrastructure , 2012)

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[27] http://www.ourenergypolicy.org/wp-content/uploads/2012/05/11_1803_anga_module5_lng_dd9.pdf

10.0 Project Outcomes and Goals

The results of our work will advance the industry's understanding of requirements, feasibility, costs and timelines to deploy charging infrastructure to enable eVTOL applications. These initial findings will help guide NASA's research and support overall modeling of the ecosystem to support safe, low-emission aviation services in urban environments.

10.1 INDUSTRY OUTREACH AND SOCIALIZING FINDINGS

Following NASA's interests to share and disseminate the findings of this study broadly, the team will actively pursue events with relevant organizations that convene industry stakeholders to present our findings. Black & Veatch routinely produces industry articles, papers and presents at events that focus on transportation Electrification and welcomes the opportunity to collaborate with NASA on this outreach.

We recognize the importance of sharing this body of research with industry and public agencies and will work with NASA to identify any sensitive information that needs to remain internal.

Indicative list of targeted high-profile events:

- Electric Vehicle Symposium 32
- Aviation Forum
- Transformational Flight Workshops
- Distribu-TECH
- Electric Power Research Institute – EV Infrastructure Working Council
- EV Roadmap 12

In addition, we will collaborate with NASA to leverage our participation in the following industry organizations to raise the visibility of this topic: Smart Electric Providers Alliance, Edison Electric Institute, CALSTART and CharIN.

10.2 NEXT STEPS AND INDUSTRY PARTICIPATION

With this initial understanding of key infrastructure requirements, feasibility, costs and stakeholder alignment required to support eVTOL applications in hand, the framework has been established to iterate on this work for additional markets, facility profiles, network density scenarios and equipment specific solutions.

As the analysis progresses, logical next steps could include deeper industry collaboration across government agencies, emergency response officials, logistics and passenger transportation network providers, with input from vehicle OEMs, charging hardware and building owners to refine assumptions and operational conditions.

In addition to replicating this study for other locations across the country, we anticipate several areas that warrant investigation in support of these cross-domain infrastructure considerations:

- Charging hardware development and standards (vehicle connections, safety, sitting considerations, grid signaling, certification, permitting, cyber security and optimized layouts)
- Integration with utility planning processes (power requirements, network density, grid support, etc.)

- Vehicle development and validation (fueling, state of charge communications, interoperability, etc.)
- Pilot charging infrastructure deployments ("behind the fence" and early public deployments)
- Synergies with conventional take off vehicles fueling at rural and urban airports
- Communications infrastructure (requirements, existing networks and implications of upcoming 5G, vehicle-to-vehicle and vehicle-to-infrastructure communications)
- Mission critical control facilities (requirements gathering, siting, security and resilience needs for government and third-party network control facilities)
- Synchronizing North American requirements with international organizations

11.0 Appendix: Cost Estimates

NASA eVTOL Existing Building Landing Single Charging Station, Five Story Building

Revision .00
Date 26-Oct-18

Project Scope:

Direct Cost Summary		$	683,248.50
02	Existing Conditions	$	25,000.00
03	Concrete	$	-
04	Masonry	$	-
05	Metals	$	-
06	Wood, Plastics, & Composites	$	-
07	Thermal and Moisture Protection	$	-
08	Openings	$	-
09	Finishes	$	-
10	Specialties	$	-
11	Equipment	$	-
12	Furnishings	$	-
13	Special Construction	$	12,000.00
14	Conveying Equipment	$	-
21	Fire Protection	$	-
22	Plumbing	$	-
23	Building HVAC	$	-
23A	*Mission Critical HVAC*	*$*	*-*
25	Integrated Automation	$	-
26	Electrical	$	-
26A	*POD Electrical*	*$*	*588,692.50*
27	Communications	$	8,000.00
28	Electronic Safety & Security	$	9,929.00
31	Earthwork	$	-
32	Exterior Improvements	$	1,248.00
33	Utility Service Switchgear	$	-
34	Transportation	$	38,379.00
35	Waterway and Marine Transportation	$	-
40	Process Piping	$	-
41	Material Processessing and Handling Equipment	$	-
44	Pollution Control Equipment	$	-
46	Water and Wastewater Equipment	$	-
48	Electronic Power Generation	$	-

General Conditions		$	18,789.33
80	Construction Management	$	-
81	Construction Indirects	$	6,832.49
82	Construction Equipment	$	3,416.24
85	Commissioning / Start-Up	$	6,832.49
86	Commissioning / Start-Up Indirects	$	1,708.12
Design Costs		**$**	**-**
	Site Design	$	-
	Building Design	$	-
	Structural Engineering	$	-
	Mechanical Engineering	$	-
	Electrical Engineering	$	-
Site Acquisition Costs		**$**	**-**
	Land / Leasing	$	-
	Zoning	$	-
	Environmental / Regulatory	$	-
Soft / Indirect Costs		**$**	**58,076.12**
	Taxes	$	40,994.91
	Bonding	$	-
	Permits	$	10,248.73
	Insurance	$	6,832.49
Contingency		**$**	**68,324.85**
	Escalation	$	-
	Estimating Contingency	$	34,162.43
	Contractor's Contingency	$	34,162.43
Fee		**$**	**54,659.88**
	Construction Fee	$	54,659.88
	Grand Total	**$**	**883,098.69**

Material, Labor, and Equipment Totals (No Totaling Components)

Material	$	126,583.00
Labor	$	178,534.00
Equipment (Construction)	$	378,131.50

Project Assumptions

- All pricing is budgetary and subject to change based on detailed design documents
- Adequate space is available to support project requirements
- All utilities are on site, ready for connection within 15' from building
- Utility services are adequately sized to support new equipment loads
- Sufficient space on site for all crane & rigging operations
- Material can be staged on site
- All work to be performed Monday - Friday 7am - 5pm
- Suitable soil conditions for construction

Building Program

Building Program	SF
Overall Footprint	

Project Exclusions

- Payment & Performance Bonds
- Special Insurance Costs
- Escalation
- Utility company fees
- Taxes & Fees
- Third Party Testing
- Modifications to correct existing code / building violations
- Off Hours / Out-of-Sequence Work
- Seismic bracing of existing equipment or structures
- Site Acquisition & Development Costs
- Communications Cabling
- Engineering costs and Project Management
- Preventative Maintenance

Shell Quantity Parameters

Shell Quantity Parameters	Quantity

NASA eVTOL Three Charging Stations Ground

Revision	.00
Date	4-Dec-18

Project Scope:

Direct Cost Summary		$	2,035,226.56
02	Existing Conditions	$	-
03	Concrete	$	457,200.00
04	Masonry	$	-
05	Metals	$	-
06	Wood, Plastics, & Composites	$	-
07	Thermal and Moisture Protection	$	-
08	Openings	$	-
09	Finishes	$	-
10	Specialties	$	-
11	Equipment	$	-
12	Furnishings	$	-
13	Special Construction	$	12,000.00
14	Conveying Equipment	$	-
21	Fire Protection	$	-
22	Plumbing	$	-
23	Building HVAC	$	-
23A	*Mission Critical HVAC*	*$*	*-*
25	Integrated Automation	$	-
26	Electrical	$	-
26A	*POD Electrical*	*$*	*1,378,930.00*
27	Communications	$	8,000.00
28	Electronic Safety & Security	$	9,929.00
31	Earthwork	$	-
32	Exterior Improvements	$	49,920.00
33	Utility Service Switchgear	$	-
34	Transportation	$	119,247.56
35	Waterway and Marine Transportation	$	-
40	Process Piping	$	-
41	Material Processessing and Handling Equipment	$	-
44	Pollution Control Equipment	$	-
46	Water and Wastewater Equipment	$	-
48	Electronic Power Generation	$	-

General Conditions		$	55,968.73
80	Construction Management	$	-
81	Construction Indirects	$	20,352.27
82	Construction Equipment	$	10,176.13
85	Commissioning / Start-Up	$	20,352.27
86	Commissioning / Start-Up Indirects	$	5,088.07
Design Costs		**$**	**-**
	Site Design	$	-
	Building Design	$	-
	Structural Engineering	$	-
	Mechanical Engineering	$	-
	Electrical Engineering	$	-
Site Acquisition Costs		**$**	**-**
	Land / Leasing	$	-
	Zoning	$	-
	Environmental / Regulatory	$	-
Soft / Indirect Costs		**$**	**172,994.26**
	Taxes	$	122,113.59
	Bonding	$	-
	Permits	$	30,528.40
	Insurance	$	20,352.27
Contingency		**$**	**203,522.66**
	Escalation	$	-
	Estimating Contingency	$	101,761.33
	Contractor's Contingency	$	101,761.33
Fee		**$**	**162,818.12**
	Construction Fee	$	162,818.12
	Grand Total	**$**	**2,630,530.33**

Material, Labor, and Equipment Totals (No Totaling Components)	$	
Material	$	245,850.00
Labor	$	687,774.50
Equipment (Construction)	$	1,101,602.06

Project Assumptions

All pricing is budgetary and subject to change based on detailed design documents
Adequate space is available to support project requirements
All utilities are on site, ready for connection within 15' from building
Utility services are adequately sized to support new equipment loads
Sufficient space on site for all crane & rigging operations
Material can be staged on site
All work to be performed Monday - Friday 7am - 5pm
Suitable soil conditions for construction

Building Program	SF
Overall Footprint	

Project Exclusions

Payment & Performance Bonds
Special Insurance Costs
Escalation
Utility company fees
Taxes & Fees
Third Party Testing
Modifications to correct existing code / building violations
Off Hours / Out-of-Sequence Work
Seismic bracing of existing equipment or structures
Site Acquisition & Development Costs
Communications Cabling
Engineering costs and Project Management
Preventative Maintenance

Shell Quantity Parameters	Quantity

NASA eVTOL Ten Vertiport Ground

Revision	.00
Date	3-Dec-18

Project Scope:

Direct Cost Summary		$	7,074,652.60
02	Existing Conditions	$	-
03	Concrete	$	1,371,600.00
04	Masonry	$	-
05	Metals	$	-
06	Wood, Plastics, & Composites	$	-
07	Thermal and Moisture Protection	$	-
08	Openings	$	-
09	Finishes	$	-
10	Specialties	$	-
11	Equipment	$	-
12	Furnishings	$	-
13	Special Construction	$	40,000.00
14	Conveying Equipment	$	-
21	Fire Protection	$	-
22	Plumbing	$	-
23	Building HVAC	$	-
23A	*Mission Critical HVAC*	*$*	*-*
25	Integrated Automation	$	-
26	Electrical	$	-
26A	*POD Electrical*	*$*	*4,829,290.00*
27	Communications	$	24,000.00
28	Electronic Safety & Security	$	29,787.00
31	Earthwork	$	-
32	Exterior Improvements	$	299,520.00
33	Utility Service Switchgear	$	-
34	Transportation	$	480,455.60
35	Waterway and Marine Transportation	$	-
40	Process Piping	$	-
41	Material Processessing and Handling Equipment	$	-
44	Pollution Control Equipment	$	-
46	Water and Wastewater Equipment	$	-
48	Electronic Power Generation	$	-

General Conditions		$	1,238,552.95
80	Construction Management	$	1,044,000.00
81	Construction Indirects	$	70,746.53
82	Construction Equipment	$	35,373.26
85	Commissioning / Start-Up	$	70,746.53
86	Commissioning / Start-Up Indirects	$	17,686.63
Design Costs		**$**	**-**
	Site Design	$	-
	Building Design	$	-
	Structural Engineering	$	-
	Mechanical Engineering	$	-
	Electrical Engineering	$	-
Site Acquisition Costs		**$**	**-**
	Land / Leasing	$	-
	Zoning	$	-
	Environmental / Regulatory	$	-
Soft / Indirect Costs		**$**	**601,345.47**
	Taxes	$	424,479.16
	Bonding	$	-
	Permits	$	106,119.79
	Insurance	$	70,746.53
Contingency		**$**	**707,465.26**
	Escalation	$	-
	Estimating Contingency	$	353,732.63
	Contractor's Contingency	$	353,732.63
Fee		**$**	**565,972.21**
	Construction Fee	$	565,972.21
	Grand Total	**$**	**10,187,988.49**

Material, Labor, and Equipment Totals (No Totaling Components)		
Material	$	1,078,369.00
Labor	$	2,327,213.00
Equipment (Construction)	$	3,669,070.60

Project Assumptions

All pricing is budgetary and subject to change based on detailed design documents
Adequate space is available to support project requirements
All utilities are on site, ready for connection within 15' from building
Utility services are adequately sized to support new equipment loads
Sufficient space on site for all crane & rigging operations
Material can be staged on site
All work to be performed Monday - Friday 7am - 5pm
Suitable soil conditions for construction

Building Program	SF
Overall Footprint	

Project Exclusions

Payment & Performance Bonds
Special Insurance Costs
Escalation
Utility company fees
Taxes & Fees
Third Party Testing
Modifications to correct existing code / building violations
Off Hours / Out-of-Sequence Work
Seismic bracing of existing equipment or structures
Site Acquisition & Development Costs
Communications Cabling
Engineering costs
Preventative Maintenance

Shell Quantity Parameters	Quantity

NASA eVTOL Three Charging Station Garage

Revision	.00
Date	4-Dec-18

Project Scope:

Direct Cost Summary		$	1,451,772.06
02	Existing Conditions	$	25,000.00
03	Concrete	$	-
04	Masonry	$	-
05	Metals	$	-
06	Wood, Plastics, & Composites	$	-
07	Thermal and Moisture Protection	$	-
08	Openings	$	-
09	Finishes	$	-
10	Specialties	$	-
11	Equipment	$	-
12	Furnishings	$	-
13	Special Construction	$	12,000.00
14	Conveying Equipment	$	-
21	Fire Protection	$	-
22	Plumbing	$	-
23	Building HVAC	$	-
23A	*Mission Critical HVAC*	*$*	*-*
25	Integrated Automation	$	-
26	Electrical	$	-
26A	*PODI Electrical*	*$*	*1,347,067.50*
27	Communications	$	8,000.00
28	Electronic Safety & Security	$	9,929.00
31	Earthwork	$	-
32	Exterior Improvements	$	1,248.00
33	Utility Service Switchgear	$	-
34	Transportation	$	48,527.56
35	Waterway and Marine Transportation	$	-
40	Process Piping	$	-
41	Material Processessing and Handling Equipment	$	-
44	Pollution Control Equipment	$	-
46	Water and Wastewater Equipment	$	-
48	Electronic Power Generation	$	-

General Conditions		$	39,923.73
80	Construction Management	$	-
81	Construction Indirects	$	14,517.72
82	Construction Equipment	$	7,258.86
85	Commissioning / Start-Up	$	14,517.72
86	Commissioning / Start-Up Indirects	$	3,629.43
Design Costs		**$**	**-**
	Site Design	$	-
	Building Design	$	-
	Structural Engineering	$	-
	Mechanical Engineering	$	-
	Electrical Engineering	$	-
Site Acquisition Costs		**$**	**-**
	Land / Leasing	$	-
	Zoning	$	-
	Environmental / Regulatory	$	-
Soft / Indirect Costs		**$**	**123,400.63**
	Taxes	$	87,106.32
	Bonding	$	-
	Permits	$	21,776.58
	Insurance	$	14,517.72
Contingency		**$**	**145,177.21**
	Escalation	$	-
	Estimating Contingency	$	72,588.60
	Contractor's Contingency	$	72,588.60
Fee		**$**	**116,141.76**
	Construction Fee	$	116,141.76
	Grand Total	**$**	**1,876,415.39**

Material, Labor, and Equipment Totals (No Totaling Components)

Material	$	135,600.00
Labor	$	218,037.50
Equipment (Construction)	$	1,098,134.56

Project Assumptions

- All pricing is budgetary and subject to change based on detailed design documents
- Adequate space is available to support project requirements
- All utilities are on site, ready for connection within 15' from building
- Utility services are adequately sized to support new equipment loads
- Sufficient space on site for all crane & rigging operations
- Material can be staged on site
- All work to be performed Monday - Friday 7am - 5pm
- Suitable soil conditions for construction

Building Program

	SF
Overall Footprint	

Project Exclusions

- Payment & Performance Bonds
- Special Insurance Costs
- Escalation
- Utility company fees
- Taxes & Fees
- Third Party Testing
- Modifications to correct existing code / building violations
- Off Hours / Out-of-Sequence Work
- Seismic bracing of existing equipment or structures
- Site Acquisition & Development Costs
- Communications Cabling
- Engineering costs and Project Management
- Preventative Maintenance

Shell Quantity Parameters

	Quantity