A BETTER CITY

REPORT AUGUST 2019

NEW MBTA BUS MAINTENANCE FACILITIES & EVOLVING BATTERY ELECTRIC BUS TECHNOLOGY

CASE STUDY: ALBANY STREET GARAGE

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A Better City is a diverse group of business leaders united around a common goal—to enhance Boston and the region's economic health, competitiveness, vibrancy, sustainability and quality of life. By amplifying the voice of the business community through collaboration and consensus across a broad range of stakeholders, A Better City develops solutions and influences policy in three critical areas central to the Boston region's economic competitiveness and growth: transportation and infrastructure, land use and development, and energy and environment.

Executive Summary

This feasibility case study assesses the potential to incorporate a battery-electric bus maintenance facility into a new mixed-use development project. On the average weekday, buses carry over 30% of Massachusetts Bay Transportation Authority (MBTA) riders, and the facilities that maintain and garage these buses are in need of significant investment or replacement. This mixed-use concept could possibly help provide a cost-effective public/private site development strategy for modernizing and expanding the MBTA's bus facility network. As transit agencies across North America begin to integrate electric vehicles into their fleets, this model could help the MBTA and other urban agencies to better achieve transportation, economic, and environmental goals.

The MBTA has a pressing need to upgrade or replace each of its eight (8) existing bus maintenance facilities, as documented in the agency's 2017 Integrated Fleet and Facilities Plan (IFFP). To execute these needed improvements, the IFFP identifies a conceptual budget of nearly $808 million (M), the source for which has not yet been identified. The most recently updated Massachusetts Department of Transportation (MassDOT) Capital Investment Program allocates $83 M for bus maintenance facilities for the 2019-2023 period. This Albany Street Garage Case Study seeks to explore the potential of whether new evolving battery electric bus (BEB) technology can form the basis of a Public-Private Partnership in which the private development sector might finance/construct a new all BEB maintenance facility as part of a larger multi-use development project.

BEB technology has been evolving for the past decade and is poised to become a significant percentage of North American transit bus fleets over the next several years. Technology improvements have led to increased vehicle range, faster charging speeds, and vehicle costs which are approaching parity with some conventionally-fueled buses. Some technical challenges around cold-weather performance remain but are being actively addressed by the industry. Most major North American bus builders now offer BEB products and have begun to focus on scaling-up production to meet increasing industry demand.

Currently, there are BEB initiatives underway at MassDOT, MBTA, and several Massachusetts Regional Transit Authorities (RTAs) to evaluate the feasibility of large-scale deployment of BEBs and gain experience operating and testing BEBs in revenue service. The MBTA is scheduled to take delivery of five, 60-foot BEBs in early 2019, which will operate on the Silver Line. While the majority of the MBTA's fleet are smaller 40-foot buses, this pilot program will still provide the MBTA with valuable first-hand experience in a demanding service environment.

Many larger peer agencies in North America also have BEB feasibility programs underway. Some larger agencies such as Los Angeles County Metropolitan Transportation Authority, Toronto Transit Commission, and King County Metro Transit, have announced aggressive goals for fleet electrification in response to local environmental or political directives. Major issues identified by peer agencies for future focus include: vehicle range and cold weather performance, weight and passenger capacity, electrical grid upgrades, and charging infrastructure.

To date, no peer agencies have built facilities dedicated to large BEB fleets, though peer agency experience suggests that most major facility functions will be similar for conventional and BEB fleets. Due to the lack of industry experience with large BEB fleet deployments, overall power requirements for a BEB facility are still being understood and will be impacted by many factors, ranging from vehicle duty cycle to weather conditions. A conservative estimate suggests that the Albany Street garage (112 buses) could require as much as 20-MW of power. Providing this level of power should be feasible but would require discussions around cost and close coordination with utility providers.

As the industry scales-up production to meet increasing demand, advances are expected that will address a variety of existing challenges. Issues of vehicle range and cold weather performance are expected to improve as battery technology evolves. Charging technology standards should become widely adopted by the industry. Smart charging and overhead charging infrastructure will evolve, easing some logistical barriers to large-fleet deployments. Manufacturing capacity and supply chains will mature as the industry transitions from a focus on demonstration programs to a focus on large production orders.

With this understanding, the case study considers a new procurement concept aimed at helping the MBTA replace one of its bus facilities at no or low public cost. Given the likelihood that a major procurement of all BEB buses appears feasible in a 5-year timeframe going forward, the concept considers the potential of whether new evolving battery electric bus (BEB) technology can form the basis of a Public-Private Partnership (PPP) in which a private real estate development sector would finance/construct a new all BEB bus maintenance facility as part of a larger, multi-use, private-sector development project.

This Case Study considers replacing the existing aged Albany Street bus garage located in Boston's South End neighborhood with a new privately financed bus facility that provides indoor storage, charging, and maintenance for BEBs as part of a mixed-use transit-oriented development (TOD). Service readiness support such as bus washing and cleaning could be performed onsite. In addition to storing and charging new BEBs, the Case Study concept includes two stories of retail space, a 17-story residential tower, and a mix of underground and outdoor parking for residents and MBTA transportation (primarily bus drivers) staff. This concept also includes a bus interchange (transit hub), which could be used to provide improved levels of transit service in a developing neighborhood with limited access to major subway lines. In total, the Case Study concept is approximately 425,000 square feet of total new development on this site.

Please note that the Case Study concept is presented not as the only nor the best program of multi-use development that may be possible on this site. Rather, the concept is offered to illustrate the kind of exciting opportunity that may be created by taking the compatibility of emerging new BEB technology (BEB) and the MBTA's urgent need to build new bus maintenance facilities in combination with the business community's ability and interest in innovative multi-use project development.

The preliminary evaluation of the MBTA's Albany Street garage performed through this study has resulted in a Case Study concept that may help provide a cost-effective public/private site development strategy for modernizing and expanding the MBTA's bus facility network. The concept warrants further exploration (and which may apply to sites other than the Albany Street parcel). Given the timeframe associated with developing a new maintenance facility and the added complexities of electrical grid infrastructure and development partnerships, engagement with stakeholders should begin now.

It is recommended that the MBTA begin discussions with the Boston Planning and Development Agency, Boston Public Works, Boston Transportation Department, the development community, the South End Neighborhood Forum, and other stakeholders related to such a mixed-use project. Understanding the cost drivers, success factors, and other objectives of these partners will be critical to developing the possibility of a MBTA-issued Request for Proposal that may support such a successful privately-financed mixed-use project.

Contents

Acronyms and Abbreviations

AAA	American Automobile Association
B	billion
BEB	battery electric bus
BPDA	City of Boston’s Planning and Development Authority
BYD	Build Your Dreams Auto Co.
CNG	compressed natural gas
EPA	U.S. Environmental Protection Agency
ft	foot (feet)
ft^2	square feet
FTA	Federal Transit Administration
IFFP	Integrated Fleet and Facility Plan
KCM	King County Metro Transit
kV	kilovolt(s)
kW	kilowatt(s)
LACMTA	Los Angeles County Metro Transit Authority
M	million
MassDOT	Massachusetts Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
Mfr(s)	manufacturer(s)
MPDGE	Miles per Diesel Gallon Equivalent
MTA	Metropolitan Transportation Authority
MW	megawatt(s)
NFI	New Flyer Industries
Plan	Harrison/Albany Corridor Strategic Plan
PPP	public-private partnership
PVTA	Pioneer Valley Transportation Authority
RTA	Regional Transit Authority
SEPTA	Southeastern Pennsylvania Transportation Authority
SFMTA	San Francisco Municipal Transportation Agency
SOWA	South of Washington
TCRP	Transit Cooperative Research Program
TOD	Transit Oriented Development
TTC	Toronto Transit Commission
WRTA	Worcester Regional Transit Authority

Case Study: Albany Street Garage

Purpose

The Massachusetts Bay Transportation Authority (MBTA) has a pressing need to replace and upgrade aging bus maintenance facilities. Documented by the MBTA in its Integrated Fleet and Facility Plan (IFFP) published in December 2017, this conclusion is consistent with at least four (4) prior studies conducted by the Commonwealth and MBTA since 2003.

MBTA 2017 Integrated Fleet and Facility Plan Assessment

Acting with this knowledge, between January and March 2017 the MBTA undertook a full condition assessment of each of its bus maintenance facilities. This physical facility assessment used the Federal Transit Administration's (FTA's) 1-5 Asset Condition Rating Scale (5 = Excellent; 1 = Poor) to rate the condition of each location.

Facility Condition

According to the FTA rating scale, a facility is considered in good repair if it has a condition rating of 3, 4, or 5 and is considered not in good repair if it has a rating of 1 or 2.

Table 1 shows the MBTA's ratings for each MBTA bus maintenance facility.

Table 1: MBTA Condition Rating for Each Bus Maintenance Facility (as of 2017)

Facility	Age	Capacity	Condition Rating
Albany	76	116	2.7
Arborway	13	118	3.1
Cabot	42	180	2.8
Charlestown (maintenance)	42	254	2.0
Charlestown (storage)	42	-	2.5
Fellsway	92	76	2.4
Lynn	81	90	2.7
North Cambridge	38	28	3.2
Quincy	87	86	2.4
Southampton (maintenance)	15	98	3.6
Southampton (storage)	13	-	3.1
Fleet Average	49	1046	2.8

The MBTA reported in its 2017 IFFP that, "most [bus maintenance] facilities are in marginal condition and are at or over practical capacity. Some facilities also suffer from capability limitations, which impact efficiency." Limitations specifically identified in the IFFP include: "poor layout, uneven/degraded floors, low roofs [hamper] maintenance, door size restricts (precludes) newer model access, and maintenance pits in poor condition" (MassDOT/MBTA, 2017).

IFFP capacity and marginal condition recommendations include:

- Achieve State of Good Repair in 15 years
- Modernize and build new maintenance facilities
- Expand the 40-foot and 60-foot vehicle fleet to satisfy projected ridership increases
- Establish goals and timelines for moving toward a zero/no emission fleet

Conceptual Facility Improvement Recommendations

The IFFP determined that the cost to improve and expand the capacity of MBTA's bus maintenance facilities through 2032 would require about $808 million (M) in funding. Only $83 M of this total is currently programmed in the MBTA 2019-2023 (and recently updated) 5-year Capital Investment Program budget. The IFFP did not identify nor allocate a source (federal, state, or private sector) for improving and expanding the MBTA bus maintenance facilities over the next 15 years. Presumably, funding to meet these upgrades would represent a massive financial challenge for the MBTA.

Prior Condition Assessment Studies: Back to the Future

The MBTA's bus maintenance facility findings of marginal condition and the need to invest to bring them to a state of good repair and allow bus fleet expansion are consistent with similar studies recently conducted by the MBTA:

- *Strategic Plan for Bus Maintenance Facilities* (Alternate Concepts/Stone and Webster, 2003): Key findings identified six (6) projects ranging from major modifications to new facility locations. Estimated total cost: $116 M.
- *Condition Assessment of MBTA Bus Operating Facilities and an Evaluation of the Impacts of Advanced Technology Buses* (STV Incorporated, 2012): Key findings include issues of disrepair and disfunction at nearly every existing bus maintenance facility site.
- *MBTA Bus Maintenance Efficiency Study* (CH2M HILL, Inc., 2016): Key findings include that the "MBTA maintenance facilities are old and over capacity. The MBTA's aging facilities with widely varying conditions and capacities, are not in line with peer agencies. In most cases, the facilities are over capacity with no room for expansion."
- *Focus40: The 2040 Investment Plan for the MBTA.* State of the System Report: Bus. (Massachusetts Department of Transportation [MassDOT]/MBTA, 2018). Key findings include: (1) "Four of the MBTA's maintenance facilities are over 70 years old, with the oldest built in 1930."; (2) "Most [facilities] are near, at, or above practical storage capacity."; (3) "Many bus maintenance facilities are outmoded in key ways."; (4) "Most [facilities] in need of replacement…[or] major upgrades."; and (5) "Inadequate maintenance facilities are a barrier to providing more bus service for riders."

Since 2000, the MBTA has conducted at least five (5) independent reviews and studies related to the condition of its existing bus maintenance facilities and the limitations those facilities place on the overall size of the MBTA's bus fleet. In addition to suffering from age and deteriorating condition, some facilities have physical restrictions that place increased urgency on their replacement. As the MBTA seeks to renovate, rebuild, or replace bus maintenance facilities, significant financial and other resources will be required to support these programs and address overall service requirements.

Summary and Case Study Purpose

The MBTA faces a fiscal challenge of nearly $808 M over the next 15 years in new funding resources to bring its bus maintenance facilities up to a state of good repair and to expand the size of its total bus fleet. The most recently updated MassDOT Capital Investment Program allocates about $83 M for bus maintenance facilities for the 5-year 2019-2023 period. This funding appears to be the first specific allocation for this purpose in any Capital Investment Program of recent decades, and it is important to acknowledge this significant step recently undertaken. However, there appears to be a nearly $700 M funding gap required over the next 15 years to reach a state of good repair. Although by no means envisioned to resolve the full extent of this funding gap, this Case Study is intended to identify and explore the feasibility of one possibility to help fund the MBTA's bus maintenance facility resource needs: The potential of whether new evolving battery electric bus (BEB) technology may help provide the basis of a Public-Private Partnership (PPP) in which a private real estate development sector would finance/construct a new all BEB bus maintenance facility as part of a larger, multi-use, private-sector development project.

Battery Electric Bus Industry Overview

The current focus of the BEB industry is on vehicle technology developments and scaling up production to meet growing demand. Although some agencies have established targets and goals toward significant bus fleet electrification, programs for large-scale BEB operations have yet to be launched.

Transit industry interest in BEBs has been increasing over the past decade and will likely continue to accelerate. Most BEBs currently in service in North America are proof of concept or test fleets. Though these early applications have familiarized agencies with the technology, generally BEBs are viewed as a major component of future transit bus fleets, not the fleets of today.

Agencies who have maintained a small BEB fleet, generally do so out of maintenance facilities that service traditional bus fleets without major facility modifications beyond the installation of required charging infrastructure. Facility and infrastructure requirements for BEB fleets are just beginning to enter the discussion as large fleet procurements are considered. The industry has not yet reached consensus on what, if any, differences in maintenance facility layout, design, or function will be necessary to support large BEB fleets.

As more agencies adopt BEB fleets, significant industry focus will be concentrated on the logistics of operating large fleets of BEB vehicles in revenue service, including vehicle fueling, storage, and scheduling.

North American Market

The BEB industry in North America has been in a state of accelerating evolution for over a decade. In the early 2000s, the transit bus industry began to evaluate short-range BEBs, which are intended to operate for distances of less than 50 miles. Short-range BEBs are recharged in approximately 5 to 10 minutes during layovers or other scheduled downtime before returning to service. Early entrants to the market, such as the Proterra EcoRide, have been well received by transit properties but, because of their range, are limited to specific routes and applications.

In the last 5 years, continuing advances in battery technology have resulted in improved BEB vehicle range, performance, and reliability. Long-range BEBs can travel several hundred miles between charges, but the larger battery size requires between 2 to 4.5 hours of high-rate charging. Current industry trends toward long-range bus fleets are likely to continue. Therefore, this study focuses on long-range BEBs unless otherwise indicated.

Long-range BEBs are more compatible with traditional transit operations. Advances have led to an increasing number of transit authorities that are evaluating them as a possible future alternative to fossil fuel vehicles. Agencies are ideally looking for BEB vehicles that can match the operating range and performance of traditional transit buses, since this would result in minimal impact to operations. It also would avoid the need to purchase additional BEBs to maintain the current level of service.

The price of a conventional diesel or diesel-hybrid transit bus is currently $750,000 (approximately) each, a number that varies between manufacturers based on agency requirements, production quantity, performance parameters, accessory systems, engineering required, and other factors. BEB costs are trending downward as shown in Table 3. Once use is more commonplace, economies of scale will take effect. Early model BEBs were approximately $1 M per bus, not including infrastructure. Current BEB offerings require initial investment premiums compared to conventional buses. Costs associated with electrical power and charging infrastructure for BEBs continue to be significant.

The relatively high cost of BEBs has been primarily driven by battery cost. In recent years, batteries have become safer, yield larger capacity, and cost less to manufacture then in previous years. According to *Battery Electric Buses – State of Practice* (Transit Cooperative Research Program (Transit Cooperative Research Program [TCRP], 2018), from 2009 to 2015, Foothill Transit's per bus [BEB] purchase cost dropped from $1.2 M to $789,000. A BEB purchase cost timeline trend, from 2014 to 2018, is shown in the Table 2.

Table 2: Summary of Battery Electric Bus Purchase Costs Over Time

Type	Cost TCRP$)	Year	Agency	Source
40' Proterra E2	700,000	2018	DC's National Mall	No Need to Wait: Electric Buses Are Cost-Competitive Transit Buses Today (CleanTechnia.com)
40' Proterra E2	784,000	2017	King County Metro	Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet (Page 43)
40' Proterra E2	797,882	2016	King County Metro	Transit Cooperative Research Program (TCRP) Battery Electric Buses - State of Practice (2018)
40' Proterra E2	789,000	2015	Foothill Transit	Transit Cooperative Research Program (TCRP) Battery Electric Buses - State of Practice (2018)
40' Proterra E2	950,000	2014	The City of Seneca	Transit Cooperative Research Program (TCRP) Battery Electric Buses - State of Practice (2018)

The current base cost of BEBs are decreasing and are getting closer to cost competitive pricing with diesel-electric hybrid, compressed natural gas (CNG), and conventional diesel buses. Table 3 provides a cost comparison table for buses using these energy storage/drive technologies.

Table 3: Battery Electric Bus Pricing Comparison to Conventional Vehicles

Type	Cost ($)	Year	Agency	Source
Diesel	553,760	2015	MBTA	Jacobs Archives
CNG	585,990	2015	MBTA	Jacobs Archives
Diesel-Hybrid	769,000	2017	King County Metro	Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet (Page 43)
BEB	784,000	2017	King County Metro	Feasibility of Achieving a Carbon-Neutral or Zero-Emission Fleet (Page 43)
Diesel-Hybrid	774,000	2018	MBTA	MBTA FMCB approval to purchase 194 New Flyer diesel-hybrid buses with contract total amount: $150,163,886. FMCB 10/1/18 meeting

In response to increased demand, the North American BEB industry is showing signs that it is can begin to support larger-scale procurements of BEBs. However, further vehicle production capability and battery/charging infrastructure improvements will be required to support large-scale fleet procurement and operation.

North American Manufacturers

The conventional transit bus market has undergone significant consolidation over the past decade. Currently, three major builders – New Flyer Industries, Nova Bus, and Gillig – supply the vast majority of transit buses in North America. Of these manufacturers, New Flyer Industries is the largest transit bus and motor coach manufacturer and parts distributor in North America and has the most mature BEB product offering of any legacy bus builder.

Over the past several years, bus builders specializing in BEBs have begun to emerge and develop market share as well. The three manufacturers with the most mature BEB offerings have delivered nearly all BEBs currently operating at North American transit properties:

Build Your Dreams Auto Co. (BYD) of Shenzhen, China is a subsidiary of BYD, a global leader in rechargeable batteries. BYD manufactures a variety of battery vehicles including 30, 35, 40, and 60-foot buses. BYD reports delivering tens of thousands of BEBs worldwide, including several hundred in North America. BYD's North American operations is based near Los Angeles.

New Flyer Industries (NFI) of Winnipeg, Manitoba is the largest transit and coach bus manufacturer in North America. NFI has well-established 35, 40, and 60-foot bus models, and is using these as a foundation for their BEBs. In addition to Winnipeg, NFI has transit bus manufacturing facilities in St. Cloud and Crookston, Minnesota and Anniston, Alabama.

Proterra Inc. of Burlingame, California was founded in 2004, specializing in the design and manufacture of BEB transit buses and electric charging systems. Proterra's first entry to the market was the EcoRide, a short-range, quick charge bus, the first of which were delivered in 2010. Proterra introduced their Catalyst series in 2013 and offers several configurations including short-range 35-foot and 40-foot buses, as well as a long-range 40-foot bus. Proterra has delivered approximately 130 buses in North America to date. Proterra has manufacturing facilities in Greenville, South Carolina.

While BYD, NFI, and Proterra are currently the most mature BEB manufacturers in the North American market, other builders have recently entered the market and may warrant consideration.

- Gillig Corporation (San Francisco, California) is a well-known conventional bus builder and recently announced their offering of a 40-foot BEB with a Cummins electrified drive.
- Nova Bus (Quebec, Canada) is an established builder in the industry with plans to develop a robust BEB program for the North American market.
- Van Hool (Belgium) is an established manufacturer in the European market that is currently building a manufacturing location in Tennessee. They have built one BEB using Proterra's propulsion system under a licensing agreement.
- GreenPower Motor Company (Vancouver, Canada) builds electric buses and has operations in Vancouver and Porterville, Canada since launching a first all-electric transit bus in 2014.

Summary of Available Offerings

Many transit agencies rely on FTA matching funds (covering up to 80 percent of the vehicle cost) to assist with new vehicle procurement. To be eligible for FTA funding, production bus models must have passed testing performed by the Altoona Bus Research and Testing Center in Altoona, Pennsylvania. Testing scope includes safety, structural integrity and durability, reliability, performance, maintainability, noise, fuel economy, and emissions. These standardized tests are applied to new bus models to allow comparable assessments of transit vehicles and ensure vehicles are likely to perform in service through their FTA minimum life, generally 12 years.

To date, BYD, New Flyer, and Proterra have bus models that have completed Altoona testing. These models are therefore eligible for FTA matching funds under current rules for fleets larger than five buses (procurements of five or fewer are considered demonstrations, which are exempt from these requirements).

Test reports and other information for bus models currently undergoing testing are not available. Focus was placed on commercially available and Altoona-tested 40-foot BEBs. However, manufacturers have indicated testing is underway or scheduled for additional bus models including 60-foot BEBs.

Current Massachusetts Initiatives

There are several pertinent Massachusetts initiatives underway with a focus on studying, testing, and/or procuring all-electric transit buses at MassDOT, MBTA, and Regional Transit Authorities (RTAs). MassDOT's ongoing 40-foot BEB Feasibility Study, and upcoming MBTA testing of five 60-foot New Flyer BEBs are eagerly anticipated.

Also of interest is the MBTA's recent procurement and ongoing testing of a 60-foot extended range hybrid for operation in the Silver Line Transitway tunnel.

MassDOT 40-foot Battery Electric Bus Feasibility Study

To help achieve emission reductions required under the 2008 Massachusetts Global Warming Solutions Act, MassDOT initiated a study in late 2017 into the feasibility of operating a fleet of BEBs in Boston. This study specifically centers around the feasibility of alternative propulsion 40-foot transit vehicles, which make up approximately 90 percent of the MBTA's active bus fleet.

This scope for the BEB feasibility study includes:

- State of the industry for 40-foot BEB and charging technologies
- Determining which MBTA garages and bus routes would be best suited for operating BEBs
- Developing a roadmap for large-scale deployment of 40-foot BEBs within the MBTA
- Understanding total ownership and operations costs for BEB fleets
- Infrastructure and facility changes required to support 40-foot BEB fleets
- Developing guidance for other transit agencies and fleet owners to evaluate the feasibility of deploying 40-foot BEBs

The report is expected to be published in early 2019 and should help guide the MBTA and other agencies as they consider the large-scale adoption of BEBs.

MBTA Silver Line Battery Electric Bus Testing Program

The MBTA has identified the Silver Line as a candidate for operating BEBs due to the Silver Line Transitway tunnel. Silver Line routes operating through the Transitway tunnel serve Logan Airport, the Seaport District, and recently added routes to Chelsea. The Transitway tunnel requires that buses produce no emissions for over 2 miles as they descend to South Station and back. The dual-mode articulated buses that currently support these routes are nearing the end of their useful life.

The MBTA is currently purchasing a fleet of five, 60-foot BEBs from New Flyer under a Federal Low/No Emissions program grant. Delivery of these five buses is expected in the summer of 2019. Once received, MBTA will test these buses on the Silver Line to evaluate performance in Boston's demanding transit environment. Testing will include a review of vehicle range, charging requirements, infrastructure challenges, and other relevant factors.

In parallel, MBTA is evaluating a New Flyer extended range diesel-hybrid bus, which was delivered in September 2018. This bus, referred to as the 45th bus, is equipped with a high capacity battery that enables it to operate in the Transitway tunnel.

Data gathered on these buses will inform Boston's future decisions around adoption of BEBs. MBTA will focus on winter-weather performance issues due to inherent challenges faced with battery technologies in cold climates.

Battery Electric Bus Efforts by Massachusetts Regional Transit Authorities

There are several local efforts underway by Massachusetts RTAs to procure, study, and test the concept of BEBs in revenue service. These programs are relatively small, and no RTA has pursued a large-scale procurement to date. In many cases these programs focus on smaller buses or short-range BEBs, which would not be applicable for MBTA service. Reference Table 4 for a summary of RTA programs underway.

Table 4: **Summary of Massachusetts Regional Transit Authority Battery Electric Bus Programs**

Massachusetts RTA	Overall Fleet	BEB Fleet				Comments
		BEB Fleet	Service	Mfr(s)	Model(s)	
Worcester Regional Transit Authority (WRTA)	52 buses	6	6 years	Proterra	(5) EcoRide (35 ft) (1) Catalyst FC (40 ft)	WRTA operates short-range/on-route fast charge BEB models
Vineyard Transportation Authority	36 buses	6	<1 year	BYD	(2) Electric Bus (30 ft) (4) Electric Bus (35 ft)	First Massachusetts community to commit to an all-electric fleet
Pioneer Valley Transportation Authority (PVTA)	186 buses	3	2 years	Proterra	(3) Catalyst FC (40 ft)	PVTA uses two fast chargers and one depot charger; plans to add an additional depot charger

Notes:

ft = foot (feet)
Mfr(s) = manufacturer(s)

MBTA Better Bus Project

With 450,000 daily trips within 50 communities surrounding Boston, MBTA operates a complex bus network. MBTA has recognized that the overall network needs to be optimized and tailored to suit the communities and people served. Through extensive public outreach and transportation planning, MBTA is striving to improve the bus network and meet requirements of the Service Delivery Policy. Research, planning, and design for bus network improvements and changes will be conducted through later 2018. The Better Bus Project expects to implement a variety of planned changes to the bus network in 2019. The proposed PPP development at the MBTA's Albany Street location including the use of BEB vehicles is aligned with and supports the Better Bus Project's aim to increase the effectiveness and overall efficiency of the bus network.

Current Peer Agency Initiatives

Many of the MBTA's peer agencies in North America have programs underway to explore the feasibility of large-scale BEB deployment. Similar to local Massachusetts peer agency efforts, the majority of programs planned or underway are small-scale prototype programs intended to evaluate vehicle performance, reliability, and operations impacts in a service environment.

To date, no peer agencies have built facilities dedicated to servicing large-scale BEB fleets. Some larger agencies such as Los Angeles County Metro Transit Authority (LACMTA), Toronto Transit Commission (TTC), and King County Metro Transit (KCM), have announced aggressive goals for fleet electrification in response to local environmental or political directives. These agencies are currently developing plans to meet these electrification objectives. As the industry progresses, the validity of large-scale procurements becomes more realistic. Reference Table 5 for a summary of efforts by larger peer agencies.

Table 5: **Summary of Peer Agency Battery Electric Bus Programs**

Peer Transit Agency	Overall Fleet	BEB Fleet			
		Target	In-Service	Mfr(s)	Comments
New York Metropolitan Transportation Authority (MTA)	5700+	25 (2019)	5	NFI and Proterra	• Lease agreements from 2 manufacturers for 3-year test period • Combination of depot charging and on-route charging
Los Angeles County Metro Transit Authority (LACMTA)	2500+	210 (2020)	0	NFI and BYD	• Established goal for 100% zero emissions buses by 2030 • Current orders for up to 210 BEB • Mix of 40-foot and 60-foot BEBs
Toronto Transit Commission (TTC)	2000+	60 (2020)	0	NFI, BYD, and Proterra	• Directive to procure only zero-emissions buses starting in 2025 • Initial pilot purchase for 30 buses (10 buses from 3 manufacturers) expected in 2019 • Up to 30 additional buses to be delivered in 2020

Peer Transit Agency	Overall Fleet	BEB Fleet			
		Target	In-Service	Mfr(s)	Comments
King County Metro Transit (KCM)	1900+	350 (2025)	11	NFI and Proterra	• Bus facility design and master planning activities underway • Master bus plan calls for 125 BEBs by 2025, and conversion of entire fleet to zero emissions by 2040
Southeastern Pennsylvania Transportation Authority (SEPTA)	1400+	35 (2020)	0	Proterra and NFI	• 25 Proterra BEB vehicles under FTA Lo/No grant to enter service by June 2019 • Additional Lo/No grant for 10 additional BEBs from New Flyer granted in 2018 • Depot charging and electrical infrastructure installed
Dallas Area Rapid Transit (DART)	600+	7 (2018)	7	Proterra	• Short-range 35-foot buses for convention center and downtown routes
Nashville Metropolitan Transit Authority (MTA)	130+	11 (2019)	9	Proterra	• Plans to purchase 2 additional fast chargers

Battery Electric Bus Technology and Transit Operations

Peer agencies have reported learning many lessons from their respective BEB pilot programs and have identified several challenges facing the BEB industry. Transit agencies are generally concerned with BEB vehicle range and ability to replace conventional fleets. Cold weather cities are particularly concerned with degradation of range in colder temperatures.

To address concerns, manufacturers continue to make improvements in battery technology, with reductions in weight and increases in energy capacity. This trend is expected to continue as time passes, and the demand for longer-range buses increases. Agencies would prefer that BEB vehicles can replace traditional vehicles on a one-for-one basis, without increasing fleet size.

As the BEB industry grows, agencies recognize the need to focus on manufacturing quality, throughput capacity, and supply chain operations when selecting manufacturers for BEB programs.

Agencies appear confident that maintenance facility requirements are generally similar for BEBs and conventional transit vehicles. While tooling and techniques may be different, facility envelopes and major equipment are likely to be compatible between technologies. Charging and electrical power infrastructure are recognized as a key focal point as large-scale deployments are considered.

Vehicle Range and Cold Weather Performance

Transit authorities have built their operations and overall service plans around the performance of conventional (internal combustion engine) buses which typically have a minimum operating range of 350 miles (often more) on each tank of fuel. Many transit properties, including MBTA, do not have fuel gauges on their bus fleets, because most vehicles are fueled prior to the start of each service day and range significantly exceeds the daily demand.

Advertised ranges for long-range BEBs vary significantly depending on the manufacturer and the specific configuration of the bus batteries. Different manufacturers currently state ranges as low as 250 miles and as high as 400 miles. However, range estimates published under current test protocols generally exclude heating, ventilation, and air conditioning loads, which are a major driver of any electric vehicle range, including both private automobile and public transit BEB vehicles.

Electric vehicle range can be significantly reduced in cold weather, even in temperatures above freezing. On cooler days, significant battery energy is required to warm the passenger compartment from the overnight cold soak to a comfortable operating temperature. This past winter, with electric vehicle ownership at an all-time high, reports from owners who experience a significant decrease in driving range are widespread, compounded by the use of the vehicle's interior climate control. New research published by AAA in February 2019 shows that for outside temperatures of 20°F and the HVAC system being used to heat the inside of the vehicle, the average driving range is decreased by 41 percent from conventional published estimates. AAA found the cold weather is not the only climate factor that can influence driving range. AAA's research also found that when outside temperatures heat up to 95°F and air-conditioning is used inside the vehicle, driving range decreases by 17 percent on average. Currently, EPA driving range estimates for private automobiles published are calculated for both urban and highway driving using an outside ambient temperature of 75°F. When driven under more extreme ambient conditions, electric vehicle owners are increasingly experiencing the large role that outside temperature plays in diminishing published driving range.

In the public transit BEB business space, both vehicle manufacturers and property operators confront similar weather-related challenges to range now being increasingly felt in the electric automobile marketplace. Some properties are considering supplemental diesel heaters to address cold weather operations and range issues. In fact, a new BEB bus fleet recently deployed by the Duluth (Minnesota) Transit Authority were manufactured with a diesel auxiliary heater on each vehicle. Other properties have stated that diesel heaters would defeat the purpose of a battery bus fleet.

In terms of reduced driving range in extreme ambient conditions, an FTA research report published in February 2018 studied, in relevant part, the impact of cold temperatures on range experienced by BEBs used in a demonstration project begun in 2010 by the King County Metro transit agency in Seattle, Washington. The FTA found the average fuel economy of the BEBs corresponded well to the seasonal variation in ambient air temperature. BEB fleet fuel economy varied from a high of 17.6 MPDGE (miles per diesel gallon equivalent) in September (temperate month) to a low of 13.3 MPDGE in December (coldest month), with a general decrease of 32% in range due to cold weather, a reduction comparable to and consistent with electric vehicle automobiles as revealed in the recent study published by AAA.

One property noted that, due to their relatively mild winters, they currently store nearly all vehicles outdoors. However, due to battery vehicle range issues, indoor storage of BEBs to both prevent cold-soaking overnight and to minimize start-of-shift HVAC usage and resulting impacts to battery life and vehicle range will be required for colder climate properties such as Boston. Also see "Table 7: BEB Industry Challenges" for additional discussion of indoor storage benefits and opportunities.

During performance evaluation, it is currently incumbent upon the individual transit property to model and evaluate BEB range across different platforms, routes, weather conditions, driver habits, and more.

Resolving this performance uncertainty is a current focus of the industry and will eliminate a significant barrier to large-scale BEB deployment.

Weight and Passenger Capacity

Long-range battery buses are generally heavier than conventional buses due to the weight of the battery packs. Some available BEB vehicles have limited passenger carrying capacity due to the additional weight of larger batteries. Heavier vehicles also may have a greater impact on road infrastructure and maintenance facility needs. However, developments in battery technology have made agencies hopeful that future BEB vehicles will be equipped with lighter weight, higher capacity batteries that would eliminate current vehicle weight concerns.

Charging Technology

Conventional buses can be refueled within a matter of minutes and can reenter service. Long-range BEBs by contrast can take several hours to fully recharge. This presents a significant change to the operating model currently employed at most major transit agencies in North America. It is anticipated that demand for BEB smart charging systems will drive development of technologies that will manage charging logistics for large fleets of BEB vehicles and optimize power usage.

BEBs, depending on battery, state of charge, and charging method, currently take between 2 and 4.5 hours at a high-rate charge to reach full capacity. At the depot, future BEB facilities will most likely utilize overhead, plug-in, and/or inductive charging technologies that are still being developed. At this time very early in the development of these technologies, it is not possible to determine which charging methods will be more prevalent, but due to the inefficacies inherent for inductive charging it is reasonable to assume that overhead or plug-in technologies will prevail. Table 6 contains an overview of available charging technologies for BEB vehicles.

Table 6: Battery Electric Bus Charging Technology

Charger Type	Image	Max. Charge Rate (kW)	Benefits	Challenges
Plug-In (electric cable plugs into bus)		100 – 150	• Proven technology • Few moving parts	• Manual connection required • Limited ability to automate • Lower charge rates • Cords/equipment at ground level
Overhead (automated overhead gantry)		300 – 500	• Compatible with rapid charging • Partial to full automation • No equipment at ground level	• Developing technology • Moving parts require maintenance • Susceptible to adverse weather if placed outdoors
Inductive (charger integrated with road surface)		50 or 200	• No physical contact • Few moving parts • Full automation potential	• Developing technology • High installation costs • Maintenance access • Lower charge rates

Note:

kW = kilowatt(s)

Battery Electric Bus Existing Facilities Comparison

Maintenance facilities, particularly in dense urban environments, are purpose-built to reflect the needs of the transit agency, the limitations of the available land, and the interests of community stakeholders. Peer agencies do not appear to have established designs for BEB maintenance facilities. The focus for future development of BEB facility designs should center around the power infrastructure and charging operations required to support BEB fleets.

Local Maintenance Facility Reviews

MBTA's Albany Street Garage is a legacy facility built in 1941. Layout, roof clearances, and size do not appear in line with modern garage standards. Approximately 120 conventional diesel buses are maintained in this space. There is limited indoor storage for buses, with the majority of buses stored outside in the elements. Specific fleets that can operate out of this space are limited by ceiling and door heights.

MBTA's North Cambridge Garage was built in 1979 and is specifically for the maintenance of Electric Trolley Buses. Twenty-eight vehicles are maintained out of this space. The facility is generally more modern in design with basement storage, pull-through bay design, and higher doors/ceilings. All buses are stored outside. Functionally, there are no major differences between the North Cambridge garage and a modern conventional bus garage that are specific to the maintenance of electric buses.

WRTA's new bus garage is a modern bus maintenance facility, built in 2017. All maintenance activities, bus storage, and other traffic at the facility is indoors under the same roof. This facility is responsible for the maintenance of all buses and paratransit vehicles in the WRTA fleet, including six BEBs. Staff emphasized the importance of adequate overhead lifting and fall protection to facilitate roof work. This equipment is typical in any modern bus maintenance facility.

Peer Agency Input

Further input was sought from the industry through a peer review conference call. Representatives from various peer agencies and industry stakeholders participated in the call to discuss specific experience and concerns centered around BEB maintenance and facilities.

There was significant consensus reached through these discussions surrounding the challenges with BEB fleet operations. Participating agencies agreed that the largest challenges with operating BEBs on a large scale are associated with charging infrastructure and logistics. A condensed summary of findings are as follows:

- Agencies are just beginning to explore potential differences between ideal large-scale BEB maintenance facilities and existing traditional facilities; BEB pilot programs to date have not established these differences.
- There is an increased focus on overhead lifting equipment and fall protection, due to more roof mounted equipment on battery buses.
- Some hazardous materials storage is needed (such as oil, hydraulic fluid), but less for BEBs than for conventional buses.
- BEB facilities will not require infrastructure for conventional bus fueling (diesel or CNG).
- BEB facilities will require additional infrastructure for bus charging.

- BEB charging is assumed to take place in the bus parking area, which will represent a change in operating dynamics.

While PPP projects, such as the proposed development of the MBTA's Albany Street location, have not been completed in North America, forward-thinking agencies are considering innovative approaches to fund new facilities and infrastructure. San Francisco Municipal Transportation Agency (SFMTA) recently released a Request for Proposal (RFP) to solicit industry interest in pursuing a public private partnership (PPP) to develop a new BEB maintenance facility integrated within a larger mixed-use development. SFMTA is exploring this alternative funding method for building new facilities on existing desirable plots of land already owned by the agency. Successful execution of this program may drive further interest and pursuit of these types of PPP mixed-use developments leveraging agency land holdings in North America.

Charging Infrastructure Considerations

The industry has experience mainly with small-scale deployments of BEB fleets that do not require major power infrastructure upgrades. However, power demands increase with fleet size, and the infrastructure requirements of large BEB fleets has yet to be determined and will be affected heavily by local factors.

However, as some agencies begin to deploy larger fleets, more significant electrical infrastructure upgrades are being required. In support of their 25-bus program, SEPTA was required to install a 2-megawatt (MW) sub-station at their maintenance facility to support charging demands. SEPTA is currently taking delivery of this fleet. As larger BEB deployments are executed, significant facility infrastructure investments and upgrades will be required.

The power needs of a large-scale BEB facility are being evaluated by the industry through these demonstration programs. Due in large part to a lack of real-world data, the power needs of a medium-to-large BEB fleet are still being developed. Factors such as daily miles traveled, route profiles, and times of day vehicles are available for charging can significantly impact power needs. Agencies will need to individually optimize operations logistics behind charging BEB fleets based on local and regional electric rates, peak power surcharges, and service requirements.

In addition to depot charging methods, agencies are exploring on-route or opportunity charging to supplement depot charging, extend vehicle range, and reduce central depot power demand. Facilities that operate fleets that use significant on-route charging could require reduced-scale depot power infrastructure.

Costs of electrical power, particularly surrounding demand charges for peak-use periods, will impact operating budgets as large battery fleets are adopted. Transit properties will need to work with their electric utility providers early in the large-scale fleet electrification process to discuss infrastructure upgrades, rate structures, and more. In general, overnight charging is perceived as a method to avoid peak demand surcharge rates.

Near Future Battery Electric Bus Industry Trends

Transportation agencies appear cautiously optimistic about the future of BEB technology and charging infrastructure developments. The industry does not yet offer established roadmaps to meet agency objectives for fleet electrification. Many agencies have started to procure smaller BEB fleets for evaluation and some have aggressive future goals for fleet electrification. These small-scale pilot BEB programs are expected to continue for the next few years until large-scale BEB programs become common.

This section presents some known considerations to be addressed as part of large-scale deployment and offers some predictions about how the industry may address these considerations.

Major Considerations and Challenges

Inherent differences between BEB and conventional fleets require transit agencies to grapple with fleet electrification challenges. Table 7 highlights critical high-profile challenges that the BEB industry needs to overcome.

Table 7: BEB Industry Challenges

Issue	Conventional Fleet	BEB Fleet	Impact
Maintenance	• Typical maintenance for large vehicles • Facility ventilation for vehicle exhaust	• Very similar to conventional bus maintenance • No vehicle exhaust	Facilities: • Marginal differences in maintenance techniques and tooling • No major changes to maintenance facility envelope/layout required
Vehicle Range and Cold Weather Performance	• 350+ miles • Typically exceeds required daily range	• 200 to 400 miles in ideal conditions • Significant reduction in range due to cold weather	Operations: • Manage route profiles and fleet logistics for range restrictions • Potential fleet size increase to meet daily service needs Facilities: • Indoor storage required to preserve range in colder climates
Fueling/ Charging	• Buses can be fueled in 5 to 10 minutes and staged for next service • All buses in storage area are ready for service	• Buses take 2 to 5 hours to charge • Charging occurs in the storage area • Some buses in storage area may not be ready for service • Strategic parking/ shifting of buses required	Operations: • Elimination of fossil fuel use • Developing smart charging systems will optimize use of available power Facilities: • Vehicle charging must be done in indoor fleet storage area • Overhead charging equipment may require additional facility height clearances
Power Infrastructure	• Fuel supply chain and logistics already in place • Typical industrial electrical hookups	• Large-scale fleet power requirements are not established • Significant backup power generation required for redundancy	Operations: • Charging network potentially affects vehicle availability Facilities: • Additional electrical/facility infrastructure upgrades and local utility planning required • Backup power generation capacity required varies with fleet size

Transit Bus Emissions

Based upon recent and developing BEB technology trends, the future outlook of BEBs appears to be beneficial and offers significant environmental benefits compared to traditional propulsion methods. A variety of studies have concluded that BEB technology offers significantly reduced localized emissions compared to diesel, natural gas, and diesel-electric hybrid transit buses. Based upon assumptions for life cycle operation of transit buses, the Union of Concerned Scientists offer the data presented in Figure 1. The per mile CO_2e (CO_2 equivalent) emissions for BEB are significantly lower than all other traditional transit bus propulsion technologies. Note that national average emissions for electricity generation were used in this analysis.

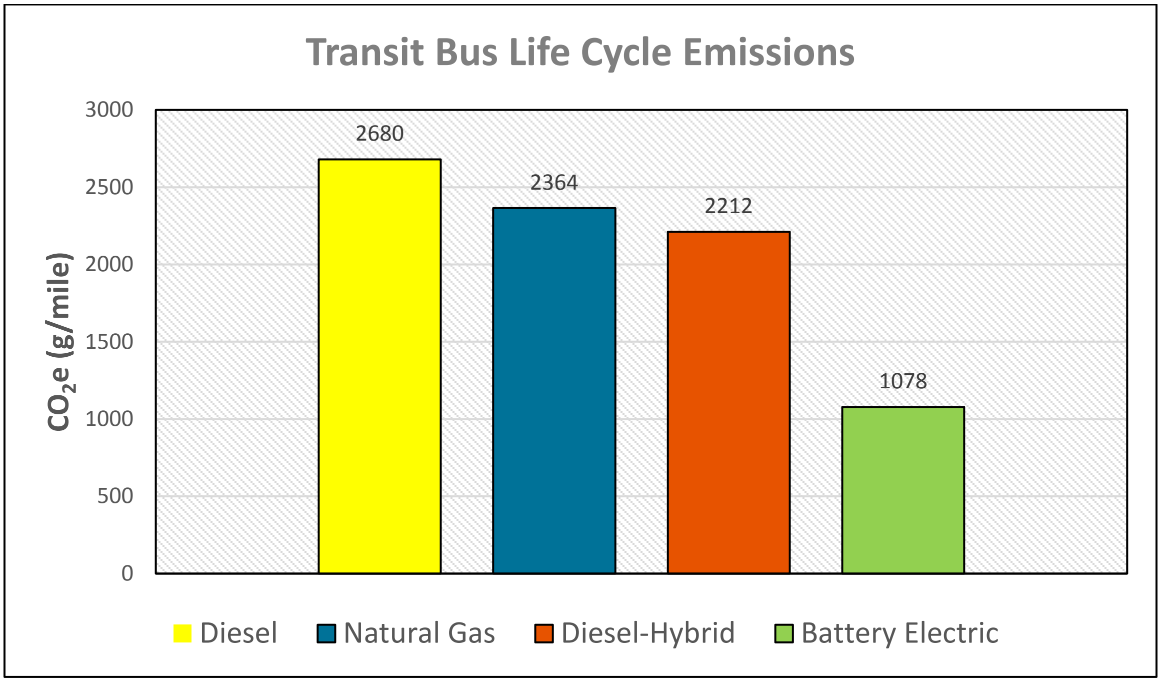

Figure 1: Case Study Option – Albany Street Conceptual Mixed-Use Development Layout. Adapted from "Electric vs. Diesel vs. Natural Gas: Which Bus is Best for the Climate?", by Jimmy O'Dea, 2018, July 19, *Union of Concerned Scientists*. Retrieved December 10, 2018, from https://blog.ucsusa.org/jimmy-odea/electric-vs-diesel-vs-natural-gas-which-bus-is-best-for-the-climate.

Possible Industry Actions

Based on local regulations and announcements to move toward all zero-emissions transit bus procurements, agencies demand for BEB vehicles has increased dramatically. This demand is placing pressure on manufacturers to dramatically increase production capacity. There will be a variety of technical, supply chain, and logistical obstacles that must be addressed as part of this production ramp-up. Based on a survey of industry builders, existing BEB programs, various local initiatives, and peer agency experience, it appears likely that significant progress toward meeting demands for large, revenue service-ready BEB fleets will be made within the next 5 to 7 years. The following areas are likely to see significant development over this time period.

Vehicle Range will likely continue to increase. As battery technology continues to evolve in response to the transit and other sector demands, BEB range should improve. Given past trends in battery technology, weight and size reductions are likely to occur in conjunction with increases in capacity.

If sufficient battery capacity can be incorporated into BEBs (without increasing weight), **cold weather performance** issues will become less a significant factor to operations.

Charging technology standards will be widely adopted by the industry. Standard charging interfaces will be critical to support large deployments and bus manufacturers and system suppliers are in active discussions around this issue. Standardizing charging interfaces for the industry are expected to yield results as market demand increases.

Smart charging infrastructure will continue to evolve as larger fleet deployments create market need for the technology. For a large fleet of BEBs, smart charging technology will be critical to managing fleet charging and minimizing operations impacts.

Overhead charging will likely become the norm for large deployments. Overhead charging equipment lends itself to more automation, takes up less real estate in limited vehicle storage areas, and is less prone to accidental damage. This likely will make overhead charging a preferred method for large fleet applications.

Manufacturing capacity and supply chains will mature in response to existing and growing demand. BEB manufacturers currently have multiyear backlogs. As BEB production becomes a larger part of the industry, supply chains will be better able to respond to demand and lead times will decrease as a result, making BEB comparable to conventional buses.

Electrical power demands will become clearer as transit agencies and utilities gain experience on medium and large BEB deployments. As information improves, utilities and transit agencies will be better able to plan for future infrastructure upgrades to support larger fleet rollouts.

Battery Electric Bus New Maintenance Facility Conceptual Design

This section presents a conceptual design for a BEB maintenance facility, located on the parcel currently occupied by the MBTA's Albany Street bus garage. The conceptual maintenance facility would have the capability to complete all maintenance activities that are the current responsibility of the existing facility.

Available information on BEB fleet operation in the North American market is currently limited to small scale procurements and test programs. The lessons learned from these programs by peer agencies should be assessed with the understanding that the facility requirements and challenges may not yet be fully appreciated. Near future large-scale procurements of BEB vehicles will provide valuable insight for facilities and infrastructure standards and requirements moving forward.

BEB maintenance facility best practices for BEBs will become more widely understood as large deployments become more common. While industry consensus is that the maintenance facility needs for BEBs and conventional vehicles are quite similar, large-scale deployments will prompt more nuanced understanding of these differences.

Changes in the layout of maintenance bays, utilization of building roof space to support electrical equipment, and configuration of parking areas to allow operational flexibility are possible areas for marginal impacts. However, the building envelope for an all BEB maintenance facility is expected to be fundamentally similar to a modern conventional bus maintenance facility.

This scenario would provide the same level of neighborhood transit support as the existing facility and also would reduce localized emissions and hazardous materials onsite. Maintenance responsibilities and capabilities of this conceptual facility would remain unchanged from levels provided currently at the Albany Street bus maintenance facility.

Space Needs Assessment

This section describes the core assumptions used in developing the conceptual maintenance facility design for this conceptual design.

Fleet Size

The MBTA's existing Albany Street garage provides storage, fueling, and maintenance support for 118 40-foot diesel buses. The conceptual facility design seeks to support a similar sized fleet of 40-foot BEBs.

Space Needs

Staffing levels at the facility are assumed as follows:

- Maintenance staff: 15 to 20 per shift (including supervisory)
- Transportation staff: 100 for peak service (including supervisory)

Not all buses assigned to a location are required for service each day, and service levels vary throughout the day. The staffing levels above represent the maximum staffing levels during peak times. The term maintenance staff includes supporting individuals such as cleaning staff.

Employee amenities such as lockers, break rooms, and restrooms are sized for these staffing levels. Personal vehicle parking is assumed for each employee, with a small number of additional spaces for visitors.

Office space for supervisory staff is preferred to be on the same level as the vehicle maintenance and storage. Employee amenities may be located on a mezzanine or second level. Parts storage and other support space can be located in a basement level if needed.

Service Bays

Industry best practices recommend approximately one (1) maintenance bay per nine (9) buses for conventional vehicles. In practice, many maintenance facilities fall short of this target. This is particularly true at legacy transit systems, which tend to have older infrastructure and more significant space constraints.

Maintenance needs for BEBs should in theory be reduced from conventional buses because they have fewer moving components. However, specific needs have not yet been established for large BEB fleet deployments. In addition to bus maintenance service bays, space is allocated for a bus wash system in the conceptual maintenance facility design.

The MBTA's current conventional 40-foot bus maintenance facilities range from 9 buses per bay to over 20. The average at MBTA is currently approximately 11 buses per maintenance bay. The conceptual design targeted a range of 9 to 12 buses per maintenance bay.

Battery Electric Bus Fleet Parking

The MBTA currently utilizes a combination of indoor, covered (roof without walls), and outdoor parking for buses. To improve vehicle longevity, industry best practices now focus on indoor vehicle storage. This is particularly true in cold weather cities, where the need to plow and remove snow from bus parking lots becomes both logistically challenging and costly.

As discussed, cold weather is particularly problematic for BEBs, which suffer from decreased range and performance if allowed to cold soak. In addition, BEB charging infrastructure will perform more reliably and require less maintenance if stored indoors.

Indoor storage and maintenance of buses has the added benefit of reducing neighborhood impacts due to noise and other factors. This can reduce resistance to siting of a standalone bus maintenance facility and would also increase the compatibility of a bus maintenance facility with a mixed-use development.

The conceptual design therefore assumes indoor parking is a requirement for BEBs.

In addition to service bays, a bus wash system is required and utilized before parking buses and storing for the next service.

Onsite Fueling

As discussed previously, the electrical power demands of BEBs vary significantly based on the specific operating environment, season/temperature, and route profile. Aggregate electrical loads for an all-BEB maintenance facility will be driven almost entirely by the recharging of BEBs, with the balance of the facility power demand dependent on the operating assumptions used.

Fueling a BEB fleet involves significantly different logistics compared to a conventional fleet and re-fueling each vehicle requires much more time. Fortunately, a BEB fleet should be able to leverage smart charging systems to optimize simultaneous vehicle charging, including during overnight storage.

Expected Power Demand from Utility

The overall power demand required to operate a fleet of BEBs is dependent upon many factors. Power modeling in conjunction with a fleet and facilities plan is important so the agency can then work with the utility company to ensure adequate power delivery capabilities before committing to a fleet of electric buses. Power modeling for a fleet of 112 buses, operating out of the newly designed BEB garage, has been conducted for this report using a worst-case, 6-hour overnight charging scenario. According to the power model, the peak power demand of this newly proposed mixed-use facility will require between 5-MW and 20-MW of power depending on operating assumptions, vehicle performance, and charging logistics. Detailed analysis of BEB test fleets in the MBTA operating environment will help inform overall power needs.

20-MW was selected as the design load for the conceptual BEB facility based on high-end assumptions for vehicle charging power requirements. This 20-MW target is considered for charging buses only. Therefore, some additional power reserve for the remaining functions of this multi-use facility may be needed.

Preliminary discussions with local utilities indicate that a 20-MW facility would require 2 or 3 redundant 13.8 kilovolt (kV) input lines. Utilities have stated that access to these input lines are available, but the integration costs will require further discussion and definition. Additional power infrastructure onsite would include 13.8 kV switchgears and appropriate transformers to provide the required 480-volt service.

In addition to the base substation power equipment, backup generators also will be needed to ensure emergency operation service. These generators will take space that needs to be accounted for during conceptual design. The overall footprint of an electrical room that can support this equipment is approximately 5,000 square feet.

Substation to Bus Charging Infrastructure

Charging of these buses will be completed while the they are in the storage lanes of the facility. Currently, the exact number and type of chargers is unknown. However, accommodating charging buses in the storage lanes will require overhead charging equipment.

Specific technology options for charging BEBs – plug-in, overhead, and inductive – are presented in a Table 7. The conceptual design assumes BEB charging will occur in the indoor vehicle parking area. The design further assumes that the charging equipment will be mounted overhead or in another manner that minimizes impact to floor space in the parking area. Overhead clearances required for any charging system need to be accounted for in the facility design.

Charging installations like these have not been widely implemented. However, development of these systems is viewed as a prerequisite for a large-scale BEB fleet deployment.

Best Fueling Practices

Buses will be charged when they are parked and out of service for the evening. These buses could be charged using an automated overhead gantry system that is operated in conjunction with smart charging software. This software will be designed to analyze the fleet, to determine an optimized charging plan, and to execute this charging plan in an automated fashion.

An approach will ensure each bus receives adequate charging, within the 6-hour storage window, and result in minimum garage personnel resources required during this time. The technology currently exists for a system like this, but currently it would be very expensive. Available chargers were developed for rapid charge buses, in an outdoor-all-seasons environment. There is a current industry initiative to redesign these chargers so this application would become more cost effective.

Site Master Plan and Building Conceptual Design

Replacing the Albany Street facility in kind with a modern bus maintenance facility and storage location for 112 BEBs was studied. In this scenario, the entire Albany Street plot will be utilized to accommodate necessary operational logistics, program elements, and technical requirements,

The project site lies within an Economic Development Area (EDA Central). This district zoning specifically does not allow a “bus terminal, bus storage or garage with dispatch”. Therefore, building a new bus maintenance and storage facility on this site is technically non-conforming. Zoning challenges would require zoning board approval.

The Floor Area Ratio of 6.5 indicates a high utilization of available land and the zoning requirements encourage market rate housing and some retail development. Zoning enforces maximum heights of 120 feet and 200 feet, as delineated on the zoning analysis plan (reference Appendix A). These parameters clearly reinforce the zoning use of high rise mixed housing.

This section describes the general requirements to be considered for this conceptual design, a BEB maintenance facility located at the MBTA's Albany Street parcel. These requirements assume the property will be exclusively used for bus maintenance. Requirements may require modification for a mixed-use project. Table 8 contrasts critical elements of the current maintenance facility to a BEB storage and maintenance facility.

Table 8: Conceptual Albany Street Battery Electric Bus Maintenance Facility

Critical Element	Diesel Maintenance Facility	BEB Storage and Maintenance Facility
Fleet Size	118	112
Maintenance Bays	6	10
100% Indoor Vehicle Storage	✗	✓
Service-Ready Vehicle Preparation	✓	✓
Bus Washing	✓	✓
Vehicle Maintenance	✓	✓
Bus Lifting	✓	✓
Diesel Fueling	✓	✗
BEB Charging	✗	✓

The conceptual site plan for this kind of facility consists of a single structure containing both maintenance and storage spaces. Nearly all vehicle travel between maintenance and storage locations would occur indoors. Bus traffic would enter and exit from Albany Street, and would be separated from personal vehicle traffic, which would enter and exit from Randolph Street.

The facility includes indoor storage for 112 buses (102 in the bus storage barn, and 1 additional bus in each of the 10 maintenance bays). There is limited outdoor storage for additional buses if needed on the west side of the building and on the northeast corner. Office space for supervisory staff would be located on the ground level, adjacent to the maintenance area.

Outdoor parking for approximately 55 passenger vehicles would be provided in the northwest corner of the lot (not pictured), where the current employee parking lot exists. See Figure 2 for a detailed layout of the conceptual BEB maintenance facility.

While Figure 2 depicts transit buses stored neatly and efficiently under a covered parking area, Figure 3 depicts typical bus parking at the existing Albany Street facility. Real estate in this downtown area is limited and use of existing land is maximized by parking buses close to one another. The proposed concetual BEB facility offers improved parking/storage compared to the existing conditions.

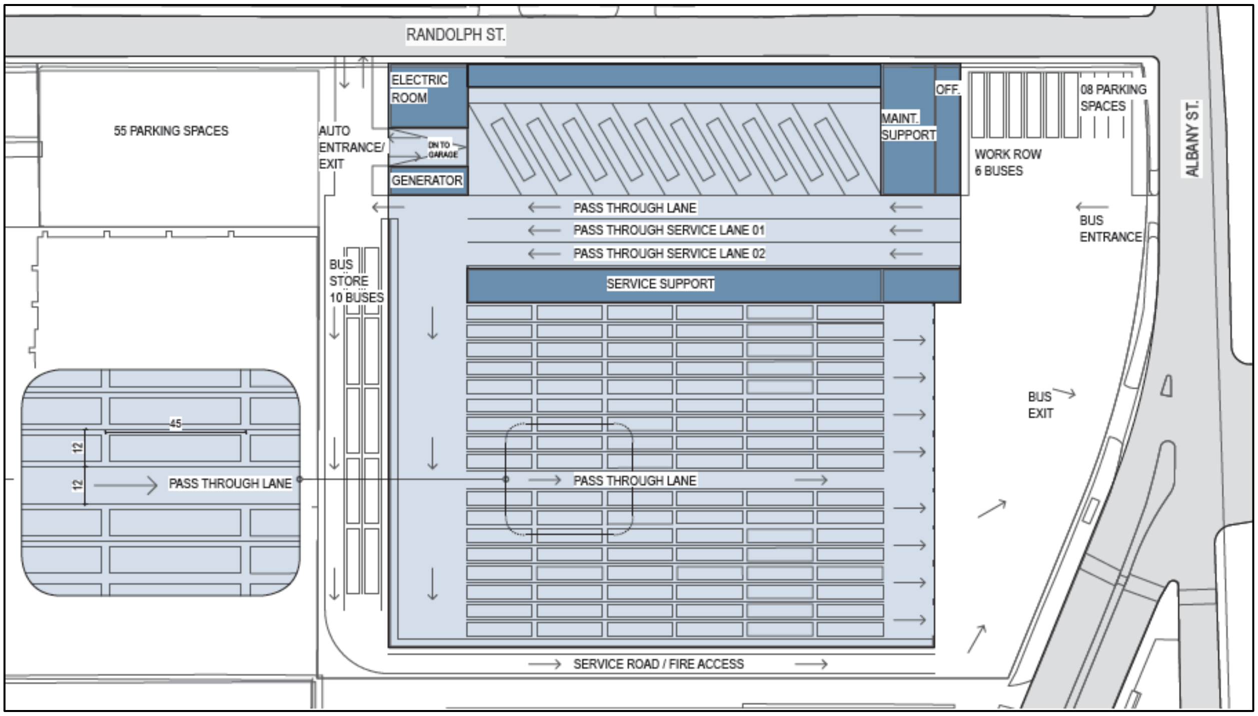

Figure 2: Albany Street Conceptual Battery Electric Bus Maintenance Facility Layout

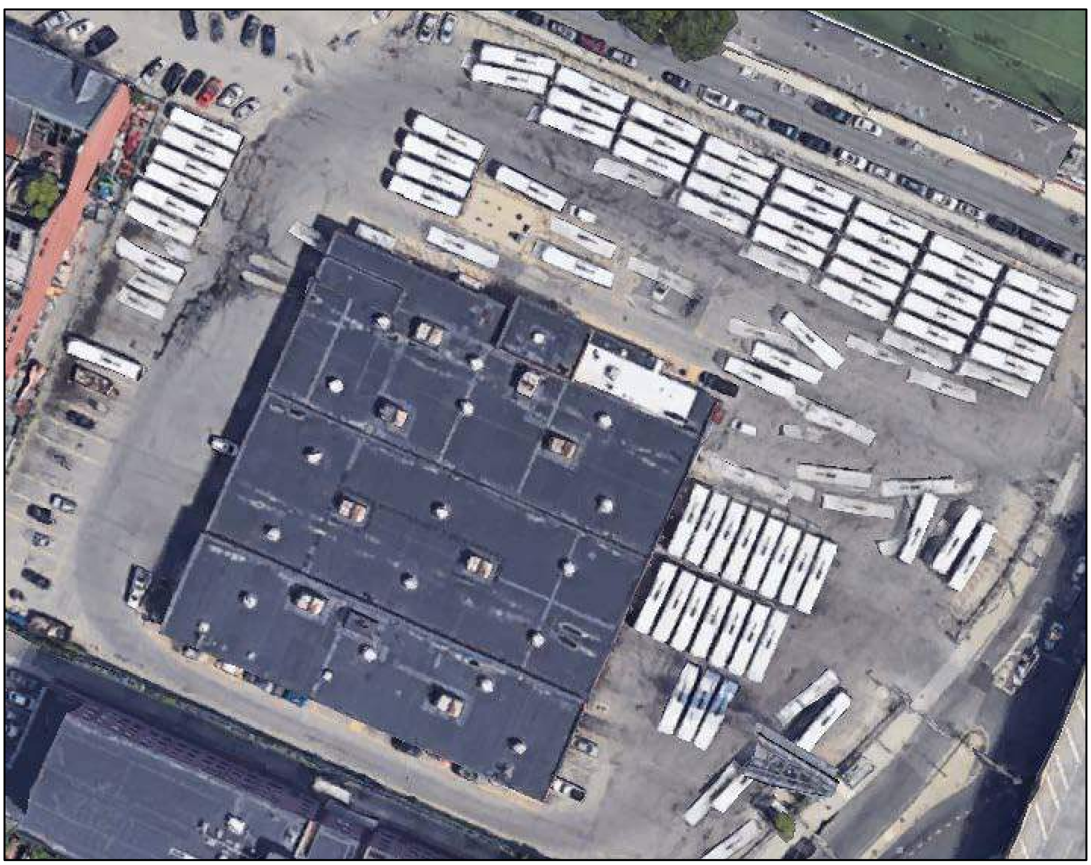

Figure 3: Existing Albany Street Maintenance Facility – Typical Bus Storage

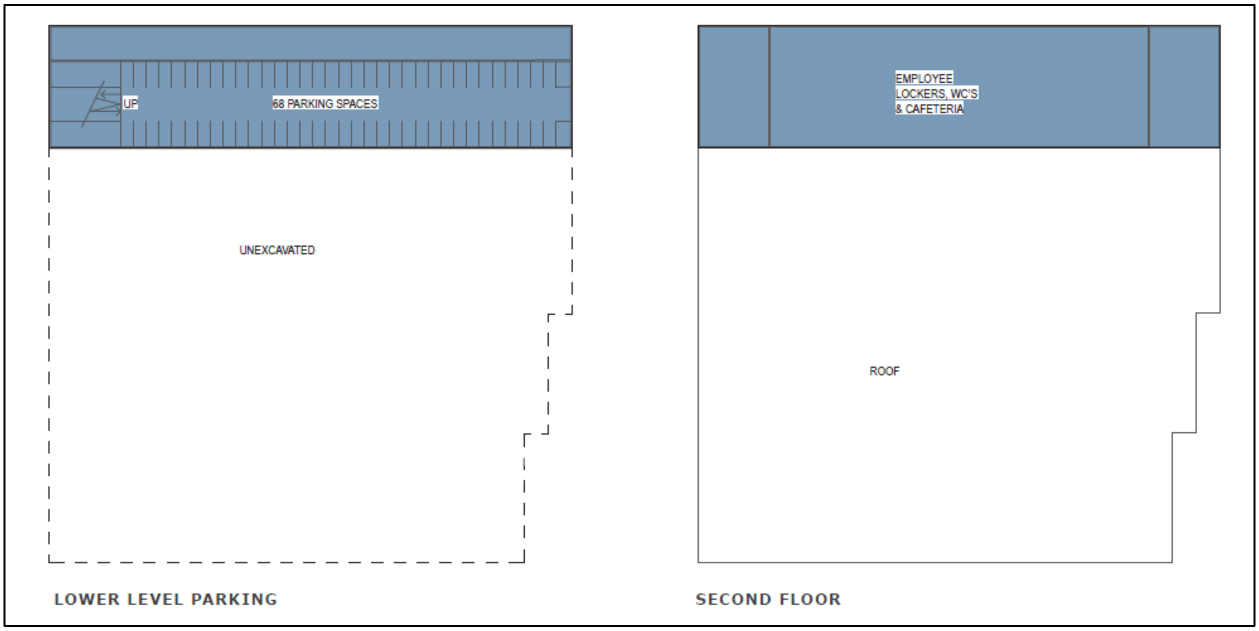

Figure 4: **Albany Street Conceptual Battery Electric Bus Maintenance Facility Lower and Second Levels**

Additional passenger vehicle parking would be provided in an underground garage, below the bus maintenance area. This level would also contain space for parts storage, workshop space to perform maintenance on vehicle components, and related support spaces.

The second level of the space would contain employee amenities, including locker rooms, restrooms, and cafeteria space. Bus charging equipment would be mounted to the roof of the bus storage barn, which would also support solar panel arrays. See Figure 4 for details on the lower and second levels of this conceptual BEB maintenance facility and Table 9 for square footage details.

Table 9: Conceptual Albany Street Battery Electric Bus Maintenance Facility Square Footage

Program	BEB Storage and Maintenance Facility
Residential Space	--
Retail Space	--
Transit Hub	--
Bus Maintenance & Support	25,366 ft^2 (10 bays)
Indoor Bus Storage	80,975 ft^2 (94 buses)
Onsite Employee Parking	25,562 ft^2 (55 cars)
Underground Car Parking	63,222 ft2 (68 cars)
Note: ft^2 = square feet	

Case Study Option: New Battery Electric Bus Facility as Mixed-Use Development

The Case Study Option for the Albany Street facility is presented as a mixed-use development, including BEB vehicle storage and maintenance, residential space, retail space, and a bus transit hub. This concept assumes that the fleet size will be slightly reduced to accommodate the TOD aspects of the concept.

Bus maintenance facility developments have historically received close scrutiny from local communities. Establishing a new bus maintenance facility in a dense urban environment with residential neighbors is a significant challenge. This mixed-use development concept would potentially mitigate some of these challenges, by providing tangible public spaces, such as retail and a transit hub, and integrating the maintenance and storage facility as a more integrated element of the neighborhood.

Neighborhood Overview

The Project site is positioned in Boston's South End neighborhood district, specifically the southeast portion of the neighborhood that was once a former industrial area and over the last decade has experienced accelerated economic growth and become a thriving new residential, commercial, and institutional development area.

According to the City of Boston's Planning and Development Authority (BPDA): "the South End is an elegant residential neighborhood known for its Victorian townhouses and many small parks. The neighborhood was originally built on tidal flats during the mid-1800s, planned to attract the wealthy merchant class with a regular street grid, elegant townhouses, and thirty parks. Today it remains a popular residential area for with a thriving restaurant and arts scene and is the United States' largest Victorian residential district."

The South End spreads from south of the Back Bay to the west of South Boston to just north of South Bay and Dorchester. The South End is home to both long-time residents and a new wave of young professionals who are drawn to the area's unique historic buildings and spaces, emerging nightlife, and easy access to downtown.

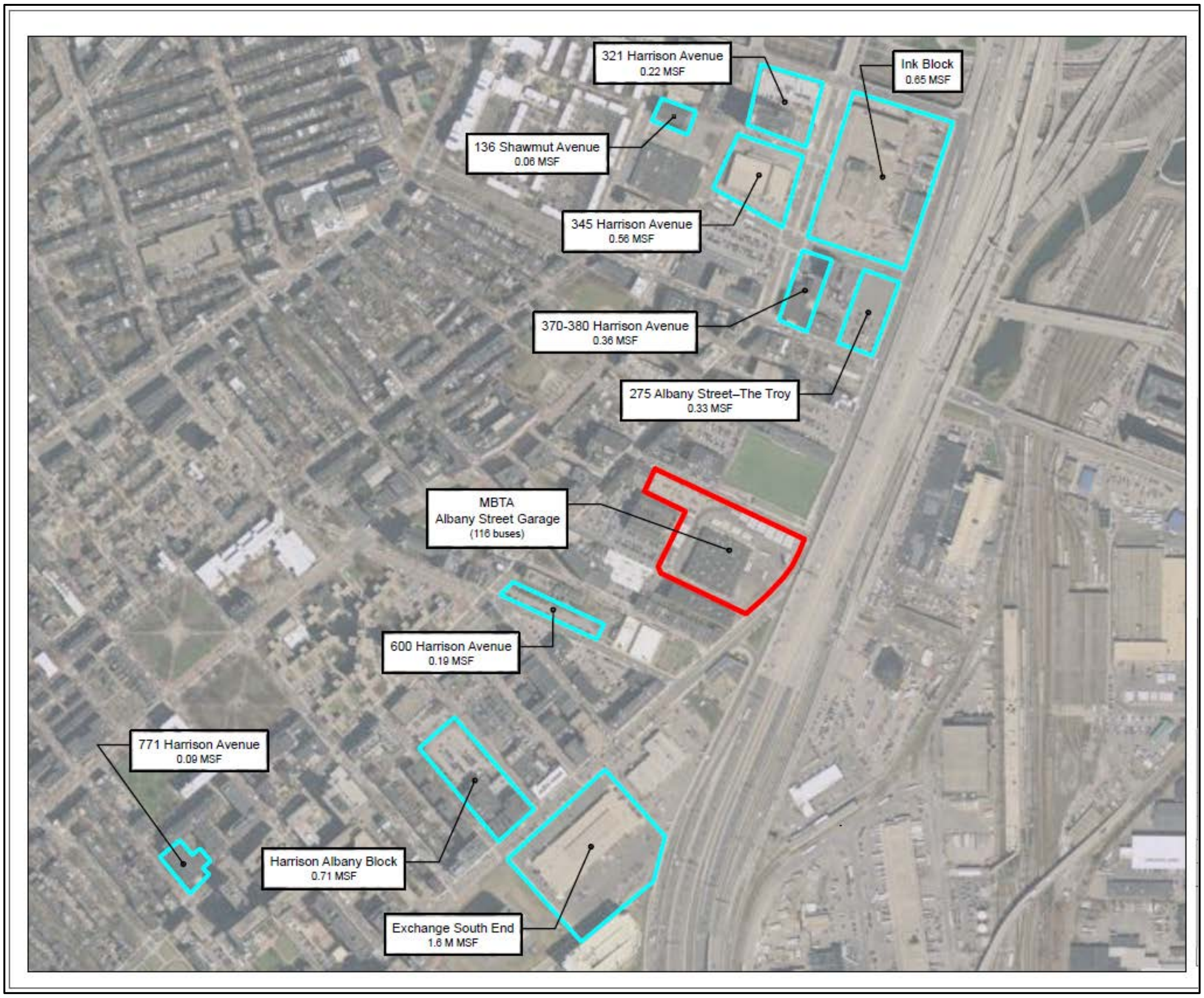

Figure 5: **Neighborhood Development Overview**

The Project Site is located in the southeast portion of the South End. This sub-neighborhood, once a thriving industrial area, abuts Interstate 93 and is currently in transition to new uses. In June 2012, the BPDA issued the Harrison/Albany Corridor Strategic Plan (Plan) which covers the Project Site area. One of the major goals of the Plan was to guide the future and identity of the area. The Plan divides the area into four sub-neighborhoods based upon the character of each area, and its potential for future growth. The sub-neighborhoods include the New York Streets, South of Washington (SOWA), the Back Streets, and the Medical Area. The Project Site is located on the border of the New York Streets, SOWA, and Back Streets sub-neighborhoods and the contemplated upgrade and possible multi-use redevelopment of the Project Site is consistent with and builds upon the goals and vision of the Plan.

The first area described in the Plan is the New York Streets sub-area, which is located southwest of the intersection of Interstates 90 and 93. This area has recently seen substantial residential and commercial development including Ink Block, Troy, 345 Harrison Avenue, and 80 East Berkeley Street, with several other major new redevelopment projects now approved and scheduled to start construction this year.

The second area is SOWA, which is located just south of New York Streets. SOWA is a vibrant mixed-use neighborhood with galleries, artist space, housing, commercial space, and strategically-located retail. Many of the industrial buildings have been renovated for new uses, including lofts and artist space. SOWA will continue to be a lively, cultural destination in the South End and remain a driving factor in defining the Harrison Avenue Corridor as a creative, artist-friendly area.

The third sub-area is the Back Streets, which is located just south of SOWA. This area has the most potential for development, as there are currently gaps in the urban fabric. The area is characterized by light industrial uses and small businesses. In the Plan, the vision for this area is to encourage the creation of new jobs. In addition to the existing light industrial and medical uses, the Plan envisioned new complementary commercial and research uses. This area has also recently seen substantial residential, commercial, and institutional development, including the BioSquare II at 600 Albany Street, a research building containing approximately 195,000 square feet known as the National Emerging Infectious Diseases Laboratories, and the newly-approved Exchange South End project at 540 Albany Street.

Located just two city-blocks from the Proposed Site, the Exchange project is a new 1.6 million square foot redevelopment of the former Flower Exchange site that's about to commence construction for office, lab, biotech, biomedical uses with a 1.1 acre publicly accessible open space, ground floor retail and other activating uses, and 30,000 square feet of civic/cultural space. This new mixed-use office, commercial and/or life science research complex will be comprised of four buildings:

- **Building A** will be a six (6) story building for laboratory and civic/community uses with ground-floor retail services
- **Building B** will be approximately twelve (12) stories and will include laboratory, office and civic uses with ground-floor retail services
- **Buildings C and D** will be approximately twenty-three (23) and fifteen (15) story buildings, respectively, for laboratory, office, and civic uses

In addition, below grade parking garages are planned for each building for a total of approximately 1,145 parking spaces.

Space Needs Assessment

The core assumptions from the full Maintenance Facility design apply to the Case Study Option as well. The Case Study Option is presented as a Transit Oriented Development (TOD) that includes BEB vehicle storage/charging and maintenance, residential space, retail space, and a bus hub.

Fleet Size

The MBTA's existing Albany Street garage provides storage, fueling, and maintenance support for 118 40-foot diesel buses. This facility design seeks to support a smaller sized fleet of 40-foot BEBs in order to accommodate the TOD aspects of the concept.

Space Needs

Staffing levels at the facility are assumed as follows:

- Service-ready preparation staff: 5 to 10 per shift (including supervisory)
- Transportation staff: 100 for peak service (including supervisory)

Required transportation and maintenance staff is slightly reduced compared to a diesel facility since the overall fleet size is slightly reduced at this conceptual facility. Employee amenities such as lockers, break rooms, and restrooms are sized for these staffing levels. Personal vehicle parking is assumed for each employee, with a small number of additional spaces for visitors.

Battery Electric Bus Fleet Parking

Both concepts include 100 percent indoor storage for the BEB fleet to maximize cold-weather vehicle performance and energy consumption by avoiding cold soak, experienced when buses are stored outdoors. In addition, indoor parking reduces visibility of MBTA operations to neighborhood stakeholders, contributing to a more complete integration of the facility with the area.

The Case Study Option also includes a bus wash system required for service-ready vehicle preparation.

Onsite Fueling

The range of expected power demand (5 to 20-MW), charging infrastructure, and logistics for the Case Study Option is assumed to be the same as the conceptual facility. Overall power consumption will be less than for the standalone maintenance facility due to the smaller fleet size. However, additional demands from residential, retail, and bus depot aspects of the Case Study Option must be considered.

Site Master Plan and Building Conceptual Design

The Case Study Option for the Albany Street site proposes a TOD project which reflects current zoning initiatives. By incorporating public-oriented program elements, the project comes much closer to meeting the zoning intent and provides a true public benefit. While technically non-conforming, the Case Study Option is more likely to receive zoning board approval than the Base Facility design.

Benefits to the operation of a BEB fleet include reduced localized emissions and hazardous materials onsite compared to a traditional diesel maintenance facility. In addition, the conceptual BEB facility would serve as a local transit hub, increasing transportation options for area residents.

This section describes the general requirements to be considered for Case Study Option, a BEB storage/charging facility integrated into a mixed-use residential, retail, and transit development. Table 10 compares the critical elements of the current maintenance facility to the Base Facility and Case Study Options.

Table 10: Conceptual Albany Street Facility Comparisons

Critical Element	Diesel Maintenance Facility	BEB Storage and Maintenance Facility	BEB Facility and TOD Mixed-Use Development
Fleet Size	118	112	94
Maintenance Bays	6	10	10
100% Indoor Vehicle Storage	✗	✓	✓
Service-Ready Vehicle Preparation	✓	✓	✓
Bus Washing	✓	✓	✓
Vehicle Maintenance	✓	✓	✓
Bus Lifting	✓	✓	✓
Diesel Fueling	✓	✗	✗
BEB Charging	✗	✓	✓

The BEB conceptual plan for the Case Study Option includes a structure containing storage/charging and maintenance space for the BEB fleet. In addition, the overall development would include a residential tower over a TOD development and retail space. This concept promotes the TOD aspects of mixed-use development as a benefit to developers, neighbors, MBTA, and other stakeholders. Figures 4, 5, and 6 provide a variety of conceptual views of the Case Study Option from a cityscape perspective to top and street views.

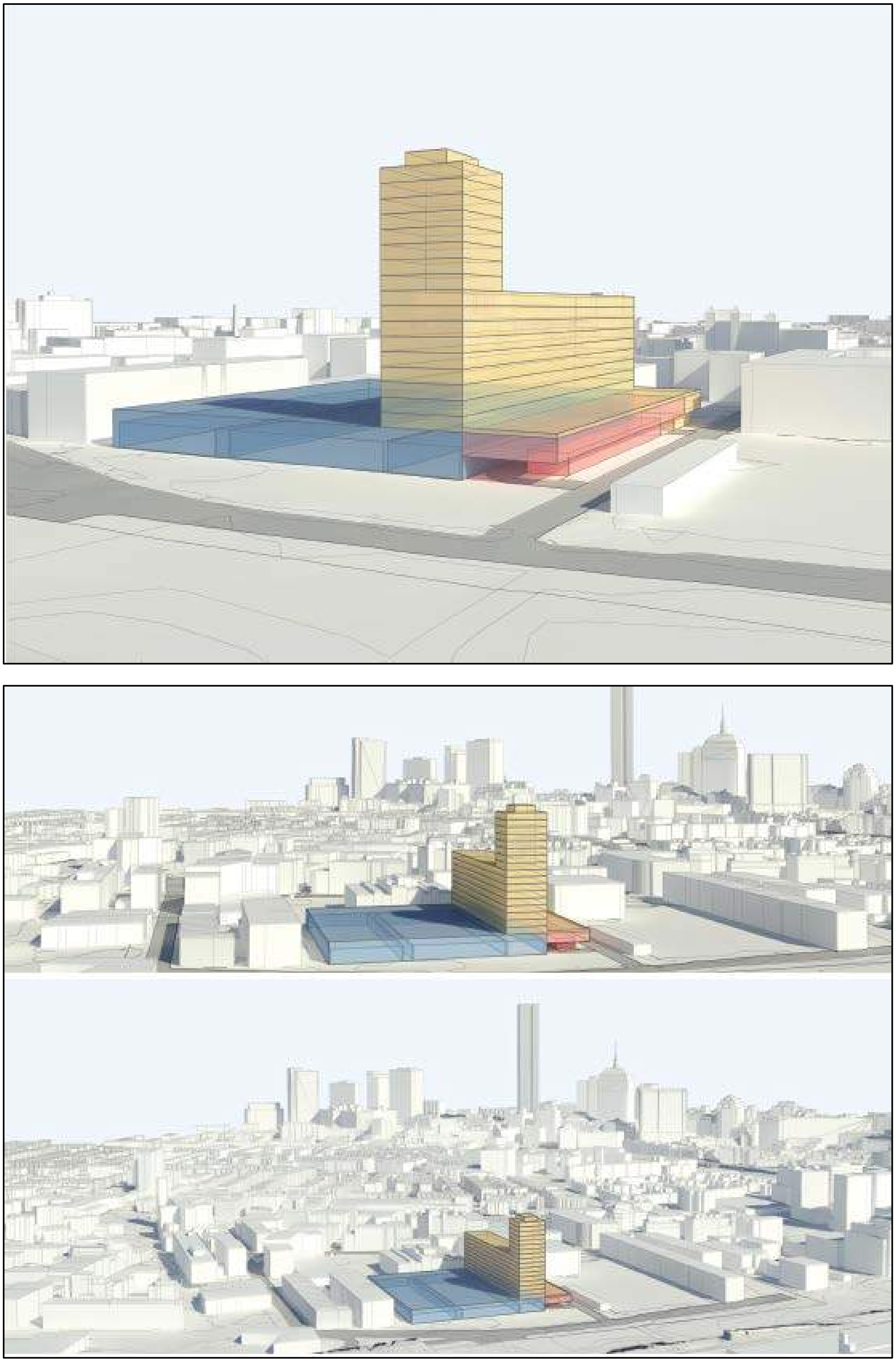

Figure 6: **Case Study Option – Albany Street Conceptual Mixed-Use Development Layout**

Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

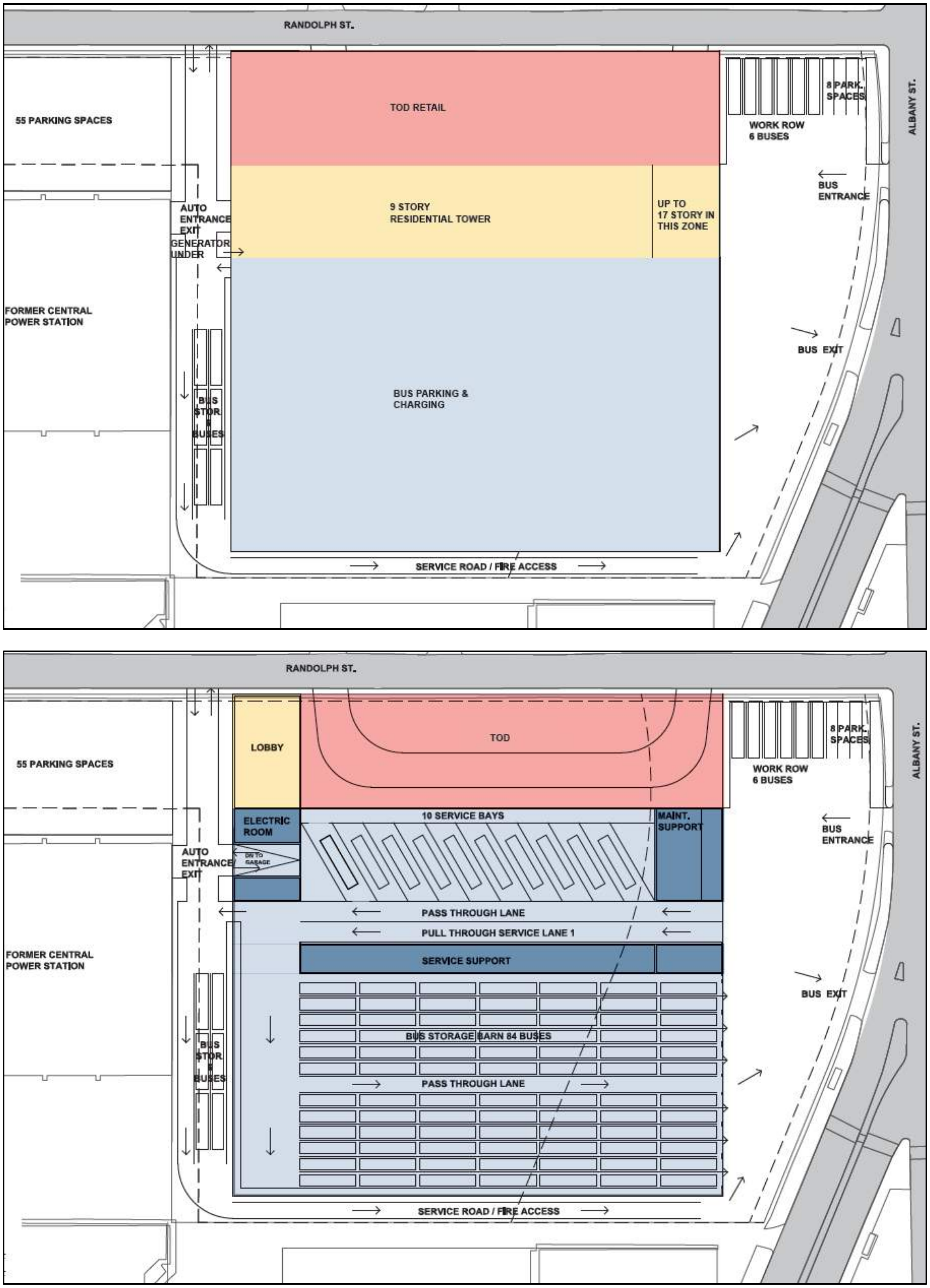

Figure 7: **Case Study Option – Albany Street Conceptual Mixed-Use Development – Top View**

Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

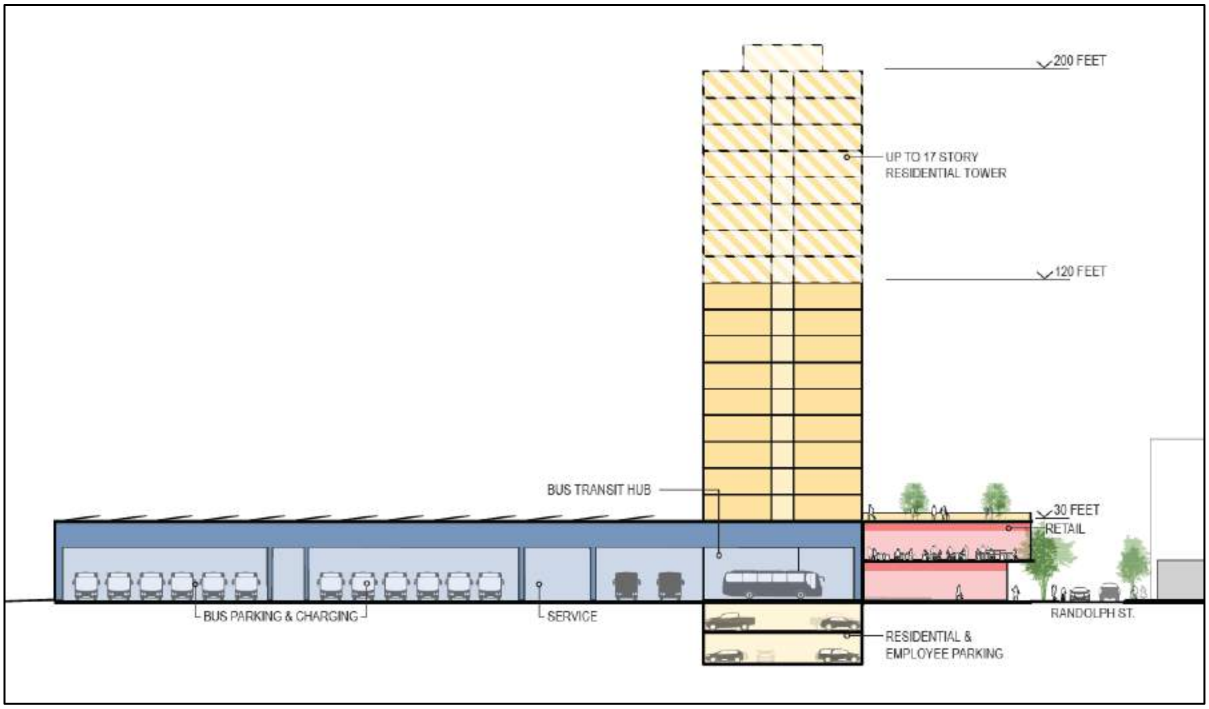

Figure 8: **Case Study Option – Albany Street Conceptual Mixed-Use Development – Albany Street View**

Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

Both concepts offer additional passenger vehicle parking in an underground garage below the Albany Street development. The balance of the lower level would remain unexcavated. If needed, part of this space could be excavated to provide additional parking or support space. Extra underground parking could be required if space in the aboveground parking area is needed to accommodate electrical power equipment for BEB charging.

Table 11: **Conceptual Albany Street Development Square Footage Comparison**

Program	BEB Storage and Maintenance Facility	BEB Facility and TOD Mixed-Use Development
Residential Space	--	226,548 ft^2
Retail Space	--	22,766 ft^2
Transit Hub	--	12,232 ft^2
Bus Maintenance & Support	25,366 ft^2 (10 bays)	25,366 ft^2 (10 bays)
Indoor Bus Storage	80,975 ft^2 (94 buses)	80,975 ft^2 (94 buses)
Onsite Employee Parking	25,562 ft^2 (55 cars)	25,562 ft^2 (55 cars)
Underground Car Parking	63,222 ft2 (68 cars)	63,222 ft2 (68 cars)
Note: ft^2 = square feet		

Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

Conceptual Program Budgets

Cost estimating for the design and construction of large residential, commercial, and industrial developments is challenging and highly sensitive to project specifics. Project complexity, zoning limitations, potential environmental issues, and other specific issues can have significant impacts on the cost of a program. Real estate development partners considering such a project would perform a detailed project review including cost estimates, to evaluate the profitability of the opportunity. Methodology for such an analysis would likely be closely held by these developers.

This section seeks to provide an "order of magnitude" cost estimate for the design and construction of the Mixed-Use Case Study project, with the understanding that information presented for the conceptual Case Study Option are preliminary in nature.

While historical costs for such a project are not available to establish trends, costs associated with the construction of major elements within the overall design can be estimated. Table 12 describes estimated costs for a facility to support approximately 100 BEBs.

Table 12: Bus Maintenance Facility and Electrification Costs

Program	Estimated
Bus Storage	$42,000,000
Bus Maintenance	$20,000,000
Bus Electrification Needs	$30,000,000

These estimates account for demolition and construction costs (including surface and underground parking) based on other maintenance and storage facility projects in this size range. These estimates exclude factors such as architectural / design, permitting, environmental, and construction administration. Electrification costs are based on available information from the industry and assume that major upgrades to the local electrical grid will not be required. Costs have been adjusted for the higher cost Boston market, and include significant (40%) contingency due in large part to the early level of project definition.

Table 13 takes the BEB storage facility and electrification costs above and combines them with estimated costs for the mixed-use residential / commercial space, based on estimates for mixed-use projects in the Boston market. Costs are rounded to the nearest million dollars.

Table 13: Conceptual Albany Street BEB Maintenance Facility Construction Costs

Program	Assumed Cost	BEB Storage and Maintenance Facility	BEB Facility and TOD Mixed-Use Development
Bus Storage	$42,000,000	$42,000,000	$42,000,000
Bus Maintenance	$20,000,000	$20,000,000	$20,000,000
Bus Electrification Needs	$30,000,000	$30,000,000	$30,000,000
Apartment Tower	$500 / square foot*		$130,000,000
	Total	**$92,000,000**	**$222,000,000**

**Note: Assumed apartment tower construction cost selected as a rough order of magnitude estimation to be refined as design elements and specific details are determined.*

As stated, the costs above are intended to provide an order of magnitude only and are not intended to be inclusive of all project elements. As a project becomes better defined and other factors are included, estimates will change accordingly.

Summary and Recommendations

As the MBTA moves forward with needed investments in their bus maintenance facility network, significant funding, human capital, and other resources will be required. This study explores the possibility that bus fleet electrification may present opportunities for the MBTA to leverage outside resources to accelerate bus facility investment that can be readily integrated into local communities.

Maintenance facilities for traditional transit buses include vehicle storage areas, fueling infrastructure, maintenance bays, work staging areas, bus wash systems, as well as amenities for drivers, mechanics, administration, and other agency personnel. Although the overall layout of a maintenance facility will be dictated by many local factors, the functional areas remain the same.

BEB maintenance facilities will require many of these same core functions to support service. Major differences between conventional bus and BEB facilities will come in the form of reduced vehicle noise, the absence of tailpipe emissions, and smaller quantities of oils and other hazardous materials. It is hoped that these differences will make a BEB maintenance facility an appealing candidate for joint development.

Using this concept, agencies may be able to leverage land ownership in developing, high-density areas to engage the private sector in PPP to increase the utility of this land and accelerate the replacement of aging maintenance facilities. Our investigation has not found any examples of these PPPs to date, although SFMTA recently announced their intent to pursue a similar project (SFMTA, 2018). However, given the interest from developers for desirable real estate currently owned by urban agencies, such PPPs could enable agencies across North America to maximize utilization of land use rights and air rights over existing property to provide better transit service at a lower overall cost.

The preliminary evaluation of the MBTA's Albany Street garage performed through this study has resulted in a possibly viable concept that warrants further exploration. Given the timeframe associated with developing a new maintenance facility as well as the added complexities of electrical grid infrastructure and development partnerships, engagement with stakeholders should begin now.

Sustainability will play a key role in selecting specific program requirements for either proposed concepts. This study considered sustainability aspects for both proposed concepts including conducting a preliminary investigation into potential for Leadership in Energy and Environmental Design (LEED) certification and evaluating emissions profiles for BEBs compared to conventional diesel.

Significant pieces for a LEED investigation for the proposed options are heavily dependent on specific program requirements. Reference Appendix D for a detailed preliminary case study of LEED potential, requirements, and challenges for further analysis. Additional local requirements for sustainability may dictate the ultimate approach for pursuing either option.

In addition, while this study focused on the development of the Albany Street garage parcel, the same principles may help provide insight into the development of other current MBTA properties. Additionally, the MBTA could apply the same approach to new bus maintenance facility projects by engaging private developers early in the process.

It is recommended that the MBTA begin discussions with the BPDA, Boston Public Works, Boston Transportation Department, the development community, and other stakeholders related to such a mixed-use project. Understanding the cost drivers, success factors, and other objectives of these partners will be critical to developing a Request for Proposal that may help support a successful project.

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Appendix A: Albany Street Lot Info and Zoning

PARCEL ID – 0306509000

ADDRESS – 439 Albany St., Boston, MA 02118

LOT SIZE – 219,068 SF

GROSS AREA – 51,244 SF

PROPERTY TYPE – Exempt

ZONING DISTRICT – South End Neighborhood

SUBDISTRICT TYPE – Economic Development Area, EDA Central

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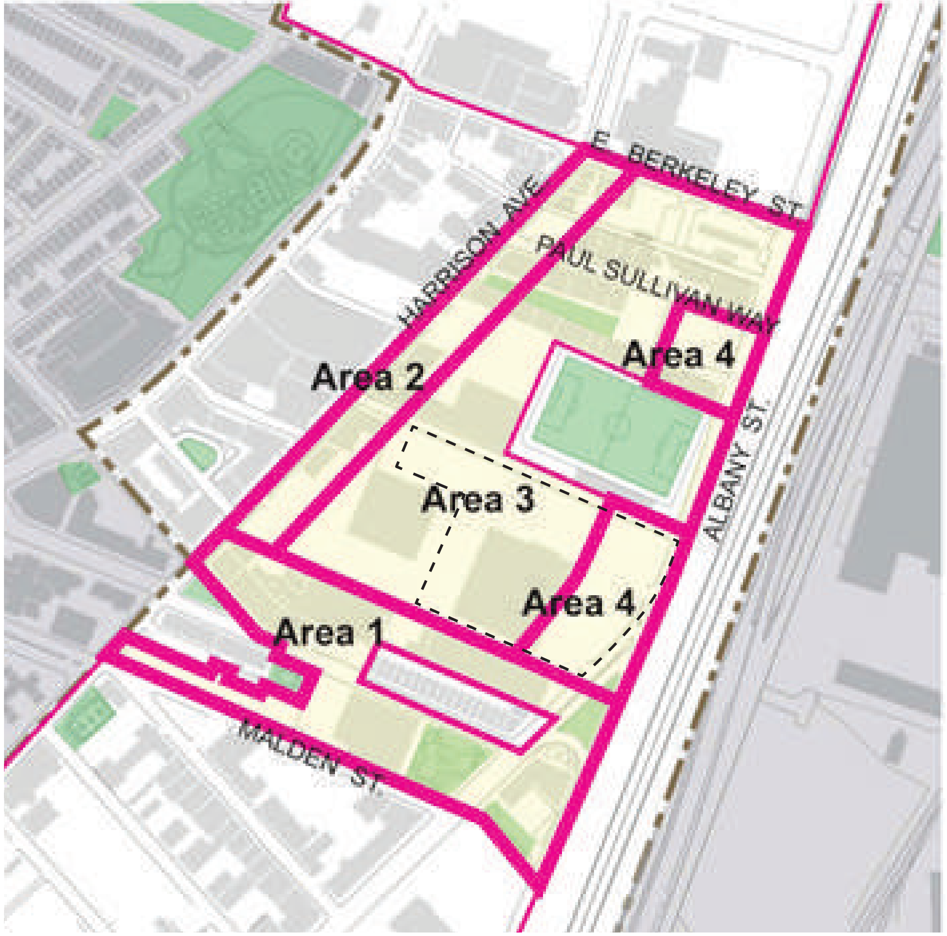


Area 1: *Within that portion of the subdistrict that is shown in this Appendix D as Area 1 and that is between the western Street Line of Albany Street and the eastern Street Line of Harrison Avenue.*

Area 2: *Within that portion of the subdistrict that is within 100 feet of the eastern Street Line of Harrison Avenue.*

Area 3: *Within that portion of the subdistrict that is beyond 100 feet from the eastern Street Line of Harrison Avenue.*

Area 4: *Within 165 feet from Albany Street running from the centerline between Paul Sullivan Way on the north and the southern parcel boundary for the existing MBTA operations site to the south.*

The purposes of establishing the EDA are to encourage economic growth, including light manufacturing, research and development, and commercial activity, in a manner that is sensitive to the needs and interests of the community; to provide for economic development that is of a quality and scale appropriate to the surrounding neighborhood; and to encourage the diversification and expansion of Boston's and the South End's economy, with special emphasis on the creation and retention of job opportunities.

The EDA Central is established to maintain the existing vibrant mixed-use neighborhood. Existing historic resources and industrial character should be preserved while fostering a diverse range of uses including housing, commercial, artist space and strategically-located retail. Streetscape improvements should be focused to improve the pedestrian experience and reinforce connections to public transit

The following building types are forbidden in EDA Central (Refer to attached Table for detailed information):
Drive-in bank, Dormitory, Fraternity, College or University, Adult entertainment, Amusement game machines in commercial or non-commercial establishments, Drive-in theatre, Private clubs, Funerary buildings/uses, Group care residence, Hospital, Motel, cleaning plant, Restricted industrial use, Gold driving range, Stadium, Penal institution, Outdoor payphone, Mobile home-park, one or two family detached or semi-attached dwelling, triple family detached dwelling, solid waste transfer station, Drive-in restaurant, Check cashing business, Kennels, Storage buildings, Storage of flammable liquids and gases, Wrecking yard, Airport, **Bus terminal, Bus servicing or storage, Garage with dispatch,** Helicopter landing facility, Motor freight terminal, Rail freight terminal, Railroad passenger station, Outdoor sale of new and used motor vehicles, Carwash, Truck servicing or storage

	EDA North	EDA Central	EDA South	EDA BioSquare
Maximum Floor Area (2)	4.0	4.0	4.0	4.0
Maximum Building Height (2)	100	70 (4)	70 (5)	110 (6)
Maximum Street Wall Height (3)	n/a	(7)	n/a	n/a
Residential Use	none	none	none	none
Minimum Usable Open Space Per Dwelling Unit (sq ft) (1 2)	50	50	50	50
Minimum Lot Size	none	none	none	none
Minimum Lot Width	none	none	none	none
Minimum Lot Frontage	none	none	none	none
Minimum Front Yard	none (8)	none (9)	none (10)	none
Minimum Side Yard	none	none	none	none
Minimum Rear Yard	20 (11)	20 (11)	20 (11)	20 (11)

4.Except that within 165 feet of the Albany Street public right-of-way running from the centerline of Paul Sullivan Way on the north and the southern parcel boundary for the existing MBTA operations site to the south, the maximum Building Height shall be one hundred (100) feet.

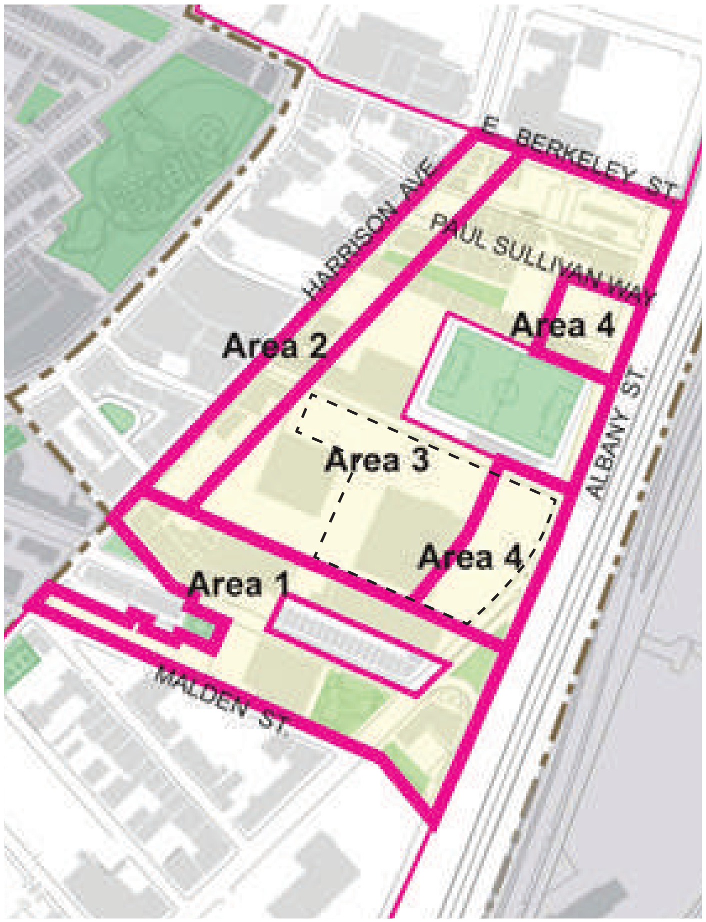
7.The maximum street wall height on the north side of East Canton Street shall be 70 feet. Any portion of a building taller than 70 feet must step back no less than 10 feet from the street wall

9.Ten (10) feet along Albany Street.

11.Except that any Rear Yard for any Proposed Project that is subject to or has elected to comply with the provisions of Large Project Review shall be determined through such review.

Dimensional Requirements

EDA Central Areas	Maximum Building Height	FAR
Area 1	70'	4.0
Area 2	70'	4.0
Area 3	120'	4.0
Area 4	200'	4.0



Lot Coverage

For all Proposed Projects in a PDA, the development footprint shall not cover more than eighty percent (80%) of the lot. The remaining twenty percent (20%) shall be designed and built to ensure public access or enhance the public realm. Development features that would be counted towards the overall development footprint of eighty percent (80%) include, but are not limited to, building footprints located on a lot, structured parking located on a lot, surface parking and service area(s). Public realm features to be built and maintained by the development or other private party that would be counted towards the overall public realm footprint of twenty percent (20%) includes, but not is not limited to: a) a street (private way) would be a through-block connection linking streets at both ends and be open to public vehicle and pedestrian access including cyclists, and would be owned and maintained by the development or other private party; b) a pedestrian way that would be open to the sky with a minimum number of minor projections over it and would be a through-block connection that is open to the public and limited to pedestrians and cyclists where feasible, with each end of a pedestrian way visible from the street, and which would be owned and maintained by the development or other private party; c) an alley that would be a through-block connection that would provide access to the development site for activities such as drop-off, parking, loading, or other service areas that would be open to public access and may be limited to vehicular traffic but may accommodate pedestrians and cyclists where feasible, and would be owned and maintained by the development or other private party; and d) a place-making space, such as a plaza , open space, or a park, that is located on the ground level and open to the public, and would be owned and maintained by the development or other private party.

Screening and Buffering of Parking, Loading, and Storage Areas.

Any off-street parking facility or lot, off-street loading area, or accessory storage area that abuts (a) a public street, (b) a public park, (c) a Residential Subdistrict or Residential Use, or (d) an Institutional Subdistrict, shall be screened from view as provided in this Section 64-33.2. Such screening shall consist of trees and shrubs densely planted in a strip at least five (5) feet wide on the outside edge of a steel-picket or stockade or board-type wooden fence. Such fence shall not be more than fifty percent (50%) opaque and shall be no less than three (3) feet and no more than four (4) feet high. The planting strip shall be separated from any parking area by a curb six (6) inches in height.

Planned Development Areas (“PDAs”),

PDAs are permitted within Economic Development Areas (EDAs), Neighborhood Development Areas (NDAs), Community Facilities (CF) Subdistricts, and Community Commercial (CC) Subdistricts, except that no Planned Development Area shall be permitted for any Proposed Project to which the Institutional Master Plan Review requirement of Section 64-27 applies. PDAs are not permitted elsewhere in the South End Neighborhood District, provided that a PDA overlay district and PDA Development Plan may include contiguous area within an adjacent Open Space subdistrict, provided that the provisions of the PDA Development Plan setting forth the use and dimensional controls applicable to the area located within such adjacent Open Space subdistrict are consistent with those of the underlying zoning for that subdistrict, without giving effect to the transition zoning provisions of Article 12 of this Code. The purposes of permitting PDAs in the subdistricts specified above are to provide for a more flexible zoning, law; to provide public benefits to the South End community, including the creation of new job opportunities and housing for individuals and families of all economic groups; to allow for the diversification and expansion of Boston’s economy through manufacturing, commercial, and scientific research and development uses; to encourage economic development while ensuring quality urban design by providing planning and design controls; and to provide connections for the South End to the downtown economy.

Planned Development Areas: Use and Dimensional Regulations.

1.Use Regulations. A Proposed Project within a PDA shall comply with the use regulations applicable to the underlying subdistrict for the location of the Proposed Project, except as those regulations are expressly modified by an approved Development Plan.

(a)Specific Requirements for Proposed Projects Incorporating Only Residential Uses. The Proponent of any Proposed Project within a PDA devoting one hundred percent (100%) of the Gross Floor Area to Residential Uses must construct or cause the construction of either:

1.Affordable Housing, as defined in Section 64-41.1, in an amount equivalent to no less than twenty percent (20%) of the Dwelling Units included within the Proposed Project, with all such Affordable Housing located on-site; or

2.A combination of such Affordable Housing and another significant contribution, consisting of: (a) on-site Affordable Housing in an amount equivalent to no less than ten percent (10%) of the Dwelling Units included within the Proposed Project; and (b) an equivalent contribution to the Inclusionary Development Program Fund, administered by the Authority, and/or the creation of off-site Affordable Housing, the combination of which shall be the equivalent of 10 percent (10%) of the Dwelling Units included within the Proposed Project.

(b)Specific Requirements for Proposed Projects Incorporating Only Non-Residential Uses. The Proponent of any Proposed Project within a PDA devoting one hundred percent (100%) of the Gross Floor Area to Non-Residential Uses must:

1.Construct or cause the construction on-site of not less than five percent (5%) of the total Gross Floor Area of any and all Proposed Project(s) within an approved PDA, above that allowed as-of-right in the underlying zoning subdistrict, for use by an existing or start-up business, or not for profit Affordable Cultural Space, as defined in Section 64-41.2, to be determined and agreed upon by the Proponent, the Authority and/or the Boston Local Development Corporation; or

2.A combination of such existing or start-up business or not-for-profit Affordable Cultural Space, as defined in Section 64-21.2, and another significant contribution, consisting of: 1) up to five percent (5%) of the total Gross Floor Area of any and all Proposed Project(s) within an approved PDA, above that allowed as-of-right, for on-site use by an existing or start-up business or not-for-profit Affordable Cultural Space, to be determined and agreed upon by the Proponent, the Authority and/or the Boston Local Development Corporation; and/or 2) an additional contribution to the Harrison/Albany Corridor Business and Cultural Loan Fund, administered by the Boston Local Development Corporation. Said combination shall be determined by the Authority and shall be the equivalent of five percent (5%) of the total Gross Floor Area of any and all Proposed Project(s) within an approved PDA, above that allowed as-of-right in the underlying zoning subdistrict.

(c)Specific Requirements for Proposed Projects Incorporating Residential Uses and Non-Residential Uses. The Proponent of any Proposed Project within a PDA must construct, cause the construction of, or make an equivalent contribution as set forth below:

1.The Proponent of any Proposed Project within a PDA devoting any amount of Gross Floor Area to Residential Uses must construct or cause the construction of either:

a.Affordable Housing, as defined in Section 64-41.1, in an amount equivalent to no less than twenty percent (20%) of the Dwelling Units included within the Proposed Project, with all such Affordable Housing located on-site; or

b.A combination of such Affordable Housing and another significant contribution, consisting of: (a) on-site Affordable Housing in an amount equivalent to no less than ten percent (10%) of the Dwelling Units included within the Proposed Project; and (b) an equivalent contribution to the Inclusionary Development Program Fund, administered by the Authority, and/or the creation of off-site Affordable Housing, the combination of which shall be the equivalent of 10 percent (10%) of the Dwelling Units included in the Proposed Project; and

2.The Proponent of any Proposed Project within a PDA devoting any amount of Gross Floor Area to Non-Residential Uses must construct or cause the construction of either:

a.Five percent (5%) of the total Gross Floor Area allocated to non-residential uses of any and all Proposed Project(s) within an approved PDA, above that allowed as-of-right in the underlying zoning subdistrict, for on-site use by an existing or start-up business, or not-for-profit Affordable Cultural Space, as defined in Section 64-41.2, to be determined and agreed upon by the Proponent, the Authority and/or the Boston Local Development Corporation; or

b.A combination of such existing or start-up business or not-for-profit Affordable Cultural Space, as defined in Section 64-21.2, consisting of: 1) up to two and a half percent (2½%) of the total Gross Floor Area of any and all Proposed Project(s) within an approved PDA for on-site use by an existing or start-up business or not for profit Affordable Cultural Space, to be determined and agreed upon, by the Proponent, the Authority and/or the Boston Local Development Corporation; and 2) an additional contribution to the Harrison/Albany Corridor Business and Cultural Loan Fund, administered by the Boston Local Development Corporation. Said combination shall be determined by the Authority and shall be the equivalent of five percent (5%) of the total Gross Floor Area allocated to non-residential uses of any and all Proposed Project(s) within an approved PDA, above that allowed as-of-right in the underlying zoning subdistrict.

Appendix B: Albany Street Garage Development Context Map

/Users/glenberkowitz/Documents/ABC 2018/GIS Bus Maintenance /Albany_Set.dwg

General Notes

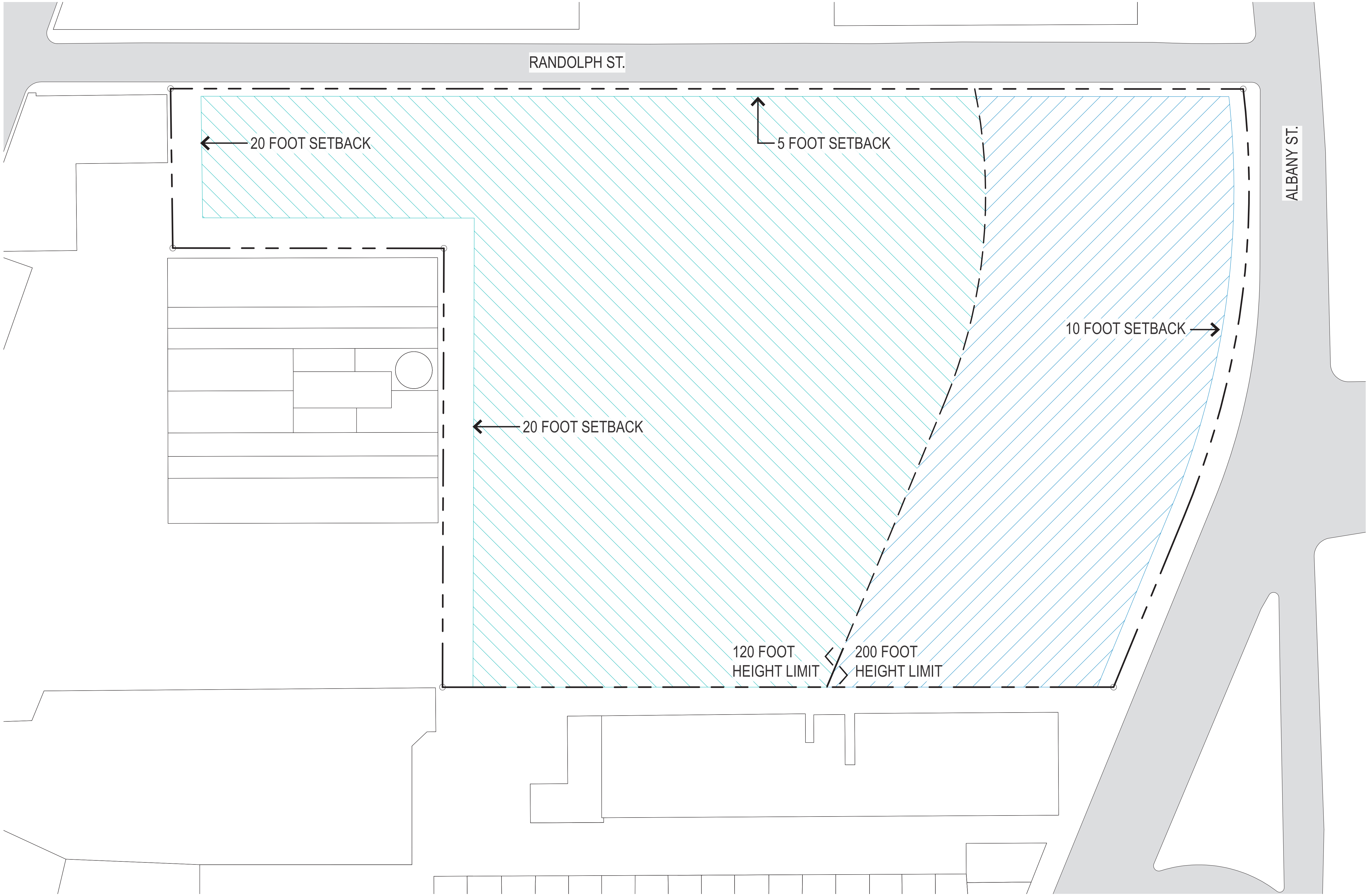
1. Highlighted Projects =4.68 MSF
2. Note: Prudential Center = 1.20 MSF

Sheet Title:

MBTA Bus Maintenance Facility: Albany Street Garage: Development Context

Prepared by	GAB
Drawn by	GAB
Date	1/9/18
Scale	1"= 400'
Sheet	1

Appendix C: Albany Street Conceptual Development Drawings



ZONING PLAN

BEB STORAGE AND MAINTENANCE FACILITY
ELECTRIC BUS GARAGE & SERVICE CENTER

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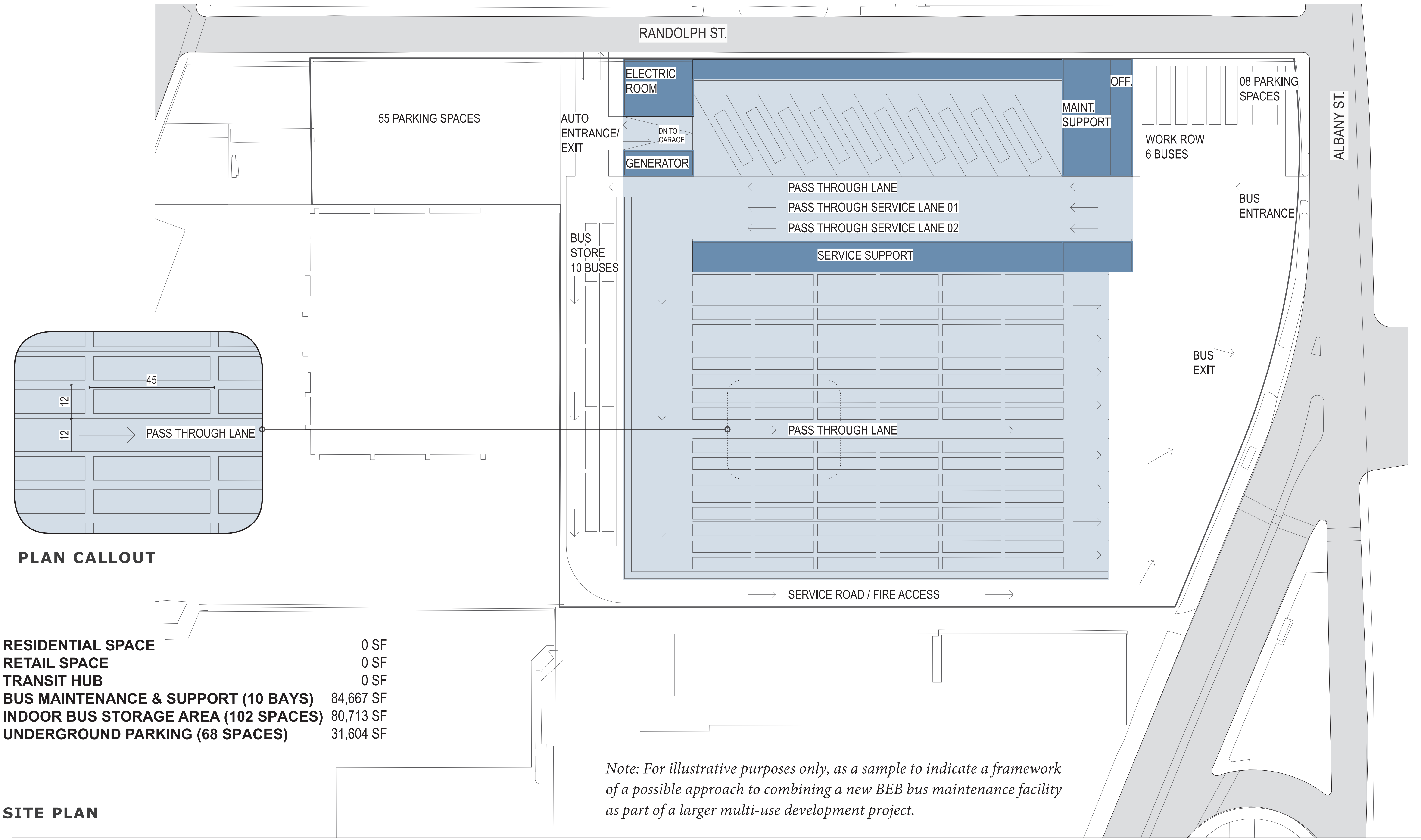
MARCH 15, 2019



RESIDENTIAL SPACE	0 SF
RETAIL SPACE	0 SF
TRANSIT HUB	0 SF
BUS MAINTENANCE & SUPPORT (10 BAYS)	84,667 SF
INDOOR BUS STORAGE AREA (102 SPACES)	80,713 SF
UNDERGROUND PARKING (68 SPACES)	31,604 SF

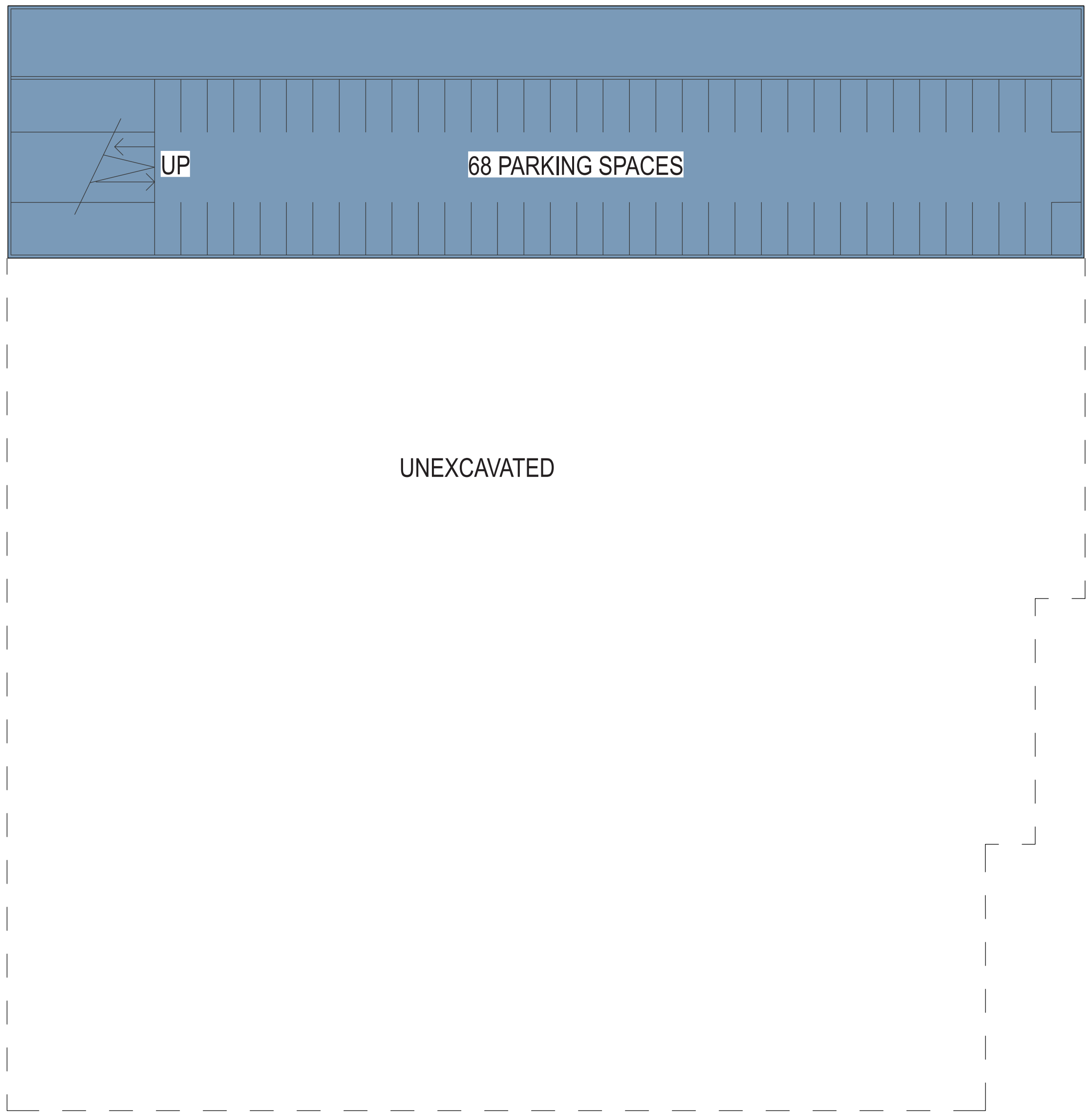
Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

SITE PLAN

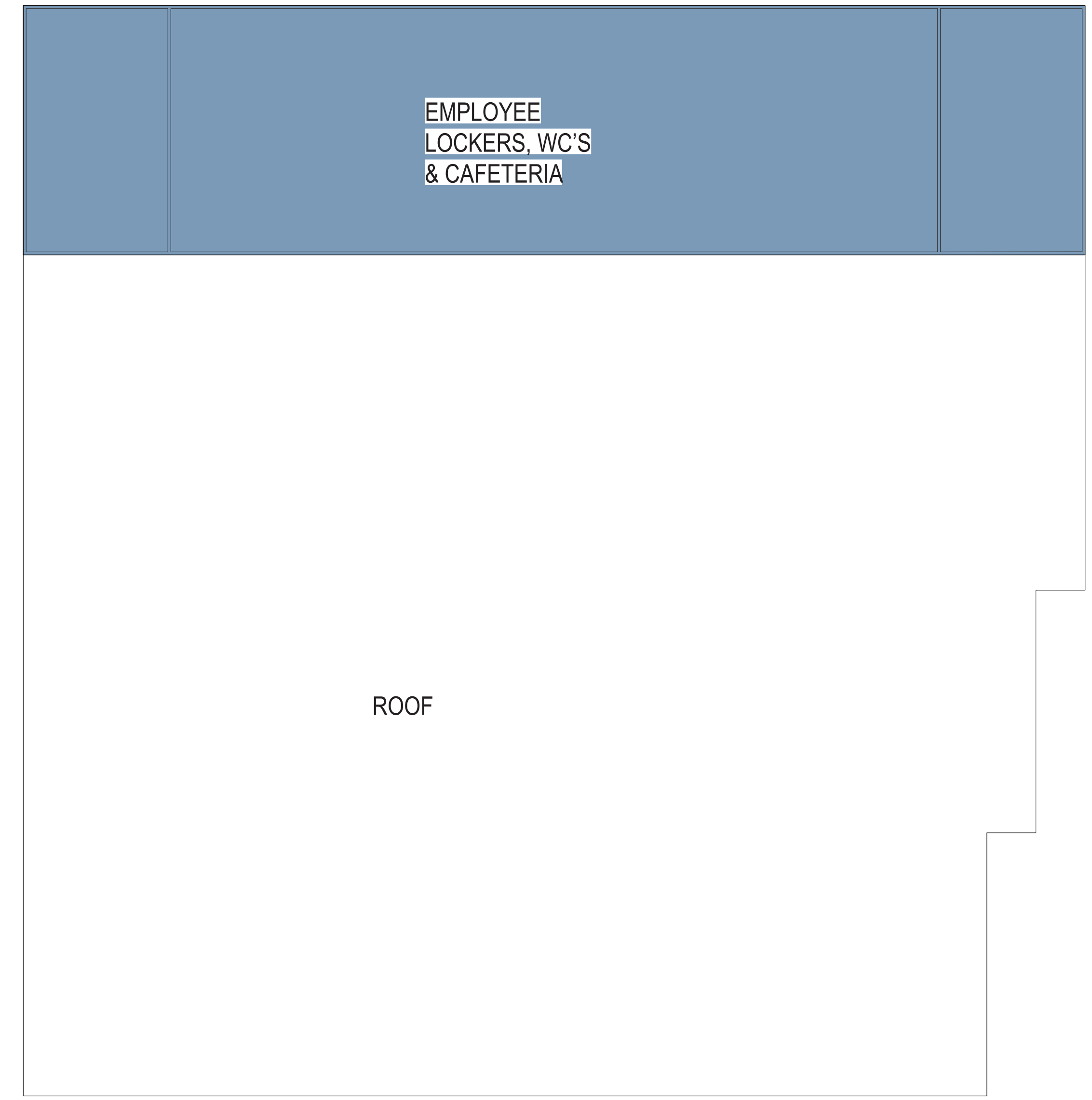
BEB STORAGE AND MAINTENANCE FACILITY
ELECTRIC BUS GARAGE & SERVICE CENTER
(without transit hub)

JACOBS

MARCH 15, 2019

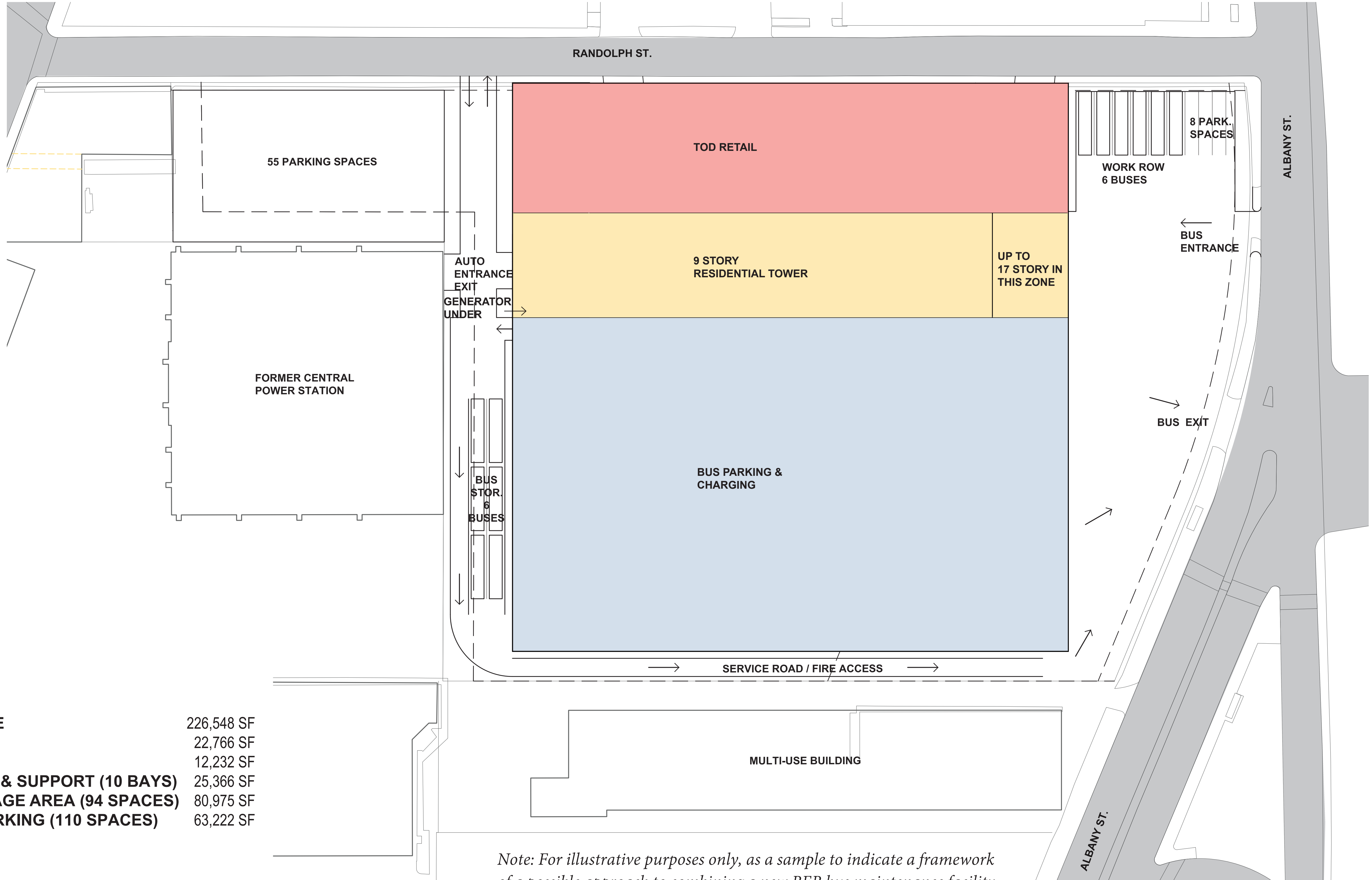


LOWER LEVEL PARKING



SECOND FLOOR

Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.



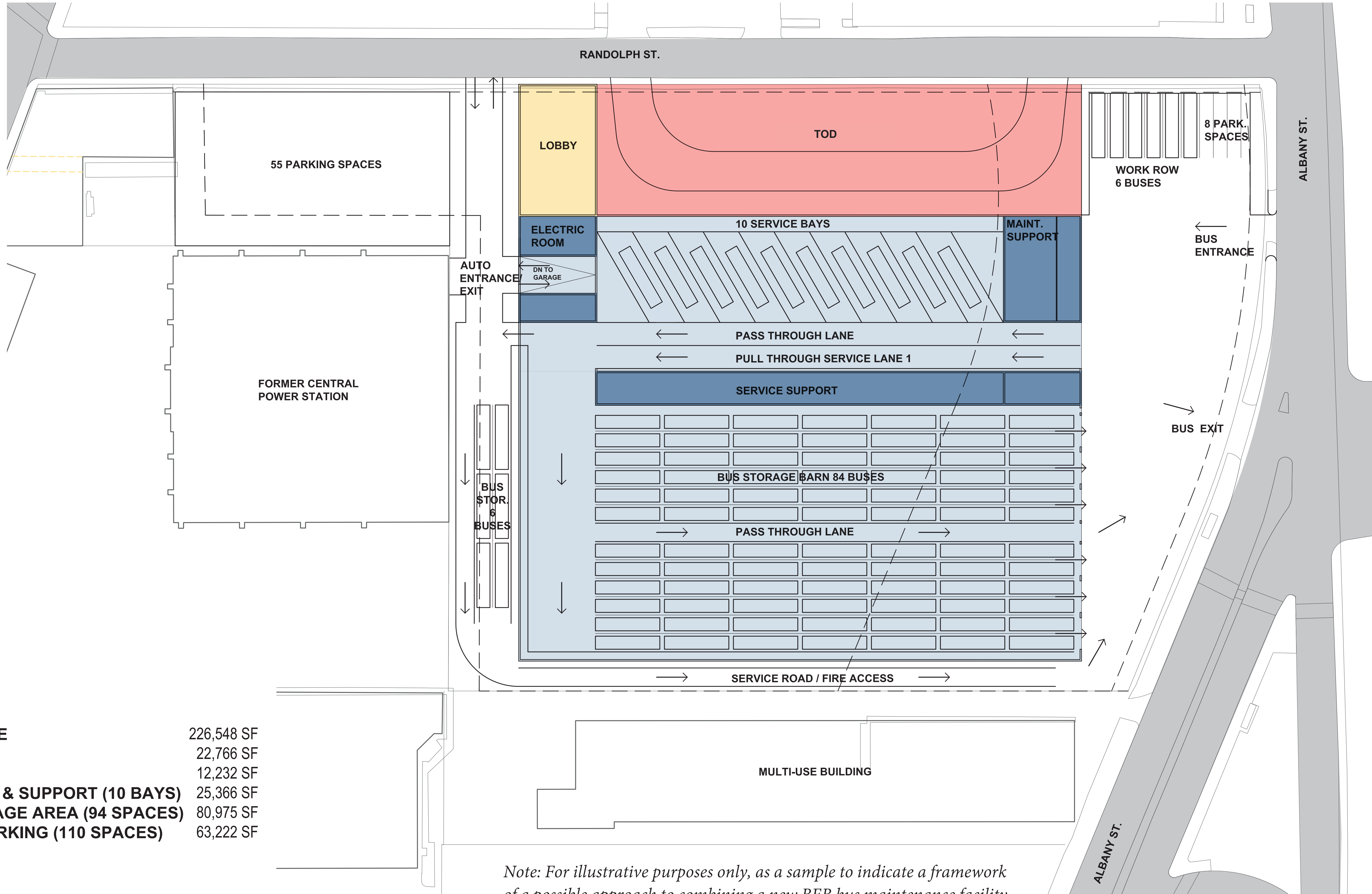
RESIDENTIAL SPACE	226,548 SF
RETAIL SPACE	22,766 SF
TRANSIT HUB	12,232 SF
BUS MAINTENANCE & SUPPORT (10 BAYS)	25,366 SF
INDOOR BUS STORAGE AREA (94 SPACES)	80,975 SF
UNDERGROUND PARKING (110 SPACES)	63,222 SF

Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

SITE PLAN

BEB STORAGE AND MAINTENANCE FACILITY
ELECTRIC BUS GARAGE & SERVICE CENTER
(with transit hub)

JACOBS
MARCH 15, 2019



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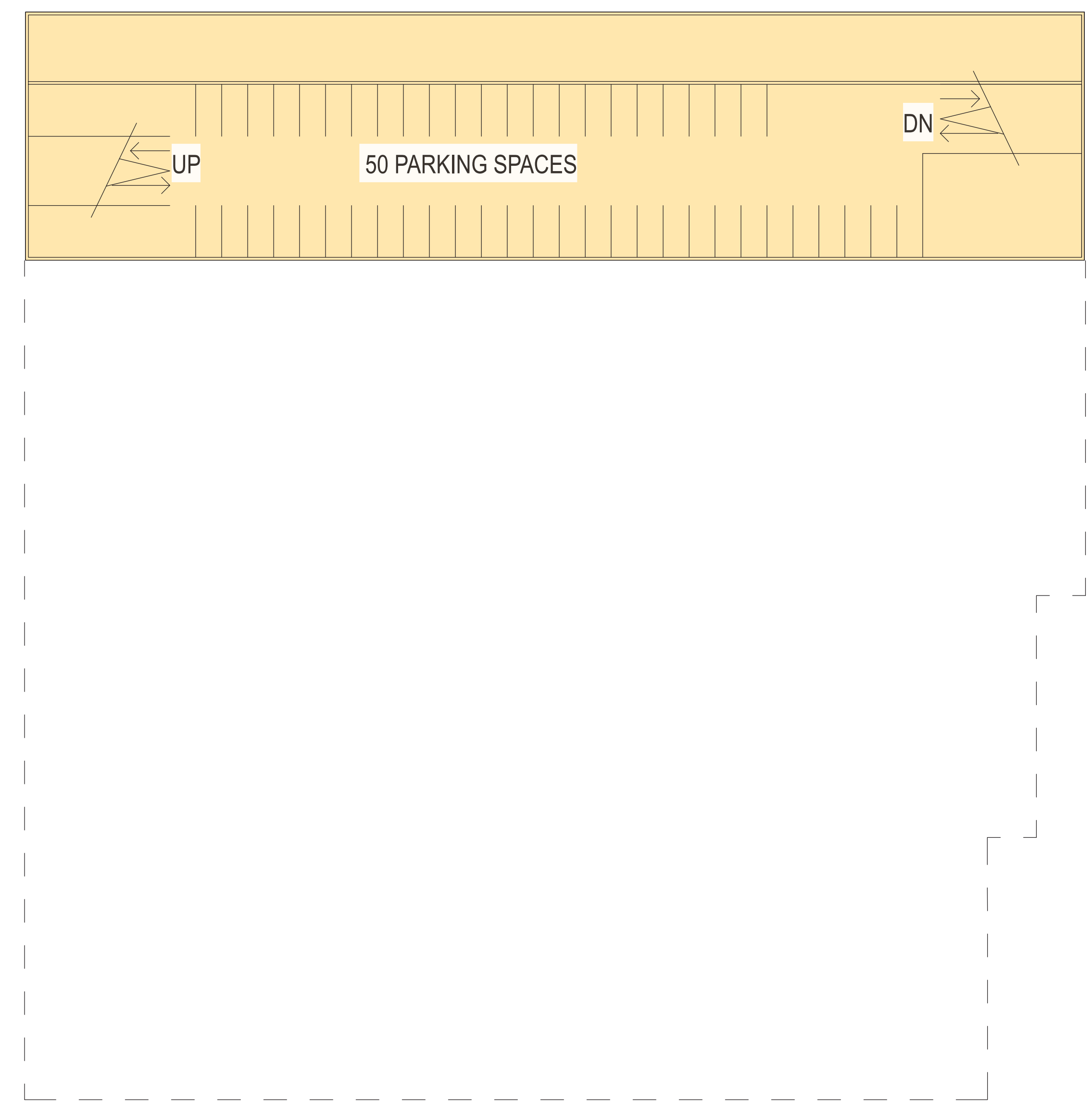
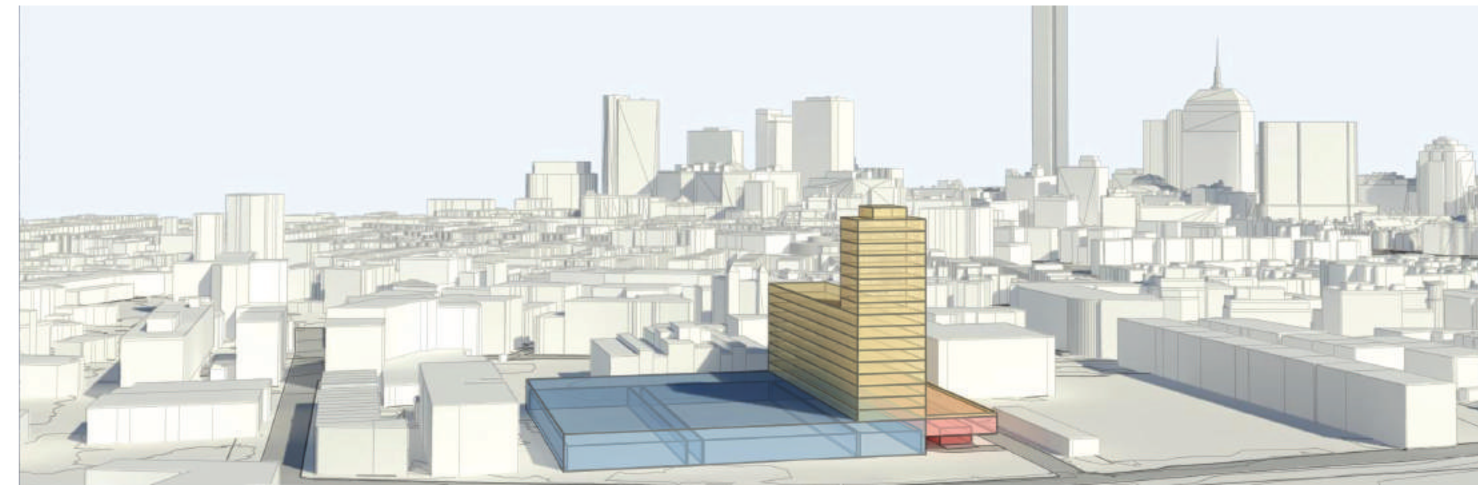
JACOBS

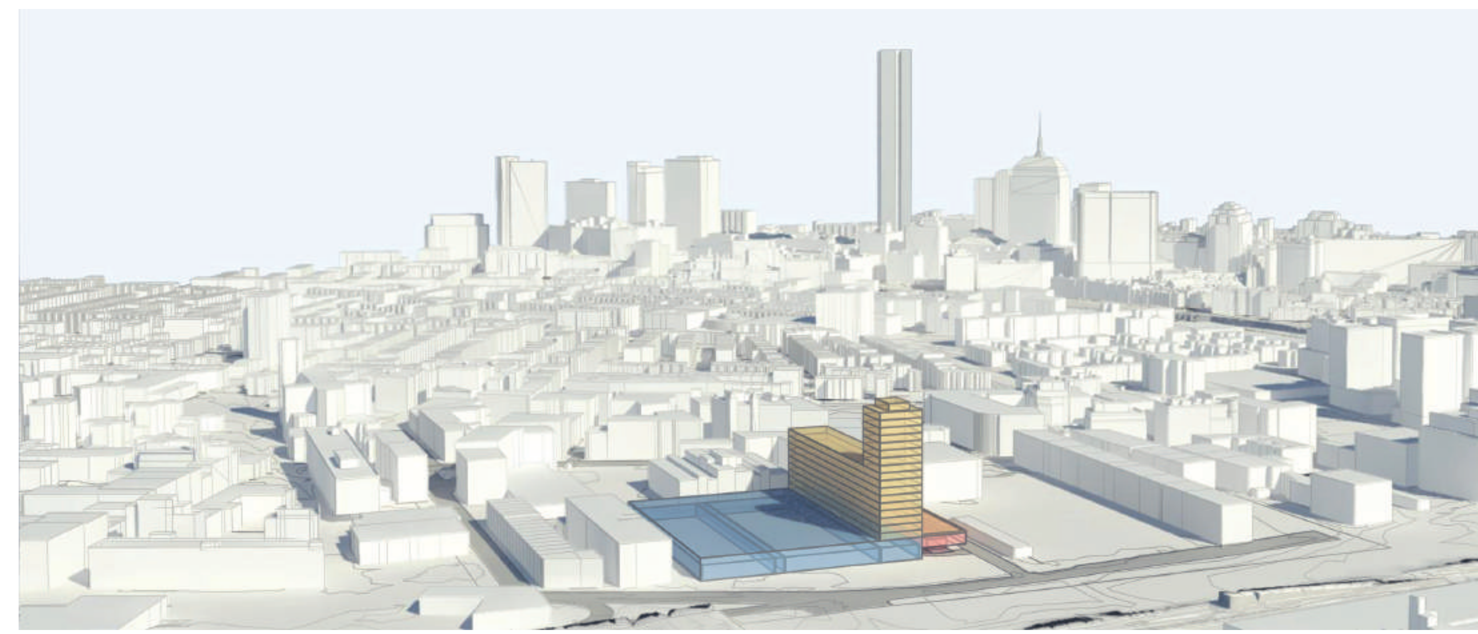
MARCH 15, 2019



Note: For illustrative purposes only, as a sample to indicate a framework of a possible approach to combining a new BEB bus maintenance facility as part of a larger multi-use development project.

TYPICAL LOWER LEVEL PARKING





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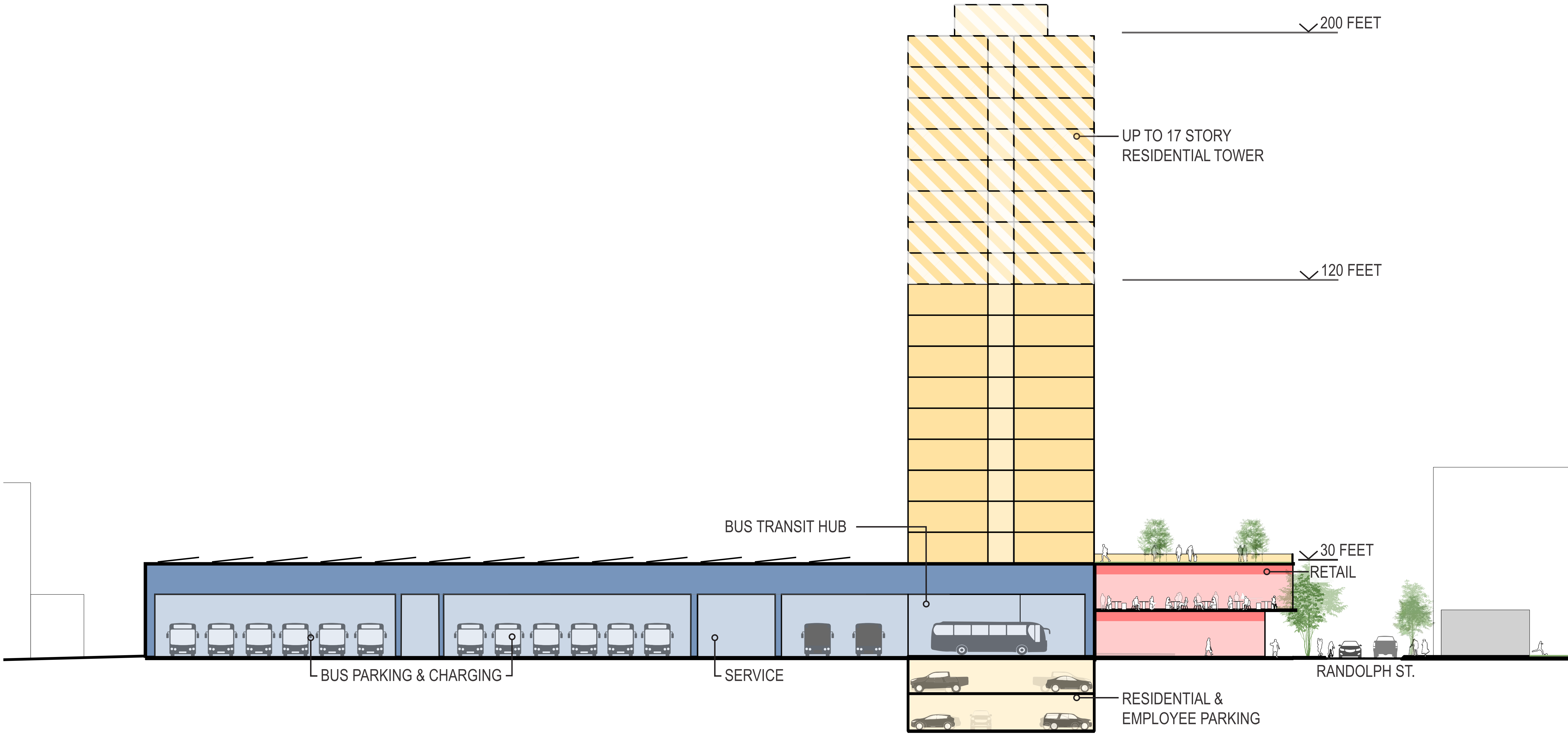

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SECTION

BEB STORAGE AND MAINTENANCE FACILITY
ELECTRIC BUS GARAGE & SERVICE CENTER
(with transit hub)

JACOBS
MARCH 15, 2019

Appendix D: Albany Street LEED Case Study

JACOBS

BEB Albany Street Garage

Boston, MA

LEED BD+C v4, New Construction
Sustainability Case Study
December, 2018

Project Introduction

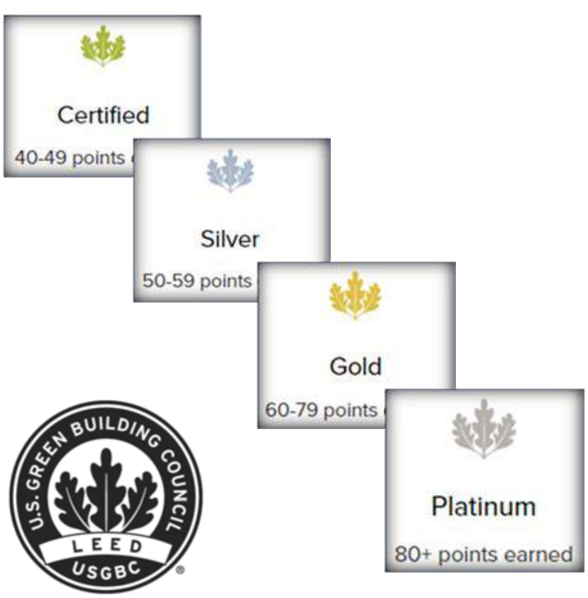
A Better City and the Barr Foundation are performing a Feasibility Study to assess the potential that advanced battery electric bus technology might help to provide a new cost-effective public-private site development strategy for modernizing and expanding the network of the MBTA's bus maintenance facilities to increase ridership and better meet the transportation, economic growth, and climate change/environmental needs of the Greater Boston region.

A Better City advances the Boston metropolitan area's economic health, access, sustainability, and quality of life through applied research, planning, targeted services, and advocacy; the Barr Foundation focuses regionally, and selectively engages nationally, working in partnership with nonprofits, foundations, the public sector, and civic and business leaders to elevate the arts and creative expression, to advance solutions for climate change, and to connect all students to success in high school and beyond. In pursuit of their missions, this case study explores the potential of an MBTA project to utilize the United States Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED) rating system as both the primary guide for sustainability, as well as the measure for achievement of sustainability goals.

This case study will serve as an introductory dive into what would be required of the project to meet sustainability goals based on the preliminary information available, the project's urban context, and the likely features of the proposed facility, itself.

Project Information

Address	439 Albany St., Boston, MA 02118
Lot Size	219,068 SF
Context	Dense Urban
Land Type	Previously Developed



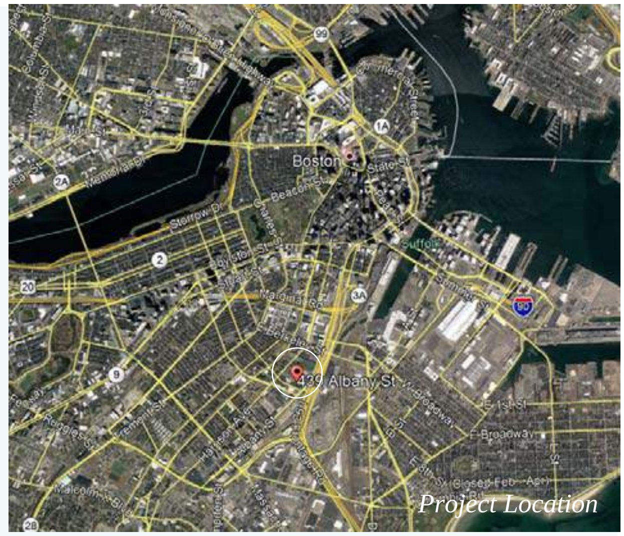
The LEED Rating System

LEED is a program of the U.S. Green Building Council (USGBC) that establishes performance goals in seven environmental categories: Integrative Process, Location & Transportation, Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials & Resources, and Indoor Environmental Quality. An eighth category—Innovation & Design Process—addresses environmental issues not included in other categories, such as community enhancement, education, and expertise in sustainable design. The final category for Regional Priority awards up to four additional points if the project is able to achieve credits that the USGBC deems most important to the project's area.

The LEED v4 Building Design and Construction (BD+C) Rating System is a set of performance standards for certifying the design and construction of commercial or institutional buildings, and high-rise residential buildings of nine or more stories, both public and private. The intent is to promote healthful, durable, affordable, and environmentally sound practices in building design and construction.

The system is comprised of 110 points, which are awarded for sustainable design or construction aspects in a project. The graphic shown at left illustrates the levels available for qualifying projects, and point requirements needed to achieve each level. Achieving any level of LEED v4 certification requires commitment from every member of the project team: the owner, the design team, the general contractor, and finally the building occupants and staff.

LEED Analysis



A preliminary LEED analysis was performed based on the project location, surrounding community, and typical achievements from other comparable LEED projects. The results indicate that certification should be achievable, with the final level being determined by numerous factors currently unknown regarding specific design elements and construction activities.

For purposes of the assessment, all Minimum Program Requirements (MPRs) and Prerequisites are assumed achievable, as they are required for any level of certification; further, there were no concerns apparent for these items when reviewed. Information on what each entails can be found in the USGBC website's Credit Library, located here: https://www.usgbc.org/credits/new-construction/v4.

Additionally, detailed information specific to each Prerequisite and Credit can also be found within the BD+C Reference Guide, available for purchase on the USGBC website: https://www.usgbc.org/resources/leed-reference-guide-building-design-and-construction.

In the summary Project Checklist shown on this and the following pages, credits that were deemed achievable are shown in the first column for "Yes" or "Y" items. Credits that were deemed possible to be achieved but depend on design or construction decisions made are shown in the "Maybe" or "?" Column. Finally, those in the "No" or "N" column were not achievable or very unlikely to be feasible for the project.

The following analysis is divided into each of the main LEED categories, and recommendations for the design and construction aspects of each (as applicable) are provided.

Integrative Process (IP)

(0 Prerequisites; 1 possible point)

Y	?	N			
1	0	0	Credit 1	Integrative Process	1

This credit strives to identify and use project team and stakeholder opportunities to achieve synergies across disciplines and building systems. There are no specific design recommendations from the project associated with this credit; however, the team will need to be aware of the information needed to populate the credit worksheet beginning in pre-design and continuing throughout the design phases. The project team can use the recommended processes to identify and implement opportunities to achieve synergies across disciplines and building systems. Discussions throughout the design process should be used to inform the owner's project requirements (OPR), basis of design (BOD), design documents, and construction documents.

Location & Transportation (LT)

(0 prerequisites; 16 possible points)

Y	?	N			
			Location and Transportation	*Total Possible:*	**16**
0	0	0	Credit 1	LEED for Neighborhood Development Location	16
1	0	0	Credit 2	Sensitive Land Protection	1
1	1	0	Credit 3	High Priority Site	2
5	0	0	Credit 4	Surrounding Density and Diverse Uses	5
1	2	2	Credit 5	Access to Quality Transit	5
0	1	0	Credit 6	Bicycle Facilities	1
0	1	0	Credit 7	Reduced Parking Footprint	1
1	0	0	Credit 8	Green Vehicles	1

This category deals with project site selection, including credits that encourage compact development, alternative transportation, and connection with amenities, such as restaurants and parks. The LT category considers the existing features of the surrounding community and how this infrastructure affects occupants' behavior and environmental performance.

Location & Transportation (LT) - *continued*

For this category, projects that are located in urban cores are typically able to capitalize on more of the points available as compared to those located in suburban or rural areas. In order to maximize point achievement, the project team should consider the following:

- Perform a soil investigation to identify if site contaminants exist that should then be remediated (1 point)
- Determine if bus transportation services will be available from the new facility, and quantify the services (2-4 points)
- Provide both short– and long-term bicycle storage for the various visitors and occupants, as well as showering/changing facilities. Determine if a qualifying bicycle network exists; if not, work with the city of Boston to identify and/or provide a suitable network. (1 point)
- Design the occupant and visitor parking to provide at least 40% fewer spaces than the minimum identified by code. Also provide preferred parking spaces for carpools & vanpools. This further promotes the use of alternative modes of transportation, such as the buses that will be housed and maintained at the facility. (1 point)
- Provide preferred parking spaces for Green Vehicles, as well as electric charging stations for privately-owned vehicles. (1 point)

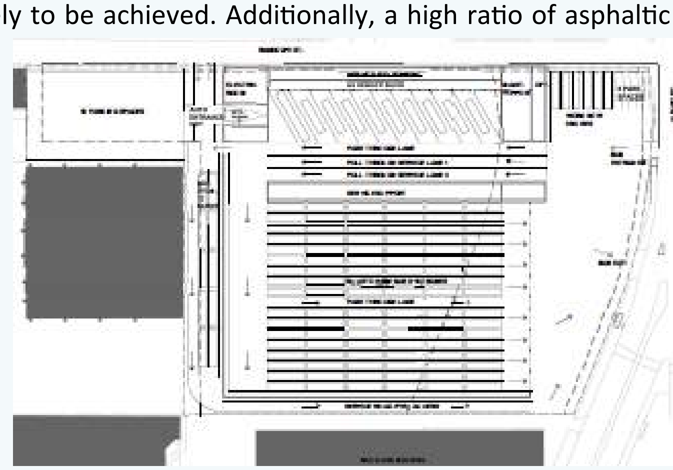
Sustainable Sites (SS)

(1 prerequisite; 10 possible points)

This category rewards decisions about the environment surrounding the building, with credits that emphasize the vital relationships among buildings, ecosystems, and ecosystem services. It focuses on restoring project site elements, integrating the site with local and regional ecosystems, and preserving the biodiversity on which natural systems rely.

Y	?	N				
			Sustainable Sites		*Total Possible:*	**10**
Y			Prereq 1	Construction Activity Pollution Prevention		Required
1	0	0	Credit 1	Site Assessment		1
0	0	2	Credit 2	Site Development - Protect or Restore Habitat		2
0	0	1	Credit 3	Open Space		1
0	2	1	Credit 4	Rainwater Management		3
0	2	0	Credit 5	Heat Island Reduction		2
1	0	0	Credit 6	Light Pollution Reduction		1

The only prerequisite in this category requires the project to have a stormwater pollution prevention plan (SWPPP) and/or an erosion and sedimentation control (ESC) plan, and site monitoring during construction, which is typically required of projects anyway. Many points in this category may not be available to the project based on the nature of the ground-level, vehicular-centric function. Without a notable overall percentage of vegetated site area with native/adapted plantings, the “Protect or Restore Habitat” and “Open Space” credits are unlikely to be achieved. Additionally, a high ratio of asphaltic hardscape versus the more reflective typical concrete complicates the likelihood of the “Heat Island Reduction” credit being achieved. Based on the existing site constraints and facility needs, the project should consider installing accessible green roofs with area-appropriate plantings, as well as specifying highly reflective site hardscape and rooftop materials. Stormwater treatment should be addressed for both quality and quantity issues, especially considering the minimal greenscape currently anticipated. If needed, the project could consider sponsoring off-site financial support of square footage equal to that of the project site area through a LEED-approved land trust or conservation organization.



Water Efficiency (WE)

(3 prerequisites; 11 possible points)

Y	?	N	Water Efficiency		Total Possible: 11
Y			Prereq 1	Outdoor Water Use Reduction	Required
Y			Prereq 2	Indoor Water Use Reduction	Required
Y			Prereq 3	Building-Level Water Metering	Required
1	1	0	Credit 1	Outdoor Water Use Reduction	2
3	2	1	Credit 2	Indoor Water Use Reduction	6
0	2	0	Credit 3	Cooling Tower Water Use	2
1	0	0	Credit 4	Water Metering	1

This section addresses project water use holistically, looking at indoor use, outdoor use, specialized uses, and metering. The requirements are based on an "efficiency first" approach to water conservation. As a result, each prerequisite looks at water efficiency and reductions in potable water use alone. A minimum reduction of 30 percent for outdoor, and 20% for indoor water use must be achieved; additionally, permanent water meters for the building and grounds must be installed. Then, the credits additionally recognize the use of nonpotable and alternative sources of water. These credits encourage project teams to take advantage of every opportunity to significantly reduce total water use.

To maximize water savings as well as points available, the following strategies are recommended for incorporation:

- Consider integrating a rainwater or graywater capture/treatment system for reuse as irrigation and/or toilet and urinal flushing.
- Select outdoor plantings that do not require irrigation past the 2-year establishment period.
- Specify efficient, but effective fixtures with low-flow flush and flow rates, such as 1.1 GPF toilets, 0.35 GPF urinals, 0.35 GPM lavatories, and 1.5 GPM showers.
- If cooling towers are included in the design, have the mechanical engineers assess if the systems can be tested and calibrated to meet the criteria of the "Cooling Tower Water Use" credit.
- Consider including permanent water meters for at least two water subsystems in addition to meeting the requirements of the "Building-Level Water Metering" prerequisite.

Energy & Atmosphere (EA)

(4 prerequisites; 33 possible points)

Y	?	N	Energy and Atmosphere		Total Possible: 33
Y			Prereq 1	Fundamental Commissioning and Verification	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	Building-Level Energy Metering	Required
Y			Prereq 4	Fundamental Refrigerant Management	Required
3	3	0	Credit 1	Enhanced Commissioning	6
4	4	10	Credit 2	Optimize Energy Performance	18
1	0	0	Credit 3	Advanced Energy Metering	1
0	2	0	Credit 4	Demand Response	2
0	1	2	Credit 5	Renewable Energy Production	3
0	1	0	Credit 6	Enhanced Refrigerant Management	1
2	0	0	Credit 7	Green Power and Carbon Offsets	2

As the most heavily weighted category, this section approaches energy from a holistic perspective, addressing energy use reduction, energy-efficient design strategies, and renewable energy sources. Energy efficiency should start with a focus on design that first reduces overall energy needs, such as building orientation and glazing selection, and the choice of climate-appropriate building materials. Strategies such as passive heating and cooling, natural ventilation, and high-efficiency HVAC systems partnered with smart controls can further reduce a building's energy use. The generation of renewable energy on the project site or the purchase of green power and carbon offsets allows portions of the remaining energy consumption to be met with non –fossil fuel energy, lowering the demand for traditional sources.

Prerequisites for this category require certain commissioning-related activities to occur during the design and construction phases, and must demonstrate a minimum energy use reduction of 5 percent over the baseline without considering on-site renewable energy generation as dictated by ASHRAE 90.1-2010. New to LEED v4, projects must also provide building-level energy meters that represent the total building energy consumption; the project must also commit to sharing energy consumption data with USGBC for a five-year period beginning at the date of certification. Finally, the project must confirm that no chlorofluorocarbon (CFC)-based refrigerants are used in the heating, ventilating, air-conditioning, and refrigeration (HVAC&R) systems.

ENERGY & ATMOSPHERE (EA) - *CONTINUED*

To maximize the potential energy savings available, as well as capitalize on available points, project teams should focus on energy modeling early and often, starting in preliminary design phases, and then continuing through construction and occupancy. When initiated early in the design process, an energy simulation serves as a design tool instead of a compliance check. One of the greatest benefits of early energy modeling is better integration of interrelated design issues, which encourages dialogue about assumptions concerning building components and systems. Information on energy use and costs thereby plays a bigger role as design decisions are made.

Early involvement of a commissioning authority helps prevent long-term maintenance issues and wasted energy by verifying that the design meets the owner's project requirements and functions as intended. Enhanced commissioning services can provide further oversight and verification that the building will meet their expectations and requirements beyond the first day of occupancy. These optional services, along with envelope commissioning to test and verify the building's thermal envelope, can help the project achieve better building performance and less energy expenditure over the lifetime of the building, thus also reducing ongoing maintenance and operation costs. Along with the benefits for the owner and occupants, pursuing additional commissioning services above those required by the prerequisite can also award the project with up to six additional points.

Renewable energy generation can reduce carbon emissions and offer local environmental benefits by reducing air pollution. The use of renewable energy systems on site can protect projects from energy price volatility and reliance on the grid while reducing wasted energy lost in transmission. Per the preliminary facility layout, the rooftop area above the electric bus facility is an ideal location for a solar photovoltaic installation. Power generated from the panels can help power both the building as well as the electric buses, themselves. The project's electrical engineer will be able to quantify the potential output to determine how much of the building's total electricity use can be supplied by the panels, and hence the number of associated points for LEED will be attainable. Final recommendations for this category include considering additional energy metering for the facility above that required of the prerequisite.

MATERIALS & RESOURCES (MR)

(2 prerequisites; 13 possible points)

The Materials and Resources (MR) credit category focuses on minimizing the embodied energy and other impacts associated with the extraction, processing, transport, maintenance, and disposal of building materials. The requirements are designed to support a life-cycle approach that improves performance and promotes resource efficiency.

Y	?	N			
5	3	5	**Materials and Resources**	*Total Possible:*	**13**
Y			Prereq 1	Storage and Collection of Recyclables	Required
Y			Prereq 2	Construction and Demolition Waste Management Planning	Required
0	3	2	Credit 1	Building Life-Cycle Impact Reduction	5
1	0	1	Credit 2	BPDO - Environmental Product Declarations	2
1	0	1	Credit 3	BPDO - Sourcing of Raw Materials	2
1	0	1	Credit 4	BPDO - Material Ingredients	2
2	0	0	Credit 5	Construction and Demolition Waste Management	2

The first prerequisite in this category requires the project building to provide recycling services as well as logical collection and storage points in the facility. The project must plan to collect the following items, at a minimum: mixed paper, corrugated cardboard, glass, plastics, and metals. New to LEED v4, the project must also accommodate the safe collection of at least two of the following: batteries, mercury-containing lamps, and electronic waste (e-waste). The second prerequisite, new to LEEDv4, requires planning ahead for construction waste management by requiring the development of a plan prior to construction, as well as an updated report detailing all major waste streams generated, including disposal and diversion rates.

All credits in this category, although identified by USGBC as "construction" credits, rely heavily on decisions made and products specified during the design phase. Recommendations for strategies to achieve these credits are as follows:

- Building Life-Cycle and Impact Reduction—New Construction (versus major renovation) projects are only eligible to pursue Option 4 for performing a Whole-Building Life-Cycle Assessment (3 points). Identify a team member who can

Materials & Resources (MR) - *continued*

perform the work necessary for exploring the credit criteria, and working with the structural team and contractor to determine the best design elements that are reasonable for the project. While completion of the life-cycle exercise will occur during the construction phase, the efforts made starting as early as design development shape the outcome of the work and likeliness of achieving the credit requirements.

- Building Product Disclosure and Optimization credits—These three credits involve selecting products that carry a variety of qualifying certifications and/or redeeming environmental qualities such as recycled content and/or certified wood. It is recommended that project team both seek out and track qualifying products throughout design in order to provide the contractor with an informed starting point during construction, and to most easily achieve these available points.

Indoor Environmental Quality (EQ)

(2 prerequisites; 16 possible points)

The prerequisites and credits in this category reward decisions made by project teams about indoor air quality and thermal, visual, and acoustic comfort. Buildings with good IEQ features and practices protect the health and comfort of building occupants, and also enhance productivity, decrease absenteeism, improve the building's value, and reduce liability for building designers and owners.

Y	?	N				
7	6	3	**Indoor Environmental Quality**		*Total Possible:*	**16**
Y			Prereq 1	Minimum Indoor Air Quality Performance		Required
Y			Prereq 2	Environmental Tobacco Smoke Control		Required
2	0	0	Credit 1	Enhanced Indoor Air Quality Strategies		2
1	1	1	Credit 2	Low-Emitting Materials		3
1	0	0	Credit 3	Construction Indoor Air Quality Management Plan		1
2	0	0	Credit 4	Indoor Air Quality Assessment		2
0	1	0	Credit 5	Thermal Comfort		1
1	1	0	Credit 6	Interior Lighting		2
0	1	2	Credit 7	Daylight		3
0	1	0	Credit 8	Quality Views		1
0	1	0	Credit 9	Acoustic Performance		1

Prerequisites in this category are largely unchanged from previous versions of LEED. Of note, smoking is still prohibited within 25 feet of entrances, operable windows, and outdoor air intakes, but is now also prohibited in spaces outside the project property line that are used for business purposes.

Similar to the MR category, the Low-Emitting Materials credit requires careful product selection during the design phase. All disciplines that specify products within the building envelope must be aware of restrictions associated with paints, coatings, adhesives, sealants, flooring, composite wood, ceilings, walls, thermal and acoustical insulation, and for some projects, furniture. Other recommendations for consideration are as follows:

- Particularly for the Boston climate, install entryway systems (e.g. walk-off mats, in-floor grates, etc.) that capture dirt and particulates entering the building at all regularly used entrances, including those in parking garages and at exterior terraces.
- Sufficiently exhaust any chemical use areas, and provide those spaces with at least MERV 13 filters, self-closing doors, and either hard-lid or deck-to-deck partitions.
- Consider one or more of the following for ventilated areas:
    - exterior contamination prevention
    - increased ventilation
    - carbon dioxide monitoring
    - additional source control and monitoring
    - natural ventilation room by room calculations
- Require the contractor to provide and implement a Construction Indoor Air Quality Management Plan prior to the start of construction, as well as pursue a building flush-out or air testing prior to occupancy.
- Design the project to provide sufficient controls for lighting, thermal comfort, and acoustically appropriate spaces, as well as access to proper levels of daylighting and quality views.

Innovation & Design (ID)

(0 prerequisites; 6 possible points)

Y	?	N			
4	2	0	**Innovation**	*Total Possible:*	**6**
3	2	0	Credit 1	Innovation	5
1	0	0	Credit 2	LEED Accredited Professional	1

The purpose of this LEED category is to recognize projects for innovative building features and sustainable building practices and strategies. Occasionally, a strategy results in building performance that greatly exceeds what is required in an existing LEED credit. Other strategies may not be addressed by any LEED prerequisite or credit but warrant consideration for their sustainability benefits. In addition, LEED is most effectively implemented as part of a cohesive team, and this category addresses the role of a LEED Accredited Professional in facilitating that process.

The potential strategies for this category can vary greatly. It is recommended that project teams use existing USGBC guidance for identifying approved paths for both Innovation credits and Pilot credits. These approved lists can be found on the USGBC website's LEED Credit Library for BD+C v4 projects: https://www.usgbc.org/credits/new-construction/v4 Some of the specific strategies currently available that should be explored in more detail are as follows:

- Innovation Credits:
  - Green Building Education
  - Purchasing—Lamps
  - Occupant Comfort Survey
  - Walkable Project Site
  - Design for Active Occupants
  - LEED O&M Starter Kit
- Pilot Credits:
  - Bird Collision Deterrence
  - Enhanced Acoustical Performance - Exterior Noise Control
  - Social Equity within the Project Team

It should be noted for projects that are pursuing all points available, that the strategies must include at least one Innovation strategy, at least one Pilot Credit, and may pursue no more than two Exemplary Performance points. Additionally, to earn the LEED Accredited Professional credit, the person claiming the role must be a LEED AP BD+C (not a legacy LEED AP, or LEED AP ID+C or other), and must play a significant role with the project team.

Regional Priority (RP)

(0 prerequisites; 4 possible points)

Y	?	N			
1	3	0	**Regional Priority**	*Total Possible:*	**4**
0	1	0	Credit 1	RP: Optimize Energy Performance	1
0	1	0	Credit 2	RP: High Priority Site	1
1	0	0	Credit 3	RP: Surrounding Density & Diverse Uses	1
0	1	0	Credit 4	RP: Outdoor Water Use Reduction	1

Because some environmental issues are particular to a locale, USGBC has identified distinct environmental priorities within their areas and the credits that address those issues. These Regional Priority credits encourage project teams to focus on their local environmental priorities. The ultimate goal of RP credits is to enhance the ability of LEED project teams to address critical environmental issues across the country and around the world.

Of the six credits identified for this project's location, those credits listed above appear to have the most relevance to the project based on current information available. When making decisions about which credits to pursue for the project, the team should consider the significance of the RP credits, as well as the potential for an extra point.

CONCLUSION

The case study provided within this document explores the requirements and possibilities for the BEB Albany Street Garage to pursue LEED certification. It should be noted that for projects within the City of Boston, there may be additional requirements related to sustainability and/or climate resiliency, such as Article 37, that would require separate study if deemed applicable to this project. For the LEEDv4 evaluation at hand, the overall preliminary checklist shown below illustrates the collective possibilities that are most suitable for the project given the information available at this time.

Y	?	N			
1	0	0	Credit	Integrative Process	1
9	**5**	**2**	**Location and Transportation**	*Total Possible:*	**16**
0	0	0	Credit 1	LEED for Neighborhood Development Location	16
1	0	0	Credit 2	Sensitive Land Protection	1
1	1	0	Credit 3	High Priority Site	2
5	0	0	Credit 4	Surrounding Density and Diverse Uses	5
1	2	2	Credit 5	Access to Quality Transit	5
0	1	0	Credit 6	Bicycle Facilities	1
0	1	0	Credit 7	Reduced Parking Footprint	1
1	0	0	Credit 8	Green Vehicles	1
2	**4**	**4**	**Sustainable Sites**	*Total Possible:*	**10**
Y			Prereq 1	Construction Activity Pollution Prevention	Required
1	0	0	Credit 1	Site Assessment	1
0	0	2	Credit 2	Site Development - Protect or Restore Habitat	2
0	0	1	Credit 3	Open Space	1
0	2	1	Credit 4	Rainwater Management	3
0	2	0	Credit 5	Heat Island Reduction	2
1	0	0	Credit 6	Light Pollution Reduction	1
5	**5**	**1**	**Water Efficiency**	*Total Possible:*	**11**
Y			Prereq 1	Outdoor Water Use Reduction	Required
Y			Prereq 2	Indoor Water Use Reduction	Required
Y			Prereq 3	Building-Level Water Metering	Required
1	1	0	Credit 1	Outdoor Water Use Reduction	2
3	2	1	Credit 2	Indoor Water Use Reduction	6
0	2	0	Credit 3	Cooling Tower Water Use	2
1	0	0	Credit 4	Water Metering	1
10	**11**	**12**	**Energy and Atmosphere**	*Total Possible:*	**33**
Y			Prereq 1	Fundamental Commissioning and Verification	Required
Y			Prereq 2	Minimum Energy Performance	Required
Y			Prereq 3	Building-Level Energy Metering	Required
Y			Prereq 4	Fundamental Refrigerant Management	Required
3	3	0	Credit 1	Enhanced Commissioning	6
4	4	10	Credit 2	Optimize Energy Performance	18
1	0	0	Credit 3	Advanced Energy Metering	1
0	2	0	Credit 4	Demand Response	2
0	1	2	Credit 5	Renewable Energy Production	3
0	1	0	Credit 6	Enhanced Refrigerant Management	1
2	0	0	Credit 7	Green Power and Carbon Offsets	2

Y	?	N			
5	**3**	**5**	**Materials and Resources**	*Total Possible:*	**13**
Y			Prereq 1	Storage and Collection of Recyclables	Required
Y			Prereq 2	Construction and Demolition Waste Management Planning	Required
0	3	2	Credit 1	Building Life-Cycle Impact Reduction	5
1	0	1	Credit 2	Building Product Disclosure and Optimization - Environmental Product Declarations	2
1	0	1	Credit 3	Building Product Disclosure and Optimization - Sourcing of Raw Materials	2
1	0	1	Credit 4	Building Product Disclosure and Optimization - Material Ingredients	2
2	0	0	Credit 5	Construction and Demolition Waste Management	2
7	**6**	**3**	**Indoor Environmental Quality**	*Total Possible:*	**16**
Y			Prereq 1	Minimum Indoor Air Quality Performance	Required
Y			Prereq 2	Environmental Tobacco Smoke Control	Required
2	0	0	Credit 1	Enhanced Indoor Air Quality Strategies	2
1	1	1	Credit 2	Low-Emitting Materials	3
1	0	0	Credit 3	Construction Indoor Air Quality Management Plan	1
2	0	0	Credit 4	Indoor Air Quality Assessment	2
0	1	0	Credit 5	Thermal Comfort	1
1	1	0	Credit 6	Interior Lighting	2
0	1	2	Credit 7	Daylight	3
0	1	0	Credit 8	Quality Views	1
0	1	0	Credit 9	Acoustic Performance	1
4	**2**	**0**	**Innovation**	*Total Possible:*	**6**
3	2	0	Credit 1	Innovation	5
1	0	0	Credit 2	LEED Accredited Professional	1
1	**3**	**0**	**Regional Priority**	*Total Possible:*	**4**
0	1	0	Credit 1	RP: Optimize Energy Performance	1
0	1	0	Credit 2	RP: High Priority Site	1
1	0	0	Credit 3	RP: Surrounding Density & Diverse Uses	1
0	1	0	Credit 4	RP: Outdoor Water Use Reduction	1
44	**39**	**27**	**TOTALS**	Possible Points:	**110**

Certified: 40 to 49 points, **Silver:** 50 to 59 points, **Gold:** 60 to 79 points, **Platinum:** 80 to 110

Notes:

LEED® Facts

Preliminary Analysis

Certification Attainable

Total Points Achievable.........up to 83/110

Location & Transportation.............up to 14/16

Sustainable Sites.........................up to 16/10

Water Efficiency...........................up to 10/11

Energy and Atmosphere..................up to 21/33

Materials and Resources.................up to 8/13

Indoor Environmental Quality.........up to 13/16

Innovation and Design.....................up to 6/6

Regional Priority.............................up to 4/4

Sustainable design is an increasingly necessary component of good overall project design. Incorporating sustainable design principles not only responds to the MBTA's current needs for their building occupants, but it is also mindful of the environmental necessities of generations to come.

The analysis and recommendations provided within this study indicate that LEED Certification is possible for the proposed project; actual achievement, and at which level, will be entirely dependent on design team, owner/operator, and construction team decisions. Further analysis will be required once the project advances to the preliminary design phases, and more details can be determined.

A Better City and the Barr Foundation's commitment to sustainability will allow this project to not only encourage sustainable design principles, but to alter the way buildings are designed, built, and maintained in the communities where we have worked.