Low Emissions Transition Plan

FORT WAYNE PUBLIC TRANSPORTATION CORPORATION (CITILINK)
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CONTENTS

EXECUTIVE SUMMARY:

The transportation sector accounts for substantial greenhouse gas emissions in the United States. Greenhouse gases are comprised of a combination of emissions of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and various fluorinated gases.

Among the compilation of greenhouse gases, CO_2 has the largest share, about 79%, according to the US EPA. The primary source of CO_2 emissions is the use of fossil fuels in traditional, internal combustion engine vehicles. Public transportation agencies, as providers of essential transportation services in communities, and as significant users of traditional, internal combustion engine vehicles, play a critical role in the transition to a more sustainable future for the environment.

The Fort Wayne Public Transportation Corporation (Citilink) is committed to evaluating CO_2 emissions reduction initiatives at the state, federal, and local levels. This commitment will be accomplished primarily by considering the value-added benefits of converting to a low- or zero-emission bus fleet. A bus fleet conversion replaces traditional diesel- or gasoline-powered vehicles with alternative propulsion technologies.

Citilink has already taken incremental steps towards CO_2 reduction with the acquisition of diesel-electric hybrid (hybrids) as well as modern clean diesel buses. The promised fuel savings and operating cost reductions did not materialize to the expected levels which would justify the vehicle's increased purchase price and technical complexity compared to clean diesel buses. The Citilink Hybrid electric vehicles have demonstrated a combined efficiency of less than 13% versus the combined clean diesel fleet; however, when compared with the latest clean diesel vehicles received the difference drops to 9%. These factors combine to approach the possibility of introducing zero-emissions buses (ZEBs) carefully as the past experiences have not lined up with promises from the technology and vehicle suppliers. However, Citilink recognizes the emission-reduction benefits of hybrid buses over clean diesel buses and the benefits of having a fleet with the same propulsion technologies. Continued investment in hybrid buses would provide an opportunity to proceed with the most efficient low-emission fleet as a financially attainable solution.

In considering the possibility of a zero-emission fleet, the goals of a reduced carbon footprint and the realities of operational impacts and funding need to be balanced to maintain Citilink's primary role of providing safe, reliable, and affordable transportation to the citizens of Fort Wayne.

Key considerations and recommendations are summed up as follows:

Facility Requirements: To transition to a zero-emissions fleet, Citilink would need to invest significantly in a new facility capable of maintaining and charging electric buses and/or fueling fuel cell electric buses with hydrogen (FCEB). The existing facility is simply inadequate for this purpose due to infrastructure and layout limitations required to operate a full zero-emissions fleet. Transitioning to a hybrid electric fleet will not require extensive facility upgrades for the zero-emissions buses.

Cost Implications: (Facility)

The construction of a new facility or upgrading the current facility for a zero-emissions fleet would incur substantial costs. Note, that upgrading the current facility is not recommended as the cost to build ground up would be almost identical. Similarly sized facilities have been costed at $100-150 million. A hybrid electric fleet will require more of the same facility requirements of the existing hybrid electric buses.

Cost Implications: (Vehicles)

As of writing, zero-emissions vehicle costs have been on the rise and are expected to continue to climb as the demand for vehicle batteries increases and bus suppliers dwindle. In recent news, Proterra has filed for Chapter 11 and Nova Bus will no longer sell vehicles in the United States. Although Citilink has not historically purchased vehicles from either supplier this situation increases the demand on the remaining bus suppliers thus reducing vehicle availability and increasing lead times and pricing. Recent pricing on 35' battery electric buses has been in the range of $1.1 million, with fuel cell vehicles being significantly more expensive with a current market price of $1.7 million.

Given the above considerations, it would be recommended to hold off on an immediate transition to zero-emissions buses for Citilink. Instead, the following approach is proposed:

Continue with Hybrid Electric Buses: Citilink should continue operating its current fleet of hybrid electric buses to reduce emissions. As discretionary funding becomes available, hybrid and diesel vehicles past their useful life can be replaced with a low-emission hybrid solution instead of diesel vehicles.

Continue with Clean Diesel Buses: Citilink should continue operating its current fleet of clean diesel buses. These buses are compliant with the latest emission standards and offer a reliable and cost-effective means of transportation. While diesel-powered vehicles do still emit tailpipe emissions, the latest generation of clean diesel buses are significantly cleaner than those from even just a few years ago. These newer vehicles do contribute to lower environmental carbon levels as they replace the aging buses.

Pilot Program for Plug-In Battery Electric Buses: In the interest of environmental sustainability and as a potential next step towards zero emissions, Citilink may consider piloting a small fleet of plug-in battery electric buses on selected routes. This pilot program can help assess the feasibility of electric buses without committing to a full-scale transition. It would also provide valuable data for future decision-making.

While a transition to zero emissions is an admirable goal, the high cost of a new facility and vehicles, as well as the limitations of available funding make an immediate shift unfeasible for Citilink. The recommended approach of continuing with hybrid and clean diesel buses and exploring a pilot program for plug-in battery electric buses balances sustainability goals with fiscal responsibility.

Citilink can revisit the zero emissions transition in the future as funding becomes available or as technological advancements make it more economically viable. In the meantime, Citilink can maintain its commitment to providing reliable and efficient public transportation services to the community while taking measured steps toward a greener future.

INTRODUCTION

Established in 1968, Citilink was founded to provide comprehensive public transportation services to the residents of Fort Wayne, IN. As a separate division of the local government, Citilink operates independently from the city and county governments. The board of directors, consisting of seven members, is appointed by the Fort Wayne mayor and city council. With a population of approximately 266,000 residents, Fort Wayne stands as the second-largest city in the State of Indiana.

Citilink offers a range of transportation services, including fixed route, deviated fixed route, and ADA complementary paratransit services. To support these operations, Citilink employs a dedicated team of 125 professionals, encompassing management, administrative personnel, and unionized bus operators and maintenance personnel represented by ATU Local 682.

Prior to the impact of the pandemic, annual ridership stood at 1.6 million passenger trips. Although faced with challenges, ridership has shown a steady rebound, reaching 1.3 million trips in 2021. To sustain services and maintenance, Citilink operated on an annual budget of $17.1 million for 2022. This funding is utilized for the smooth operation and maintenance of the combined fleet of 65 buses.

As of the end of 2022, Citilink operates a fleet of 34 heavy-duty transit buses, all manufactured by Gillig, LLC of Livermore, CA, in its fixed route operations. These buses are 35 and 40 feet in length, both lengths being equipped with either a traditional diesel or diesel-electric hybrid powertrain:

- 10 – 35-foot traditional diesel (with 4 new buses due to be delivered in 2023)
- 14 – 35-foot diesel-electric hybrid
- 2 – 40-foot traditional diesel
- 8 – 40-foot diesel-electric hybrid

This fixed-route bus fleet ranges in age from 1 to 17 years.

The balance of the service fleet is comprised of 6 cutaway-style vans for the FLEXLINK operations (a deviated fixed route operation), and an additional 18 cutaway-style vans for the Access paratransit operations. Fourteen of these vehicles are scheduled to be retired and replaced with new vehicles in 2023.

To facilitate day-to-day operations and maintenance needs, Citilink operates a non-revenue fleet consisting of 15 vans and trucks.

It is important to note that the study conducted, and the subsequent recommendations provided, are primarily focused on analyzing Citilink's fixed route operations, aiming to enhance services and a possible path forward to a zero-emissions fleet.

Technology options are listed below as a reference for the rest of the report:

- Clean Diesel

- Diesel-electric hybrid (HEB)
- Compressed Natural Gas (CNG)
- Battery Electric Bus (BEB)
- Fuel Cell Electric Bus (FCEB)
- Electric Trolley Bus (ETB)

This report will not expand on ETB operations for practical reasons. This zero-emissions solution has some distinct advantages such as maturity, light vehicles, and highest efficiency. Unfortunately, the disadvantages are significant:

- Deploying a systemwide catenary/substation network along with the staff to support it
- Design, permitting, and construction of this network
- The small number of ETB systems in North America makes it challenging to procure vehicles for the fleet

Capital vehicle acquisition costs are approximate: a 40′ traditional diesel bus can cost $600,000, a CNG about 30% to 40% more, a FTA qualified HEB costs approximately $1,1 million, while the zero-emission options from FTA qualified vendors begin at $1.3 million per BEB and $1.7 million per FCEB, respectively.

Capital infrastructure for the zero-emissions options also requires infrastructure investments of approximately $500,000 per vehicle for BEB charging infrastructure based on comparatives from other US transit agencies' ZEB transitions.

Capital infrastructure required to support the different types of ZEBs such as BEBs, would require chargers, dispensers, power transformers, and switchgear. The Power Utilities needs to be able to provide required energy and may need to install a substation for this purpose.

For FCEBs, options are to make hydrogen on-site or have it delivered in liquid or gaseous form. On-site generation with electrolysis will need electrical utility service upgrade comparable with the upgrades needed for battery charging infrastructure. A liquid truck-in hydrogen system may need a minor electrical upgrade if no spare is available.

Logistics for the zero-emission options that have onboard electrical systems that operate at about 200-900 volts DC, will require the same safety equipment and training that diesel-electric hybrids in the current fleet do. Additionally, safety needs now extend to the facility infrastructure for chargers/hydrogen fueling station/catenary system. Spare parts and asset management are more critical and/or more complex with zero-emission solutions (e.g., a transformer failure with current 80-week lead times can have significant impacts on the operation, same with a pump for the hydrogen fueling station)

Operating cost of zero-emission options will vary from current system. It will include the cost of specialized-labor and parts for maintenance of the installed infrastructure and ZEB and cost of utility and commodity. Some of these expenses are currently unknown as the new generation of ZEBs have not reached end-of-life, and they are estimated here based on known industry conditions.

REDUCING EMISSIONS – FLEET OPTIONS

To support GHG reduction goals, Citilink plans to consider the following options in choosing the best path forward which balances the need for GHG reductions and the operational feasibility of implementing various fleet options currently available targeted at reducing GHGs.

- Continue purchasing Hybrid Electric Buses (HEBs), which offer better emissions due to reduced fuel consumption. Citilink is already experienced in maintaining and operating hybrid buses.

- Continue with the purchase of clean diesel buses. This will reduce emissions by retiring older technology diesel and HEBs as they are replaced modern vehicles whose tailpipe emissions have been continuously improving over the past few years. The operational benefits of these vehicles are considerable as there are no range issues or additional infrastructure requirements to service and maintain these vehicles.

- BEBs are an option to quickly transition or explore the nature of purchasing, operating, maintaining ZEB vehicles. The vehicles are relatively available as of writing, although long lead times are an industry issue. The major concerns with BEBs is their range, charging times, and performance in cold weather, secondly the capital investment is significant and requires major facility work to exploit even a pilot fleet.

- FECBs offer a lot of promise as they eliminate range anxiety, charge times, and cold weather performance. FCEBs have only been trialed at a few agencies and therefore remain as the technology option with which the industry has had the least experience with. Up front capital costs are more significant than with BEBs, although they are amortized as the FCEB fleet grows. Current H_2 pricing translates to a cost per mile at 2-3 times that of BEBs. The high cost of entry and operation has slowed the adoption of the technology.

1. FLEET AND PROCUREMENT

Citilink is seeking to understand the state of the low and zero-emission vehicle market and plan for how to navigate the ever-evolving state of the bus industry while planning for future fleet purchases. Citilink's priority in offering safe, reliable, and affordable transportation is at the forefront of its priorities to the public.

1.1 FLEET OVERVIEW

As of writing, Citilink operates a fleet of 34 heavy-duty transit buses, manufactured by Gillig, LLC of Livermore, CA, in its fixed-route operations. These buses are 35 and 40 feet in length, respectively. With both variants equipped with either a diesel only, or diesel-electric hybrid powertrain:

This fixed-route bus fleet ranges in age from 1 to 17 years.

The balance of the service fleet is comprised of 6 cutaway-style vans for its FLEX ROUTE operations (a deviated fixed route operation), and an additional 18 cutaway-style vans for its Access paratransit operations. It should be noted that 14 of these vehicles are scheduled to be retired and replaced with new vehicles in 2023.

To facilitate day-to-day operations and maintenance needs, Citilink operates a non-revenue fleet consisting of 15 vans and trucks.

Bus Fleet Replacement Plan

The table below was developed from Citilink's existing active roster of buses including the planned useful life provided. The plan can be adjusted based on available funding, or a desire to procure buses in larger batches if there is a financial incentive for doing so.

Bus Model Year

Bus Fleet by Calendar Year	2006	2008	2010	2012	2013	2015	2016	2017	2018	2019	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	Total
2023	2	3	7	2	5	4	1	1	2	2	5												34
2024	2	3	3	2	5	4	1	1	2	2	5	4											34
2025	0	3	0	2	5	4	1	1	2	2	5	4	5										34
2026	0	0	0	0	5	4	1	1	2	2	5	4	5	5									34
2027	0	0	0	0	0	4	1	1	2	2	5	4	5	5	5								34
2028	0	0	0	0	0	4	1	1	2	2	5	4	5	5	5	0							34
2029	0	0	0	0	0	0	1	1	2	2	5	4	5	5	5	0	4						34
2030	0	0	0	0	0	0	1	1	2	2	5	4	5	5	5	0	4	0					34
2031	0	0	0	0	0	0	0	0	2	2	5	4	5	5	5	0	4	0	2				34
2032	0	0	0	0	0	0	0	0	2	2	5	4	5	5	5	0	4	0	2	0			34
2033	0	0	0	0	0	0	0	0	0	0	5	4	5	5	5	0	4	0	2	0	4	0	34

As the buses currently in operation age, their odometer mileage increases, and they meet their useful life, they should be replaced with the most operationally efficient, environmentally beneficial, and financially appropriate buses. The priority for replacing buses should be based on their propulsion type (replace diesel for low or no emission buses), if they have met their useful life, their odometer mileage, the year they were built, and their existing condition (including if major maintenance work is needed).

This plan does not assume a propulsion type; however, as the projected vehicle type is to be HEBs and clean diesel, there would not be a disruption to the procurement schedule due to infrastructure construction or delays. The delays would typically result in procurement gaps that would then lead to a purchasing bubble.

A large, sudden influx of vehicles would be difficult for Citilink to manage and a gap in purchasing could potentially have an impact on O&M costs due to running older vehicles past their expected service life.

This plan assumes that buses will be procured in groups of 2-5 buses at a time.

All buses are expected to be retained for an average of 14 years.

1.2 EMISSIONS ANALYSIS

There are environmental benefits to be had every time a portion of the fleet is replaced with newer vehicle models. Key tailpipe emissions elements from internal combustion diesel engines are nitrogen oxides (NOx) and particulate matter of 2.5-micron diameter and smaller (PM2.5). Well-to-wheel emissions are modeled for greenhouse gas emissions (GHG), which are comprised of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and various other fluorinated gases that can act as a factor in ozone depletion.

Appendix B of this plan provides more detail calculations regarding the emissions analysis; presented here is the overall summary. The reference data has been provided by the Argonne National Laboratory, Heavy-*duty Vehicle Emissions Calculator,* Heavy-Duty Vehicle Emissions Calculator (anl.gov); which in turn bases its emissions data from both the EPA's *MOVES* and Argonne's *GREET* models.

If the entire Citilink fixed-route bus fleet were to be replaced in 2023 with zero-emissions buses, the following would be the rough estimate of the "Vehicle Lifetime Benefit" of emissions over a 12-year period, averaging 40,000 miles per year per bus:

- NOx ~74,500 pounds
- PM2.5 ~212 pounds
- GHG ~25,500 tons

1.3 TESTING ZERO-EMISSIONS TECHNOLOGY

A pilot program can be designed and implemented to inform the agency regarding capital/operating costs. Pilot projects allow for weeding out technologies or solutions that are not ready for the rigors of transit operations.

Financing of test and evaluation pilot projects can be done through leasing, local funding as well as through federal Lo-No or CMAQ grants. The need for data collection and KPI definition as this ensures that the agency can capture, document, and compare the emission reducing technologies.

Data analysis can compare reliability and availability of not only the buses but also of the required infrastructure for charging or fueling. An example of a useful KPI is the mean time to repair (MTTR) as this accounts for the availability of support staff, time to troubleshoot, and parts delays.

1.4 PROCUREMENT STRATEGY AND STANDARDS

STV has performed an energy consumption analysis, ***Performance and Evaluation of Electric Bus Routes*** (**PEER)**, which is detailed in appendix A of this document to ascertain how current zero-emission technologies compare in Citilink's service profile. This analysis provides a picture of what type of vehicles would be required and when to then create a low or zero emissions fleet replacement plan.

Note: *The energy consumption analysis is focused in zero emissions technologies; BEB and FCEB, respectively as both technologies offer operational limitations when compared to diesel or hybrid-diesel buses.*

Ideally, a replacement schedule would replace a fixed number of buses per year until 100% of the fleet is renewed. Alternatively, buses can be replaced when they reach a certain age based on their condition and agency funding status and contracting mechanisms applied.

A critical driver for procurements for zero emission buses begins with the infrastructure planning as building or refurbishing an existing garage to support zero-emission vehicles requires on average approximately five years.

Procuring buses can generally be accomplished in 18-24 months, depending on propulsion type; however, supply chain issues have impacted recent projects of comparable size. At the time writing two major bus manufacturers have left the US market which will inevitably lead to longer lead times and increased pricing as the manufacturing pressure falls to the remaining manufacturers. Gillig states that hybrid or clean diesel buses can be delivered in 15-18 months.

Conductive Charging/Plug-in

Standardization within the automotive industry will ensure that plug-in solutions are more reliable, durable, and lower in cost.

Ford and General Motors recently announced that they will use the TESLA/NACS standard for their cars and trucks while Mercedes and Stellantis also announced that they will consider this option and likely follow suit.

ABB, a major bus charging supplier, has also announced that their equipment can and will be provided with the Tesla/NACS charge plug and requisite software.

The versatility, ease of installation, and relatively lower cost makes plug in charging an attractive solution for Citilink as its fleet size is manageable with this type of solution.

Conductive Charging/Pantograph Down

This technology uses a rail-type pantograph that is inverted and mounted on infrastructure (roof or gantry). The bus has charging contacts/rails on the roof, it is positioned under the pantograph and the connection is between charger and bus are automated.

Agencies have selected this solution as shown later in this document, for depot charging or on-route charging. The standard pantograph is significantly more expensive than the plugin dispensers; however, for larger fleet sizes they do offer savings in terms of logistics and resources required.

The latest standardized units are carry-over rail solutions and thus have an expected durability in line with heavy duty bus operations.

The BEB charging methods described above have their unique maintenance/inspection requirements, as well as recommended spares that must be procured at the onset and accommodated in stock rooms.

BEBs and agency operations benefit when implementing an effective charge management system (CMS). The CMS can help with electricity load-leveling and charging scheduling as well as to provide overall visibility of the fleet in terms of battery state-of-charge, alerts/alarms, and dispatching functions

Inductive Charging

There are currently no standards for inductive charging and therefore an agency would be vendor locked in the foreseeable future.

There are transit agencies which have deployed pilot programs to validate the technology specifically for on-route or opportunity charging to extend BEB range.

Inductive charging remains an emerging technology with specific limitations today; however, if these limitations can be overcome does address constraints of the other solutions (i.e. overhead space, visual appeal)

2. FACILITIES AND INFRASTRUCTURE

The existing facility located at 801 Leesburg Road, has two buildings on the site. The first is a storage building originally constructed in the 1950s with an addition constructed in the early 1970 s. The building is in fair to poor condition and in need of roof and possibly roof structural repairs. The second building on site was constructed in 1960s (estimated) and houses the administration, driver facilities, and the repair activities and is in good condition.

Existing facilities are suitable for housing, maintaining, and operating hybrid and diesel buses, however, the poor condition of the bus barn will require facility rehabilitations to extend its use. The administration facility is in need of replacement of electrical systems, HVAC systems, and plumbing. The fuel storage and dispensing system and bus washer also need to be replaced.

If BEBs are selected the facility will require a new electrical service to serve the charging units and the heating and ventilation systems in the storage barn will need to be enhanced to address the heat generated by the charging process. If pantograph charging is utilized, at a minimum the roof structure of the storage barn will need to be removed, the exterior wall will need to be raised, and a new roof structure installed that will provide additional load carrying capacity and interior clearance for the equipment. If pantograph charging is selected, complete replacement of the storage barn should be given consideration. In the case of plug-in charging, the roof extension would not be required and charging reels could be supported from the floor. Note the amount of rust on the roof structure and deck is a concern and suggests that the existing ventilation system is not providing adequate exhaust to remove moisture. Whether due to rain or the bus washer, water from buses is trapped in the building where evaporates, rises to the roof, and condenses on the roof structural elements and metal deck. Further investigation of the building structural and mechanical systems is recommended. Though fire protection standards have not yet been established for BEB vehicle storage areas, current practice is to provide additional sprinkler coverage in the storage/charging areas, which often requires the addition of a fire pump or the up sizing of an existing fire pump. In either scenario, modifications to the repair areas would include the addition of plug-in chargers, additional hose reels, and mobile or fixed platforms as well as a fall arrest system for worker protection while accessing the roof mounted equipment.

If hydrogen is selected, both the storage barn and the repair areas will require the installation of a gas detection and evacuation system. In addition, all electrical devices that could be a source of ignition will need to be relocated a minimum of 18” below the roof deck. Similar to the BEBs, a hydrogen bus fleet will require mobile or fixed work platform for access to roof mounted equipment and a fall arrest system for worker safety. It does not appear the existing site could accommodate a hydrogen plant and facilities for the delivery and storage of hydron would be required.

In most scenarios with contractor coordination, it is likely modifications to accommodate ZEBs could be made while the facility remains in operation. In the event of BEBs with pantograph charging and full storage building replacement, storage of vehicles will need to be accommodated off-site, however, the maintenance activities would be able to continue operation.

3. ENERGY ANALYSIS (PEER)

To better understand the feasibility of a full 100% ZEB fleet conversion, an energy assessment of Citilink's current operations was needed. The first step in this assessment was to simulate Citilink's system with the performance and evaluation of electric bus routes" (PEER). PEER is a proprietary simulation model designed to predict the energy consumption of a BEB as it travels along a specified route under specified loading and weather conditions. The purpose of the PEER analysis is to provide an evaluation of a BEB's expected performance on every trip on each of the transit system's routes to develop a real-world operating range that accounts for, among other things:

- Bus stop dwell time
- Ambient temperature
- Passenger counts
- Route grades and elevation
- Bus type and properties
- Schedules
- Depot layout

Results from the PEER analysis will allow for the creation of Citilink's transition plan and identify areas of the existing schedule that may need additional adjustments. The tables below provide an overview of the PEER analysis conducted. A more detailed explanation of the approach and results can be found in Appendix A: Performance and Evaluation of Electric Bus Routes (PEER).

Table 3-1 below shows an overview of the estimated completion of Citilink's blocks operating in winter conditions, based on the results of the PEER analysis. Winter conditions are typically the worst-case scenario when operating ZEBs, due to the additional energy needed to heat the vehicle for passenger and operator comfort. This analysis was done using both current and predicted future 35-foot BEBs and current 40-foot FCEBs, due to the lack of availability of 35-foot FCEBs on the market.

As shown above, the best block completion rate can be achieved when operating 40-foot FCEBs with a DFH. When operating a fleet with BEBs or without DFH, the block completion rate falls drastically. This is to be expected, as FCEBs tend to have a higher mileage than BEBs. Additionally, as previously mentioned, winter conditions require additional energy to heat the vehicle. DFH supplements the electric heat, thus reducing the overall energy spent on heating, which in turn increase the energy available to operate the ZEB.

TABLE 3-1: COMPLETABLE BLOCKS OVERVIEW (DEGRADED BATTERY)

Bus Type	Heater	Usable Energy	Total Blocks	Completable Blocks
BEB	DFH	282kWh	26	4
	No DFH			0
BEB (Future)	DFH	419kWh	26	8
	No DFH			3
FCEB	DFH	562kWh	26	20
	No DFH			5

Based on these block energy and completion rates, the number of buses needed to complete Citilink's entire system was determined. This was done by an algorithm in PEER that splits incompletable blocks into smaller, theoretical blocks that are expected to be completable with ZEBs. These blocks are then linked together to better replicate Citilink's actual operating conditions, based on service ID, start and end time, bus type, energy consumption, and mid-day charging or refueling. Table 3-2 below shows the estimated number of buses needed during winter conditions for future 35-foot BEBs and 40-foot FCEBs equipped with DFH.

TABLE 3-2: THEORETICAL BLOCK COMPLETION SUMMARY – DEGRADED BATTERY IN WINTER

Bus Type	Heater	35-foot BEB/40-foot FCEB (800kWh Battery/734kWh Fuel Cell)			
		Original Blocks	Complete Blocks	Theoretical Blocks	Service Buses Needed
BEB	DFH	26	18	44	44
	No DFH	26	23	63	63
FCEB	DFH	26	6	32	31
	No DFH	26	21	47	44

The service buses needed in the table above does not account for spare ratio. The current fleet size is composed of 34 large transit buses, therefore all scenarios listed in the table above except FCEB with DFH would require a fleet size increase to provide the same level of service. The primary cause of this is the lack of on-board energy that make current schedules incompletable. The existing facility may be able to house enough buses for all options except BEB without DFH, however space will likely need to be used in a more strategic manner.

Based on the estimated number of BEBs needed, the overall electrical requirements needed to support a 100% BEB fleet was determined. Using the estimated block energies and schedule from the analyses described in tables 3-1 and 3-2 and an assumed charging rate of 150 kW accessible at all times by every bus in the garage, the power demand requirements were calculated. This calculation was done for three different scenarios. The first scenario, “first-in, first-out” (FIFO), assumes that buses will begin charging as soon as they arrive at the depot. The second scenario, “demand shift”, attempts to minimize the peak charging demand while also minimizing any charging during a specified time window. The third scenario, “min power”, only minimizes the peak charging, without regard to any time constraints. Table 3-3 below shows the yearly energy and peak charging demands.

Additionally, the hydrogen requirements needed to support a 100% FCEB fleet was also determined. Similarly, the estimated block energy and schedule from tables 3-1 and 3-2 were used to determine the overall yearly hydrogen and cost for each scenario.

TABLE 3-3: WEEKLY DEPOT ENERGY/POWER DEMAND – FUTURE DEGRADED BATTERY IN WINTER

Bus Type	Number of Buses (Full ZEB Schedule)	Yearly Energy/Fuel	Yearly Energy Cost (Mil USD)	Power Demand (MW)		
				FIFO	Demand Shift	Min. Power
BEB - DFH	44	3,101 MWh	0.65	3.6	0.6	0.5
BEB – No DFH	62	3,280 MWh	0.66	5.54	1.00	0.85
FCEB – DFH	31	157.3 Mg	1.30	Not Applicable		
FCEB – No DFH	44	200.6 Mg	1.60			

4. MICROGRID ANALYSIS

METHODOLOGY

A microgrid analysis is conducted by STV for Citilink’s bus depot. This analysis is accomplished by utilizing The National Renewable Energy Laboratory’s (NREL)

System Advisor Model (SAM) tool, designed for microgrid simulation and design (National Renewable Energy Laboratory, n.d.). Prior to running the analysis through SAM, a yearly depot load profile is generated by STV's PEER tool. This tool inputs Citilink's General Transit Feed Specification (GTFS) data that is utilized to evaluate Citilink's depot schedule and provide an understanding of Citilink's service energy usage. This understanding of the service energy usage ultimately leads to the needed yearly load profile. This load profile is made across a weekly schedule, that is evaluated for each season. After collecting a weekly profile for each season, this data can then be concatenated into a profile that is representative of the yearly energy usage. This analysis evaluates two separate microgrid scenarios. One scenario is within the spatial context of the depot and the other tries to evaluate a more optimal design, that is based on the evaluated load profile and does not consider spatial limitations.

SAM ANALYSIS

Figure 4-1 shows Citilink's electric generation compared to the total energy needed to facilitate BEB operations by month, for the spatial analysis. This figure shows that the system is a relatively good match for the projected load of the system. In the summer months the PV array can outperform the depot utilization and in all other months is able to offset a large portion of the BEB operational load.

Figure 4-2 shows the resiliency of the system to outages. This system performs decently to short power outages. However, other backup options, like a diesel generator should still be considered.

Figure 4-3 provides the yearly cashflow of the system. The first year there is a large negative cashflow, due to the initial investment of the system. There is a negative cashflow for all evaluated years, with slightly decreasing negative cashflow, year-over-year. This sums to a net present value of $-2,831,612.

Figure 4-1: Spatial Analysis

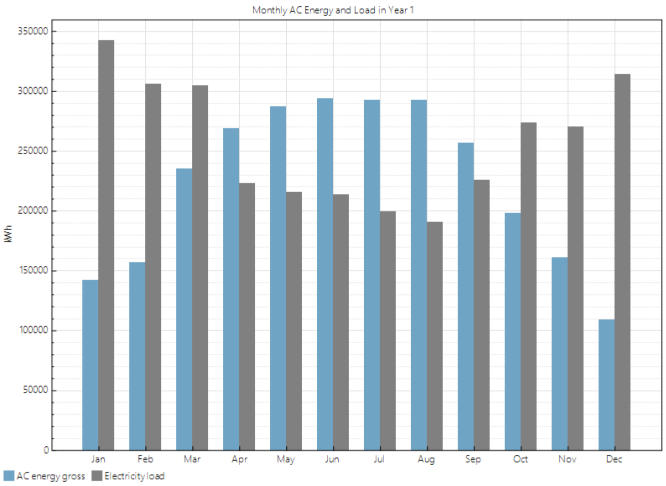
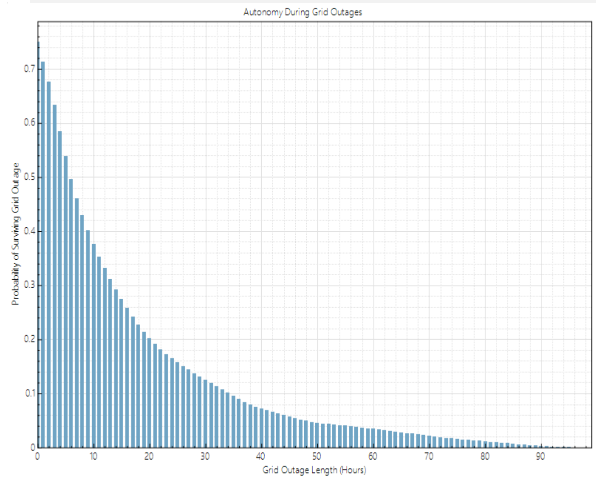


Figure 4-2: Spatial Analysis



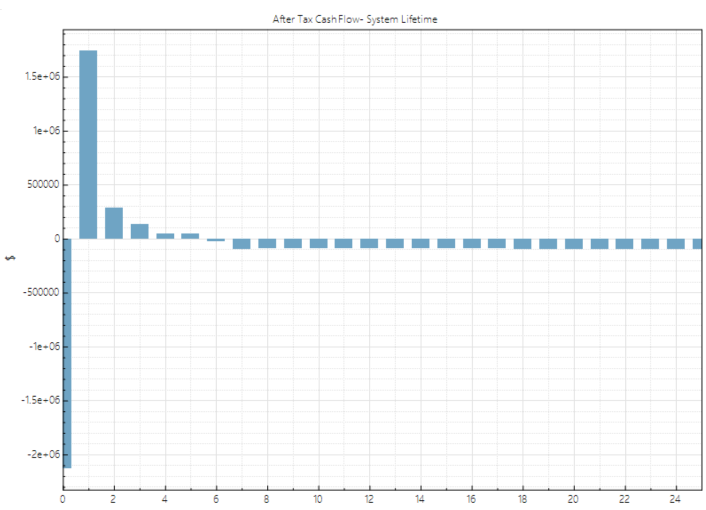


Figure 4-3: Spatial Analysis

Figure 4-2 shows the power generation in comparison to the projected load, for the load-based analysis.

Figure 4-3 shows the resilience of the system to potential grid outages. This system performs similarly to the load-based analysis in terms of probability that the system will be able to weather potential interruption in grid generated power.

The cashflow trend of this system is very similar to spatial analysis. However, on a greater scale, due to the increased size of the system, this results in a net present value of -3,114,464.

Figure 4-2: Load Based Analysis

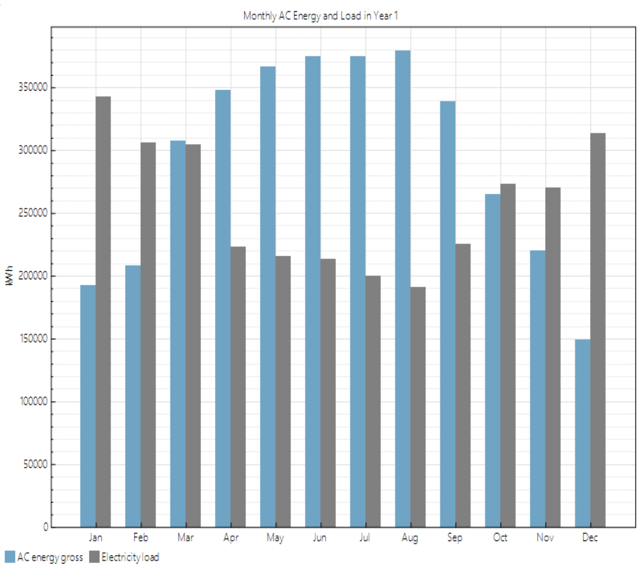
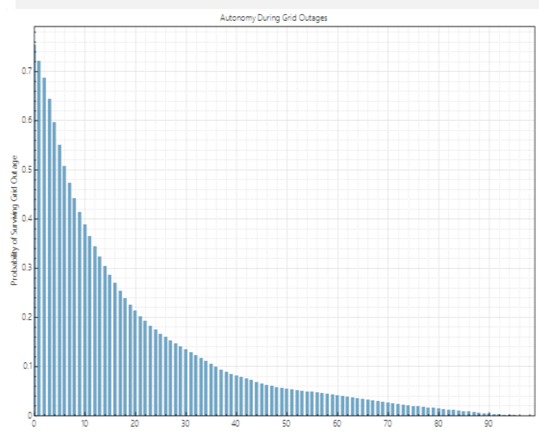


Figure 4-3: Load Based Analysis



5. UTILITY PARTNERSHIPS

Facilities that are either converted built to support BEBs and/or FCEBs, will require additional energy as part of the facilities work. Continuing the implementation of HEBs will not require additional partnerships with utility providers or alternative fuel providers as the diesel-electric hybrid buses do not need to be charged.

For BEBs, this also means that transformers, switchgear, and new contracts would come into effect to manage the additional electrical loads. The variability of pricing due to changing loads will encourage the application of a charge/load management system.

As an example, reviewing the tariff for large general service (LGS), on-peak billing is from 7 a.m. to 9 p.m. Monday through Friday when the energy charge basically doubles from $0.6/kWh to $0.13/kWh.

There are also demand charges with seasonal variations, and lastly there may excess demand charges that are investment recovery fees. Utilities typically have a mechanism to recover investments in excess demand or unused energy by charging back to the customer the difference between the service application/load letter request and the actual used energy. Oversizing the service has a cost. It is therefore critical to ensure that request match the needs.

For hydrogen to support FCEBs, there are options to reduce investments, the first would be to partner with another local agency (e.g. trash collection, fire department) and to jointly assess performance and costs during a pilot such as a LO-NO grant sponsored one.

The closest source for liquid or gaseous hydrogen that can be delivered by over the road truck is Linde in East Chicago, IN. Their current pricing is fluctuating at $8-$10/kg, which is in line with national pricing. Agencies are pushing for $3/kg at which point FCEB would match BEBs in cost per mile.

No matter the fuel source, discussion with energy providers need to commence well in advance of any vehicle purchases or infrastructure upgrades. Lead times for these providers can exceed ZE project timelines and therefore must be consider as a critical path to a ZE implementation.

6. INFORMATION TECHNOLOGY (IT)

6.1 IT *PLATFORM*

Data from buses is desirable to support operations, such as location information or communications. BEBs have additional data needs and costs. Format and ability to process the new data formats and quantities determine complexity and costs. Transferring the data from buses and chargers to a central location is needed to support operations. Security can also impact operations and measures need to be applied during technology selection and later during operations. The data will reside at some on or off-site location and will be accessed for processing by monitoring systems, charge management systems and other clients internal or external to Citilink.

6.2 DATA

Depot Wi-Fi for data and fiberoptic for chargers are two examples on how data moves between buses, chargers, and a central IT location.

Battery buses or all buses will be critically relying on these data packages for efficient recharging and dispatching. INIT, Clever, ViriCiti, Connect, Hastus, and other solutions do different things, and fees are monthly and/or with each data-dictionary revision.

7. OPERATIONS

7.1 YARD AND SHOP OPERATIONS

In evaluating future fleet procurements and technology options; Citilink must evaluate the effects of ZEB operations. Clean Diesel and HEBs do not require any change to operations as they are currently part of the day-to-day operations of the agency. The following will be focused on BEB and FCEBs to highlight the implications of operating to these types of vehicles.

7.1.1 EFFECTS OF ZEB TECHNOLOGY ON GARAGE OPERATIONS

The impact on garage operations from continued investment in HEBs and clean diesel buses would be minimal. Citilink would need to employ strategies to incorporate systemic changes from the transition from diesel buses to ZEBs. Citilink must review and update all standard operating procedures, including bus circulation, maintenance procedures, and how these vehicles deliver service.

7.1.2 SERVICING

The transition to a ZEB fleet would require additional space at the facility to accommodate ZEBs, chargers, or hydrogen fueling stations depending on the choices made. These added space requirements may raise concerns regarding movement of buses overnight.

As shown in the PEER summary in Section 3; if Citilink were to proceed with a BEB fleet, bus-to-block assignments will need to be more rigid, due to limited battery capacities of part of the fleet during the transition. This is especially important when supporting a BEB fleet of mixed battery capacities. The fleet will have mixed battery capacities if buses are procured at different years, as batteries will improve as the transition progresses. These issues result in lower flexibility in bus deployment. While this inflexibility can be mitigated with smart charging software and automatic vehicle location systems, the flexibility will still be reduced compared to current operating conditions and should be taken into consideration.

If Citilink transitions its fleet and infrastructure to support ZEBs, the agency's focus will continue to be on its priority of delivering service to its riders; therefore, in order to mitigate risks associated with a transition, staff will be required to evaluate threats that could potentially impact service and operations. Understanding these threats and vulnerabilities will enable Citilink to develop strategies and mitigation measures to ensure the continuity of operations, service, and emergency response. Some examples of threats and vulnerabilities are natural disasters, such as extreme heat, fires, flooding, extreme cold , physical and cyberattacks, , threats to the power grid, pandemics, fuel (Hydrogen) delivery interruptions and human error.

Back-up power can meet service requirements during short-term outages and long-term emergency events. Stationary batteries can store electrical energy but require considerable space and are expensive. Depending on their type and size, batteries typically provide emergency power during short outages. They can also flatten a facility's peak load throughout the day, reducing operating costs. Solar panels at bus stops combined with a microgrid strategy can supplement the power supply for opportunity charging and potentially reduce the peak demand requirements at a facility.

7.1.1.2 Maintenance

The transition from a diesel bus fleet to BEBs or FCEBs requires planning and utilization of the maintenance planners and material control group. As with all fleet changeovers, some common parts may remain in inventory.

Operating mixed fleets, here consisting of HEBs, diesel,BEBs or FCEBs, typically require more inventory storage space as each type of bus with unique parts to be stored separately. Citilink will be required to maximize every opportunity to expel outdated stock. A sequenced replacement of the bus fleet provides Citilink with an option to plan out its stockroom conversion to BEBs over time in a controlled manner.

7.1.2 POTENTIAL CHANGES FOR YARD OPERATIONS

The impact on yard operations from continued investment in HEBs and diesel buses is minimal. The addition of BEB charging infrastructure to the existing garage will add additional hazards to the garage that must be properly mitigated. Yard personnel also need to be aware of these hazards as well.

7.1.2.1 Charging Locations and Capacity

The infrastructure required to support BEBs will decrease the amount of space available at the facility for bus parking and storage. This infrastructure includes substations, charging equipment, any potential generators and battery electric storage systems. Additionally, if FCEB are used in conjunction with BEBs or diesel buses, additional space may be needed to support hydrogen fuel storage. Furthermore, any transition plan would operate a mixed fleet of HEBs and diesel buses in addition to ZEBs. Thus, semi-temporary supplementary space would be required to support the different types of buses that are to be operated. This additional space would be cleared once full transition is achieved and the HEB and diesel buses no longer needed to be supported as they age out. Finally, as demonstrated in PEER analysis, there would be a fleet size increase required to meet Citilink's service obligations, once again requiring additional space at the facility

7.1.2.2 Dispatching and Circulation of Vehicles

The dispatch of buses will change when utilizing BEBs for revenue service. As a result of the service schedule, BEBs would have varied overnight charging times, depending on the energy required to complete a block and the amount of opportunity charging received between blocks or possible terminal charging. Additionally, since BEBs would be procured over time, the BEBs will have varied battery capacities. Based on the analysis conducted in Section 3, these varied battery capacities will have an impact on service completion, as some blocks require more energy than currently available. This will result in a fleet mix that will require stricter bus-to-block assignments, as not all buses will be able to complete all blocks. Both bus-to-block assignments and recharging times need to be considered for overnight charges at the facility.

The reduction in available facility space described in Section 7.1.2.1 may also hinder the circulation of ZEBs within the facility. The layout of buses when recharging would likely also hinder circulation. Infrastructure and charging layout of the facility would be required to be factored in space to circulate vehicles as necessary.

7.1.2.3 Mixed Fleet Operations

If Citilink were to transition towards ZEBS, and as with all US agencies, they would purchase the ZEBs in phases, which would be based on a transition end date or timeframe. As a result, ZEB and typical diesel and hybrid electric buses would be in use at the same time. Based on the PEER analysis, it would be recommended that BEBs are assigned to blocks that are less energy intensive and that diesel and hybrid electric buses service the longer, more energy intensive blocks.

As battery technology improves, the newer BEBs should be assigned to the longer blocks that were once serviced by the older conventional buses. Any FCEBs purchased could be utilized in place of BEBs as their operation, range, and fueling times are similar enough to diesel that they could be utilized directly in place of diesel or HEBs for route planning.

Mixed fleet operations, as previously mentioned, will greatly impact the amount of available space. Not only will there be facility space constraints due to infrastructure, but spare and maintenance parts for all supported vehicles needs to be stored as well, further limiting space. Facility staff and personnel also would need to be trained to perform maintenance on ZEBs as well as conventional diesel and hybrid electric buses.

7.1.2.4 Electrical Hazards

Arc flashes are violent releases of energy-when current leaves the intended path and travel through air from one conductor to another to ground. Fire, pressure blast, flying objects (often molten metal), sound blast as loud as a gun, and heat upwards of 35,000 degrees F can be produced from arc flashes associated with the voltage and current used in BEB charging. These hazards must be addressed by the agency through training of employees, personal protective equipment, insulated tools, working de-energized, and warning labels. While these hazards are inherent in the use of this equipment, they can be managed and mitigated. Agencies may already have these competencies and skills in the rail, trolley, or subway system.

BEB chargers, inverters, and electric motors can create electromagnetic fields that can interfere with other devices, such as pacemakers. Equipment with low electromagnetic radiation, isolation from public/non-essential workers, testing, shielding, and signage can control the hazard that-electromagnetic interference (EMI) poses.

7.2 MAINTENANCE NEEDS

Citilink is already well-experienced with maintaining HEBs and diesel buses. While reduced fuel costs are the key financial benefit of electrification, reduced maintenance costs are a close second. According to the Transit Cooperative Research Program (TCRP) Synthesis 130 report, the average maintenance costs for supporting BEBs is $0.62 USD/mile. This could be as much as a 30 percent reduction when compared to the $0.86 USD/mile needed for conventional bus maintenance, according to Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transport (AFLEET) Tool.

BEB propulsion systems utilize much simpler propulsion systems with fewer moving parts that require less frequent service intervals. Full courses along with repair procedures on any ZEB being evaluated are provided by the bus manufacturers; a similar style course would be required for the Citilink maintenance department, prior to any ZEB implementation.

The baseline bus preventive maintenance intervals on diesel buses are predominantly driven by engine oil service requirements. Depending on the bus OEM and specific subcomponent supplier requirements, recommended baseline ZEB service intervals are generally pushed out to 15,000-20,000 miles.

Although ZEBs have some fluid and filter replacements that are comparable to conventional diesel bus requirements, they do not require fuel filters, engine air filters, or crankcase filter replacements. The majority of ZEBs available in the marketplace also use a direct-drive traction motor arrangement, which removes the need for transmission and thus fluid and filter maintenance. ZEBs also utilize regenerative braking to increase efficiency of operation, resulting in a reduction of brake wear as compared to conventional buses.

7.2.1 Effects on Spare Ratio from ZEBS

Based on cumulative industry feedback from operators of electric buses (BEB and/or FCEB), many agencies have not been experiencing the need to increase their spare ratio.

On the contrary, the consensus indicates that ZEBs will provide increased reliability, availability, and lower maintenance costs when compared with traditionally fueled vehicles, especially as the market matures. Factoring in these positive trends in vehicle performance and reliability, agencies are recommended to focus on maximizing the performance of their charging infrastructure, and, to the extent practicable, minimizing their exposure to significant infrastructure failures, rather than planning to address operational worst-case scenarios by increasing the size of their spare vehicle fleets.

It is important to note that there are caveats to consider with the state of the industry at the time of writing. Agencies are generally not reporting a need for increased spare ratios on the vehicles the vehicles themselves seem to be getting more and more reliable as subsequent generational improvements are released. ZEB vehicle is still mostly a traditional vehicle with a different powertrain; therefore, most systems will have the same reliability as their diesel counterparts.

There are areas of a ZEB fleet that can cause operational issues as the technologies mature. The first, is parts availability and cost as replacement powertrain components have long lead times and significant cost. The reason is simply due to availability as the market is focusing on production for new vehicles, which leaves the after-sales service parts availability very low and expensive. Charging equipment is currently the main issue any zero-emission fleet operator is having to contend with. Chargers and dispensers are being improved to deal with the harsh environment of transit operations by increasing reliability, decreasing maintenance requirements, and improving replacement parts availability.

As with any technology or piece of equipment, failures are guaranteed to occur. When they do, planning for redundancy will minimize the impact to the agency's ability to make service. Regarding BEBs specifically it is recommended to maximize backup generation capacity at the depot and utilize as many grid connection redundancies from power utilities as possible.

Agencies are recommended to purchase additional depot and on-route chargers. A minimum recommendation of 5% beyond what would be required to support weekday peak service requirements are suggested. Agencies should also assess and prioritize their ability to quickly respond to charger failures with a float stock of spare chargers, replacement parts, trained in-house technicians, and/or service contracts with 24-hour support and immediate response times will be essential to minimizing potential service interruptions

Planning for equipment failures is a critical part of any successful fleet operation, but consideration must also be given to the impacts of fleet electrification on other agency requirements such as providing emergency service, temporary shelters, evacuation plans, etc. While careful planning can make an agency's transition successful, the fact remains that, in many cases, BEB range limitations may not allow for a 1:1 replacement of conventional buses under worst-case scenarios.

When transitioning to ZEB vehicles agencies are recommended to be proactive in engaging with stakeholders and federal, regional, state, and local officials at the onset of fleet electrification efforts. Discussions should occur regarding the impacts of fleet electrification and whether a need exists to reassess Citilink's capabilities involving emergency service operations or similar obligations.

If not already being utilized, agencies may also consider provisioning Emergency Contingency Vehicles in accordance with FTA guidelines. This allows an agency to retain a group of vehicles as a contingency fleet, once beyond their useful service life. The contingency fleet is stored in an inactive state in preparation for emergencies. Conventionally fueled vehicles may be the ideal contingency fleet candidates throughout an agency's transition to full electrification, as they may provide the range and flexibility needed during emergencies while advancements in battery technology are still catching up.

Agencies are also encouraged to consider employing charging operations that take advantage of as many opportunities to replenish a vehicle's SOC as possible. Maximizing your fleet's SOC will provide increased readiness, flexibility, and the best ability to respond to any unforeseen service and operational issues that arise. This approach also has the benefit of extending battery life over its life cycle, by reducing the degradation caused by deeper battery Depth-of-Discharge levels. When using this approach, agencies will want to be mindful of utility rate and tariff structures that might preferably be avoided.

A well-tuned Charge Management System will be essential in assisting agencies with finding the right balance between maximum fleet readiness and avoidable energy costs for BEBs. It should be noted that it has been shown that maintaining a SOC of 100% slightly increases the risk of thermal runaway, as well as degrades the battery more than maintaining a SOC of a high, but not full SOC such as 80% or 90%. A number of factors are being looking into by the manufacturers with improvements in thermal control, and safeguards are already in place, regardless, it might be beneficial to set the charge management system to charge slightly below full capacity especially as battery technology improves an the full charge is not needed as much for sufficient operational flexibility.

7.2.1 Principal Wear Factors

Overall, ZEB maintenance requires a different skillset when compared to diesel bus maintenance. Due to the electrical systems used to drive the electric motor in ZEBs, OEMs or personnel familiarized with the electric propulsion and charging systems used are needed to support these systems. For example, the bearings in electric motors are prone to wear and therefore may require replacement during the operational lifespan of the ZEB.

Additionally, brake pad replacements are required for ZEBs. While ZEBs utilize regenerative braking to slow the vehicle down, friction brakes are still utilized in emergency situations and at lower speeds when bringing the vehicle to a full stop. However, since regenerative brakes are primarily used, friction brakes are used less often and do not need to be replaced at the same frequency as typical diesel buses.

A final wear item, and typically the largest expense of both BEBs and FCEBs are the lithium-ion batteries as their performance will degrade over time. The severity of this degradation, however, will depend greatly on the use case of the battery. Depth of charge, charge rate, and operational temperature of the battery are some of the factors that will affect the degradation. Depending on the severity of the degradation, battery replacements may be necessary as part of a mid-life refresh.

A good indicator of how any ZEB batteries would fair in Citilink's operation is to examine the HEB currently in the fleet, while keeping in mind that technological improvements are being released on a fairly regular and rapid rate of introduction.

7.3 ASSISTANCE TECHNOLOGIES FOR ZEBS

7.3.1 Charge Management Software

The procurement and implementation of a Charge Management System (CMS) is strongly recommended for agencies electrifying their bus fleets with BEBs. There are several operational and financial benefits that can be gained from using a CMS, all of which become especially important as agencies' BEB fleet sizes continue to grow.

Most CMS products take into consideration charging infrastructure, energy management (sometimes referred to as "smart charging"), vehicle and charging telematics data, and offer a user interface to the customer to visualize live or real time data. The CMS optimizes charging based on operational requirements and electricity rates, which will ensure the lowest total cost of operating can be achieved. CMS technology can allow an agency to customize and implement different charging strategies, such as phased charging, where separate groups of vehicles or sections of a depot can be charged in phases rather than all at once, even if all vehicles are connected to chargers at the same time.

As with BEBs and chargers, the CMS marketplace is also seeing rapid growth. Agencies should continue to monitor and explore new product options as technology improves, but the CMS products available today already offer significant benefits to agencies transitioning to full electrification. Ideally, selected CMS products will be compatible with all current industry charging standards, able to be upgraded to meet future standards and/or compatibility requirements, and not be restricted to any specific charger or bus manufacturers.

CMS products currently available provide many of the following features and capabilities:

7.3.1.1 Planning and Historical Data

Integrate data from the agency's operational requirements to the buses and chargers and allow integration into its planning system. This will permit the agency's electric bus operation to be intelligent, efficient and can reduce operational inefficiencies. This step is necessary for smart charging which will enable the agency to lower its peak demand charges and automate the entire charging routine.

7.3.1.2 Energy Management System

Energy management system or smart charging is used to avoid the higher charge rates during the peak charging period. Energy Management is usually accomplished by limiting the total capacity of the grid over the number of buses that need to be charged using load balancing which consist of charging the buses in relation with their schedules combined with their state of charge.

7.3.1.3 Telematics

Real time data monitoring and range prediction are key factors to operate electric buses without range anxiety often influenced by driver behavior, weather, traffic, passenger load, elevation etc.

Real time charger data can provide a transit agency with a tool to plan or adapt the bus routes according to the information received from the chargers (Example: if one charger is malfunctioning) so that the bus can run and accomplish its daily route without any risk. Additionally, 80% of the charger malfunctioning can be solved with a simple reset which can be done behind a computer. This feature is available with most CMS solutions.

Real time data enables a transit agency to monitor, plan or adapt the bus routes according to the information received from the buses. This permits transit agency to make real time operational decisions depending on the daily circumstances.

7.3.1.4 Graphical User Interface

A graphical user interface is necessary to alert the dispatchers or operations staff in a case on the status of the charging processes, hydrogen levels & pressures, maintenance or system failing issues, operational issues etc.

The charge management system can also automatically activate vehicle preconditioning to prepare interior temperature for the operator starting his shift in the case of extreme weather conditions.

7.3.1.5 Advancements and Standardization

The emergence of smart charging, smart grid, a large and a still evolving ecosystem of new players, devices, protocols and charging technology companies, has pushed the industry to design and accommodate any type of charging into one communication standard which is called Open Charge Point Protocol (OCPP). OCPP is the industry supported standard communication between charging stations and charging Management Systems. When connecting charge stations to an appropriate backend, OCPP protocol allows for remote resets, saving time, and making the operation run smooth and efficiently.

It is important to note that there is no adopted industry standard for CMS. CMS vendors can offer some features without offering the others. For example, some vendors can offer smart charging without offering Fleet Management Software.

The landscape for hydrogen is similar as there is little standardization, although regulatory restrictions (i.e., max onboard pressure) have impeded some FCEB development. FCEB vehicles, hydrogen delivery, storage would benefit greatly in performance if for example liquid hydrogen were to become widely available.

7.4 BEST PRACTICES FOR ZEBS

7.4.1 Alameda-Contra Costa Transit District

Alameda-Contra Costa Transit District (AC Transit) is the third-largest public bus-only transit property in California. AC Transit is based in San Francisco Bay Area's East Bay and serves a 364 sq. mi. area, including the Alameda and Contra Costa counties.

Currently, AC Transit operates 129 fixed routes with a fleet of 635 transit buses. AC Transit's current goal is to transition their bus fleet to zero-emission by 2040. Of the 635 transit buses, 36 are 40-ft FCEBs and 7 are 40-ft BEBs, with ZEB deployments prioritized for disadvantaged communities. AC Transit has secured funding for an additional 20 40-ft FCEBs and 21 40-ft BEBs.

Best practices learned from AC Transit's previous experiences include targeting specific routes and blocks for early ZEB deployments. As previously discussed, the main obstacle with BEB is limited range compared to conventional diesel buses.

Thus, agencies should consider the strengths of ZEB technologies and assign routes and blocks that may take advantage of those strengths. For example, BEBs should be used on short to medium-range blocks and routes, whereas longer blocks can be exploited utilizing FCEBs. AC Transit has been trialing different technologies over the past years and is a great North American reference for Citilink to observe the challenges and successes achieved in operating ZEB vehicles.

7.4.2 Battery Preservation Best Practices

The battery of a BEB is the most critical component of the vehicle. Thus, due to its importance and cost of the battery, extra care should be given to preserve the battery to maximize its operational life and maintain bus performance. Multiple factors, such as operating temperature, charging methods, depth of discharge, and average state of charge, can influence the degradation of the battery.

7.4.2.1 Temperature

Extreme temperatures can greatly influence degradation rate of a battery. Higher temperatures cause side reactions at the cathode of the battery to occur faster, resulting in the loss of cyclable lithium. These side reactions occur naturally, regardless of temperature, but are sped up when operating under higher temperatures.

Conversely, lower temperatures change the viscosity of the liquid electrolyte used, which lowers the ionic conductivity of the electrolyte. This results in lower acceleration, limited benefits of regenerative braking, and decreased range. Lower temperatures cause the anode to become negatively polarized in regard to the lithium ionic pairs; this negative polarization initiates lithium plating on the anode surface, which reacts with the electrolyte to result in the loss of cyclable lithium and therefore loss of capacity.

Batteries should optimally be stored and operated between 60F and 85F degrees. While most BEBs will have battery temperature regulation systems built in, it is recommended that buses are parked in shaded areas during warmer days and within a garage during colder days.

7.4.2.2 Battery Charging and Usage

Factors regarding battery usage and charging also affect the rate of battery degradation. Higher charging rates can degrade the battery faster, especially when charging to higher SOCs.

A battery charging from 0% to 50% consistently will show less degradation in capacity when compared to a battery charging from 50% to 100% consistently.

Additionally, fuller depth of discharge will also increase the rate of degradation. This is also related to the average state of charge of a battery. It is recommended that batteries operate at around 50% SOC on average. However, the degree to which these factors affect degradation differ greatly.

According to a study of impacts of SOC on battery lifetime, after 10,000 cycles of charging and discharging, batteries discharging from 30% to 20% SOC maintained 94% capacity when charged at a C-rate of 0.5C (Charge Rate) When discharging from 30% to 20% SOC at a rate of 2C; however, the batteries maintained 90% of their original capacity. Note that the C-rate of a battery is the measure of the rate at which a battery is charged relative to its capacity. A C-rate of 1C will fully charge a battery in one hour. Conversely, after 10,000 cycles, when charged at the same C-rate of 1C, batteries discharging from 50% to 30% maintained 80% of their original capacity. However, batteries discharging from 50% to 0% SOC lost more than 80% of their original capacity after only 7,500 cycles. Also seen in the data is that when being cycled at a higher SoC (generally above ~50%), the capacity drops below 80% after far fewer cycles, as seen in Fig. 7-1. Thus, the depth of discharge and state of charge have a greater effect on degradation of the battery when compared to the charging rate.

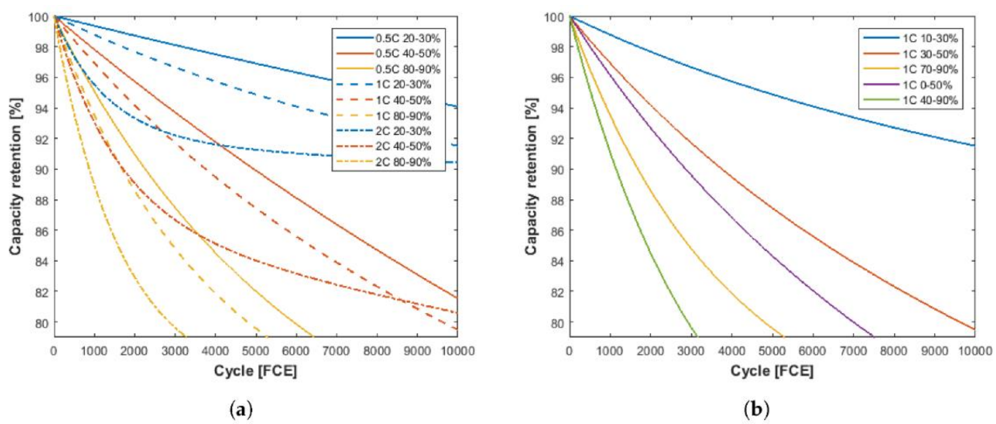


***Figure** 7-1: Capacity Retention through Cycle Life for Different Charge Rates and DoDs [34]*

On-route chargers typically use high charging rates which degrade batteries faster, but they can improve battery life instead of accelerating degradation by reducing the depth of discharge. This allows the bus to operate in an optimal SOC zone, which results in a longer lifespan when compared to typical depot charging. The potential benefit that on-route fast chargers can provide is dependent on the characteristics of the bus route system.

8. WORKFORCE

8.1 WORKFORCE DEVELOPMENT AND TRAINING

The transition to a ZEB fleet will require significant changes to Citilink's daily operations compared to a HEB/diesel fleet. HEBs are already in operation, and Citilink staff participates in ongoing training for the maintenance and operation of the HEBs. A ZEB fleet requires (re)training employees to safely operate new and changing technologies by comprehending the differences and similarities between the current HEB and any upcoming ZEB vehicles.

Citilink's HEBs are Gillig buses with Allison hybrid drives. These vendors offer workforce development training that covers the topics below. To transition to a full HEB fleet, Citilink staff will continue these training sessions.

- Operator Instruction
- Gillig Battery Electric Bus Operator Training
- Maintenance Department General Vehicle Orientation
- Gillig Battery Electric Bus Service Personnel Training
- Air Systems and Brake
- Basic Bus Electrical System
- Multiplex Electrical System
- CNG System
- Hydraulic System
- EFAN System
- Allison Hybrid Familiarization
- BAE hybrid Familiarization
- Gillig Emissions
- Entrance/Exit Door Systems
- Gillig Battery Electric Bus Technician Training

Citilink will need to continue providing operational training for bus operators, mechanics, and other support employees on the ever-evolving changes to these vehicles. This of course will begin with safety procedures and precautions to be taken with these types of vehicles.

Fortunately, Citilink's experience with hybrid-electric buses (HEBs) will serve as a great foundation for workforce training and adaptation. ZEBs pose a different set of concerns typically centered around fire prevention and mitigation which involves that all personnel be aware of the particularities of these vehicles. As with any relative technologies, there are legitimate concerns that will be raised by the workforce, and which need to be addressed for operational continuity. New problems require new solutions and ZEBs solve many issues both technical and societal. However, they also bring forth new challenges.

While preparing this plan, STV interviewed and spoke with representatives from several groups within the Citilink organization to gain a sense of the concerns and misgivings that the workforce may have with ZEBs, and the transitional support required. In the context of the workforce, the operators and maintenance personnel expressed their fears regarding fire mitigation, evacuation procedures, vehicle performance, and personnel training to keep up with the changes and procedures. The same points were echoed by the supervisor and executive teams, respectively. Once again Citilink's HEB experience provides a great steppingstone for the introduction of ZEBs as many of the same safety protocols and training can be reused and expanded upon. To convert to a full HEB fleet, Citilink will continue to provide the same workforce development training for HEBs.

The significant differences will be apparent with fueling when comparing ZEBs to existing operational training and workforce skills. In an oversimplification, BEBs will require knowledge and training on chargers and dispenser repair and maintenance; whereas with FCEBs they require specific knowledge and certifications to maintain the pumping station(s) and fuel cells. These specific areas do not have a comparative skill set within Citilink's workforce and will need to be addressed with training or external solutions such as turnkey lease agreements or vendor maintenance contracts. Citilink is currently operating HEBs, and will therefore continue workforce training in the operations and maintenance of HEBs.

8.2 MAINTENANCE TRAINING PLANS FOR ZEBS

A ZEB transition requires coordination with internal stakeholders and vendors to prioritize training sessions for targeted employees based on the technology choices.

Bus and equipment manufacturers will provide familiarity and safety orientation for the delivery of the ZEBs and their associated equipment such as dispensers and pumping stations. This basic training course would be for all Citilink employees who have hands on the vehicle whether they fuel (charge), maintain, or operate the vehicle.

This orientation will be led by a representative from the bus manufacturer and will include high-voltage safety training, personal protective equipment (PPE), safety measures, and preventive maintenance. It is highly recommended that all members of the Citilink organization attend at least the introductory sessions to gain a better understanding of the systems.

8.3 BUS SYSTEMS TRAINING FOR ZEBS

To ensure Citilink maintenance personnel, trainers, and supervisors are well-versed in the various bus components and their operations, it is essential for the vehicle manufacturer to provide any additional training required or requested.

These comprehensive training sessions will encompass a wide range of standard bus systems and components diagnostics and repair. Bus and equipment manufacturers rely on components or systems from various manufacturers to build their products which leads to interchangeability, lowered costs, and increased reliability as the expertise is focused on these specialized systems or components.

Specifically related to electric vehicle components such as electric motors, drives, batteries, and fuel cells, it is highly probable that these components will evolve with time and additional training will be required periodically. It is therefore crucial for these specialized manufacturers to provide the comprehensive training required to Citilink and its staff.

To plan for the costs of these programs they can and should be part of the procurement strategy when purchasing these vehicles and be incorporated as part of the purchase price. This would allow for predictable planning and control of funding and expenditures.

9. POLICY ENVIRONMENT

9.1 POLICY AND MANDATES

Citilink is compliant with all state, federal, and local laws regarding emissions from its bus fleet. Citilink is not under any mandate to field a zero emissions fleet by a target date imposed by a regulatory agency or a self-imposed deadline. However, the regulatory landscape, and increasingly coercive nature of the funding requirements will force Citilink to begin to consider zero tailpipe emission vehicles in the coming years. As early as 2016 the Fort Wayne, IN Board of Public works included the goal to "reduce harmful emissions" as a part of a Complete Streets Resolution and the Climate Action & Adaptation Plan. [1] This regulatory policy trend will continue.

At the federal level, the government will continue to use various carrots and sticks to move transportation to the stated goal of zero tailpipe emissions. President Biden's executive order to all federal agencies requiring 100% zero-emission vehicle procurements by 2035 will be enshrined in the various regulatory processes and rules.[2]

This process is already seen in the FY2023 Bus Grants from the Federal Transit Administration (FTA). The FTA awarded $1,689,864,104 in grants of which $1,216,941,397 were to projects under the FY2023 Low or No Emission Grant Program (Low-No).[3] This is a whopping 72% of the total award and will continue to grow as the administration implements the President's executive order.

The Bipartisan Infrastructure Law amended the statutory provisions for the Grants for Buses and Bus Facilities Competitive Program Low or No Emission Program to include a requirement for any application for projects related to zero emissions vehicles include a Zero-Emission Transition Plan.[4]

The Bipartisan Infrastructure Law requires States to create a Carbon Reduction Plan no later than two years following the law's enactment or November 2023.[5] The Indiana Department of Transportation (INDOT) has developed Carbon Reduction Strategy to support efforts to reduce carbon dioxide emission within the State of Indiana. The report identifies that 80% of the transportation sector emissions come from cars, trucks, and buses. The INDOT draft strategy further states that one of three pathways to reduce emissions is to "Switch to Low/Zero Emission Fuels for on-road vehicles such as using electric vehicles which have no tailpipe emissions."[6] There are no targets or transition dates specified in the document. Citilink should anticipate additional requirements for the use of Low/Zero Emission Vehicles either regulatory action or through conditions on funding at both the state and federal levels.

9.2 ENVRIONMENTAL REGUALTIONS

On April 21, 2023, Fort Wayne Mayor Tom Henry launched the initial phase of *Sustaining Fort Wayne*. The plan is called a Climate Action and Adaptation Plan and it addresses diesel emissions from the transit it fleet and sets a goal of "Zero Greenhouse Gas Emissions."[7] The document makes no firm commitments to any targets, other than to propose a strategy of developing a reduction target for transit fleet emissions and completing an "alternative fuel and cost benefit analysis."[8]

At the state level, the Indiana Department of Environmental Management (IDEM) identifies the health risks associated with diesel emissions on its web page, there is little discussion of greenhouse gas emission targets from heavy duty vehicles beyond the current vehicle inspections required under state law.[9] The carbon reduction strategy produced by the Indiana Department of Transportation is discussed in the policy section of this plan, above.

At the federal level, the Environmental Protection Agency (EPA) has taken the lead on regulating greenhouse gas emissions from heavy duty vehicles including transit buses. EPA and National Highway Traffic Safety Administration (NHTSA) first regulated greenhouse gases in what is known as phase 1 Green House Gas Rule for model years 2014-2018 in September 2011 for medium and heavy-duty vehicles, which includes transit buses. In October 2016, EPA and NHTSA finalized phase 2 Greenhouse Gas Rule for model years 2019-2027 for medium and heavy-duty vehicles.[10] This rule making aim affects the engine and vehicle manufacturers rather than agencies or consumers. The rule requires new engines and vehicles to meet the new standard, constricting supply in the market to only those vehicles that comply with the increasingly strict emissions standards.

On April 12, 2023, EPA announced a proposal to revises existing standards to reduce greenhouse gas emissions from heavy-duty vehicles in model year 2027 and set new, more stringent standards for model years 2028 through 2032. This proposed program, known as "Phase 3 greenhouse gas," builds upon the success of two previous rulemakings, Phase 1 greenhouse gas and Phase 2 greenhouse gas, which act collectively to reduce greenhouse gas emissions from heavy-duty vehicles and engines.

The Phase 3 greenhouse gas standards would apply to heavy-duty vocational vehicles (such as delivery trucks, refuse haulers, public utility trucks, transit, shuttle, school buses, etc.) and tractors (such as day cabs and sleeper cabs on tractor-trailer trucks).[11] The proposed rule is separate from federal fuel economy standards; new proposals for those rules are expected soon. These rules are also separate from, and differently designed than, the zero-emission vehicle mandates adopted by California and some other states.

The EPA is not directly proposing that 67% of vehicles be zero-emissions by 2032. The Agency states that the new emission rules are so stringent that it believes companies will need to produce 67% zero-emission vehicles in order to comply.

If OEMs can meet the standards through other means, it is acceptable, making the proposal "technology-neutral." The new proposed standard would limit emissions to 82 grams/mile across a company's production by model year 2032, a 56% reduction from the 2026 target.[12] Written comments on the proposed rule were due to EPA on 16 June 2023. Virtual public hearings were held on 02-03 May 2023.[13]

It is likely that implementation of the final rule is a priority of the current administration to complete on the current term in office though it may be delayed by litigation and challenges from lawmakers.

[1] Fort Wayne Board of Public Works, *RESOLUTION REGARDING COMPLETE STREETS POLICY,* Resolution NO: 1003-11-2-16-2, 02 November 2016, Complete_Streets_Resolution_11-02-16_002.pdf (cityoffortwayne.org)

[2] The White House, *FACT SHEET: President Biden Signs Executive Order Catalyzing America's Clean Energy Economy Through Federal Sustainability,* 08 December 2021, FACT SHEET: President Biden Signs Executive Order Catalyzing America's Clean Energy Economy Through Federal Sustainability | The White House

[3] Federal Register, *Announcement of Fiscal Year 2023 Low or No Emission Program and Grants for Buses and Bus Facilities Program and Project Selections,* 88FR 43003, 2023-14193, 05 July 2023, pp. 43003-43008, Federal Register :: Announcement of Fiscal Year 2023 Low or No Emission Program and Grants for Buses and Bus Facilities Program and Project Selections

[4] Federal Transit Administration, *Zero-Emission Fleet Transition Plan,* Zero-Emission Fleet Transition Plan | FTA (dot.gov)

[5] 23 USC 175: Carbon Reduction Program, 23 USC 175: Carbon reduction program (house.gov)

[6] Indiana Department of Transportation, DRAFT *Carbon Reduction Strategy,* December 2022, pp. 7, Final-Draft-Carbon-Reduction-Strategy-December2022v1.pdf

[7] City of Fort Wayne, *Mayor Henry Makes Climate Action A Priority with Greenprint Initiative,* 21 April 2023, MAYOR HENRY MAKES CLIMATE ACTION A PRIORITY WITH GREENPRINT INITIATIVE - City of Fort Wayne

[8] City of Fort Wayne, *Sustaining Fort Wayne for Today and Tomorrow,* 21 April 2023, pp. 11, Climate Action and Adaptation Plan | Sustaining Fort Wayne

[9] Indiana Department of Environmental Management, *Vehicle Emissions Testing Program,* IDEM: Air Quality: Vehicle Emissions Testing Program

[10] United States Environmental Protection Agency, *Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses,* 12 April 2023, Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses | US EPA
[11] United States Environmental Protection Agency, *Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses,* 12 April 2023, Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses | US EPA
[12] Domonske, Camila, NPR, *The Big Reason Why the U.S. Is Seeking the Toughest-ever Rules for Vehicle Emissions,* 12 April 2023, What to know about the EPA's stringent auto emission rules proposal : NPR
[13] Environmental Protection Agency, *Greenhouse Gas Emission Standards for Heavy-Duty Vehicles – Phase 3,* Federal Register, Vol. 88 No. 81, 27 April 2023, pp. 25926, 2023-07955.pdf (govinfo.gov)

10. FINANCIAL RESOURCES

Post COVID-19 recovery of service has impacted Citilink's financial situation, similarly to many agencies around the country. This recovery in terms of human resources, funding, as well as strategy impact is ongoing and challenging. Hybrid work schedules, retirements and changing mobility patterns are currently impacting the operation.

Future geographic needs or funding availability will move priorities for Citilink, for example if the service area experiences a growth in population density which will require increase in service frequency, fleet makeup, or even type of service operated such as bus rapid transit. This type of change can adversely impact a program timeline without additional agency resources.

The agency may find that during a transition to low or zero emissions, competing programs are underfunded and over-subscribed. Priorities on investments can be managed to minimize impacts on operations or on program target dates.

Federal grants are currently available for purchasing of low or no emission buses and some infrastructure such as BEB chargers or FCEB hydrogen fueling. These funds may need to be supplemented by local or state sources as required by the various projects. A dedicated grants team or external supporting entity can develop the material required for the various grants or budget requests.

Example of new, currently non-existing elements (for BEBs in this example):

- Transformer
- Switchgear
- Charger
- Dispenser (plug-in chord or pantograph)
- CMS
- Battery storage racks/area

These new elements would need to be incorporated into Citilink's asset management program. Budgets would require adjustments for maintenance, staff, parts, and support equipment purchasing, rentals or service contracts.

STV has compiled a listing of funding and finance opportunities that are available to Citilink, results are listed with Appendix E of this document.

11. EQUITY AND SOCIAL JUSTICE

The White House committed to advance equity through national policy that is likely to extend to FTA practices in how grants are reviewed. Citilink will evaluate its service changes and the fleet transition to low/zero to meet requirements of historically disadvantaged communities.

Advancing Equity and Racial Justice Through the Federal Government | The White House

There are benefits to the operator and the transit maintenance workforce, beyond the potential for advancement opportunities through job skills training. Compared to existing bus propulsion technologies, driving a zero-emissions bus can reduce fatigue because of reduces noise, vibration while reducing exposure to the driver and operations staff to criteria air pollutants and toxins.

Low/zero-emissions buses also benefit residents that live near bus garages or along the routes by reducing ambient noise and local pollution. Historically, priority populations (people of color, low-income individuals, and people with limited English proficiency) tend to live in areas that have higher concentrations of pollutants and increased noise due to proximity to industrial parks, highways, and garages. Allison's new e-Gen Flex hybrid drive includes geofencing capabilities that would allow Citilink the option of operating buses solely on zero-emission battery power in areas of vulnerability.

While the benefits outlined, are clear and measurable, the introduction of new technologies also introduces operational risks such as more frequent breakdowns until they reach technical maturity or operational stability. These new risks must be balanced with the benefits to produced positive outcomes.

APPENDIX

APPENDIX A: PERFORMANCE AND EVALUATION OF ELECTRIC BUS ROUTES (PEER)

This section attempts to assess how much of the current Citilink service plan can be delivered by ZEBs, assessed system wide. Where the analysis indicates that a ZEB transition would be problematic, specific recommendation will be made to have a transition which leads to a full operational coverage. These recommendations may include re-blocking, on-route charging, and alternative technologies. Each of these recommendations are designed to increase completability of service with the ZEBs available throughout the plan and ultimately increase feasibility.

The first step in this assessment was to simulate Citilink's system with a program called PEER. PEER is a simulation model designed to predict the energy consumption of a BEB as it travels along a specified route under specified loading and weather conditions. The purpose of the PEER analysis is to provide an evaluation of a BEB's expected performance on every trip on each of the transit system's routes to develop a real-world operating range that accounts for:

- Bus stop dwell time
- Ambient temperature
- Passenger counts
- Route grades and elevation
- Bus type and properties

Results from the PEER analysis will allow for the creation of Citilink' transition plan and identify areas of the existing schedule that may need additional adjustments. The sections below provide an overview of the PEER analysis conducted. The full PEER analysis for both the BEBs and FCEBs, respectively, can be found beginning on page 62 of this plan.

KEY FINDINGS

Using an industry-typical 35-foot BEB and 40-foot FCEB, the following table shows how many blocks in the current schedule can be completed. The completability percentage is indicative of how conducive the current schedule and service level is to BEBs.

TABLE A-1: COMPLETABLE BLOCKS OVERVIEW (NEW/CURRENT BATTERY)

Bus Type	Heater	Usable Energy	Total Blocks	Completable Blocks
BEB	DFH	352kWh	26	6
	No DFH			0
FCEB	DFH	661kWh	26	26
	No DFH			7

The above analysis is an important insight for scheduling efforts, however it does not necessarily directly translate to the number of buses that can be replaced with ZEBs, because buses will often complete more than one block during the day. A full analysis of the schedule was conducted to determine how many vehicles would be needed to run the same level of service with a ZEB Fleet. An overview of the number of vehicles currently in the fleet and how many would be required for different scenarios of ZEB fleet replacement is shown in the table below.

TABLE A-2: VEHICLE REQUIREMENT SUMMARY – CURRENT/DEGRADED BATTERY

Bus Type	Heater	Vehicles Required	Vehicles Required (Including 20% Spares)	Current Fleet Size
BEB	DFH	44	52	38
	No DFH	63	75	38
FCEB	DFH	32	39	38
	No DFH	47	56	38

METHODOLOGY

The PEER BEB energy consumption model considers three major energy-drawing components of a BEB. These components include the dynamic/propulsion system, the HVAC system, and the auxiliary loads. By combining the energy demands for all three systems, the model delivers an estimated kWh/mile value for a specific bus traveling along a specific route under certain weather conditions.

The dynamic/propulsion system takes into consideration inputs including a bus's velocity, accelerations, displacement, and weights. The model also considers several forces, such as the drag, rolling resistive forces, and gradient forces, that act on the bus as it travels on its block. Inputs for the dynamic/propulsion system include the type of bus used for the simulation, route the bus travels on, travel time, the acceleration of the bus, the size of the battery, and the efficiency of the bus.

The next system that the PEER model considers is the HVAC system. The model utilizes a "ground-up" approach to determine the HVAC system energy requirements. Using inputs such as passenger loading, ambient temperatures, desired internal bus temperatures, fresh air, solar loads, and heat losses through walls and windows, the energy demand for the HVAC system is calculated.

In determining the energy demands of the auxiliary loads, the model assumes all non-HVAC auxiliary appliances will be drawing power at a constant rate while in operation based upon the power rating of all the auxiliary loads equipped on the modelled bus.

The PEER model can be utilized to generate different predicted energy consumption rates each under different conditions. The energy consumption rates can be calculated for conditions representing ideal conditions, minimal HVAC needs, off peak traffic patterns and passenger loads.

CONSIDERATIONS

The PEER analysis simulation was conducted using the latest 2023 GTFS data available at the time of the analysis. Results from the PEER simulation may differ when analyzing more recent GTFS data. Because current GTFS data was used for the basis of the analysis, any future expansion was not included.

PEER INPUTS

To model the potential variety of operating conditions in Citilink's service area, a variety of ambient temperatures and bus types were simulated in PEER. Based on the current operating conditions described in Section 1, the following inputs were used for the PEER analysis.

- January 2023 GTFS data pertaining to Citilink's fixed-route service
  - 26 unique blocks identified from GTFS data
  - 13 unique routes identified from GTFS data
- 2022 passenger loading for 13 unique routes
- Fort Wayne historical seasonal temperature data [24]
- Minimum Temperature: -18°F
  - Winter: 29°F
  - Spring: 56°F
  - Summer: 70°F
  - Fall: 43°F
  - Average temperature during Winter operations with a Diesel Fueled Heater (DFH): -18 - 40°F
    - DFH Specifications:
      - 35 kW of heater power [25]
      - 3.6 kg/h diesel consumed [25]
      - 11.49 (kg-CO2/hr) emitted
- Vehicle types modeled with both new and seasoned batteries
  - Technical data on 35-ft BEB (440 kWh capacity)
  - Technical data on 40-ft FCEB (734 kWh capacity)

There is currently no 35-ft FCEB available on the market, so a 40-ft FCEB was used in the analysis.

- Current, degraded, and estimated future battery capacities
    - Future battery capacities are based on assumption that battery density will increase by ~5% every year. The specific future battery capacity to analyze in-depth was chosen to be 800kWh.
    - This value is deduced by reviewing data provided by energy.gov, which shows an average year-over-year energy density increase from 2008-2020 of 24.5% in conjunction with a review of historical BEB energy values [26].

ASSUMPTIONS

Battery Technologies and Capacity

The battery capacities used in these simulations are consistent with the capacities that OEMs currently offer. The term "service energy" is used to describe the amount of energy that can practically be used regularly. Just like battery capacity, service energy is expressed in kWh, but the value is significantly smaller because not all the battery capacity can be (or should be) used daily. The industry standard reduction for usable service energy is 20%. The graph below illustrates the usable energy in a battery, using a typical 40-foot BEB as an example.

The graph below also compares a new battery and degraded battery. Degradation of the battery "removes" an additional 20% of available battery energy. This reduction happens over about six years, but the rate and degree to which the battery degrades is largely dependent on how much stress the battery undergoes in use and charging. A 2016 study on lithium-ion degradation concluded that when discharging from 100% to 25% SOC at an operating temperature of 20°F, the battery capacity degraded to 80% after roughly around 4000 cycles (Oudalov, Ulbig, Andersson, Xu, & Kirschen, 2016). Note that a cycle is defined as a battery discharging from 100% to 25%, then charged back up to 100%. While one cycle can be correlated to one day, this may not be true if the bus is cycled multiple times per day. A bus may cycle multiple times per day if the bus runs multiple blocks per day and utilizes mid-day charging between blocks. Thus, if a bus performs 1 cycle per day, battery capacity would be reduced to 80% after 11 years. However, if a bus 2 cycles per day, the battery capacity would take only 5.5 years to reduce to 80%.

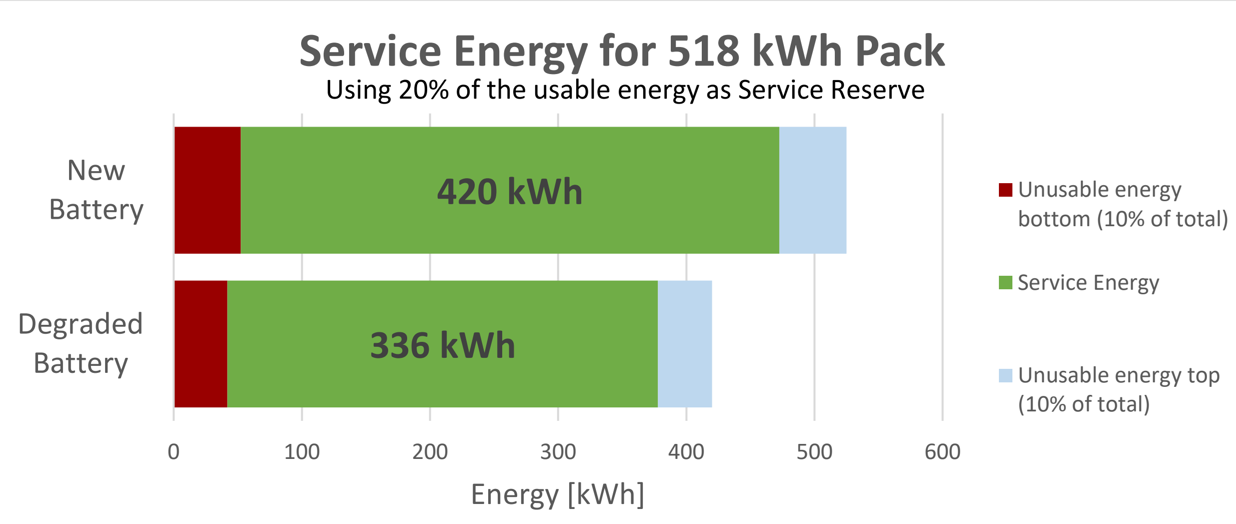


Figure A-1: Representation of Regularly Usable Energy for Typical 40-ft Buses

Temperature Historical Data

Winter bus operations have always had unique requirements. Buses must deal with navigating through occasional snow and ice but there is also the important requirement to maintain customer comfort by heating the bus interior. For many decades the interior heating requirement had not been a problem due to the abundance of waste heat available from the internal combustion engine and transmission systems which were propelling the bus. With the advent of 100% electric propulsion, the resource to heat the bus interior must now be obtained utilizing systems and components that need to consume electrical energy to maintain the bus interior temperature. This results in a substantial decrease in the operating range of the bus when compared to summertime operations. The PEER simulation tool uses the historical ambient temperatures for the Citilink service region, and desired bus interior temperatures, as inputs to calculate the total energy requirement.

The highest ambient temperature of 70°F has been used in the simulations as a worst-case scenario for the needs of cooling the bus interior. Conversely, the lowest ambient temperature used is 29°F. It's important to know the operating range of the bus on the most extreme days since that will dictate whether the bus can be used reliably throughout the year. It should be noted that by using these values the simulation has a built-in safety factor, since in the winter the simulation will assume the temperature of 29°F for the entire day, which often won't be the case. On a typical day the temperature will rise and fall with the sun, creating times where the heater won't have to work as hard. In short, by selecting this worst-case temperature, the simulation is inherently conservative.

Use of Diesel Fueled Heaters

The interior of the bus is heated by way of a mixed, heated fluid of water and glycol (a.k.a antifreeze, engine coolant) being circulated through the heating system's heat exchangers by electric pumps, then air either blown across the heat exchangers by electric-driven fans, and/or the air naturally moving throughout the bus interior (e.g., across natural convection heaters installed along the bottom of interior walls). In a conventional diesel bus, this fluid is heated by waste combustion heat from the engine as the fluid circulates through the engine before it is routed to the bus's heating system.

In a BEB, this fluid must be heated by an electric heater and/or a DFH, not too different from the principle of a household water heater using natural gas, propane, or electricity to heat its water. DFHs are commonly employed on conventional diesel or hybrid electric-diesel buses in service locations with extremely cold winter weather, and where modern clean-diesel engines have less waste heat available for the passenger compartment heating system compared to much older diesels with a lower level of exhaust pollutant reduction technology.

For a BEB equipped with both types of fluid heaters, the electric heater is generally used at ambient temperatures at or above 40°F. The DFH is then used only when the ambient temperature drops below 40°F. Because of this, a BEB with a DFH will consume more battery energy at 40°F than it would at 39°F and lower — when the DFH takes over from the electric heater.

The use of DFHs changes the outcome of the BEB operational simulations. Therefore, the analysis in this plan accounts for two winter operating scenarios. The first scenario is a bus which is not equipped with a DFH. This scenario's simulation is run at 29°F ambient temperature. The simulation at this temperature is intended to show the relative importance of using a DFH, and the viability of eliminating it in the future as battery technology improves.

The second winter operating simulation scenario is run at 40°F, to capture the worst electrical energy consumption that a bus will experience when it is equipped with a DFH. This scenario is more realistic for the near-term and the current level of battery energy capacity, since DFHs will almost certainly be used to increase the range during the winter. It is important to note that even though the simulation is run at 40°F for this scenario, the results remain valid for temperatures down to 0°F (or below) because at those lower temperatures the heat needed will be provided by the DFH and will not increase the electrical load on the battery.

Block Combinations

The analysis of block completion assumes that one bus is completing on block per day, which may not reflect how Citilink operates. One way to better reflect Citilink's operation more realistically and optimize a BEB fleet is to combine blocks such that a single BEB completes more than one block per day.

To conduct this analysis, blocks were combined based on the availability of each bus at the end of an existing block. Part of the analysis shown for each garage determines if a block could be combined with a later block based on its mileage, energy consumption, start time, and end time. Additionally, the analysis assumes that there will be a 2-hour minimum time between blocks, the bus will be charging using a 130kW charger at the garage when waiting for the next block, and that there is a 30-minute delay before charging begins. The analysis does consider the maximum battery capacity of a bus and will not charge over that capacity when combining blocks. Finally, the analysis will not combine blocks that cannot be completed with the selected battery condition.

For example, consider a 40-ft bus, with a new, 414 kWh service energy battery, that leaves Citilink garage at 9:00 am on Block 1, returns at 11:00 a.m., and has depleted half of its energy, or 207 kWh. While the bus is waiting, it will begin charging at 11:30 a.m. and continue charging until the next block or if the battery is fully charged. Block 2 begins at 1:30 p.m., returns at 5 p.m., and requires 300 kWh of energy. Since the original bus from Block 1 was charging at the garage, it was able to recharge the energy lost from Block 1, and now has 414 kWh of service energy to run Block 2. Since Block 2 meets the requirements listed above, the analysis will combine these two blocks together.

The analysis continues to assign additional blocks to a bus in a similar manner until there are no blocks that could be completed with the remaining energy in the battery, or there are no more blocks left in the day. No additional assumptions, such as available driver work hours, were made in this analysis.

BLOCK ANALYSIS

The PEER analysis provides essential information to determine if blocks can be completed with facility-only charging, or if in-route charging is required for a full-fleet of BEBs. If in-route charging is deemed necessary, then proposed locations can be evaluated for satisfying block range needs and providing desired comfort levels in terms of block completion and remaining state of charge (SOC). Additionally, the block analysis that determines the SOC remaining after each bus returns to the facility, can be used to determine a peak kW charging demand for each half-hour period throughout the night.

Blocking is used in this analysis to refer to the practice of optimizing schedules by dividing parts of scheduled routes among vehicles and drivers. Blocks are defined as paths taken by a bus from when it leaves the facility to when it returns to the facility. During this period, the bus may assist in providing service on multiple routes. Routes are a prescribed geographical path a bus might take according to a fixed schedule.

Energy requirements are simulated for each block and are determined by simulation every stop pair on every block. Energy requirements are based upon:

- Temperature
- Route elevation profile
- Regional solar loading

- Passenger loading by route
- Bus type and properties
- Heating mechanism (diesel versus electric)

Completion Rates Using Citilink's Existing Block Schedule

Table A-3 shows the number and percentage of Citilink's existing block assignments that could be completed with BEBs, under winter conditions, with a DFH, and Table A-4 shows the same without a DFH. These tables show that the most favorable scenario in terms of block completion is the FCEB with a DFH. This is due to the long range associated with the FCEB, and the DFH being able to supplement the battery energy on the coldest days of the year.

TABLE A-3: BLOCK COMPLETION SUMMARY — NEW/DEGRADED BATTERY WITH DFH

Bus Type	Battery/Fuel Cell State	35-foot BEB/40-foot FCEB (440kWh Battery/734kWh Fuel Cell)		
		Number of Blocks	Blocks Completable	Completion Percentage
BEB	New	26	6	23%
	Degraded		4	15%
FCEB	New	26	26	100%
	Degraded		20	77%

Figure A-2, A-3. A-4, and A-5 below shows a graph representing all blocks in Citilink's system and its completion with ZEBs when operating with and without a DFH in worst-case winter conditions. This graph takes into consideration the battery capacity of the bus as well as the 20% unusable portion of the battery. Every horizontal bar represents a block, where blue represents the completable portion, red represents the incompletable portion, and green represents additional leftover energy. The benefit of this graph is the ability to easily see a high-level overview of how close various blocks are to completability, and how much energy is needed to compensate for incompletable blocks.

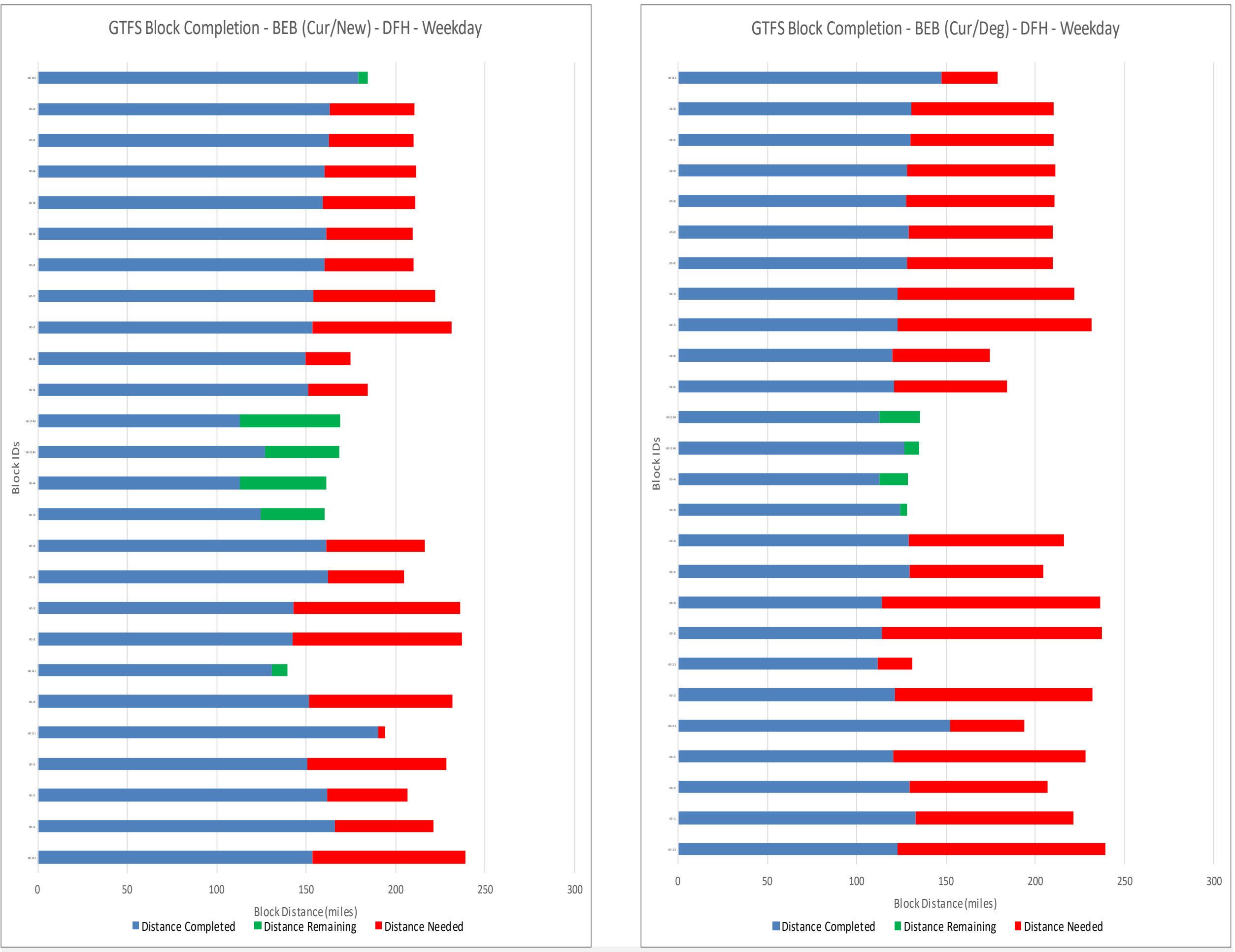


Figure A-2: Block Completion for All Blocks using (a) New and (b) Degraded 35-ft BEB in Winter with DFH

Figure A-3: Block Completion for All Blocks using (a) New and (b) Degraded 40-ft FCEB in Winter with DFH

TABLE A-4: BLOCK COMPLETION SUMMARY — NEW/DEGRADED BATTERY WITHOUT DFH

Bus Type	Battery/Fuel Cell State	35-foot BEB/40-foot FCEB (440kWh Battery/734kWh Fuel Cell)		
		Number of Blocks	Blocks Completable	Completion Percentage
BEB (35ft)	New	26	0	0%
	Degraded		0	0%
FCEB (40ft)	New	26	7	27%
	Degraded		5	19%

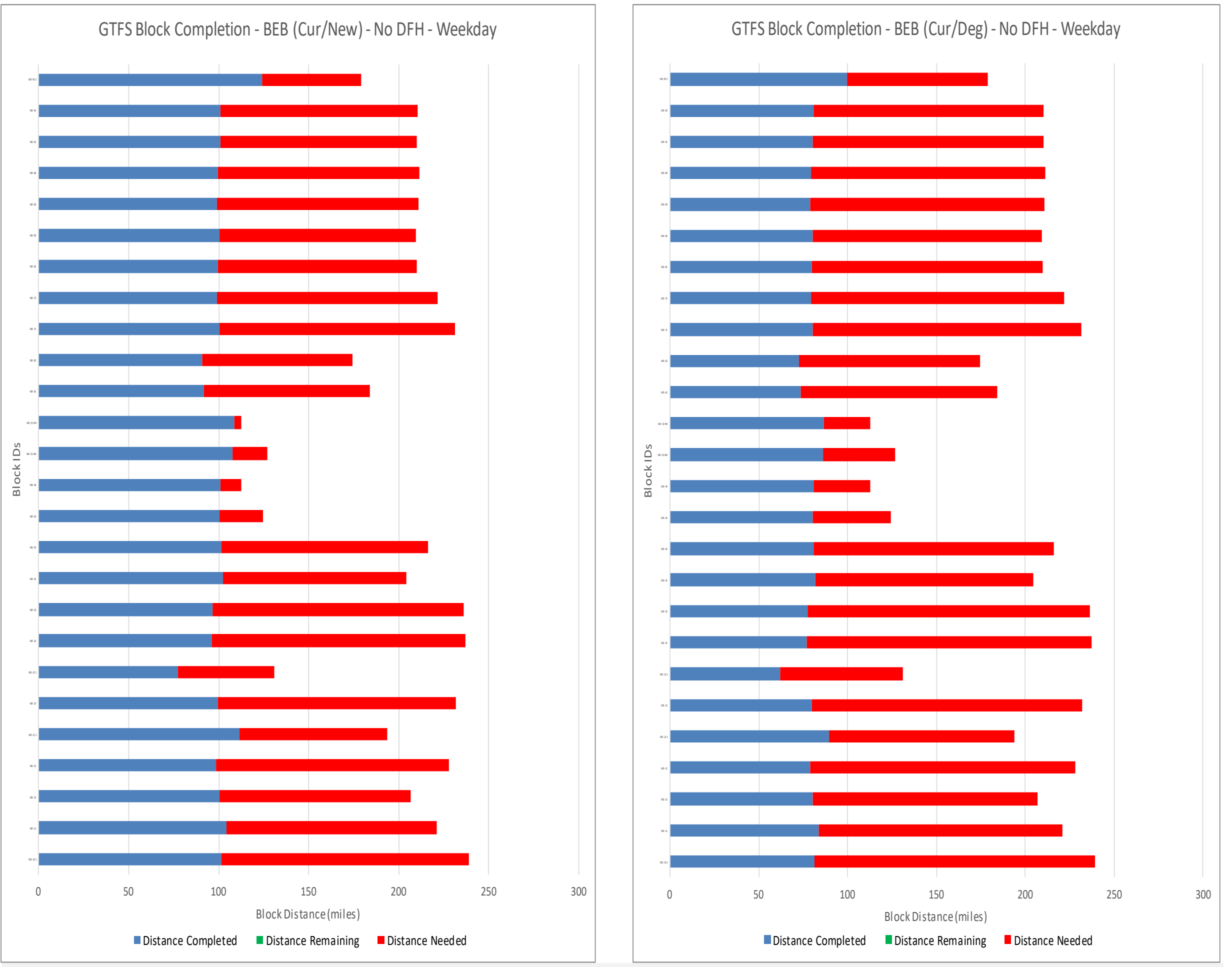


Figure A-4: Block Completion for All Blocks using (a) New and (b) Degraded 35-ft BEB in Winter without DFH

Figure A-5: Block Completion for All Blocks using (a) New and (b) Degraded 40-ft FCEB in Winter without DFH

Future Battery Technology

From the route and block analysis data generated from PEER, the energy required to complete each block was calculated. Using these results, the minimum theoretical battery capacity needed to achieve 100 percent completion on all blocks without any rescheduling was calculated.

TABLE A-5: BATTERY CAPACITY NEEDED FOR 100% BLOCK COMPLETION

Bus Type	Heater	Modeled Battery/Fuel Cell Capacity (kWh)	Battery/Fuel Cell Capacity Needed for 100% Completion (kWh) Degraded Battery
BEB	DFH	440	1,000
	No DFH	440	1,400
FCEB	DFH	734	900
	No DFH	734	1,200

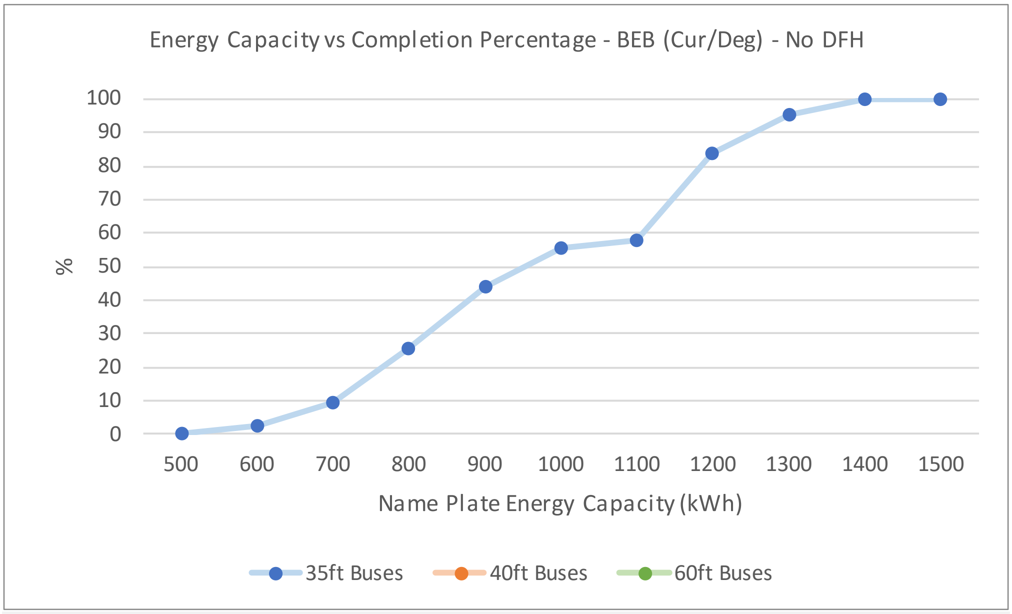


Figure A-2: Battery Capacity versus Completion Percentage for BEB (no DFH Degraded)

As shown in Table A-5, 100% of Citilink's 2023 service blocks can be completed with a battery capacity reaching 1000 kWh even with a seasoned battery on a 35-foot bus, and a FCEB with 900-kWh or 60kg of hydrogen storage. These values increase to 1400 kWh and 1200 kWh, respectively, when a DFH is not used. For BEBs, some of these capacities may be achievable in the future, but will take considerable time before they become available for commercial purposes. For FCEBs, some suppliers have high-capacity tanks, for example Eldorado has a 40-foot FCEB with 57.5kg of on-board hydrogen storage. However, hydrogen improvements are not expected to happen in the same fashion as battery improvements. While batteries are expected to continuously improve steadily over time, FCEBs will likely stay where they are unless the tank pressure is allowed to increase. The technology is in place already in other applications that allows for a pressure twice that of commercially available FCEBs, which would allow for roughly twice the range. For some of the extremely long and energy intensive blocks, re-blocking is suggested, even if alternative technologies like in-route charging or fuel cells are used.

The energy values for each block were also used to determine block completion based on a range of theoretical battery capacities. This analysis was done on all blocks, assuming winter conditions with DFH.

Energy Consumption

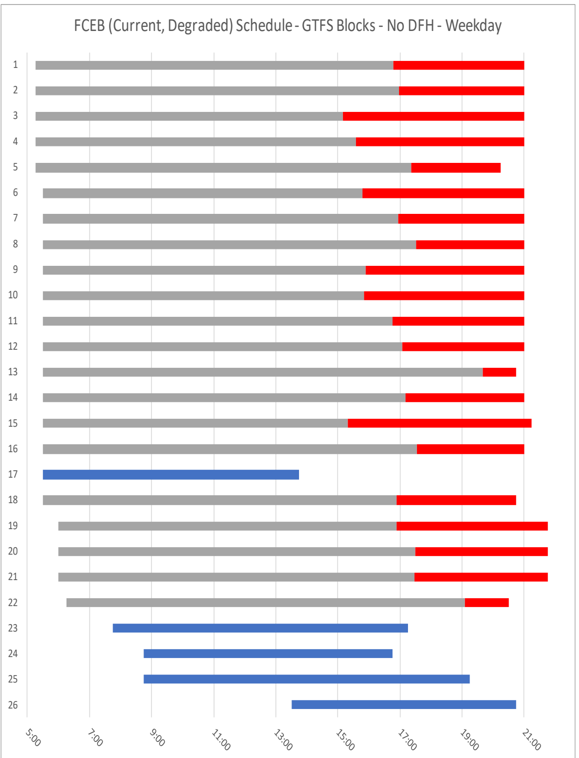
Table A-6 shows the minimum, average, and max energy consumption of each heater type on all blocks when the buses are operated in winter. When operating with a DFH, significantly less energy is being pulled from the battery per mile, which allows for greater block completion and operation flexibility.

TABLE A-6: ALL FACILITY ENERGY CONSUMPTION AT WINTER WITH DFH-EQUIPPED BEBS

Header	Minimum Energy Consumption (kWh/mile)	Average Energy Consumption (kWh/mile)	Maximum Energy Consumption (kWh/mile)
DFH	1.85	2.25	2.94
No DFH	2.18	2.62	3.54

Theoretical Re-Blocking

As shown above, not all blocks can be completed with ZEBs. One approach to solving the incompletable blocks is to restructure incompletable blocks by splitting them into two or more theoretical blocks. These incompletable blocks can be split into smaller blocks such that the new theoretical blocks can be completed by a ZEB. Additionally, to maximize efficiency and produce a more realistic result, these restructured blocks can then be combined with the completable blocks. These block combinations were formed using an algorithm that considers the service ID, start time, end time, energy consumption, bus type, and mid-day charging or refueling to determine availability of block linkages. The output of this algorithm is a schedule where one bus does multiple blocks in a day to minimize the total number of buses needed to complete the same amount of work. The result of this exercise is a theoretical block schedule that can be entirely completed with current or future battery technology. Figure A-3 below shows an example of Citilink's weekday blocks being split and linked together with an algorithm, where the x-axis represents time and the y-axis represents the blocks. In Figure A-3, the blue portions represents the completable portion of the block, red represents the incompletable portion of the block, and yellow represents the time spent at the garage between blocks.



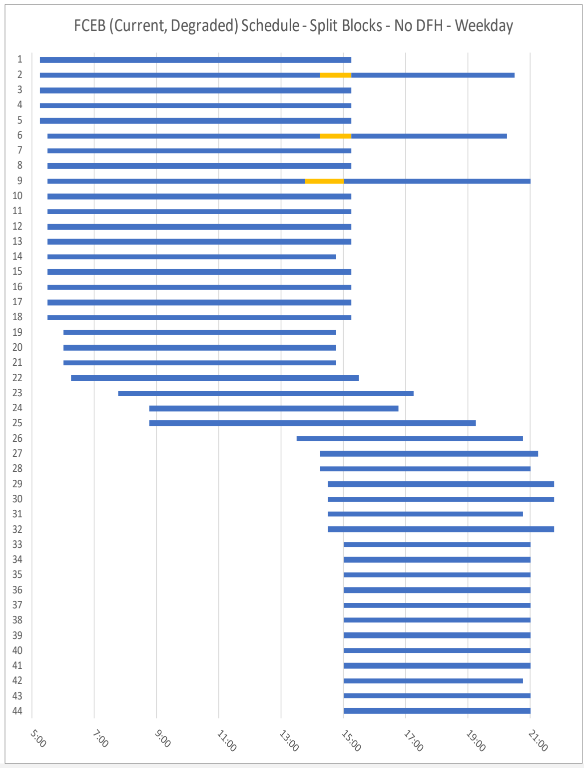


Figure A-3: Battery Capacity versus Completion Percentage for BEB (no DFH Degraded)

If we consider this exercise in the context of a full fleet conversion, the future case becomes particularly more relevant. As more diesel buses are retired and replaced with ZEBs, a schedule optimized for ZEBs becomes more important. Table A-7 below lists the results of this theoretical block splitting exercise utilizing 35-foot BEBs equipped with future battery technology and 40-foot FCEBs operating in winter conditions with DFH.

TABLE A-7: THEORETICAL BLOCK COMPLETION SUMMARY – FUTURE BATTERY IN WINTER WITH DFH

Bus Type	Heater	35-foot BEB / 40-foot FCEB (800kWh Battery / 734kWh Fuel Cell)			
		Original Blocks	Complete Blocks	Theoretical Blocks	Buses Needed
BEB	DFH	26	18	44	44
	No DFH	26	23	63	63
FCEB	DFH	26	6	32	31
	No DFH	26	21	47	44

The columns from the above table and their explanations are listed here:

- The number of original blocks indicates the blocks listed in the GTFS data.
- The number of incompletable blocks are the results of the PEER block analysis based on a bus equipped with a new, future battery operating in winter conditions.
- The number of theoretical blocks indicates the total number of blocks in the completable schedule that was created. This include completable blocks, as well as the incompletable blocks that were split into multiple, completable blocks.
- The Number of Buses Needed is the result of combining the theoretical blocks, using the algorithm described in Section 4.8. This column indicates the minimum number of BEBs needed to complete this theoretical schedule. Note that this minimum number of buses does not account for spare ratios.

Additional insight can be gleaned from comparing the above-mentioned minimum number of buses with the current garage capacity. Below, Figure A-2 and Figure A-3 compare the projected number of buses based on the analysis above, including spare ratio with the current fleet size and depot capacity. Figure A-2 shows that with a DFH, the FCEB scenario can be completed within the current depot dimensions. Without a DFH, the number of buses for both scenarios increase past the current depot dimensions, in the BEB case nearly doubling the depot capacity.

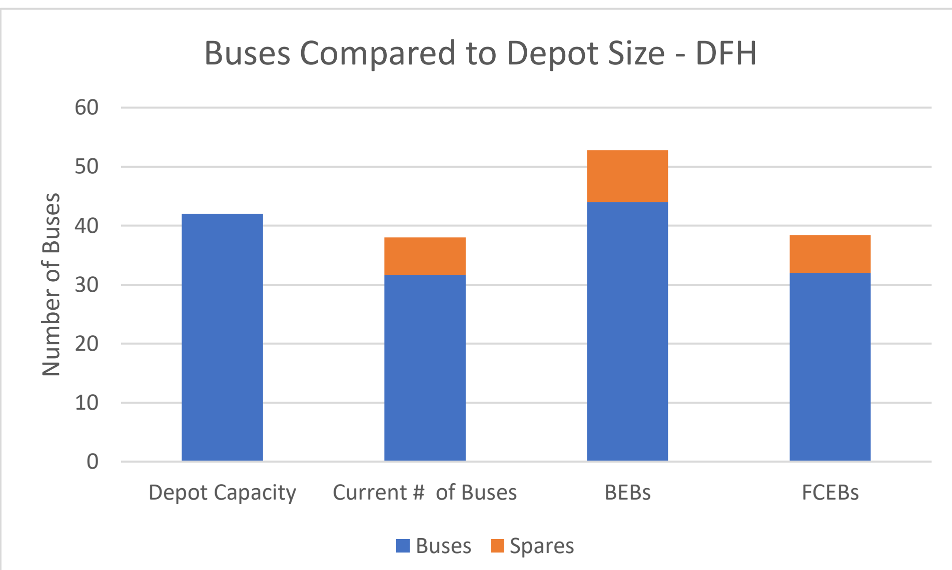


Figure A-3: Estimated Number of ZEBs Needed for 100% Completion (with DFH)

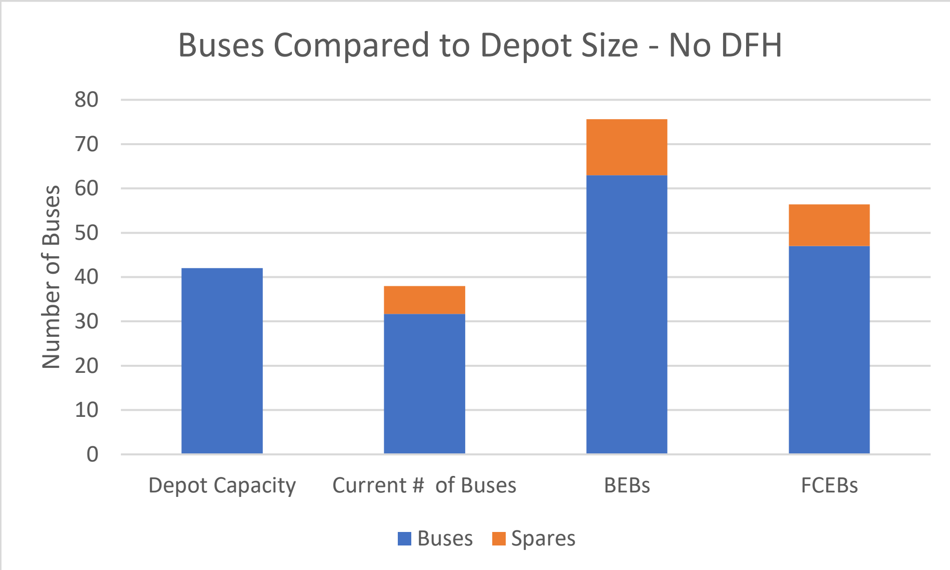


Figure A-4: Estimated Number of ZEBs Needed for 100% Completion (without DFH)

The fleet required to complete the theoretical schedule described above is not necessarily comprised of buses only with future batteries. Some buses with smaller batteries can be purchased today and still meet the 100% completability described in Table A-7. However, the number of buses with smaller batteries depends on the block lengths and schedule structure. Below are two figures showing a breakdown of the number of buses required in each energy capacity category, based on the theoretical schedules generated in Table A-7, during winter conditions with and without a DFH.

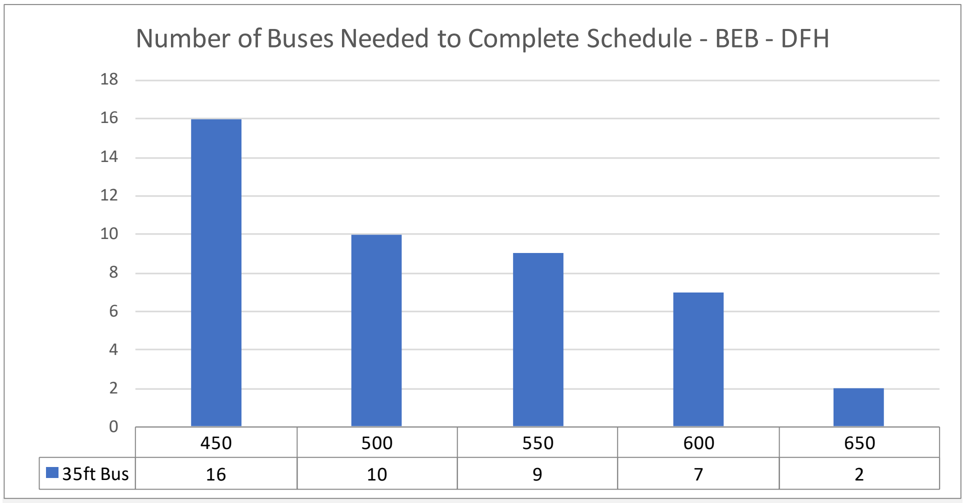


Figure A-5: Estimated Number of ZEBs Needed for 100% Completion (with DFH)

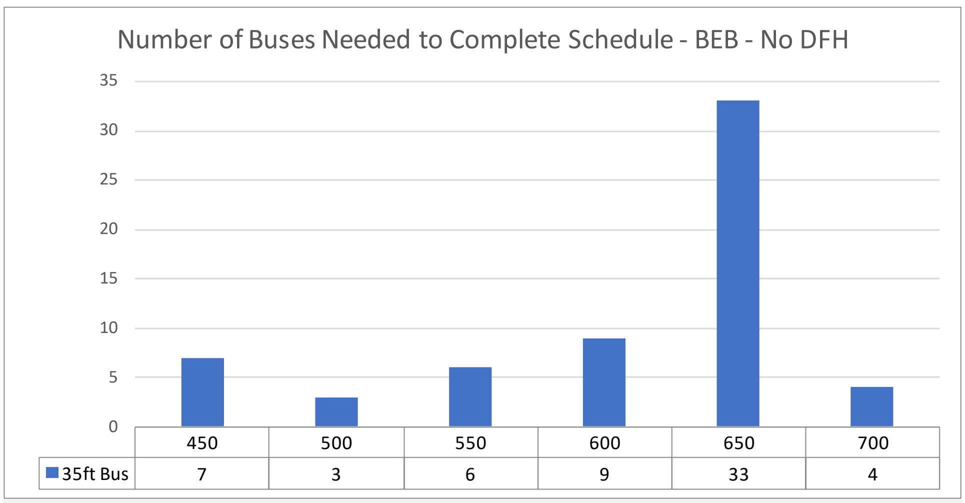


Figure A-6: Estimated Number of ZEBs Needed for 100% Completion (without DFH)

GARAGE POWER AND ENERGY REQUIREMENTS

Table A-8 shows the total energy requirements needed to complete all of Citilink's service. This table assumes that incompletable blocks have been split to make new theoretical blocks that can be completed by BEBs, with future battery technology. This table gives an overview of what Citilink can expect its power demands to be throughout the year and gives a worst-case scenario. This worst-case scenario should be utilized for infrastructure and planning. The power required for future battery technology is listed, which assumes a service capacity of 512 kWh. The power demands listed are those required to fully recharge the entire fleet with future battery technology, charging at a rate of 150kW. The load requirements were calculated for three scenarios. The first scenario is described as the FIFO approach. This scenario assumes that once a bus arrives at the depot, it will begin charging until it has reached 100% SOC. The second scenario is described as the optimized approach. This scenario attempts to minimize the peaks in demand by level-loading the charging while the buses are charging at the garage. The third scenario also attempts to reduce the peak, but in tandem, attempts to eliminate charging during a time range that is designated as "on-peak".

TABLE A-8: WEEKLY DEPOT ENERGY/POWER DEMAND – FUTURE DEGRADED BATTERY IN WINTER

Season	Heater	Total Block Energy Required per Week (MWh)	Power Demand (MW)		
			FIFO	Demand Shift	Min. Power
Winter	DFH	68	3.6	0.6	0.5
	No DFH	107	3.8	0.7	0.6
Spring	DFH	51	3.0	0.5	0.4
	No DFH	51	3.0	0.5	0.4
Summer	DFH	45	3.0	0.4	0.4
	No DFH	46	2.8	0.4	0.4
Fall	DFH	65	3.6	0.6	0.5
	No DFH	64	3.3	0.6	0.5
Min. Temperature (-18F)	DFH	68	3.6	0.6	0.5
	No DFH	107	5.5	1.0	0.8

Based on the results of the PEER analysis, the total number of chargers and staging area capacity needed was determined. The staging area in this analysis is assumed to be a section of the depot that holds fully charged buses, allowing for another bus to charge. This minimizes the total number of chargers needed, at the expense of an additional staging area needed to hold the fully charged buses. Additionally, as previously stated, these numbers assume that buses are charging at a rate of 150kW. Higher charging rates may change these values. It is noted that the algorithm found that a 1:1 charging ratio is needed even with the addition of DFH. Without DFH, the number of buses increases, and the staging area is utilized.

TABLE A-9: CHARGERS NEEDED FOR EACH SECTION

Heater	Buses	Chargers	Staging Area
DFH	44	44	0
No DFH	63	45	18

MODEL RECOMMENDATIONS

In summary the transition strategy recommendation is:

1. Sequence the procurement of BEBs over several years to match blocks that can be completed with current technology, in anticipation of future technology that will allow for most, if not all, blocks to be completed. This approach can also be used to reduce or even eliminate the need for block splitting. Coordinating the Fleet Replacement Plan with charging infrastructure installation based on the PEER results will allow the agency to take advantage of the time required to install charging infrastructure prior to BEB deliveries. As the infrastructure and fleet installation/delivery continues, energy density increases will be experienced allowing additional blocks to be completable until 100 percent fleet electrification is achieved.
2. Combine separate blocks for buses that return to the facility with significant SOC remaining. As shown in the block analysis above, mid-day charging can increase the number of blocks that a BEB can operate in a day. However, this may increase operating costs due to higher “peak” or “demand” electricity costs during the mid-day hours.
3. Adjust or split longer blocks. As shown in the block analysis, there are several blocks that cannot be completed, even with a 54 percent increase in battery capacity from future battery technology. By splitting these longer blocks, the current schedule can become completable without compromising service levels. However, this may increase operating costs due to the operation, maintenance, and storage of the additional buses that may be required, particularly if no DFH is used.
4. FCEBs offer 100% completability due to the higher onboard energy assuming the use of a DFH. FCEBs offer a feasible way to convert the fleet to ZEB with today’s technology in theory. There are other challenges associated with hydrogen that should be considered such as infrastructure upgrades, and sourcing hydrogen, as well as the higher ongoing cost for fuel that will.
5. Install a charge management system to optimize the facility charging requirements and minimize (or eliminate) peak power demand.

APPENDIX B: EMISSIONS CALCULATIONS

There are environmental benefits to be had every time a portion of the fleet is replaced with newer vehicle models. Key tailpipe emissions elements from internal combustion diesel engines are nitrogen oxides (NOx) and particulate matter of 2.5-micron diameter and smaller (PM2.5). Well-to-Wheel emissions are modeled for greenhouse gas emissions (GHG), which are comprised of carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and various other fluorinated gases which can affect act as ozone depletion rates.

The analysis reported here is based on modeled data from the U.S. Department of Energy's Argonne National Laboratory, which offers an analytical tool called the Heavy-Duty Vehicle Emissions Calculator (HVDEC). As stated on their webpage, "This tool is ideally suited to aid fleets and decision makers [to] compare vehicle technologies for emission reductions and [to] consider allocation of funding."

NEW DIESEL VERSUS OLD DIESEL

As the incumbent fleet of internal combustion engine buses ages, the performance of their tailpipe emissions reduction systems gets less effective. Therefore, replacing older traditional diesel engine buses with newer traditional diesel engine buses has positive environmental impacts. In Citilink's case, the positive impact would result from not only replacing worn out engines and emissions systems, but also would benefit from much lower emissions output due to tighter emissions limits and the associated newer diesel engine and emissions aftertreatment technologies. For example, it is estimated that replacing each of the 2006 Gillig buses with 2023 conventional diesel models could reduce the lifetime emissions (over the following 12 years, at 40,000 miles per year) of NOx by 652 pounds and reduce PM2.5 by 39 pounds However, it is estimated that there would be zero reduction of lifetime GHG emissions.

Replacing the newer diesel engine buses would not result in as much of an impact due to the emissions law changes that took effect in 2007 and 2010, and as the systems technology continued to mature. For example, replacement of Citilink's 2008 Gillig buses (equipped with DPFs, whereas the 2006 buses do not have DPFs) is estimated to reduce lifetime emissions of NOx by 296 pounds and reduce PM2.5 by 2 pounds. The reduction of lifetime emissions continues to trend towards less significance until the 2017 models (and onward to include the 2022 models). If those are replaced with 2023 diesels, there is zero change in the lifetime emissions of NOx and PM2.5.

DIESEL-ELECTRIC VERSUS TRADITIONAL DIESEL

Replacement of diesel buses with HEBs will have better emissions effects than the replacement with traditional diesel buses. Because the hybrids' diesel engines are certified to the same standards as are the diesel engines mated to conventional transmissions and diesel-hybrid buses tend to have smaller engine displacements, the engines work hard when they are needed to generate the additional power needed to accelerate the bus beyond what the hybrid's electric drive system can produce.

CNG VERSUS DIESEL

When traditional diesel buses are replaced with traditional CNG buses, the emissions impact is more significant than when replaced with new diesel buses. For example, it is estimated that replacing the 2006 Gillig buses with CNG engine buses would reduce each bus's lifetime emissions of NOx by 1,985 pounds, reduce PM2.5 by 39 pounds, and reduce GHG by 118 tons. As with the progression of replacements of old diesels with newer diesels, the trend of NOx and PM2.5 lifetime emissions reductions steps downward until the replacement of the 2017 diesels. However, GHG lifetime reductions remains steady at 118 tons per bus for any diesel engine bus replaced by a CNG engine bus.

BATTERY-ELECTRIC (OR FUEL CELL ELECTRIC) VERSUS DIESEL

When traditional diesel buses are replaced with BEBs or FCEBs, the emissions impact is the most significant than when replaced with new diesel buses. Across all diesel buses, each BEB is estimated to reduce GHG emissions by 749 tons over its 12-year life. Reductions in lifetime NOx emissions is estimated to be as high as 2,703 pounds per bus for a 2006 diesel replacement, then steps downward with newer diesel buses until the 2017 models, at which the lifetime NOx emissions reduction stabilizes at 2,051 pounds. per bus. Reductions in lifetime NOx emissions tops out at 43 pounds per bus for replacement of the 2006 diesel buses, then steps downward and stabilizes at 3.5 pounds per bus for 2017 and newer diesel buses.

APPENDIX C: TECHNOLOGY MEMO

ZERO-EMISSIONS - TECHNOLOGY MEMORANDUM

Prepared by STV for Citilink – 10 July 2023

STATE OF THE PRACTICE

The most recent 25 years have seen some developments in battery technology that allowed electric vehicle engineers to develop products that reached beyond the concept stage. Starting with the GM EV1, a successful platform for its time, the industry grew at a steady rate while developing personal cars, scooters, bicycles, and larger vehicles such as transit buses. These battery electric vehicles (BEVs) and their subset buses (BEBs) also allowed FCEBs to develop in parallel as they are basically a BEV/BEB with a fuel cell used for range extension and steady-state propulsion. Supporters of both solutions have been, and continue to be, aggressive with their predictions as they relate to market growth and the replacement of internal combustion engine (ICE) powered vehicles. This expected growth has been encouraged by various government financial incentives yet at the same time hampered by safety and range-related challenges.

In the bus space, BEBs have grown at a faster rate than FCEBs, primarily because most of the world has mature electrical grid networks and transit agencies do not have to concern themselves with recharging the batteries to the same extent as sourcing hydrogen. Hydrogen can be produced through a variety of methods, some with greater impact on the environment than others, and today there are designations such as "green, blue, or gray" hydrogen. Green hydrogen implies that renewable electricity and hydrolysis are used to produce the hydrogen. Blue hydrogen uses carbon sequestration from the grey production process. Grey hydrogen is primarily produced from natural gas using a process referred to as steam methane reformation (SMR). The latter is the lowest cost product. Hydrogen (H_2) can be produced on-site, delivered by pipeline once this is built, or it can be shipped via truck either in liquid or gaseous form, reducing the benefits due to the emissions in the transportation of this fuel. Furthermore, the electrical grid can also have some emissions from powerplants that support it. Most electrical grids are supported by natural gas fired Peaker plants that can remotely start up and support the local load pockets during surge demand, such as on a hot summer afternoon when a lot of air conditioning units may be turned on in a city.

Batteries are used to support both BEBs and FCEBs, with the larger battery packs found in BEBs, and much smaller ones in FCEBs, for buses of the same size and type, 500 kWh and 150 kWh, respectively. Lithium-Ion technologies are the primary solution due to acceptable power, energy density, and reasonable safety during normal operations. It is this technology, combined with the large available real estate on buses, that has allowed for BEBs and FCEBs to develop to the point where municipal transit operators can perform a significant portion of their service (40%-70%) with existing technology. Further range enhancements can be supported by splitting the AM/PM service blocks, adding layover or en-route charging stations, pre-charging, or adding diesel-fired heaters.

Why use diesel-fired heaters in BEBs? Because in traditional, ICE buses, the ICE generates a significant amount of waste heat as a normal byproduct of the combustion process. That waste heat can be used to heat the passenger space. Conversely, electric drive systems powered by a battery pack are more energy efficient than are ICEs, which results in less heat dissipation in the propulsion system while they are running. With much less waste heat available from the electric propulsion system to heat the passenger space, additional heating energy has to be generated, using energy from the battery pack. However, the magnitude of such heating energy needed significantly reduces the amount of energy otherwise needed to drive the bus, thus reducing the BEB's driving range. Therefore, some BEB operators in cold climates make use of diesel-fired heaters to preserve battery energy for driving the bus. In contrast to diesel ICEs, diesel-fired heaters consume much less fuel, and consume it in such a way that pollutants are much less than they would be from a diesel ICE.

FCEBs do not experience the same magnitude of driving range reduction, since they have the capacity to store more energy. Most of the energy needed for propulsion is provided by the fuel cell, which also recharges the batteries during steady state or low-power operating conditions. While regenerative braking can recapture some of the energy used, current deployments have shown that the amount of energy recovered is generally less than the energy produced through mechanical, hydro-mechanical, or other means, such as transmission retarders commonly found on transit buses and some trucks. The amount of regenerative braking energy recuperated is also carefully controlled by the battery management system (BMS) on the vehicle, to maintain a safe operating profile for the batteries, and to protect them from spiking currents that could reduce their life. The larger the swing between voltages (charge-discharge), the shorter the overall life of the battery pack.

Lastly, an alternative zero-emissions technology is the ETB. There are approximately 1,000 ETBs in operation in the U.S. and Canada, with an additional similar number in Mexico. An ETB is basically a BEB with a small (20-75 kWh) battery for off-wire operation, but which primarily uses a catenary energy supply system, where two bus-mounted poles collect current from two overhead wires. Along the system there are several small (250-500 kW) transit substations that convert utility AC voltage to catenary DC voltage, placed at distances of 0.5 to 1.5 miles apart. ETBs are the lightest vehicles and have an infinite range. If a detour is needed due to an accident or a water main break, the poles can be retracted by the driver. Re-poling would require the driver to stop the ETB, set the parking brake, and manually re-pole, a practice that generally leads to the driver operating on battery until it is depleted, or when end of line is reached. Challenges include maintenance of the catenary, trimming of surrounding trees, as well as maintenance and replacement of poles or structures that attach the guy wires. It is important to consider the challenges entailing the complexity of insulators and frogs/switches at busy intersections, especially if streetcar operations crisscross with ETB, resulting in what opponents of this technology call visual pollution.

Vehicle and Fuel Costs

BEBs and FCEBs are more expensive than their ICE or hybrid equivalents due to battery costs, ($750-$2,000/kWh), as well the volume of vehicles sold is significantly less at under 10% of total transit bus production (~40,000 transit buses in the US with an average life span of 15 years). In the personal automotive space, the entry point has been the luxury market, where the premium cost is more easily absorbed by the customers. The same observations are applied to electric bicycles, where (again) their higher costs are absorbed in the luxury market. Lower-cost alternatives have been imported from China, the current world leader in lithium-ion battery manufacturing and electric vehicle manufacturing. China has deployed some 600,000 BEBs, of which in the U.S. there are about 3,000. Europe is somewhere closer to the United States in the number of BEBs in operation, as is South America, a large importer of Chinese BEBs.

FCEBs have also been expensive, and their deployed quantities have been too small to leverage economies of scale. This technology has been primarily supported by Japan, South Korea, the United States, and Europe, with substantial government incentives and developmental work done by legacy automotive manufacturers. While hydrogen fuel-cell electric buses are currently in the "green" space, their advantage is that hydrogen can be extracted from any hydrocarbon molecule.

The introduction of synthetic kerosene/diesel is driven by the aviation sector, where neither battery nor hydrogen fuel cell can perform the function needed for typical commercial aviation operations. Synthetic fuels can be produced either by extracting hydrocarbon molecules from biological matter, or by combining hydrogen with carbon. Both processes are higher in cost than existing refining methods, thus are currently an unlikely long-term solution.

Returning to battery technology, vehicle OEMs and battery OEMs have been able to reduce the costs at the battery cell level until 2022, when the first price increase was recorded in more than 10years.

If the goal is to eliminate local tailpipe emissions, societal benefits will need to be monetized or credited to sustain the transition to zero-emissions. For fuel cells to become more acceptable, in terms of costs and fueling infrastructure challenges, a global solution set needs to be developed which accounts for hydrogen production and distribution to perspective customers. An alternative application of hydrogen is found by looking at data centers which can use large storage cryogenic tanks, like those at the NASA space facilities in Florida and Mississippi. As transit agencies do not operate in the fuel production space, the number of large-scale deployments will continue to see a slow growth rate for the foreseeable future. The United States Federal government is supporting the development of hydrogen hubs to stimulate the market.

Recycling or repurposing of batteries is an ongoing challenge that is being worked on by the U.S. Department of Energy through National Laboratories' various projects. Currently, fleet operators will continue to field the costs related to the disposal of end-of-life lithium batteries, as well as those suspected of damage due to accidents or exposure to onboard fires. Capital costs for fielding BEBs and FCEBs can be offset by leveraging federal LOW-NO grants, which (in some cases) is augmented by state or local funds available for this transition. Larger agencies have started to move beyond R&D or T&E projects with 5-10 buses in the recent five years. Scaling up these programs is now starting to provide a clearer picture of costs beyond the purchasing of BEBs and chargers for BEBs or purchasing of FCEBs and a small fueling station for FCEBs. These additional costs include safety, training, operations, maintenance, IT/data, fuel (electricity or hydrogen), facilities, and stranded assets (i.e., a charger OEM that is no longer in business, has sold, or has discontinued support of the business). Incorporation of these new assets into an organization's enterprise asset management system also brings some complexities and costs.

In terms of cost relating to ETBs, they are primarily driven by the acquisition of buses, installation of the catenary and the substations to support the system, modifications to the garage/depot/bus wash, and some extensive work to locate and install the poles that support the guy wires that in turn support the catenary wires. Lastly, parts, training, and some specialty platform trucks are required to complete the maintenance of this ecosystem. A positive cost driver is that the FTA considers ETBs as being on a fixed guideway, like streetcars, thus making the system eligible for funds which can cover a substantial portion of the M&O costs for the infrastructure. The small size and power requirements of the TSSs do not pose a significant load to the electric utilities, however they must be located and installed which could become very expensive in downtown areas where most real-estate is occupied.

Agency Operations

Citilink – Operations of Bus and Non-Bus Fleet assets provides a safe and reliable service to its customers during and post-transition to zero-emission technologies.

Zero Emissions – Options and Recommendations

1. BEBs

- **Buses.** BEBs are the fastest-growing segment of zero-emissions transit buses. They are simpler than the alternatives, while they take advantage of technologies that have developed in the passenger car electrical vehicle market, such as direct current fast chargers (DCFCs) . Buses have also started to employ modularized battery packs with design features like those found in personal car electrical vehicles. Their primary competition is from fuel cell electric buses, which are basically BEBs with a fuel cell functioning as a range extender. Another option currently not under consideration in the United States is the ETB , again a BEB with a small battery pack for off-wire operation, but with two current collector poles mounted on the roof for on-wire operation.

  Transit agencies have been looking at technologies that help reduce, and eventually eliminate, local emissions. Starting with diesel emissions technologies that reduce particulate matter, in conjunction with the use of low-sulfur diesel fuel, then with diesel-electric hybrids, the alternative for many years was CNG, while some agencies experimented with ethanol/methanol (alcohol type fuels), LPG, and more recently with hydrogen fuel cell and battery-electric designs. Currently CNG, Diesel, and Diesel-Electric Hybrid, are the dominant technologies, while battery and fuel cell are the emerging ones. Another legacy technology is ETB; however, in this country at this time, there is limited understanding and appetite for growth of this older, proven zero-emissions technology. Of the two emerging technologies, the former is growing faster, and every major bus manufacturer currently has a BEB on offer, with various battery capacities to meet range and cost priorities. The range has improved, charging standards developed, costs have stabilized in-line with other battery vehicles, and reliability is improving, all typical improvements of an emerging technology. CMS are starting to be deployed where multiple buses or chargers are located to better manage electrical loads, and these developments can allow transit operators to potentially develop rates with their utility, rates that reflect the advantages provided. Where rates cannot be negotiated, charge management systems can benefit the agencies by shifting the load to avoid/reduce demand charges or to a lower cost time of use rate.

- **Chargers.** BEBs require chargers that can restore the energy used on routes in the time available when the buses are not being used. The time available can be overnight, midday, or en-route at layover locations. The latter option requires coordination with municipalities or property owners.

  At bus depots, garages, or bases, charging systems can become complicated, due to several factors such as flood mitigation, equipment location, data acquisition, electrical distribution, and other schemas that can provide benefits to project costs, resiliency, reliability, or even complexity. A complex installation can add solar panels, on-site battery energy storage systems (BESS), or multiple transformers.

The selection of chargers and other supporting equipment implies vetting of solutions, suppliers, and design integration, with consideration for both scheduled and unscheduled maintenance activities. Industry standards are desirable for they allow equipment from multiple vendors to be integrated and managed by a single charge management system. Charging can be accomplished a few ways and the solutions are dependent on desired outcomes and availability of manufacturers. For inductive charging, there are currently two OEMs, and each one has a proprietary solution, and the result is that buses equipped with a solution from one OEM, cannot currently charge at an infrastructure from the other OEM. Inductive charging does not save space, however by placing some or most of the equipment underground, fewer pieces of equipment claim space on a sidewalk or other place on the property. Conductive charging is currently the prevalent method, and most buses are available with plug-in charging port(s) as well as with roof-mounted rails, on which an inverted pantograph descends to make the connection. While there are standards being developed for inductive charging, they already exist for the conductive solutions, i.e., SAE J1772 CCS 1 for plugging-in, and SAE J3105-1 for the automated pantograph-down solution.

The power transfer methods for these conductive charging standards are adequate for most bus needs. The chargers do not have to be operated at their rated power levels. The available power levels for plug-ins are up to 180 kW, and up to 600 kW for pantograph down systems. The latter may sound attractive, and one could infer reduced recharging times, however charge power is determined by the battery's chemistry and charge capacity. A battery's life can be reduced by higher charging power levels: thus they are managed by the bus charge controller (BCC) with information from the battery management system(s), (BMS). Buses deployed at a transit agency have limited power to ~300 kW, so the agency selected a combination of chargers for its pantographs capable of 300 or 450 kW, while the pantographs deployed are all rated and tested to >600kW at 1,000V continuous. Future upgrades are possible by replacing the charger's cabinets without having to change wire size or conduit diameter or pantographs. For the plug-in solutions, pin and socket physics limit the power, and some OEMs reach higher power levels by adding additional receptacles on the vehicle and additional cords on the infrastructure side, resulting in a less than optimal solution. Calculations for energy consumption and time available, indicate that 75-125 kW is sufficient during most normal operations, allowing lower overall facility power level and their decreased energy costs. Ideally, power consumption can be level across time, not always practical in transit operations, where typically a.m. and p.m. weekly peaks conspire against this outcome. Potentially an on-site BESS can be used to reduce the difference between the peaks and valleys, at least to a level that improves the economics of the overall system. Higher power chargers may be desired in small quantities to accommodate recovery events, such as buses that complete maintenance activities too late to have sufficient time to recharge, at say 100 kW, but may become available for service with 300-450 kW. Similarly, in case of a power outage or unscheduled maintenance/down-time of a bank of chargers, cycling buses through the higher power chargers can restore fleet availability to acceptable levels. A 450-kW installation is more expensive than one that only needs to dispense 150 kW, so careful analysis of needs and solutions will optimize cost vs. capabilities at a site. A layover charging solution can help the overall system by allowing charging to take place where buses from multiple routes normally have >15 minutes available as part of the schedule. Transit centers can be natural locations for this type of solution. Distributed charging improves system resiliency at an added cost. The increased cost and system complexity can be beneficial for the longer blocks that may not be split, and which during inclement weather can experience a significant reduction in range of up to 50%, especially if the vehicles are not equipped with diesel fired heaters. Furthermore, layover chargers can also be used to restore energy at the end of the block, and the bus can be returned almost fully charged and be parked in a bypass lane for immediate dispatch without charging again at the depot. A charge management system can support both dispatcher and bus control center functions by allowing staff to see the state of charge of each bus, and this can help with decisions such as which lane to park the buses in, or to swap vehicles on the road. In addition, developing faults can be acted upon to prevent road-calls or tow jobs, i.e., if one of the seven battery packs drops out and the vehicle continues to operate yet with reduced range, it can be swapped before it gets too low SoC or too far away from a depot or layover charger. En-route chargers are typically high-power chargers (300-600 kW) placed on the street to serve a single route. More than one transit agency installed en-route chargers to support a long BRT route. Other agencies installed en-route chargers to eliminate deadheading of buses due to distances to their home-base or depot. Rush hour traffic in some cities can result in long deadheading times, which could be addressed by re-blocking and swapping operators at a terminal, or even in the middle of a route, where a charger could charge up a bus even if it is for a few minutes.

- **Safety and Training.** New technologies introduce new risks which require mitigation strategies. The primary risks are safety and training. In terms of safety, the concerns revolve around unscheduled thermal events, fires. The amount of energy stored in the Lithium-Ion batteries improves vehicle abilities in terms of range and at the same time if this energy is released in a fire, it requires analysis and damage reduction strategies. The energy is contained inside the batteries which are packaged in battery packs. These battery packs are designed to contain thermal runaways and their BMS systems monitor temperatures and voltages to allow for protection features to be activated such as opening contactors (open a circuit) or stopping power flow (charging or discharging) by simultaneously communicating to relevant controllers to terminate activities that could exacerbate pre-defined conditions. Once a fire starts, what type of protective measures can be effective and beneficial? Fire containment (battery pack design), fire detection (communicate the fire alarm to relevant recipients), or even fire extinguishment (is this possible with these batteries). Lastly, what type of training is available to the first responders (most likely hazmat firefighters), the operator, others? How does the adopting agency communicate the introduced risks to the first responders, or entities that capture risks and mitigation strategies? Once risks are clearly identified and communicated to affected agencies, it is time to move to training. Training begins with awareness of risks and how to recognize them. Risks once identified, can be mitigated through design, maintenance, or operations. Ideally risks are reduced or eliminated through the design phase so that once the equipment is placed in service, the likelihood that a customer must deal with a risk are reduced substantially. In the unlikely event that an event occurs while the equipment is with the customer, processes or procedures can manage the outcome while reducing risks to the customer, risks to the equipment, operation, or adjacent assets. The customer in this case is the transit agency. The transit agency also has customers that it is responsible for their safety. Transit agencies rely on the American Public Transportation Association (APTA) *Bus Procurement Guidelines* and other industry documents to provide protection from risks. Should these documents be inadequate to the risk mitigation from vehicles cradle to grave span, the transit agency expects the bus OEM or in this topic also the charger OEM to clearly identify risks and strategies to mitigate or prevent them. Based on experience with diesel, CNG or diesel-electric hybrids most agencies realize that they will have to manage certain incidents where buses experience unscheduled thermal events, and it is unrealistic to expect bus or bus system OEMs to fully manage all risks in the design and manufacturing phases of vehicle production. Ideally, each transit agency develops an emergency response plan that cover failure modes of zero-emissions vehicles.

Training programs must cover most of the agency staff including supervision and leadership. They should cover key elements as they relate to acceptance, commissioning, operation, and retirement of fleet assets such as buses or chargers. Good training programs enable and prepare qualified, talented, and interested staff to manage any normal or abnormal operations. Training covers internal staff as well as external staff such as emergency responders or other staff that can interface with equipment or agency personnel that perform maintenance and operations functions. Electrical safety training can be coordinated with a local electrical utility or an equipment manufacturer, one that builds electric buses or chargers or other ancillary equipment. Accident safety training can also be developed, delivered, and practiced with affected agencies such as the operator, local emergency responders and equipment OEMs. Additionally, industry consultants can provide direction or resources for standards that cover equipment, operation, and incident response. An effective training program provides initial and recurrent training to make sure staff is proficient and up to date with changes in equipment or requirements over the life of the asset. Lastly the measure of an effective training program is the operation of technology that results in minimal or no incidents, injuries, or property damage. Resources exist in many places such as OEM literature, the National Fire Protection Association (NFPA) and other industry focus groups, historical event analysis, and sister agency knowledge.

For BEBs, risks revolve around the energy storage systems and how they can experience thermal events while charging, normal operations or post-accident. Awareness and management of these systems can reduce intensity of outcomes. Understanding of causes of thermal runaways can lead to better training programs as well as improved communications with bus OEMs and Project companies that specify requirements for or build infrastructure components. The list of applicable starts with standards development organizations (SDOs) where information ranges from incident or fire safety, electrical code, design, or vehicle systems or charging components, commissioning, operations, communications, and other relevant requirements. Emerging technologies lead SDOs in the timeline of deployment and implementation. There are three types of communications that SDOs use to inform on topics of interest technical information reports (TIRs), recommended practices (RPs), and standards. One can think of these documents as may, should and shall. Regardless of their status information contained is provided by industry to inform users on how to implement new technologies while improving operational reliability, safety, and interoperability. Some SDOs may use different names for their phases of standard development efforts without resulting in different outcomes or intent. SDOs can be local, national, and international. Involvement in key works improves knowledge. In addition, there are industry groups, research laboratories, technical universities, and some non-profit consultants that aggregate knowledge or research on topics of interest. Standards have sprung from the works produced by these entities, which facilitate or accelerate transition through newly developing technologies.

Safety is improved through gain of knowledge and feedback mechanisms that inform design, manufacturing, operations as well as retirement from the prime application sometimes into a recycling or secondary life set of requirements. Research by a national laboratory in the United Stated is being conducted on how to integrate, manage, and safely operate Lithium-Ion batteries in a secondary life application such as a BESS. Based on lessons learned the same laboratory is standing up a fire safety group that will study and inform on best practices applicable to operations and to tactics used by fire departments or their hazmat teams when responding to unscheduled thermal events involving Lithium-Ion batteries in mobile or stationary applications, new or repurposed. The NFPA publishes codes and standards for BESS, for construction such as the National Electrical Code (NEC) . Two important NFPA communication packages consist of a virtual training course, Alternative Fuel Vehicle Training, and a collection of more than 100 emergency response guides provided by vehicle OEMs, documents that identify locations of hazards found on hybrids, BEBs, EVs, FCEBs, and other vehicles that do not rely solely on diesel or gasoline for energy storage and propulsion. After more than 75 years of primarily operating diesel/gasoline fueled vehicles, training which is a core component of basic handling or fire-fighting tactics, the growing percentage of alternative fueled vehicles necessitated the development of newer tools and practices. Some of these tools and practices can be evaluated by operators for incorporation into their operations, training requirements and safety plans.

Training beyond a safety plan starts with an assessment of current skills and a review of new skills. This gap assessment informs on training packages procured with BEBs or their chargers in addition to in-house or customized solutions that cover the transition period, and the future recruitment needs. Resources can be found at local utilities, trade schools or training institutes that cater to specific industries. In the bus space for example APTA and the NTI could be useful resources when it comes to converting the fleet. Another good resource is on-the-job training available during installation or commissioning work where buses and their charging equipment are used to validate normal and non-normal operations. IT solutions can have their own unique training packages designed to prepare agency staff for monitoring and dispatching operations using software tools. It is desirable to train mechanics and tow truck operators in the handling of accident vehicles with a course such as the one from NFPA, in addition to OEM procedures. Lock-out/tag-out processes require review against existing ones due to new risks relating to the high voltage systems, which mechanics may occasionally be required to work on while they are energized. Shock hazards and potentially arc-flash hazards may be encountered and need to be safely managed by all affected staff. Specialty tools such as insulated wrenches or digital multi-meters (DMMs) rated for higher protective classes need to be procured and managed carefully as part of the overall agency protection system. Some items such as high-voltage gloves, or insulating blankets require inspections prior to each usage in addition to periodic non-destructive testing and recertification. Torque wrenches and DMMs require periodic calibration and documentation. Facility or shift managers need a designated safety representative that is trained and current in procedures should questions arise.

Asset management of items that can store energy for long periods of time including accident vehicles or their components should be part of the overall agency safety plan. Racks for batteries should be located away from work areas or outside of structures that can be compromised by unscheduled thermal events. A designated area that is kept clear and is part of the training program should be kept clear and be of sufficient size and separation from adjacent structures. The purpose of this area is to be repository for suspect buses or battery packs. The local fire department should also be made aware of this area during familiarization training and again during incidents. Either agency staff or the fire department could opt to pull, posh, tow or drive a vehicle from inside a structure or a parking lane to increase safety pre, during or post-incident.

2. FCEB

- **Buses.** FCEBs are zero-emissions buses with a smaller battery than in BEBs and with a fuel cell range extender. This configuration is a bus that has similar range to a diesel, hybrid, or CNG bus, and has refueling times not much longer than those existing technology vehicles. The fuel cell operates in a near steady-state profile while batteries are used for acceleration and to recover some of the braking energy. As the battery depth of discharge is relatively small and the battery packs themselves are small, battery life cycle costs could be reduced if the life of the unit can exceed that of the typical 12- to 15-year bus useful life. Recent fuel cell designs have improved unit life and reduced size. On a vehicle that is heavier than the alternatives, reducing component weight erodes some of the advantages found in BEBs or ETBs. Vehicle weight/mass has impacts on tire/brake/suspension/bushing and the frame components' life. Currently a fuel cell electric bus costs a little more than a battery bus, and if hydrogen cost and availability improve, then bus procurement prices can further be reduced, possibly to parity with the alternative zero-emissions options.

- **Fueling**. FCEBs require hydrogen (H_2) fuel to be dispensed in gaseous form, similar to CNG buses. Tank capacity, pressure levels, and station design all determine fueling times, which can be 5-10 minutes, which is longer than CNG at about 3-5 minutes or diesel at 1-2 minutes. Even so, all of these refueling times are substantially less than that of BEBs, whose battery recharging times is measured in hours per day. These factors affect facility design, staffing, and yard operations. Hydrogen can be produced on- or off-site. For a small fleet of FCEBs, gaseous hydrogen could be trucked in and dispensed from the trailers. For larger fleet, greater than 2-5 buses, liquid hydrogen can be trucked in, stored, and converted to gaseous form on-site, when needed. Both methods result in emissions from the truck tractors that deliver the trailers from the point of production to their customer transit agency locations. The trucks are typically diesel fueled.

Hydrogen can be produced on-site and several agencies in North America have experienced with this method. Potentially, in the future, technologies may support regional or national pipeline distribution networks like the natural gas or steam systems. Once such systems develop, transit agencies would be able to receive hydrogen the same as natural gas or electricity. Recent federal funding support is designed to encourage the building of hydrogen hubs to encourage the deployment of FCEBs.

- **Additional Safety and Training Requirements.** FCEBs are BEBs with a hydrogen fuel cell range extender and are subject to all the BEB training requirements supplemented by safety and training topics that are unique to the handling of hydrogen gas and the associated risks. Agencies that have experience with FCEBs are currently one of the best resources. Some members of the Zero Emission Bus Resource Alliance (ZEBRA) are experienced with FCEB operations and training.

3. ETB

- **Buses**. ETBs are the smallest growth segment of zero-emission buses in North America. The few surviving systems have been in operation for more than 75 years. These buses can stay in service indefinitely, similar to electric trains or subways. They are equipped with a small battery pack, sized from 20-70 kWh, to allow for off-wire operation ranging from 5-20 miles in inclement cold weather. Off-wire operation is necessary to detour from the route or to pass through a de-energized section of catenary such as adjacent to construction zones where equipment or personnel may need to operate near the wires. Detouring can occur due to accidents or other street closures. A button on the bus dash allows the operator to retract and stow the poles without leaving the driver's seat. Re-poling can be accomplished manually using ropes or automatically if inverted hats are installed on the wires at a pre-designated spot. The hats are made from a non-conductive polymer, about 60" long and about 20" inches wide at their lowest point. The bus must be positioned and stopped relatively centered longitudinally and laterally using visual cues at the location for the re-poling to be automatically completed. Some ETB garages also have these hats installed so that the number of wires and switches can be reduced. A European company is working on a sensor package that could allow re-poling anywhere without any mechanical aids. Newer and larger battery packs allow for route extensions without or until the catenary and supporting TSS units can be built and tied to the system. There are some advantages to ETBs that may not be initially obvious such as reliability of legacy technology, a distributed power network that is unaffected by local power outages and lastly (most important benefit) up to 80% of the infrastructure costs are funded through the FTA under fixed guideway state of good repair guidelines, like subway or rail streetcar systems. For agencies that operate ETBs or tracked electric systems, this zero-emission solution can easily be scaled as the agency has all the required components in place in terms of safety, training, maintenance, and organizational knowledge. For agencies that do not have experience with ETBs, the challenges involved with transitioning to this technology can be comparable to BEBs or FCEBs. In compact cities additional challenges spring from permitting and contractual requirements for locating and building the catenary system.

- **Catenary and Transit Substations – Infrastructure.** ETBs require a distributed infrastructure that consists of a pair of overhead wires (catenary system) and TSS units each .25 to 1 mile apart at power levels of 250-500 kW each. The frequency of the locations and their power levels increase on wider streets where multiple ETBs bunch up, by-pass catenary sections exist for passing or local/express operation, and they operate on both sides of the street. In downtown core areas the TSS installations can be networked and fed from more than one utility source. This improves system reliability in case one utility substation or feeder is out of service and other can supply the TSS. While in many areas guy wires can be attached to existing traffic or power poles, transit agencies prefer to procure and install dedicated poles for their system reducing interference with other utility systems. This solution is easy to implement in terms of locating, installing, and maintaining dedicated infrastructure and reduces reliance of permitting requirements in parts of cities where the guy wires are attached to buildings or other structures not owned by the operating agency. In either case, and similarly to BEBs systems that may install en-route or layover chargers, agencies that pursue the ETB path require services of legal and real-estate professionals to negotiate the various permits, easements and other contracts associated with installing ETB infrastructure.

  At a bus garage/base, infrastructure is required to power a partial catenary system for the parking yard and for some other activities such as maintenance and bus washing. Maintenance bays require their own solution set or may forgo catenary inside the garage but there is a need for some DC power to be made available for the current collecting poles as some troubleshooting activities require the ETB to be powered up.

- **Additional Safety and Training Requirements.** Road crews qualified as lineman and supporting equipment such as platform trucks are needed to inspect and maintain the catenary system. In addition to the substations along the catenary, some systems have larger power substations and metered switchgear from where the distribute lower voltage AC or DC power through their own feeders and distribution network, to smaller TSS units reducing the working voltage through the system and the associated training/tooling/safety equipment. These road crews are certified to work with medium voltage AC systems (12,000-26,000 VAC) and low voltage DC systems (0-1,000 VDC). Typically, they are a different labor qualification that vehicle or facility mechanics. Electrical knowledge, training, and certification is required of these folks. They are similar to utility line workers in terms of skills, education, PPE, and tool usage. Due to the constant hazards for this job classification, apprenticeships and journey level positions are important and often required before transitioning to lineman examination and promotion level.

  Mechanics that work in the garages or on the road do not require any special electrical certification class, however they do get training that covers low voltage hazards (50 VDC exposure can result in fatal injuries) and use of PPE rated for the tasks at hand, insulated tools, arc-flash prevention, no lone work zones, and such. The training required of these individuals is quite similar to the skillset required for BEBs (ETBs without poles and with larger batteries).

  Fire department training is less intensive for ETBs than for BEBs, primarily because the battery packs store a lot less energy, which consumes the pack quickly in cases of unscheduled thermal events. Firefighters, especially hook and ladder operators, receive additional familiarization because the catenary system wires can be hard to see, and they present hazards similar to the overhead power lines, which must be avoided during erecting of equipment.

APPENDIX D: FACILITIES AND INFRASTRUCTURE

INTRODUCTION

The purpose of this section is to document the condition of the existing facility and infrastructure while providing additional information to inform future studies and to measure the ability of the facility to support conversion to low and zero emission technologies. The existing facility is located at 801 Leesburg Road, Fort Wayne, IN, in Allen County (Figure D-1) and was initially constructed in the mid 1950’s with an addition to the storage barn constructed in the 1970s. This assessment of the facility did not include a review of the administration portion of the facility. Limited documentation, including existing drawings of the buildings and site were not available.

GENERAL CIVIL SITE NOTES

The existing facility is situated on a site approximately 7.2 acres in area and bounded by a vacant property to the north that was recently purchased by a local animal rescue, by Orff Avenue and Indiana Michigan Power parcel to the south, and by Lindenwood Cemetery to the west. Vehicular access to the site is provided by two driveways from Leesburg Road. There are two buildings constructed on the site. The eastern building fronting Leesburg Road comprises a single-story maintenance facility with a small 2-story administration building. The single-story storage building is in the middle third of the site with staff parking on the western portion of the site. As built drawings of the site and facilities were not available.

Figure D- 1: Leesburg Road Bus Maintenance and Storage Facility Site aerial.

Figure D-2: South entrance looking west, general condition of pavement.

Figure D- 3: North of the storage barn, general condition of pavement.

Figure D-4: Photo north of the Storage Barn, general condition of pavement.

EXISTING PAVEMENT CONDITION

The pavement on the site appears to be in fair condition. General signs of wear can be seen throughout, with isolated areas showing more severe damage. There is little evidence of spalling, and most deficiencies are focused at the panel joints. Maintenance staff confirmed nine areas of site that are scheduled for future replacement and repairs.

EXISTING STORMWATER SYSTEM CONDITION

No noticeable issues with the site's drainage were determined during site visit. The existing stormwater system includes multiple inlets throughout the site. It appears the current system collects stormwater from the surface and discharges directly into the municipal storm water system. There are no signs of any stormwater quality or quantity features on the site, modifications to the site may trigger conformance with current stormwater management regulations and will need to be considered in future site modifications.

UNDERGROUND STORAGE TANKS

There are currently four underground storage tanks located on the site. On the north side of the site located below the facility pavement there are two 20,000 gallon diesel tanks and one 25,000 gallon gasoline tank. On the south side of the site adjacent to the administration building in a turf covered area, there is one 10,000 oil storage tank. The diesel fuel and new oil tanks are piped into the repair facility to dispensers. The gasoline fuel is dispensed outdoors adjacent to the tank location, the system is also located on the north side of the vehicle storage barn. Staff indicated future plans to replace the underground storage tanks with above ground storage tanks was being considered. No information was provided on timing for this project.

Figure D- 6: Gasoline UGS tank location.

Figure D- 7: New oil UGS tank location.

STRUCTURAL

Maintenance Building

The structural system of the maintenance area consists of exterior load bearing concrete masonry unit (CMU) walls with brick veneer. The roof structure consists of a metal deck supported by a system of 16" deep open web joists with wide flange girders (W27 with 10" flange) supported by steel columns. The exterior wall is reinforced with CMU pilasters along the CMU walls at roof girder locations, overhead door locations and periodically at the end walls of the structure. The floor of the facility is concrete. Support spaces within the building are typically 8" load bearing CMU walls with cast-in-place concrete ceilings. The parts storage mezzanine level is a steel framed floor structure supporting a perforated metal plank floor system.

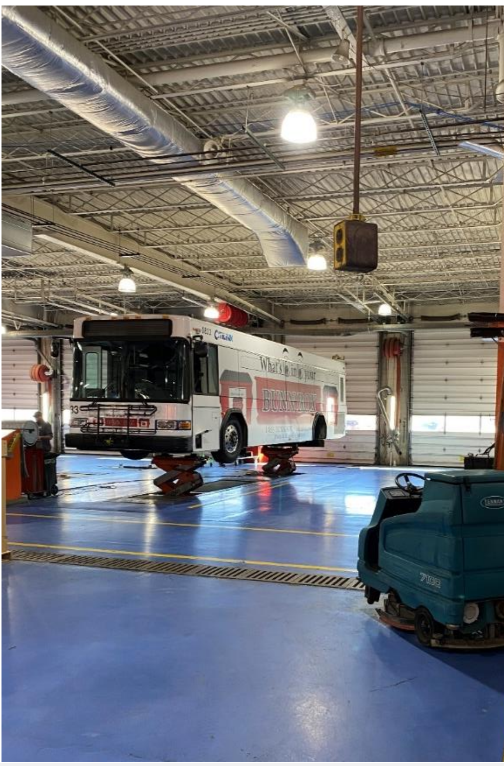


Figure D-8: Maintenance Building roof structure.

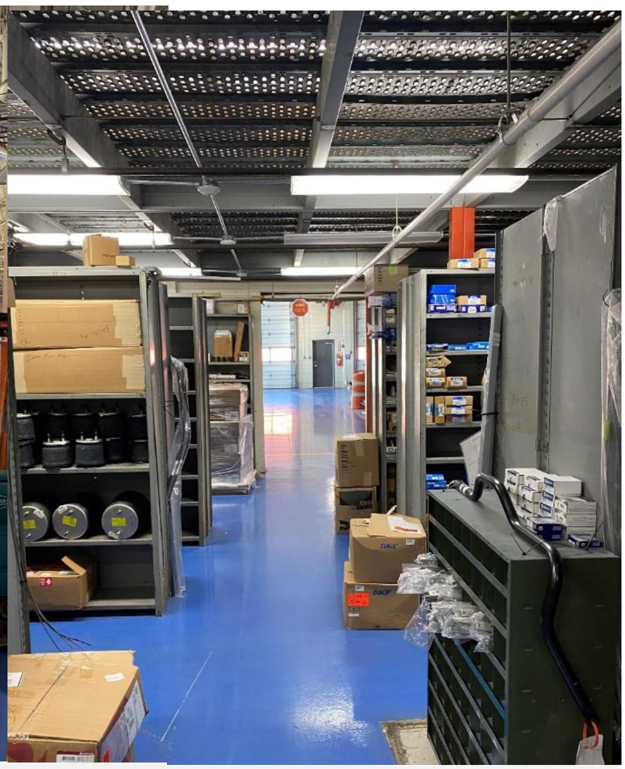


Figure D-9: Parts Room mezzanine structure.

Condition

Overall, the maintenance building structure appears to be in good condition and has no visual signs of major structural issues needing immediate repair. There is evidence of roof leaks in multiple locations that have caused corrosion and paint peeling from the structure. However, there appear to be no active leaks and where accessible the joist members showed little evidence of significant section loss. There is evidence of roof deck replacement in multiple areas most likely due to failure of the roofing system. The condition of the concrete floor slab is very good.

Recommendations

If the roof structure is to remain, it is recommended that the corroding joists and roof deck be inspected and all rust should be removed, surfaces cleaned and painted to prevent further corrosion.

Figure D-10: Corrosion developed at the base column.

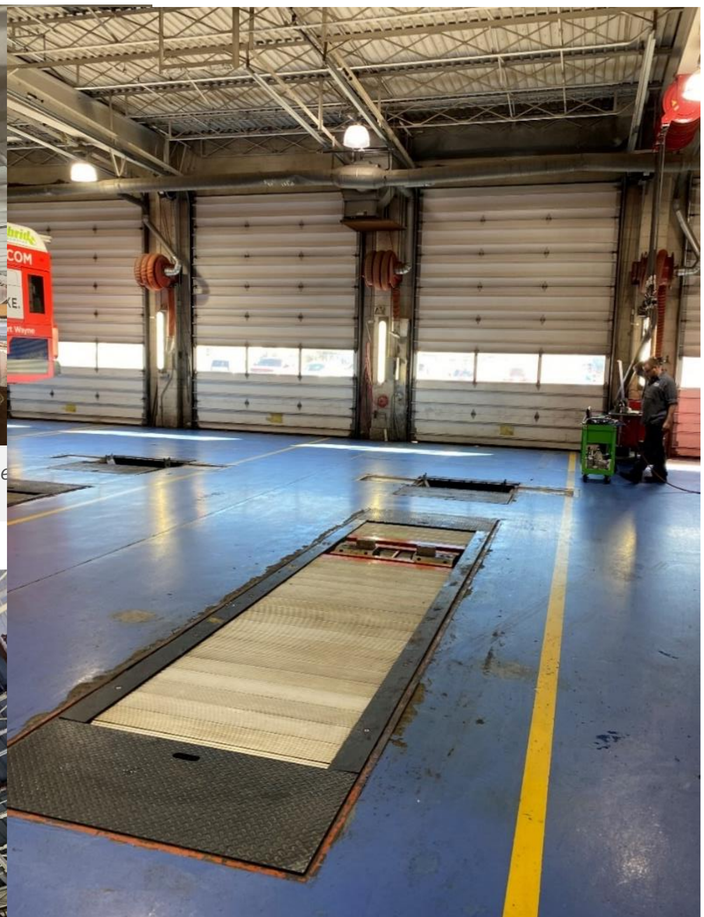


Figure D-12: Typical floor slab condition.

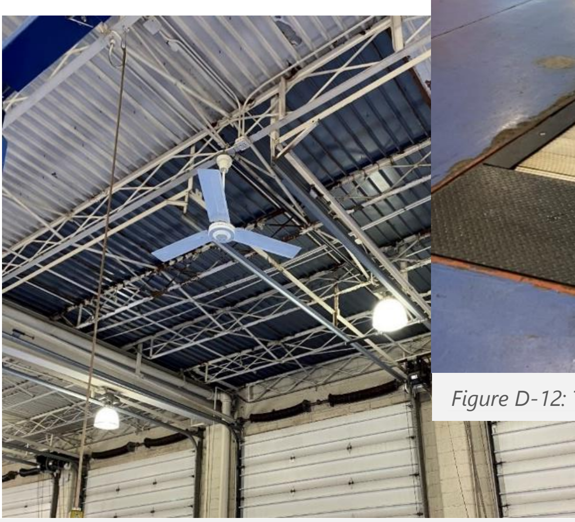


Figure D-11: Area of roof deck replacement.

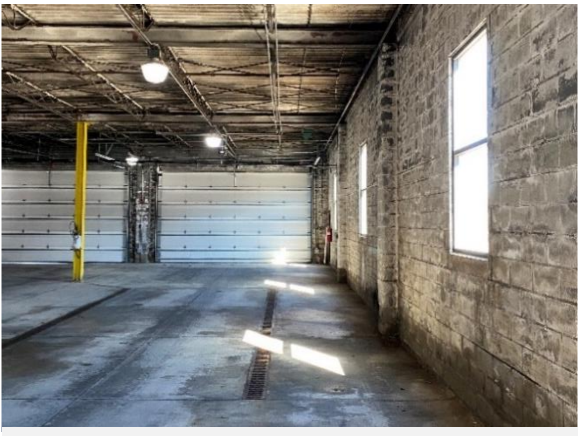


Figure D-13: Original storage barn.

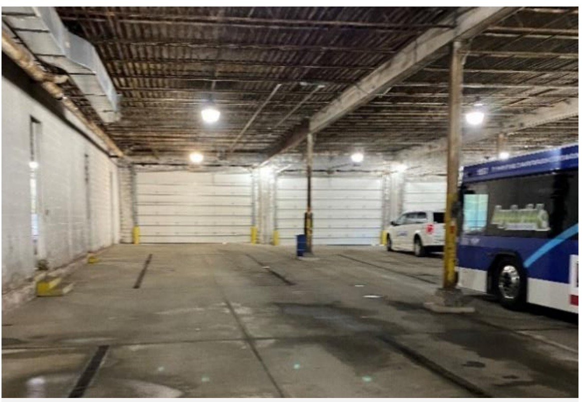


Figure D-14: 1970s storage barn addition.

Figure D_15: Storage barn roof structure.

Storage Barn

The structural system of the Storage Barn consists of exterior load bearing CMU walls with brick veneer. The roof structure consists of metal deck supported by a system of open web joists with wide flange girders (W21x55 in 1970's addition) supported by 8" wide flange steel columns (W6x20 in the 1970s addition). Drawings of the original 1950s era building are not available to confirm structure member sizes. The exterior walls are reinforced with CMU pilasters at roof girder locations and overhead door locations. The floor is concrete without coating.

Condition

Overall, the storage barn structure appears to be in fair condition. The interior and exterior CMU walls show no visible signs of cracking or bowing. The concrete floors appear to be in good condition. However, the roof support system shows significant corrosion over its entirety and appears to be in poor condition. Steel columns are in good condition and show some areas of surface rust, however the rust does not appear to be significant. Concrete columns, bases and concrete floor are in good condition exhibiting signs of normal wear. Staff has indicated there is widespread failure of the built-up roof system contributing to the corrosion of the roof structure.

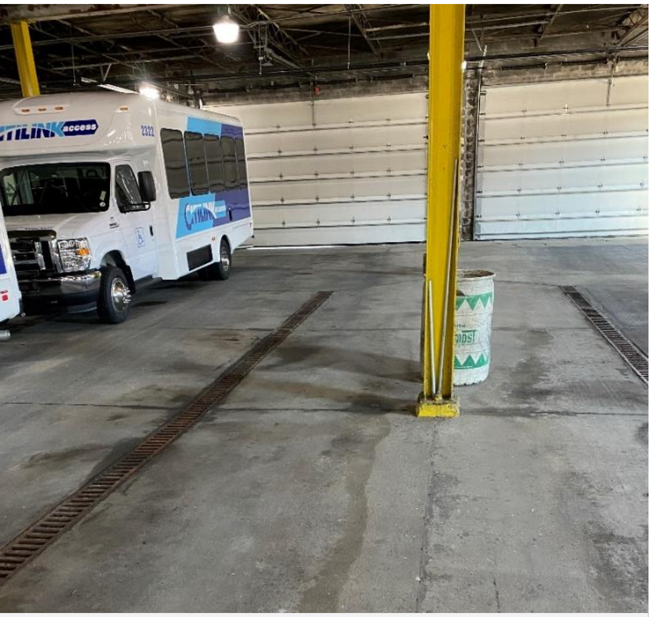


Figure D-16: Storage barn column and concrete base.

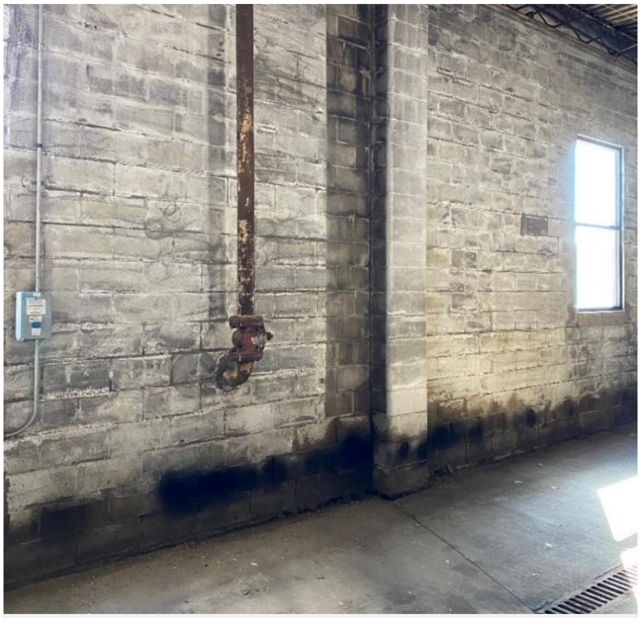


Figure D-17: Storage barn exterior wall and floor.

Recommendations

If the storage barn roof is to remain, the roof structure should undergo a detailed inspection to make sure the condition of the structure is not affecting its ability to safely carry code minimum live and dead loads. If retained, the roof deck, joist, beams, and columns should have all corrosion removed, cleaned, and painted to prevent further corrosion and extend the life of the structure. It is recommended the masonry are cleaned and painted and the concrete floor be cleaned and sealed to extend the service life of each.

all roof

pet, coping, and flashing

ARCHITECTURAL

Maintenance Building

The maintenance portion of the building has an area of approximately 31,000 square feet with approximately 4,500 square feet of mezzanine. The maintenance area includes the main repair area, paint shop, wash bay, parts storage area, welding room, engine/transmission repair room, office space, fluid storage room and an unallocated space that was previously assigned as a body shop. The northern portion of the repair area has dedicated areas for a tire shop, tool storage and battery storage. The clear height to the underside of the wide flange girders is approximately 17’-4”.

Maintenance Building Envelope

Roof

The building is covered by a built-up roofing system with a slope from east to west and is drained by gutter and down spouts. The roof parapet wall at the edge condition on the sides without the gutter is low. The roofing system over all appeared to be in good condition. Parapet flashing and limestone cap caulking appeared to be in fair condition. The age and warranty status of the roofing system in not known. Fall protection was observed adjacent to exhaust fans located less than 10’ from the unprotected roof edge.

Recommendations

Roof inspection and necessary repairs should be made to flashing and sealants to maintain a watertight roofing system.

Windows

The windows in the maintenance building appear to be original steel framed windows and are in good condition.

Doors

For buses, the maintenance area has 12’w x 16’h overhead roll-up sectional entry and exit doors with vision panels. The maintenance area also has personnel exit doors. The doors are exterior hollow metal (HM) door and frame. Doors and frames all appear to be in good condition.

Fueling, Bus Washer, and Vacuum

The Fueling, Bus Wash, and Vacuuming areas are located at the northern end of the maintenance building. Construction of this area is consistent with the rest of the facility. The south wall of the bus wash area has a plastic barrier to protect equipment behind it and the remainder of the walls are painted CMU. The floor is painted concrete with a center trench drain.

The floor is concrete slab with a center trench drain in the wash bay area. All finishes appear to be in fair to good condition.

Recommendations

Clean all surfaces, repair areas where required and apply new finishes to maintain substrate conditions.

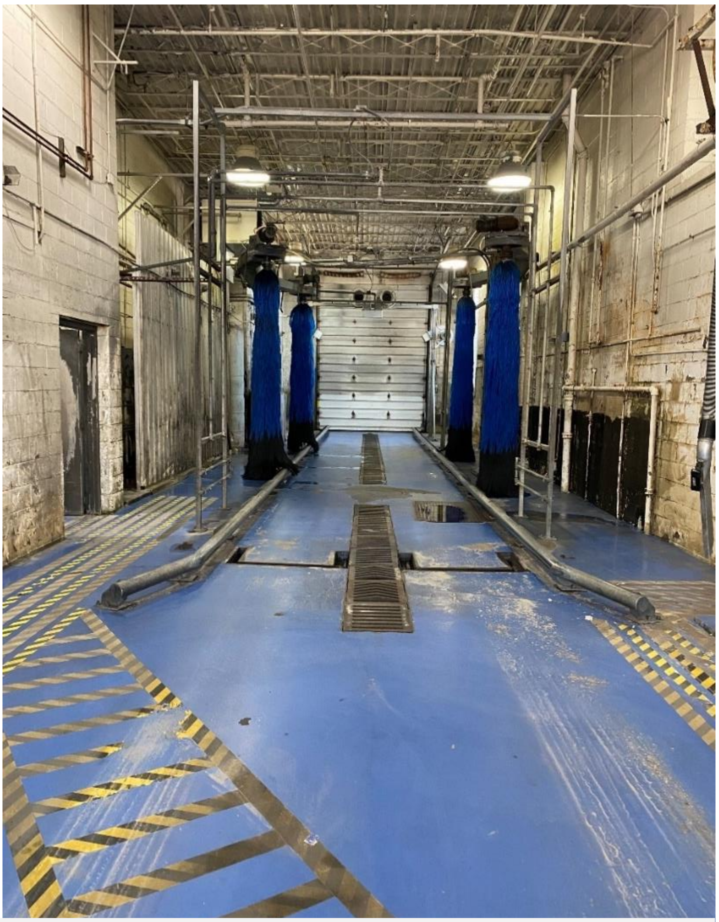


Figure D_20: Bus washer

Figure D-21: Fuel dispensing and vacuum

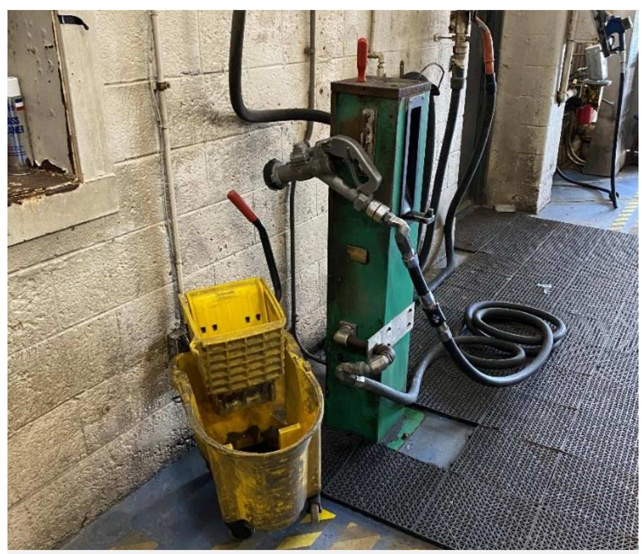


Figure D-22: Fuel dispensing

Vehicle Repair

Located in the middle of the facility, the construction of the Vehicle Repair area is consistent with the remainder of the facility. The exterior walls are CMU with brick veneer. The roof structure consists of metal deck, open web joists and wide flange girders supported by steel columns. CMU painted interior walls all appear to be in good condition.

The painted concrete slab on grade appears to be in good condition.

Yellow paint lines on floor to delineate buses and "keep clear areas" are wearing off.

There are a total of 14 bays in the repair area. Eight are equipped with in-floor lifts and there is one bay with a 10,000# post lift.

The north mezzanine is located above the men's and women's locker room. The access stair to the mezzanine and the mezzanine guardrail are constructed of wood.

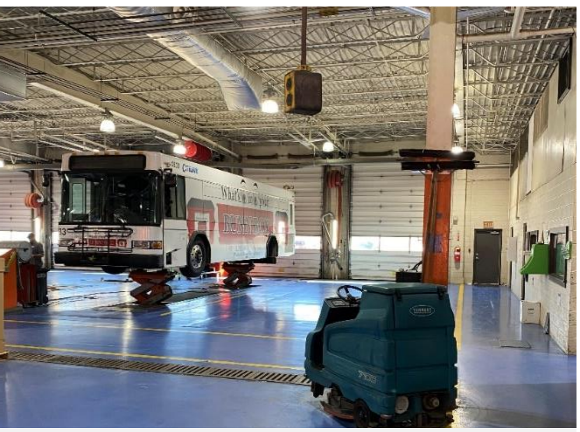


Figure D_23: Repair area

Figure D-24: Repair area

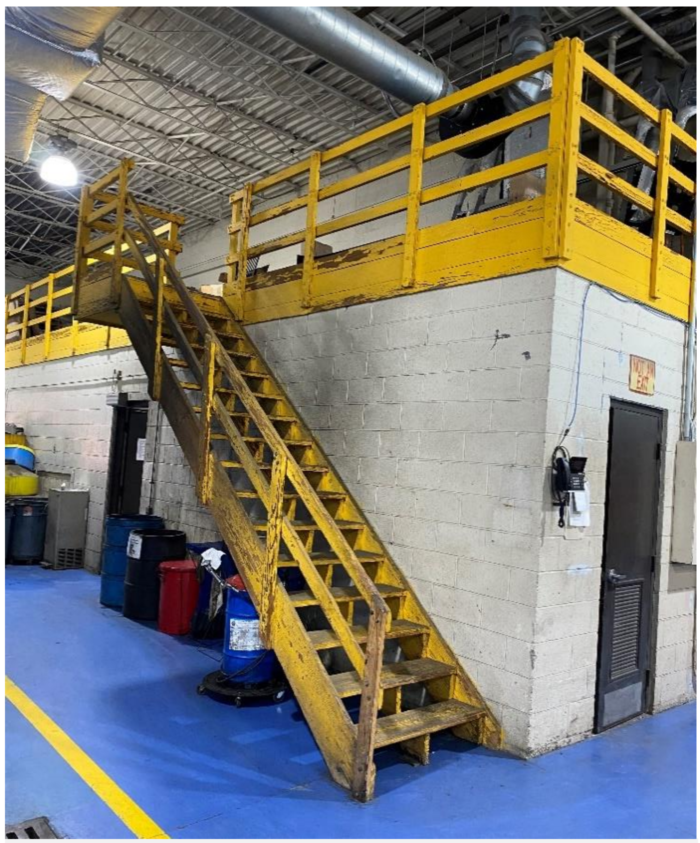


Figure D-25: Wooden stair and railing at north mezzannine

Recommendations

Where necessary, clean and prepare areas of floor for repainting. Where worn off, repaint yellow caution lines and paint all steel elements embedded in the concrete floor. Confirm construction materials and building code compliance of the stairs and railing systems, replace with code conformant materials if required.

Parts Storage

The parts storage area is constructed of painted CMU walls and concrete floor with a perforated metal plank mezzanine. All elements appear to be in good condition.

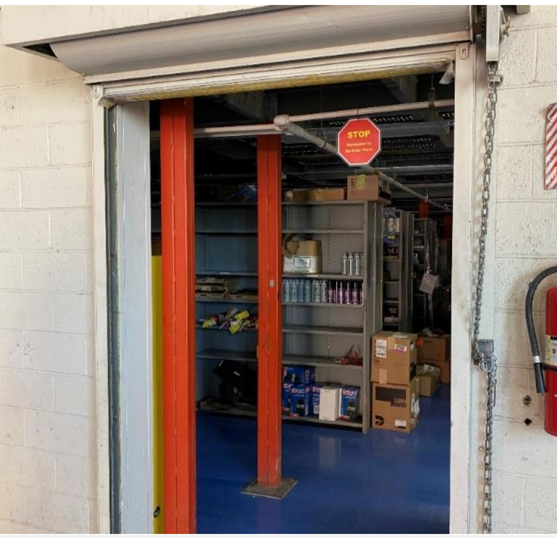


Figure D-26: Parts storage main floor

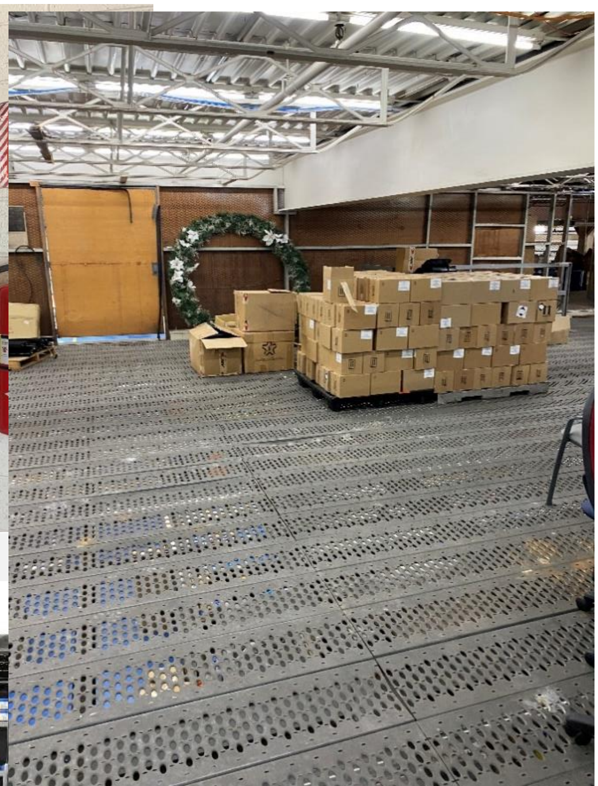


Figure D-28: Parts storage mezzanine

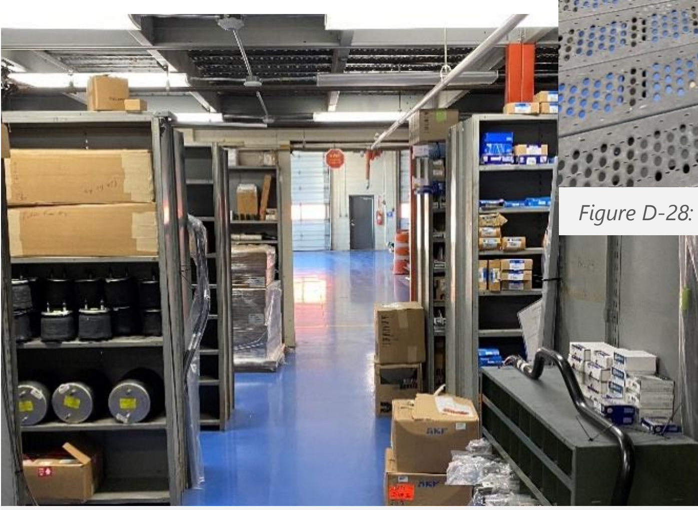


Figure D_27: Parts storage main floor

Figure D-29: Welding room

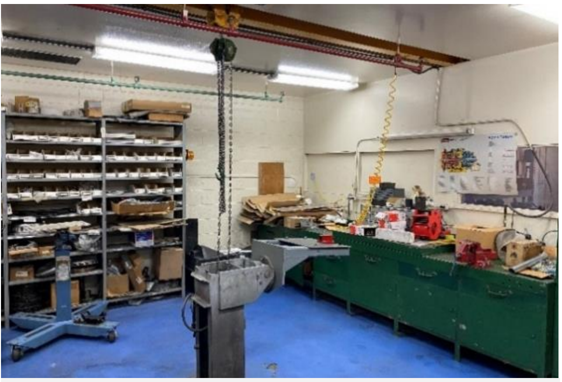


Figure D-30: Transmission repair room

Figure D-31: Unassigned

Figure D-32: Valve room

Welding

This room has one CMU painted wall and the three remaining walls appear to be wood and the ceiling appears to be gypsum. The concrete floor is painted. All finishes appear in good condition.

Recommendations

Confirm construction materials and building code compliance of this area. Replace with code conformant materials if required.

Transmission Repair

This room has one CMU painted wall the three remaining walls and ceiling appear to be wood or gypsum. The concrete floor is painted. All finishes appear in good condition.

Recommendations

Confirm construction materials and building code compliance of this area. Replace with code conformant materials if required. Touch up small area of floor finish.

Unassigned

The exterior walls are CMU with brick veneer. The roof structure consists of metal deck, open web joists and wide flange girders supported by steel columns. CMU painted interior walls all appear to be in good condition. The north wall is partial height CMU to 9'4" with framed infill above. This space is formerly the body shop and has no official use. The space has two vehicle bays each with a decommissioned in floor lift.

Recommendations

Confirm construction of infill material above CMU to verify compliance with current building code. Replace with code compliant materials if required.

Fluid Storage Room

Concrete ceiling, CMU painted walls, HM door, blast door and concrete floor appear to be in good condition.

Figure D-33: Maintenance office

Maintenance Office Area

Acoustical lay-in ceiling tile, CMU painted walls, HM door, HM borrowed lights, and concrete floor appear to be in good condition.

Paint Shop

Exposed structure, CMU painted walls, HM doors and concrete floors appear to be in good condition.

Men’s and Women’s Locker Rooms

Acoustic lay-in ceiling, CMU painted walls, ceramic glazed tile on wet walls 12x12 vinyl composition tile (VCT) floor, rubber coved wall base. Both locker rooms have floor mounted painted metal partitions, porcelain fixtures and one shower unit. The men’s shower unit is a prefabricated fiberglass unit. The men’s locker room is also equipped with a stainless-steel hand wash fountain. The condition of the finishes in the men’s locker room is fair. It is recommended to consider replacing the finishes.

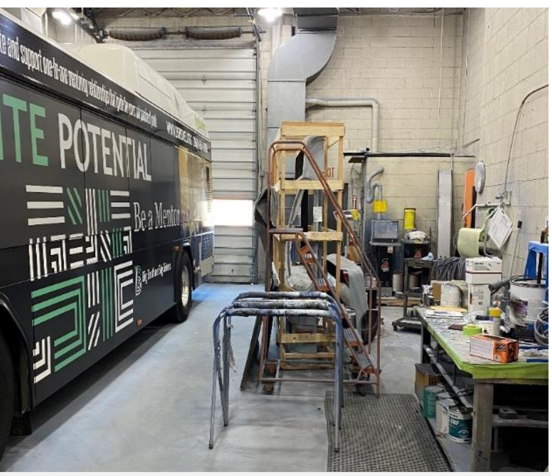


Figure D-34: Paint shop

’s locker room

Figure D-36: Men’s locker room

Figure D-39: Tire shop

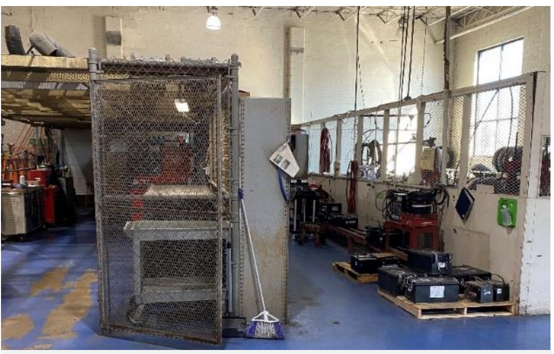


Figure D-40: Battery storage area

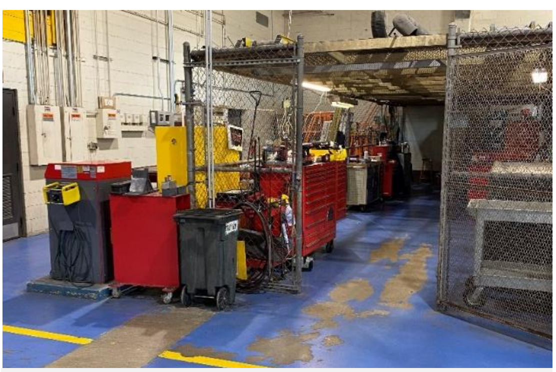


Figure D-41: Trim area

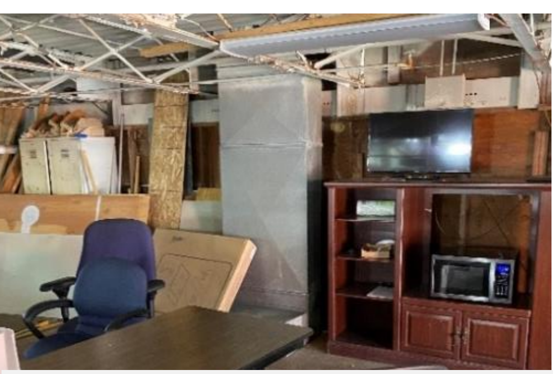


Figure D-42: Men's toilet room

Tire Shop, Battery Charging and Trim Areas

The tire shop, battery charging, and trim areas are open areas at the northern end of the maintenance building and are defined by chain link fence and wooden divider walls. The trim area chain link enclosure is capped with a wooden structure. Floor finish is worn and peeled away in some areas.

Recommendations

Confirm construction of tire shop walls and trim area cap structure are in compliance with current building code. Clean, prepare, and paint areas of floor were required.

Shop Break Area

Mezzanine area located above the Welding Room and Engine/Transmission Repair room. Flooring is exposed oriented strand board (OSB) and ceiling is exposed structure. Head height within the space is extremely low.

Recommendations

Confirm construction of mezzanine is in compliance with current building code.

Storage Barn

The storage barn has a building area of approximately 35,000 square feet and was initially constructed in the 1950s with an addition to the west constructed in the early 1970s. The clear height to the underside of the wide flange girders varies from each building section though the roof height remains constant. The lowest portion is the eastern most bay with a clear height to the underside of the girders of approximately 14'-8" and increases westerly to a clear height of approximately 16'-8".

Figure D-43: Storage barn roof

Figure D-44: Storage barn roof drain

Storage Barn Envelope

Roof

The building is covered by a built-up roofing system with internal roof drains. The roof parapet wall at the edge condition is low. The parapet wall is capped with clay tile. Overall, the roofing system appeared to be in fair to poor condition. Walking surface generally felt soft (spongey) indicating a failure of the insulation and or protection board. Staff indicated the roof is experiencing widespread leaking. Some roof drain guards were damaged which may be causing blockages in the drainage system contributing to the water infiltration.

Recommendations

The roof should be inspected by a qualified roofing contractor and repairs or full replacement should be implemented per contractor's recommendation.

Windows

The windows in the storage barn are aluminum storefront type widows and appear to be in good condition.

Doors

The storage barn entry and exit doors for buses are 22'w x 12'h overhead roll-up sectional doors without vision panels. Personnel exit doors are exterior HM door and frame. All doors and frames appear to be in good condition.

Figure D-45: Storage barn interior

Exterior Walls

The Storage Barn exterior wall is load bearing CMU with brick veneer. The interior face of the exterior walls exhibit indications of efflorescence, signifying water intrusion into the CMU. The water intrusion appears most significant at the top of the wall and above overhead door openings.

Recommendations

The exterior brick veneer should have a detailed inspection. Weep holes and vents above door and window openings should be inspected and cleaned or added to allow any moisture to exit the wall cavity.

Storage Barn Interior

The interior of the storage barn consists of multiple lanes of vehicle storage. All walls are CMU and all floors are unfinished concrete, with exposed structure. The wall finishes are in poor condition and all exposed steel structure is corroded and in need of refinishing. CMU wall finishes are also in poor condition.

Recommendations

If the facility is to be retained, all surfaces should be inspected thoroughly and repaired as necessary. CMU walls should be cleaned, sealed and painted. Concrete floors should be cleaned and sealed or finished with a traffic coating. Structural steel should be cleaned and painted.

Figure D-46: In-floor lifts

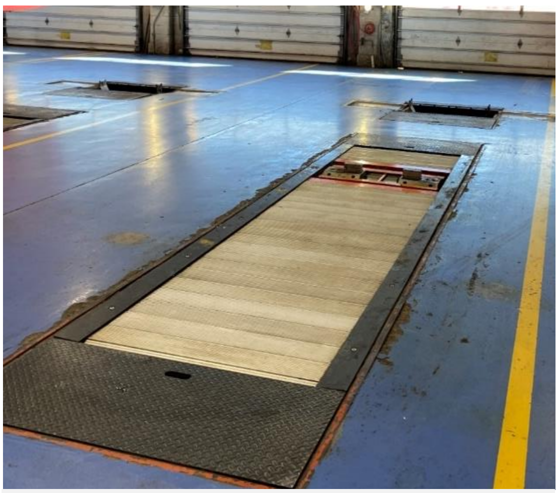


Figure D-47: Storage barn roof drain

INDUSTRIAL EQUIPMENT

Maintenance Building

The condition of equipment in Leesburg Road facility has a range from fair to excellent with most of the equipment in good working order.

Repair Area

There are 14 repair bays in the repair area. The hose reels appear to be in good working condition. There are eight bays with ECO6 in-floor lifts manufactured by Stertil-Koni with a capacity of 60,000 pounds. All the Stertil-Koni lifts appear to be in very good condition. There is one repair bay with a Bend-Pak two post lift with a capacity of 10,000 pounds. The Bend-Pak lift is in very good to excellent condition.

Parts Storage

The parts storage area is approximately 4,500 sf on the main floor and 4,000 sf located on a mezzanine above. All shelving and racking appear to be in good condition.

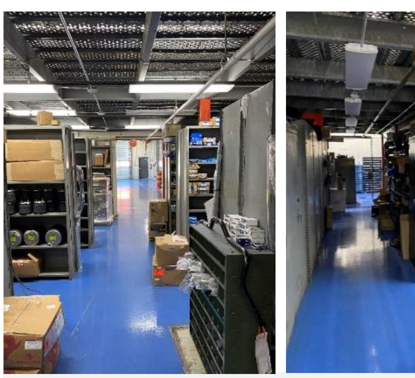


Figure D-48: Parts storage main floor

Figure D-49: Parts storage main floor

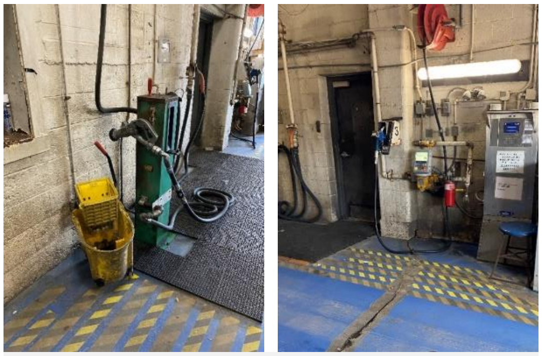


Figure D_50: Service lane fueling equipment

Service Lane

There is a single service lane at the facility, where cleaning, fueling, and fare vaulting is performed. The lane has one diesel fuel dispenser for buses, one diesel fuel dispenser for other vehicles and two DEF dispensers. Fueling devices all appear to be in fair to good condition. The vaulting equipment for the Genfare Odyssey fare boxes is in good condition.

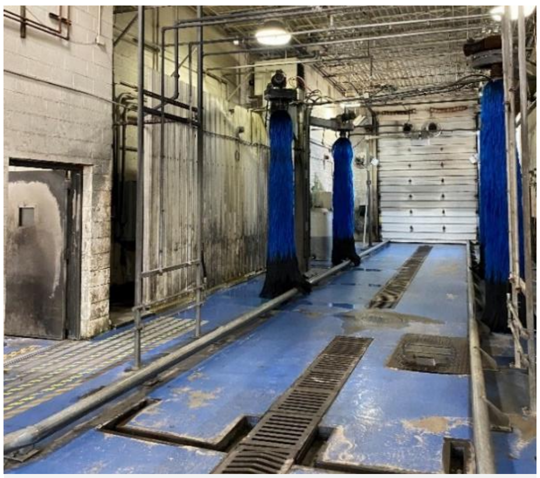


Figure D-51: Service lane fueling equipment continued

Bus Wash

There is one bus wash system. The bus wash system is in fair condition (shown below). Fluid tanks are stored right next to the bus wash system. The fluid tanks are in fair condition.

Pump/Fluids Room

In the pump/fluids room, auto trans fluid (ATS), antifreeze, and motor oil are stored in the tanks against south wall (shown below). The fluid tanks inside the pump/fluids room are in good to excellent condition.

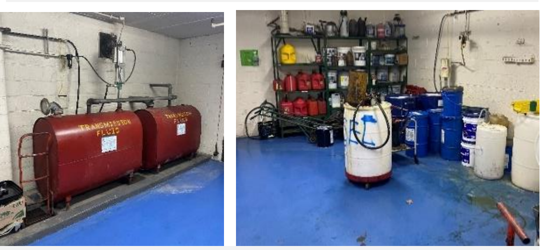


Figure D-52: Fluid storage tank room

Pressure Washer

Located on the main floor of the maintenance area is a K'a'rcher gas fired pressure washing unit, which appears to be in excellent condition

Storage Barn

The industrial equipment in the storage barn is limited to antifreeze dispensing, which is supplied from the fluids room in the maintenance building.

Figure D-53: Water service entry in service

Figure D-54: Fire water service entry

Figure D-55: NIPSCO natural gas entry

Maintenance Building

Domestic Water

The building appears to have a 2" domestic water main with pressure assumed to be between 40~60 psi. The 2" line splits after entry into the building into two lines, a 2" and an a 1-1/2" each with a meter. Though it could not be confirmed it is assumed one of the "services" is either for the bus wash system or serves the storage barn. The facility's hot water system was reported to be in good working condition, but the equipment was not observed or evaluated.

Fire Protection

The building is equipped throughout with an automatic sprinkler system. The 6" fire water service entry is located within the repair area on the western exterior wall.

Natural Gas

Natural gas is served to the building by NIPSCO meter # G0032647. Size of service and delivery pressure could not be determined, the meter is located at the west side of the maintenance building. Confirmation of NIPSCO service capacity and pressure is under review.

Storage Barn

Domestic Water

The building is serviced with domestic water from the maintenance building. Water is dispensed by hose bibs located on building columns. There was no indication of hot water within the building.

Fire Protection

The building is equipped throughout with automatic sprinkler system. The 8″ fire water service entry is located within the eastern most storage lane on the eastern exterior wall. Staff indicated that heads were recently added under overhead doors to provide coverage when the doors are in the open position and all heads have been replaced. It also appears the fire entry has been recently updated. Overall the system appears to be in good condition.

Natural Gas

The building is serviced with natural gas from the maintenance building. Natural gas is distributed to roof mounted heating and ventilating units.

Figure D-56: Fire water service entry

MECHANICAL

Maintenance Building HVAC

The maintenance building service area is served by 2 roof-mounted energy recovery ventilators (EVRs) (MAU-1 and MAU-2) manufactured in 2013 and multiple unit heaters throughout the facility. The Paint shop is served by MAU-3 and filtered exhaust system. Summertime exhaust is provided by Greenheck roof mounted exhaust fans. The maintenance office HVAC appears to be served by roof mounted RTU that also serves the administration building.

Figure D-57: Roof mounted equipment

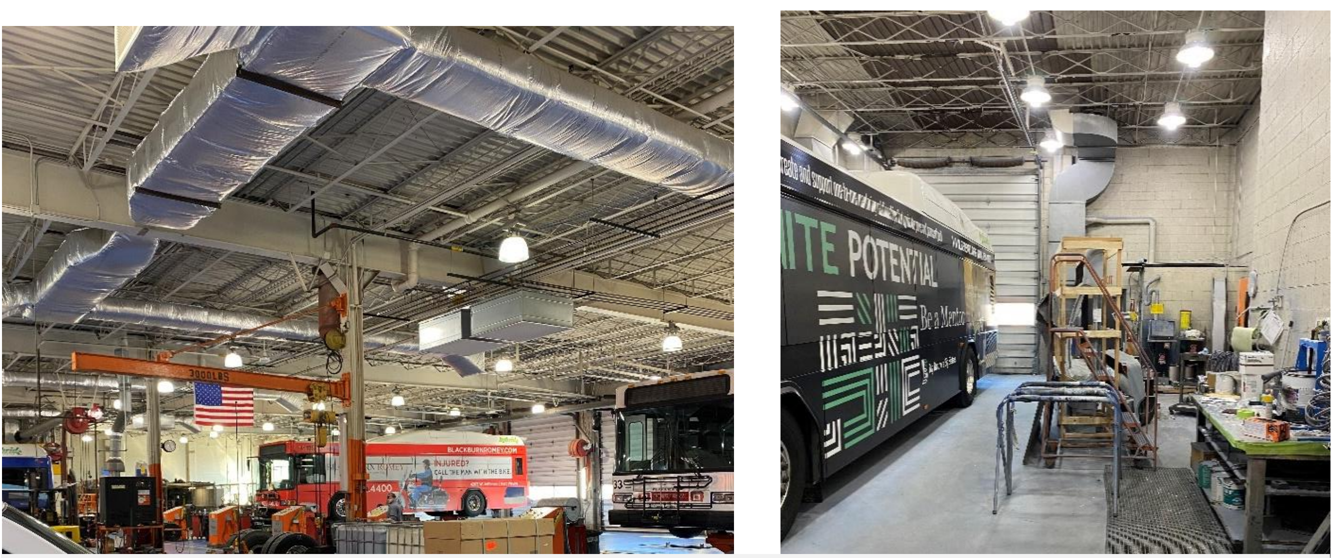


Figure D-58: Interior distribution

Condition

Overall, the existing HVAC system are well maintained and in good working condition. It appears from nameplate information there was an HVAC renovation project in 2013.

Storage Barn HVAC

The storage barn is served by two roof-mounted custom Reznor HVUs (HVU-1 and HVU-2) and 12 Greenheck Centrifugal down blast exhaust fans. There is limited information on the HVU equipment to determine the capacity of the units. As the equipment is not original and the exhaust fans are similar to the fans serving the maintenance building, it is assumed the equipment was installed as part of the 2013 HVAC improvement project. The equipment and distribution ductwork appear to be in good condition.

Figure D-59: Roof mounted HVAC equipment

ELECTRICAL

Maintenance Building

Maintenance Building Main Distribution

The building is supplied by Indiana Michigan Power owned pole mounted transformer and an 800 A 240 V main breaker service disconnect. The transformer rating was not observable.

The service feed enters the building from a roof mounted weather head, the meter equipment was not located.

Staff indicated standby power is provided by a small generator serving only small equipment in the administration building.

Figure D-60: Service entrance and distribution

Figure D-61: Utility pole, transformer, and weather head

Figure D-62: Utility pole, transformer and weather head

Maintenance Building Electrical Infrastructure

The incoming electrical service distribution panel appear to be in fair to good condition and may by original installed equipment.

Minor electrical equipment such as panel boards throughout the facility were generally in good condition.

Much of the lighting in the facility was fluorescent or HID which should be replaced with LED with energy saving lighting controls.

Figure D-63: Service entry panel

Storage Barn Main Distribution

Storage Barn Maintenance Distribution

The building is supplied by Indiana Michigan Power owned pole mounted transformer and a 220 A 240 V main breaker service disconnect. The cables enter the building from a weather head located on the exterior of the east wall. The transformer rating was not observable.

Maintenance Building Electrical Infrastructure

Minor electrical equipment such as panel boards throughout the facility were generally in fair to good condition. Many panels appear to be original equipment and thus are ending their end of service life expectancy.

The lighting appeared to be HID, which should be replaced with LED with energy saving lighting controls.

Figure D-64: Typical panelboard

Figure D-65: Typical panelboard

ZERO-EMISSION EVALUATION

Clean Transit

Given the fact that transit has a significant effect on emissions and consequently air quality as per the EPA; a transition to zero-emissions is supported by federal and state agencies. Accordingly in November 2021 Congress passed, and President Biden signed the Infrastructure Investment and Jobs Act (Public Law 117-58), also known as the Bipartisan Infrastructure Law (BIL). The BIL is investing $66 billion to provide healthy, sustainable transportation options for the entire United States by modernizing and expanding transit and rail networks across the country. From this amount $1.1 billion each year for FY2022-2026 is planned to be spent for low- or no- emission vehicles and supporting infrastructure. Per strategic plan and roadmap from FTA the goal is to achieve 100% zero-emission by 2050.

Under this law, any application to receive funding must include a zero-emission transition plan.

Zero-Emission Transition Plan requirements

A Zero-Emission Transition Plan must, at a minimum:

1. Demonstrate a long-term fleet management plan with a strategy for how the applicant intends to use the current request for resources and future acquisitions.
2. Address the availability of current and future resources to meet costs for the transition and implementation.
3. Consider policy and legislation impacting relevant technologies.
4. Include an evaluation of existing and future facilities and their relationship to the technology transition.
5. Describe the partnership of the applicant with the utility or alternative fuel provider.
6. Examine the impact of the transition on the applicant's current workforce by identifying skill gaps, training needs, and retraining needs of the existing workers of the applicant to operate and maintain zero-emission vehicles and related infrastructure and avoid displacement of the existing workforce.

Technologies that Support ZEBs

Transit agencies are currently considering two available general technologies that are available for zero-emission buses to replace their fossil-fuel buses. The options are BEB or hydrogen FCEB. Each ZEB technology has different pros and cons as well as unique operational and construction requirements.

BEBs and Supporting Infrastructure

In-depot charging infrastructure may be done in three different general configurations.

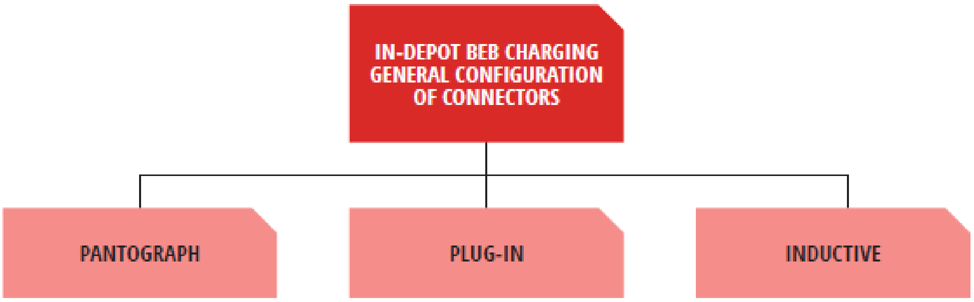



Figure D-66: Example of in-depot pantograph charging system at Edmonton, Canada

Pantograph Charging

Overhead pantograph type of connector requires to be installed on the ceiling structure or any overhead structure. It will run automatically as the bus is parked at the proper location underneath. Ordinarily STV would recommend the use of overhead pantographs for charging BEBs given their automated interface with the bus and their higher rate of charge when compared with cabled plugs. However, the existing roof deck elevation does not provide enough clearance to support the pantograph option.


Figure D-67: Example of plug-in charging ground chargers at Big Blue Bus of Santa Monica, CA

Plug-In Charging

The plug-In charging system requires dispensers with cables and connectors attached to it. After the bus is parked an operator needs to manually connect the connector to make the system ready for charging process. The charging dispenser may be installed on the ground, on pedestal, or overhead on a structure.


Figure D-67: Example of plug-in charging with overhead mount chargers at Foothill Transit in San Gabriel and Pomona valleys, CA

Figure D-68: ApproachingInductive charging spot in Southern California

Inductive charging

Inductive charging runs with no physical connection between the bus and charger. The charger induces power on the bus-mounted battery utilizing magnetic field. The standard SEA J1773 recommends minimal requirements for inductive charging of light-duty vehicles. A standard for heavy duty inductive charging system has not been established yet. This type of charging system is rather new to the industry and has not proven the expected efficiency and effectiveness yet.

DC Charging Distribution Options

Currently there are two charging system distribution types in the market for transit buses:

1. Individual systems that charge one to three buses simultaneously or alternately, and
2. Containerized charging cabinets which currently can charge up to 40 buses in combinations of simultaneous and alternately.

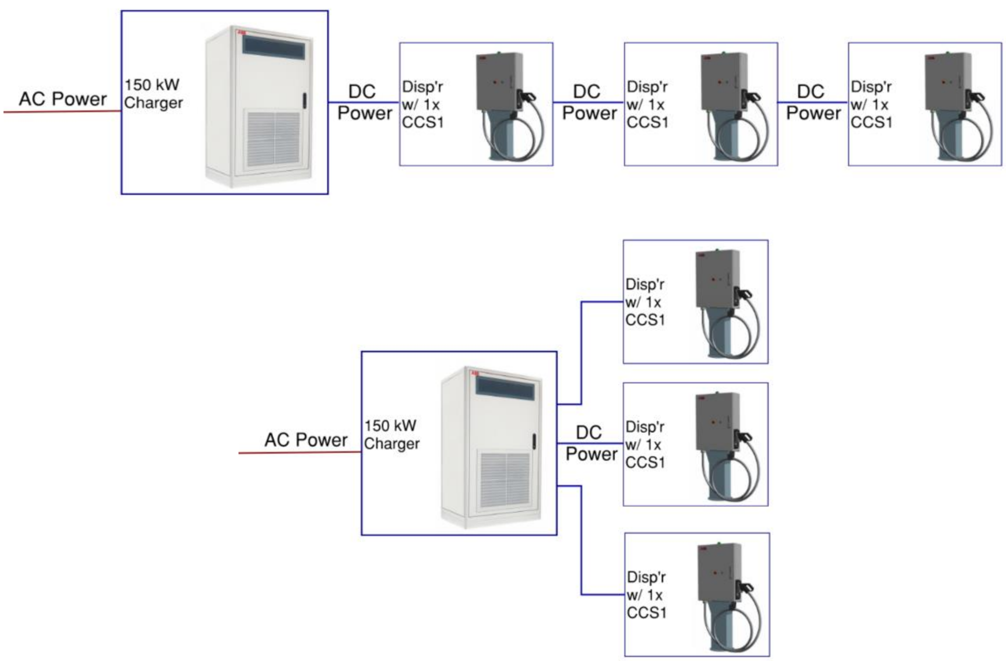


Figure D-69: Individual DC charging distribution system

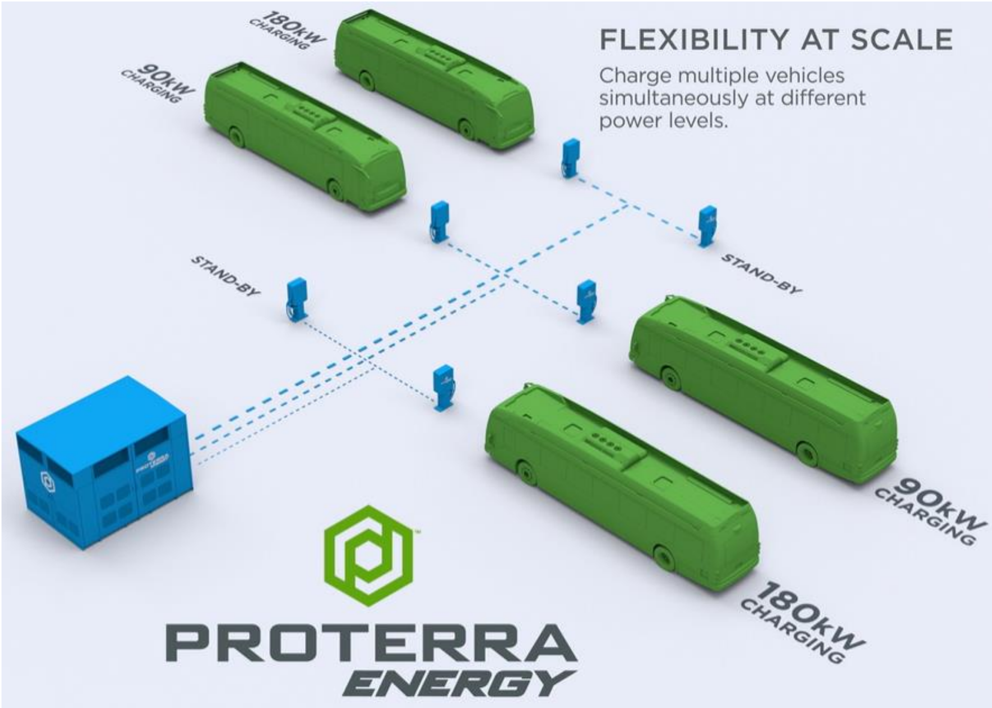


Figure D-70: Containerized DC charging distribution system

STV completed a study of the Citilink fleet using proprietary PEER software which analyzes the amount of energy each bus uses completing current blocks. The results of this study indicate that BEBs are a viable zero emission option for most of the Citilink fleet. Implementing BEBs has several inherent challenges, the most prominent of which is working with the local utility to confirm the required power is on site in the requisite quantity when Citilink begins to implement the new fleet. Based upon the implementation plan and bus retirements the infrastructure itself can be phased over several years or decades.

From the perspective of the storage and maintenance buildings, there are a range of modifications that must be completed along with the introduction of BEBs.

Storage Building Modifications

Cabled plugs on retractable reels are the recommended solution and should work efficiently given the size and composition of the fleet. While not as heavy as pantographs, cord reels represent a significant load, and a structural study will be required to confirm that the existing roof load will support this new load. If not, then an independent support system will need to be developed.

Fire suppression and prevention are important concerns with ZEBs as runaway thermal events within the lithium-ion battery arrays are presently inextinguishable. At the time of this writing most fire departments will wish to contain the fire to one bus using high rates of water flow from the building fire sprinkler system until the involved bus can be safely removed from the building.

The building roof deck's ability to support the sprinkler system load should be included in the load analysis along with the cable reel loads. Fire flow tests are recommended to be conducted to confirm sufficient flow to operate the fire sprinkler system. Depending upon the results, on-site water storage and a fire pump may be required. The typical solution is Extra Hazard Group 2 Dry System, which typically involves a minimum density/area of 0.4 gallons per minute per square foot over 3,250 square feet. The contractor has the option of using high-temperature sprinkler heads in the bus storage area to decrease the area of application by 25% in accordance with NFPA 13. A standpipe system is also recommended; however, given the relatively small footprint of the Storage Building, it may not be necessary within typical hose pull lengths. All fire suppression systems design and approach to combatting a ZEB with a thermal runaway event should be reviewed and coordinated with the local fire department. Effort should be given to coordination of actions and responsibilities in the occurrence of such an event.

Options of Plug-in Charging Systems

Currently, there are two plug-in charging system distribution types on the market for transit buses:

1. Individual systems that charge one to three buses at a simultaneously
2. Containerized charging cabinets which currently can charge up to 40 buses.

The first option works best for smaller deployments such as pilot programs of up to 20 BEBs. Individual systems that are currently available can typically supply power through cables and plug-in dispensers connected to the cabinets or suspended from overhead reels for cable management. To power a larger fleet through these cabinets, many separate elements are needed such as transformers, electrical switchgear panels, and a network of conduit to distribute the power to multiple charging cabinets throughout the bus charging area. Providing adequate space for these cabinets within the tight parking configuration of a typical bus storage area can lead to a reduction in bus storage capacity and exposes the cabinets and cables to damage from vehicle impact. When maintenance to the cabinets is required, it is likely to affect the use of one or more bus lanes. For the Citilink Bus Storage Building, there simply is not room at the floor level to accommodate pedestal or cabinet chargers and installing them on the roof would undoubtedly require major structural upgrades to the building.

Conversely, the containerized charging cabinets can be 300 feet or more away from the point of connection to a bus, located outside the building or even on a roof. Although relatively new to the BEB market DC to DC charging borrows on technology that has been used for over 100 years to power electrified rail systems. These systems take medium voltage power (12,700 volts in this application) directly from the utility to the charger, thereby eliminating a lot of electrical equipment that would take up space. DC to DC chargers is modular in construction. If one of 20 modules in a typical 3MW charger goes down, it is easily replaced, and the other 19 modules are available until the replacement is made. Advantages include centralized maintenance and the ability to connect directly to a medium voltage supply from the power utility providing high charging capacity. Placing the containers outdoors, adjacent to the building or on the roof, will reduce heat load to the building and free up space that would otherwise be dedicated to charger pedestals and their associated equipment. For these reasons, containerized charging cabinets are preferred. The north property line of the facility would be a good place for two of these units.

Maintenance Building

Modifications to the maintenance building would be required to facilitate access to the BEB roofs, where most manufacturers mount the batteries. Fall arrest systems and/or moveable platforms are common systems employed to assure worker safety. This also provides access to air conditioning units and charging rails if the buses are so fitted for high-speed on-route charging. A 2-ton monorail crane should be installed to assist in removal of battery arrays. Given the fleet size one bay fitted for this equipment should be sufficient. Several bays should have hotel power for maintaining power to buses when maintenance is required. The simplest and most cost-effective solution would include several 55kW portable chargers and outfitting every other bay with 480-volt receptacle to plug the chargers in.

Fire suppression in the maintenance bay area should conform to Ordinary Hazard Group 2 wet system (0.20 gallons per minute per square foot over 1,500).

Hydrogen

The Citilink site has ample room to incorporate a trucked, liquid hydrogen fueling system. At this time there is no commercial hydrogen production hub within 700 miles of Fort Wayne, IN, although the University of Illinois, Champaign-Urbana has a relatively small electrolyzer dedicated to the operation of two hydrogen FCEB. Generation of “green” hydrogen from this process requires significant electrical power and water resources. Given the cost, the generation of on-site hydrogen probably doesn’t make any more sense than on-site diesel production. However, the states of Indiana and Illinois are two of 33 state and coalition applicants for federal funding that would put a regional hydrogen hub within reasonable distance of Citilink for trucked liquid hydrogen.

Hydrogen FCEB behave very much like CNG counterparts with near match to diesel, making block completion and one-to-one bus replacement possible.

Microgrid

Microgrids employed by transit agencies typically include photovoltaic (PV) power generation, back-up diesel or natural gas generators, and BESS. The systems are also connected to the utility grid and work in concert to reduce the overall cost of power and improve resiliency, which is a challenge for an electrified transit fleet operation should the grid sourced power be interrupted. To reduce the high cost of standby generators, a second feed from the utility's local substation or even a second substation is a good option. For Citilink, two 1.5MW generators would be capable of supplying power to at least 50% of the fleet, while a second circuit would provide cost effective assurance that the rest of the fleet could be charged.

The BESS portion of the microgrid can also be used to "peak shave" power usage to help reduce the maximum power demand (peak) on the utility and thereby eliminate high use tariffs. Battery storage costs are continually coming down, but remain expensive investments, particularly when compared with the amount of energy that would need to be stored to charge the Citilink fleet.

PV arrays could also be implemented to improve fleet resiliency and reduce dependence upon grid-source power. The bus maintenance and storage facility has approximately 65,000 square feet of available surface area (roofs and western striped parking area) that could be used for PV panels. Given the relatively low solar irradiance (amount of daily sunshine in Fort Wayne, it might be possible to generate over 4MWh (megawatt hours) of power daily. This, coupled with a BESS, would provide a substantial amount of power to charge the transit fleet.

APPENDIX E: FUNDING AND FINANCE SCAN

FUNDING AND FINANCE SCAN FOR THE FORT WAYNE PUBLIC TRANSPORTATION CORPORATION (CITILINK)

This memorandum presents the results of a funding and finance scan that STV completed on behalf of the Fort Wayne Public Transportation Corporation (Citilink).

STV completed the funding and finance scan using the Grant Research and Analysis Navigation Tool System (G.R.A.N.T.S.) @ STV Dashboard (Dashboard). The Dashboard is an integrated, user-friendly dashboard that streamlines the grant discovery process. Through automated data extraction and a facilitated quality control process, users can leverage easily accessible grant information to better align with project planning as well as provide insight on eligibility requirements.

The Dashboard is internal tool that identifies potential available funding sources based on project type and location. The tool was supplemented by in-depth review of funding opportunities offered by the major federal departments and their respective divisions and agencies, such as the U.S. Department of Transportation, the U.S. Environmental Protection Agency, and the U.S. Department of Energy. The scan was further supplemented with a review of state and local funding opportunities.

The funding and financing scan should be considered a living document to be updated as additional funding opportunities are announced or notice of funding opportunities (NOFOs) are revised. Citilink is eligible to apply for some of the opportunities identified; for others, Citilink must partner with an eligible applicant.

The results of the funding and finance scan are shown on the following pages.

TABLE E-1: FUNDING AND FINANCE SCAN FOR CITILINK

Funding/Grant Program	Funding/ Sponsor Agency	Discretionary/ Non-Discretionary	Summary	Eligible Activities	Likelihood of Applicability (H/M/L)	Is Citilink Eligible?	Eligible Applicants (if Citilink not eligible)	BCA Needed	Sources (links)
Federal Opportunities									
Buses and Bus Facilities Competitive Program	FTA	Discretionary	Assist in the financing of buses and bus facilities capital projects.	Capital projects to replace; rehabilitate; and purchase buses, vans, and related equipment; and to construct bus-related facilities, including technological changes or innovations to modify low- or no- emission vehicles or facilities. Additionally, 0.5% of a request may be for workforce development training, and an additional 0.5% may be for training at the National Transit Institute (NTI). Applicants proposing any project related to zero-emission vehicles must also spend 5% of their award on workforce development and training as outlined in their Zero-Emission Transition Plan, unless the applicant certifies that their financial need is less.	H	Y		No	https://www.transit.dot.gov/bus-program
Congestion Mitigation and Air Quality Improvement (CMAQ) Program	EPA	Non-Discretionary	The CMAQ program provides a funding source for state and local governments to fund transportation projects and programs to help meet the requirements of the Clean Air Act (CAA) and its amendments.	Many types of projects are eligible under the CMAQ program including electric vehicles and charging stations; diesel engine replacements and retrofits; transit improvements; bicycle, and pedestrian facilities; and shared micromobility projects, including shared scooter systems. In addition to improving air quality and reducing congestion, CMAQ projects can improve equitable access to transportation services, improve safety, and promote application of new and emerging technologies. The BIL authorized funding for the purchase of diesel replacements, or medium-duty or heavy-duty zero emission vehicles and related charging equipment.	H	N	• Funding apportioned to states	No	https://www.fhwa.dot.gov/environment/air_quality/cmaq/ https://www.fhwa.dot.gov/bipartisan-infrastructure-law/cmaq.cfm
Long-Duration Energy Storage (LDES) Demonstrations	DOE	Discretionary	Development of LDES systems.	The Office of Clean Energy Demonstrations (OCED)'s LDES portfolio is focused on a range of technologies with regional diversity to demonstrate promising technologies at different scales and help innovative LDES technologies to become commercially viable. These demonstrations will contribute to one or more of the following: • Improve the security of critical infrastructure and emergency response systems • Advance the reliability of transmission and distribution systems, particularly in rural areas, including high-energy cost rural areas • Optimize transmission or distribution system operation and power quality to defer or avoid costs of replacing or upgrading electric grid infrastructure, including transformers and substations • Supply energy at peak periods of demand on the electric grid or during periods of significant variation of electric grid supply • Reduce peak loads of homes and businesses • Improve and advance power conversion systems • Provide ancillary services for grid stability and management • Integrate renewable energy resource production • Increase the feasibility of microgrids (grid-connected or islanded mode) • Enable the use of stored energy in forms other than electricity to support the natural gas system and other industrial processes	H	N	• State • Local government • Community-based organizations • National laboratories • Universities and utilities	No	https://www.energy.gov/oced/long-duration-energy-storage-demonstrations

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				• Integrate fast charging of electric vehicles • Improve energy efficiency					
Low- or No-Emission Vehicle Program	FTA	Discretionary	Provides funding to state and local governmental authorities for the purchase or lease of zero-emission and low-emission transit buses as well as acquisition, construction, and leasing of required supporting facilities.	Eligible projects include: • Purchasing or leasing low- or no-emission buses • Acquiring low- or no-emission buses with a leased power source • Constructing or leasing facilities and related equipment (including intelligent technology and software) for low- or no-emission buses • Building new public transportation facilities to accommodate low- or no-emission buses • Rehabilitating or improving existing public transportation facilities to accommodate low- or no-emission buses Additionally 0.5% of a request may be for workforce development training and an additional 0.5% may be for training at the NTI. Applicants proposing any project related to zero-emission vehicles must also spend 5% of their award on workforce development and training as outlined in their Zero-Emission Transition Plan, unless the applicant certifies that their financial need is less.	H	Y		No	https://www.transit.dot.gov/lowno
Public Transportation Innovation	FTA	Discretionary	Provides funding to develop innovative products and services assisting transit agencies in better meeting the needs of their customers.	Eligible activities: • Accelerated implementation and deployment of advanced digital construction projects that promote, implement, deploy, demonstrate, showcase, support, and document the application of advanced digital construction management systems, practices, performance, and benefits • Research activities that relate to the development and deployment of new and innovative ideas, practices, and approaches • Innovation and development activities that seek to improve public transportation systems nationwide to provide more efficient and effective delivery of public transportation services, including through technology and technological capacity improvements • Demonstration, deployment, or evaluation projects that promote the early deployment and demonstration of innovation in public transportation that has broad applicability • Low or no emission vehicle component assessments to test, evaluate, and analyze low- or no-emission vehicle components intended for use in low or no emission vehicles, and conduct directed technology research • Transit Cooperative Research Program (TCRP) activities to provide applied research that addresses key challenges facing the public transportation industry	H	Y		No	https://www.transit.dot.gov/funding/grants/fact-sheet-public-transportation-innovation
Rebuilding American Infrastructure with Sustainability and	DOT	Discretionary	Investments in road, rail, transit, and port projects	Eligible projects for RAISE grants are surface transportation capital projects that are: • Highway, bridge, or other road projects eligible	H	Y		Yes	https://www.transportation.gov/RAISEgrants/about

TABLE E-1: FUNDING AND FINANCE SCAN FOR CITILINK

Funding/Grant Program	Funding/ Sponsor Agency	Discretionary/ Non-Discretionary	Summary	Eligible Activities	Likelihood of Applicability (H/M/L)	Is Citilink Eligible?	Eligible Applicants (if Citilink not eligible)	BCA Needed	Sources (links)
Equity (RAISE) Grant Program			that promise to achieve national objectives.	• Public transportation projects • Passenger and freight rail transportation projects • Port infrastructure investments, including inland port infrastructure and land ports of entry • The surface transportation components of an airport project eligible for assistance • Intermodal projects • Projects to replace or rehabilitate a culvert or prevent stormwater runoff for the purpose of improving habitat for aquatic species • Projects investing in surface transportation facilities that are located on Tribal land and for which title or maintenance responsibility is vested in the federal government • Any other surface transportation infrastructure project that the secretary considers to be necessary to advance the goals of the program					
Surface Transportation Block Grant (STBG)	FHWA	Non-Discretionary	The STBG promotes flexibility in state and local transportation decisions and provides flexible funding to best address these transportation needs.	Eligible activities include, but are not limited to: • Installing EV charging and vehicle-to-grid infrastructure • Installing and deploying current and emerging intelligent transportation technologies • Planning and constructing projects that facilitate intermodal connections between emerging transportation technologies, such as magnetic levitation and hyperloop • Conducting value for money analyses or similar comparative analyses of public-private partnerships (P3s) • Capital projects for the construction of a bus rapid transit corridor or dedicated bus lane	H	N	• Apportioned to states	No	https://www.fhwa.dot.gov/bipartisan-infrastructure-law/stbg.cfm
Advanced Transportation and Congestion Management Technologies Deployment (ATCMTD) Program	FHWA	Non-Discretionary	Grants for the development of model deployment sites for large scale installation and operation of advanced transportation technologies to improve safety, efficiency, system performance, and infrastructure return on investment.	Grant recipients may use funds under this program to deploy advanced transportation and congestion management technologies, including: • Traveler information systems • Transportation management technologies • Infrastructure maintenance, monitoring, and condition assessment • Public transportation systems • Transportation system performance data collection, analysis, and dissemination systems • Safety systems, including vehicle-to-vehicle and vehicle-to-infrastructure communications • Technologies associated with autonomous vehicles and other collision avoidance technologies, including systems using cellular technology • Integration of intelligent transportation systems with the Smart Grid and other energy distribution and charging systems • Electronic pricing and payment systems	M	Y		No	https://www.fhwa.dot.gov/fastact/factsheets/advtranscongmgmtfs.cfm

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				• Mobility and access technologies, such as dynamic ridesharing and information systems to support human services for elderly and disabled individuals					
Advanced Transportation Technologies and Innovative Mobility Development (ATTIMD)	FHWA	Discretionary	The ATTIMD program supports the implementation and operation of various mobility-focused transportation technologies.	Eligible uses include the deployment of: • Advanced traveler information systems, advanced public transportation systems, transportation management technologies, and advanced transportation technologies to improve emergency evacuation and response by federal, state, and local authorities • Infrastructure maintenance, monitoring, and condition assessment • Transportation system performance data collection, analysis, and dissemination systems • Advanced safety systems, including vehicle-to-vehicle and vehicle-to-infrastructure communications, technologies associated with autonomous vehicles, and other collision avoidance technologies, including systems using cellular technology • Integration of intelligent transportation systems with the Smart Grid and other energy distribution and charging systems • Integrated corridor management systems • Advanced parking reservation or variable pricing systems and integration of transportation service payment systems • Electronic pricing, toll collection, and payment systems • Technology that enhances high occupancy vehicle toll lanes, cordon pricing, or congestion pricing • Advanced mobility, access, and on-demand transportation service technologies, such as dynamic ridesharing and other shared-use mobility applications and information systems to support human services for elderly and disabled individuals • Retrofitting dedicated short-range communications (DSRC) technology deployed as part of an existing pilot program to cellular vehicle-to-everything (C–V2X) technology	M	Y		No	https://www.transportation.gov/rural/grant-toolkit/advanced-transportation-technologies-and-innovative-mobility-deployment
Bus Testing Program	FTA	Discretionary	Activities relating to the testing of new bus models and the operation and maintenance of the bus testing facility.	Funds one bus testing facility for testing new bus models for maintainability, reliability, safety, performance, structural integrity, fuel economy, emissions, and noise.	M	Y		No	https://www.transit.dot.gov/research-innovation/bus-testing
Charging and Fueling Infrastructure Grant Program	FHWA	Discretionary	Funding to deploy publicly accessible EV charging infrastructure and other alternative fueling infrastructure along designated alternative fuel corridors.	Provides funding to strategically deploy publicly accessible electric vehicle charging infrastructure and other alternative fueling infrastructure. This grant program has two tracks: • Corridor charging: To deploy electric vehicle charging and hydrogen/propane/natural gas fueling infrastructure along designated alternative fuel corridors	M	N	• State or political subdivision • Metropolitan planning organization • Local government	No	https://www.transportation.gov/rural/grant-toolkit/charging-and-fueling-infrastructure-grant-program

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Funding/Grant Program	Funding/ Sponsor Agency	Discretionary/ Non-Discretionary	Summary	Eligible Activities	Likelihood of Applicability (H/M/L)	Is Citilink Eligible?	Eligible Applicants (if Citilink not eligible)	BCA Needed	Sources (links)
				• Community charging: to install electric vehicle charging and alternative fuel in locations on public roads, schools, parks, and in publicly accessible parking facilities			• Public authorities with a transportation function		
Commercial EV Charging Station Rebate - Indiana Michigan Power	Indiana Michigan Power	N/A - tax incentive	Indiana Michigan Power offers commercial, fleet, and multi-unit dwelling customers a rebate of $250 per Level 2 EV charging station port installed or five years's worth of revenue credits to apply against construction costs of new business facilities to serve newly installed EV charging stations.	Eligible activities include the installation of EV chargers.	M	Y		No	https://www.indianamichiganpower.com/clean-energy/electric-cars/business/charge-at-work-indiana
Energy Efficiency and Conservation Block Grant Program	DOE	Discretionary and non-discretionary	Program aim to reduce energy use and improve energy efficiency	Eligible uses: • Developing and implementing an energy-efficiency and conservation strategy • Retaining technical consultant services to assist the eligible entity in the development of such a strategy • Conducting residential and commercial building energy audits • Establishing financial incentive programs for energy efficiency improvements • Providing grants to nonprofit organizations and governmental agencies for the purpose of performing energy efficiency retrofits • Developing and implementing energy-efficiency and conservation programs for buildings and facilities within the jurisdiction of the eligible entity • Developing and implementing programs to conserve energy used in transportation • Developing and implementing building codes and inspection services to promote building energy efficiency • Applying and implementing of energy distribution technologies that significantly increase energy efficiency • Identifying activities to increase participation and efficiency rates for material conservation programs, including source reduction, recycling, and recycled content procurement programs that lead to increases in energy efficiency	M	N	- State - Local government	No	https://www.energy.gov/scep/energy-efficiency-and-conservation-block-grant-program

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				• Purchasing and implementing technologies to reduce, capture, and, to the maximum extent practicable, use methane and other greenhouse gases generated by landfills or similar sources • Replacing traffic signals and street lighting with energy efficient lighting technologies • Developing, implementing, and installing on or in any government building of the eligible entity of onsite renewable energy technology that generates electricity from renewable resources • Programs for financing energy efficiency, renewable energy, and zero-emission transportation (and associated infrastructure), capital investments, projects, and programs, which may include loan programs and performance contracting programs, for leveraging of additional public and private sector funds, and programs that allow rebates, grants, or other incentives for the purchase and installation of energy efficiency, renewable energy, and zero-emission transportation (and associated infrastructure) measures • Any other appropriate activity, as determined by the secretary					
Grid Resilience and Innovation Partnerships (GRIP)	DOE	Discretionary	Program aim to enhance grid flexibility and resilience	Programs include: • Grid Resilience Utility and Industry Grants • Smart Grid Grants • Grid Innovation Program	M	N	• State • Local governments • Public utility commissions	No	https://www.energy.gov/gdo/grid-resilience-and-innovation-partnerships-grip-program
Metropolitan & Statewide Planning and Non-Metropolitan Transportation Planning - 5303, 5304, 5305	FTA	Non-discretionary	Provides funding and procedural requirements for multimodal transportation planning in metropolitan areas and states. Planning needs to be cooperative, continuous, and comprehensive, resulting in long-range plans and short-range programs reflecting transportation investment priorities.	Funds are available for planning activities that: • Support the economic vitality of the metropolitan area, especially by enabling global competitiveness, productivity, and efficiency • Improve the safety and security of the transportation system for motorized and nonmotorized users • Increase the accessibility and mobility of people and for freight • Protect and enhance the environment, promote energy conservation, improve the quality of life, and encourage consistency between transportation improvements and State and local planned growth and economic development patterns • Enhance the integration and connectivity of the transportation system across and between modes for people and freight • Promote efficient system management and operation and (H) emphasize the preservation of the existing transportation system	M	N	• State DOTs • Metropolitan planning organizations	No	https://www.transit.dot.gov/funding/grants/metropolitan-statewide-planning-and-nonmetropolitan-transportation-planning-5303-5304
Multimodal Project Discretionary Grant Opportunity (MPDG), Mega, INFRA, RSTG	USDOT	Discretionary	Funds large and complex infrastructure investments.	Eligible projects include: • Highway or bridge projects on the National Multimodal Freight Network (NMFN), National Highway Freight Network (NHFN), or the National Highway System (NHS) • Freight intermodal (including public ports) or freight rail projects that provides public benefit • Railway highway grade separation or elimination projects	M	N	• State • Regional transportation planning Organization • Local unit of government	Yes	https://www.transportation.gov/grants/infra-grant-program

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				• Highway-railway grade crossing or grade separation projects • Wildlife crossing projects • Surface transportation project within the boundaries or functionally connected to an international border crossing that improves a facility owned by federal/state/local government and increases throughput efficiency • Projects for a marine highway corridor that is functionally connected to the NHFN and is likely to reduce road mobile source emissions • Highway, bridge, or freight projects on the NMFN • Intercity passenger rail projects • Public transportation project that are eligible under assistance under Chapter 53 of title 49 and are a part of any of the project types described above					
National Electric Vehicle Infrastructure Formula Program (NEVI)	FHWA	Non-discretionary	The BIL establishes a NEVI Formula Program (NEVI Formula) to provide funding to states to strategically deploy EV charging infrastructure and to establish an interconnected network to facilitate data collection, access, and reliability.	Program directs the Secretary of Transportation, in coordination with the Secretary of Energy, to develop guidance for states and localities to strategically deploy EV charging infrastructure.	M	N	• State	No	https://www.fhwa.dot.gov/bipartisan-infrastructure-law/nevi_formula_program.cfm
National Grants: Diesel Emissions Reduction Act (DERA)	EPA	Discretionary	Funds grants and rebates that protect human health and improve air quality by reducing harmful emissions from diesel engines.	Eligible diesel vehicles, engines, and equipment include: • School buses • Class 5 – Class 8 heavy-duty highway vehicles • Locomotive engines • Marine engines • Nonroad engines, equipment, or vehicles used in construction, handling of cargo (including at ports or airports), agriculture, mining, or energy production (including stationary generators and pumps)	M	N	• State • Local government • Non-profit that promotes transportation or air quality	No	https://www.epa.gov/dera/national
Public Works and Economic Adjustment Assistance Grant Program	U.S. Economic Development Administration (EDA)	Discretionary	Provides a wide range of technical, planning, and public works and infrastructure assistance in regions experiencing adverse economic changes that may occur suddenly or over time.	EDA provided catalytic investments to help distressed communities build, design, or engineer critical infrastructure and facilities that will help implement regional development strategies and advance bottom-up economic development goals to promote regional prosperity.	M	N	• State or political subdivision • Local government institution of higher education	No	https://sfgrants.eda.gov/s/funding-program/a2j3d0000000KneAAE/fy-2023-eda-public-works-and-economic-adjustment-assistance-programs

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							• Public or private non-profit		
State of Good Repair (SGR) Grants - 5337	FTA	Non-discretionary	The SGR Grants Program (49 U.S.C. 5337) provides capital assistance for maintenance, replacement, and rehabilitation projects of high-intensity fixed guideway and bus systems to help transit agencies maintain assets in a state of good repair. Additionally, SGR grants are eligible for developing and implementing transit asset management plans.	SGR Grants funds are available for capital projects that maintain a fixed guideway or a high intensity motorbus system in a SGR, including projects to replace and rehabilitate: • Rolling stock • Track • Line equipment and structures • Signals and communications • Power equipment and substations • Passenger stations and terminals • Security equipment and systems • Maintenance facilities and equipment • Operational support equipment, including computer hardware and software • Implement transit asset management plans	M	Y	• Apportioned to states	No	https://www.transit.dot.gov/funding/grants/state-good-repair-grants-5337#:~:text=The%20State%20of%20Good%20Repair,a%20state%20of%20good%20repair.
Technical Assistance and Workforce Development	FTA	Discretionary	Provides technical assistance to enhance delivery of transit services.	The law continues without change the broad range of activities eligible under Sec. 5314, including: • Technical assistance • The development of voluntary and consensus-based standards and best practices by the public transportation industry, including standards and best practices for safety, fare collection, intelligent transportation systems, accessibility, procurement, security, asset management to maintain a SGR, operations, maintenance, vehicle propulsion, communications, and vehicle electronics • Programs that address human resource needs as they apply to public transportation activities such as an employment training program and outreach • Activities related to the NTI	M	Y		No	https://www.transit.dot.gov/funding/grants/fact-sheet-technical-assistance-and-workforce-development
The Environmental Justice Collaborative Problem-Solving (EJCPS)Cooperative Agreement Program	EPA	Discretionary and non-discretionary	The EJCPS Cooperative Agreement Program provides financial assistance to eligible organizations working to address local environmental or public health issues in their communities.	Funding opportunity must address one of the following five broad categories: • Community-led air and other pollution monitoring, prevention, and remediation, and investments in low- and zero-emission and resilient technologies as well as related infrastructure and workforce development that help reduce GHG emissions and other air pollutants • Mitigating climate and health risks from urban heat islands, extreme heat, wood heater emissions, and wildfire events • Climate resiliency and adaptation • Reducing indoor toxics and indoor air pollution	M	N	• Community-based nonprofit organization • Partnership of community-based organization	No	https://www.epa.gov/environmentaljustice/environmental-justice-collaborative-problem-solving-cooperative-agreement-5

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				• Facilitating engagement of marginalized communities in local, state and federal public processes, such as advisory groups, workshops, and rulemakings					
Urbanized Area Formula Grants - 5307	FTA	Non-discretionary	he Urbanized Area Formula Funding program (49 U.S.C. 5307) makes federal resources available to urbanized areas and to governors for transit capital and operating assistance in urbanized areas and for transportation-related planning. An urbanized area is an incorporated area with a population of 50,000 or more that is designated as such by the U.S. Department of Commerce, Bureau of the Census.	Eligible activities include: • Planning, engineering, design, and evaluation of transit projects and other technical transportation-related studies • Capital investments in bus and bus-related activities such as replacement, overhaul and rebuilding of buses, crime prevention and security equipment and construction of maintenance and passenger facilities • Capital investments in new and existing fixed guideway systems including rolling stock, overhaul and rebuilding of vehicles, track, signals, communications, and computer hardware and software In addition, associated transit improvements and certain expenses associated with mobility management programs are eligible under the program. All preventive maintenance and some Americans with Disabilities Act complementary paratransit service costs are considered capital costs.	M	Y		No	https://www.transit.dot.gov/funding/grants/urbanized-area-formula-grants-5307
Accelerating Innovative Mobility (AIM)	FTA	Non-discretionary	Funds activities leading to the development and testing of innovative mobility.	Eligible activities include all activities leading to the development and testing of innovative mobility, such as planning and developing business models, obtaining equipment and service, acquiring, or developing software and hardware interfaces to implement the project, operating, or implementing the new service model, and evaluating project results.	L	Y		No	https://www.transit.dot.gov/AIM
Advanced Transportation Technology and Innovation (ATTAIN)	**FHWA**	Discretionary	Funding to deploy, install, and operate advanced transportation technologies to improve safety, mobility, efficiency, system performance, intermodal connectivity, and infrastructure return on investment.	Grant recipients may use funds under this program to deploy the following advanced transportation and congestion management technologies: • Advanced transportation technologies to improve emergency evacuation and responses by federal, state, and local authorities • Integrated corridor management systems • Advanced parking reservation or variable pricing systems • Electronic pricing, toll collection, and payment systems • Technology that enhances high occupancy vehicle toll lanes, cordon pricing, or congestion pricing • Integration of transportation service payment systems • Advanced mobility access and on-demand transportation service technologies, such as dynamic ridesharing and other shared-use mobility applications and information systems to support human services for elderly and disabled individuals • Retrofitting dedicated short-range communications (DSRC) technology deployed as part of an existing pilot program to cellular vehicle-to-	L	Y		No	https://www.fhwa.dot.gov/bipartisan-infrastructure-law/attain.cfm

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				everything (C-V2X) technology, subject to the condition that the retrofitted technology operates only within the existing spectrum allocations for connected vehicle systems • Advanced transportation technologies, in accordance with research areas described in the DOT's 5-year transportation research and development strategic plan (section 6503 of title 49, United States Code). [§ 13006(b)(6); 23.U.S.C. 503(c)(4)(E)]					
Building Resilient Infrastructure and Communities (BRIC)	FEMA	Discretionary	The BRIC grant program give states, local communities, tribes, and territories funding to address future risks to natural disasters, including ones involving wildfires, drought, hurricanes, earthquakes, extreme heat, and flooding. Addressing these risks helps make communities more resilient.	FEMA will provide financial assistance to eligible BRIC applicants for the following activities: • Capability- and Capacity-Building: Activities that enhance the knowledge, skills, or expertise of the current workforce to expand or improve the administration of mitigation assistance • Hazard Mitigation Projects: Cost-effective projects designed to increase resilience and public safety; reduce injuries and loss of life; and reduce damage and destruction to property, critical services, facilities, and infrastructure (including natural systems) from a multitude of natural hazards and the effects of climate change • Management Costs: Financial assistance to reimburse the recipient and subrecipient for eligible and reasonable indirect costs, direct administrative costs, and other administrative expenses associated with a specific mitigation measure or project.	L	N	• State	Yes	https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities
Congestion Relief Program	FHWA	Discretionary	Funding to advance innovative, integrated, and multimodal solutions to congestion relief in the most congested metropolitan areas of the United States.	Projects or an integrated collection of projects, including planning, design, implementation, and construction activities, including: • Deployment and operation of an integrated congestion management system • Deployment and operation of a system that implements or enforces high occupancy vehicle toll lanes, cordon pricing, parking pricing, or congestion pricing • Deployment and operation of mobility services, including establishing account-based financial systems, commuter buses, commuter vans, express operations, paratransit, and on-demand microtransit • Incentive programs that encourage travelers to carpool, use nonhighway travel modes during peak period, or travel during nonpeak periods	L	N	• State	No	https://www.fhwa.dot.gov/bipartisan-infrastructure-law/congestion_relief.cfm
Enhanced Mobility of Seniors and Individuals with Disabilities	FTA	Non-discretionary	Funds transportation services to meet the special transportation needs of seniors and individuals with disabilities.	Traditional Section 5310 project examples include: • Buses and vans • Wheelchair lifts, ramps, and securement devices • Transit-related information technology systems, including scheduling/routing/one-call systems • Mobility management programs • Acquisition of transportation services under a contract, lease, or other arrangement Nontraditional Section 5310 project examples include:	L	Y	• Apportioned to states	No	https://www.transit.dot.gov/funding/grants/enhanced-mobility-seniors-individuals-disabilities-section-5310

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				• Travel training • Volunteer driver programs • Building an accessible path to a bus stop, including curb-cuts, sidewalks, accessible pedestrian signals or other accessible features • Improving signage, or way-finding technology • Incremental cost of providing same day service or door-to-door service • Purchasing vehicles to support new accessible taxi, rides sharing and/or vanpooling programs • Mobility management programs					
Helping Obtain Prosperity for Everyone (HOPE) Program	FTA	Discretionary	Supports planning, engineering and technical studies or financial planning to improve transit services in areas experiencing long-term economic distress.	The HOPE program seeks to fund planning for projects that will improve transit service and facilities in areas of persistent poverty in the U.S. FTA is particularly interested in proposals that may introduce innovative technologies or practices in support of FTA's Accelerating Innovative Mobility (AIM) initiative and, consistent with the ROUTES Initiative, projects that address the challenges faced by rural areas of persistent poverty.	L	Y		No	https://www.transit.dot.gov/HOPE
Integrated Mobility Innovation (IMI)	FTA	Discretionary	The IMI demonstration program supports the transit industry's ability to leverage and integrate mobility innovations with existing services, while examining the impact of innovations on agency operations and the traveler experience.	Eligible activities include all activities leading to the demonstration, such as planning and developing business models, obtaining equipment and service, acquiring, or developing software and hardware interfaces to implement the project, operating the demonstration, and providing data to support performance measurement and evaluation.	L	Y		No	https://www.transit.dot.gov/IMI
National Clean Investment Fund (NCIF)	EPA	Discretionary	Competition to provide grants to 2–3 national nonprofit financing entities to create national clean financing institutions capable of partnering with the private sector to provide accessible, affordable financing for tens of thousands of clean technology projects nationwide.	EPA is launching three distinct but complementary grant competitions: a $14 billion National Clean Investment Fund competition to finance clean technology deployment nationally; a $6 billion Clean Communities Investment Accelerator competition to finance clean technology deployment in low-income and disadvantaged communities while simultaneously building the capacity of community lenders that serve those communities; and a $7 billion Solar for All competition to spur adoption of clean distributed solar energy that lowers energy bills for millions of Americans in low-income and disadvantaged communities.	L	N	• Non-profit with the organizational mission consistent with being "designed to provide capital, leverage private capital, and provide other forms of financial assistance."	No	https://www.whitehouse.gov/briefing-room/statements-releases/2023/07/14/fact-sheet-biden-harris-administration-launches-historic-20-billion-competition-to-catalyze-investment-in-clean-energy-projects-and-tackle-the-climate-crisis/

TABLE E-1: FUNDING AND FINANCE SCAN FOR CITILINK

Funding/Grant Program	Funding/ Sponsor Agency	Discretionary/ Non-Discretionary	Summary	Eligible Activities	Likelihood of Applicability (H/M/L)	Is Citilink Eligible?	Eligible Applicants (if Citilink not eligible)	BCA Needed	Sources (links)
Prioritization Process Pilot Program	FHWA	Discretionary	Funding to establish a Prioritization Process Pilot Program to support data-driven approaches to transportation planning, that, on completion, can be evaluated for public benefit.	The Prioritization Process Pilot Program will award grants to selected. States and metropolitan planning organizations to fund the development and implementation of publicly accessible, transparent prioritization processes to assess and score projects according to locally determined priorities, and to use such evaluations to inform the selection of projects to include in transportation plans.	L	N	• State	No	https://www.whitehouse.gov/wp-content/uploads/2022/05/BUILDING-A-BETTER-AMERICA-V2.pdf
Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) Discretionary Grants	FHWA	Discretionary	Eligible uses include highway, transit, and certain port projects that include resilience planning, strengthening, and protecting evacuation routes, enabling communities to address vulnerabilities, and increasing the resilience of surface transportation infrastructure from the impacts of sea level rise, flooding, wildfires, extreme weather events, and other natural disasters.	Grant funds the following eligible activities: • Planning projects • Resilience improvement projects • Community resilience and evacuation route grants • At-risk coastal infrastructure	L	N	• State • Local governments • Planning and project organizations	Yes*	https://www.transportation.gov/rural/grant-toolkit/promoting-resilient-operations-transformative-efficient-and-cost-saving
Regional Clean Hydrogen Hubs	DOE	Discretionary	Create networks of hydrogen producers, consumers, and local connective infrastructure to accelerate the use of hydrogen as a clean energy.	Projects that demonstrate the production, processing, delivery, storage, and end-use of, clean hydrogen through regional clean hydrogen hubs, which are networks of clean hydrogen producers, potential clean hydrogen consumers, and connective infrastructure located in proximity.	L	N	• State • Local governments • Industry utilities, universities, and national laboratories • Environmental groups and community-based organizations	No	https://www.energy.gov/oced/regional-clean-hydrogen-hubs
State Infrastructure Bank (SIB)	FHWA	N/A - loan	A SIB is a revolving loan fund program established and administered by a state to provide low-cost	Allowable activities include: • A surface transportation project located in an area that is outside an urbanized area with a population greater than 150,000 individuals, as determined by the Bureau of Census	L	N	• Public entities, including any state	No	https://www.transportation.gov/buildamerica/sibs

TABLE E-1: FUNDING AND FINANCE SCAN FOR CITILINK

Funding/Grant Program	Funding/ Sponsor Agency	Discretionary/ Non-Discretionary	Summary	Eligible Activities	Likelihood of Applicability (H/M/L)	Is Citilink Eligible?	Eligible Applicants (if Citilink not eligible)	BCA Needed	Sources (links)
			loan financing to surface transportation projects within the state. SIBs can be capitalized with federal-aid surface transportation funds and matching state funds or capitalized with a Transportation Infrastructure Finance and Innovation Act (TIFIA) loan to lend to rural infrastructure projects.	• For projects crossing rural-urban boundaries, the project is considered "rural" if more than 50% of project eligible costs are in the rural area			transportation agency, or a state-level lending institution		
Strengthening Mobility and Revolutionizing Transportation (SMART)	DOT	Discretionary	Provides grants to eligible public sector agencies to conduct demonstration projects focused on advanced smart community technologies and systems to improve transportation efficiency and safety.	A SMART grant may be used to carry out a project that demonstrates at least one of the following: • Coordinated automation • Connected vehicles • Sensors • Systems integration • Delivery/logistics • Innovative aviation • Smart grid • Traffic signals	L	Y		No	https://www.transportation.gov/grants/SMART
STATE & LOCAL OPPORTUNITIES									
Public Mass Transportation Fund	ID Department of Transportation	Non-discretionary	Program purpose is to promote and develop transportation in Indiana.	• Operating Project Grants: Provide assistance for the operations of the transit service • Capital Project Grants: Capital projects generally include expenses for purchasing vehicles, communication equipment, fare boxes, passenger shelters, and construction of and rehabilitation of transit facilities	H	Y		No	INDOT: Public Mass Transportation Fund

Grid Resilience Grant Program	ID Office of Energy Development	Discretionary	Improve resilience of the electric grid against disruptive events through physical upgrades, incorporating technology, and analyses. Workforce development necessary to achieve improvements is also supported.	The following resilience-based investments are permitted
				• Weatherization technologies and equipment
				• Fire-resistant technologies and fire prevention systems
				• Monitoring and control technologies
				• The undergrounding of electrical equipment
				• Utility pole management
				• The relocation of power lines or the reconductoring of power lines with low-sag, advanced conductors
				• The use of construction of distributed energy resources for enhancing system adaptive capacity during disruptive events, including:
				  ○ Microgrids
				  ○ Battery-storage subcomponents
				  ○ Adaptive protection technologies
				  ○ Advanced modeling technologies
					M	N	• Electric utilities	No	OED: Grid Resilience Program (in.gov)

TABLE E-1: FUNDING AND FINANCE SCAN FOR CITILINK

Funding/Grant Program	Funding/ Sponsor Agency	Discretionary/ Non-Discretionary	Summary	Eligible Activities	Likelihood of Applicability (H/M/L)	Is Citilink Eligible?	Eligible Applicants (if Citilink not eligible)	BCA Needed	Sources (links)
				○ Hardening of power lines, facilities, substations, of other systems ○ The replacement of old overhead conductors and underground cables.					
Community Energy Security Planning Grant Program	ID Office of Energy Development	Discretionary	The funding opportunity allows for efforts to develop, enhance, and implement local energy security planning for more reliable and resilient energy infrastructure. An energy security plan will identify, assess, and mitigate risks to energy infrastructure and to plan for, respond to, and recover from events that disrupt energy supply.	Supports the development of Energy Security Plans.	L	N	• County governments • Local governments • Regional planning organizations • Non-profits	No	OED: SEP Grant Programs (in.gov)
Prescriptive Incentive Program	NIPSCO	N/A - tax incentive	Agricultural, large commercial, governmental, industrial, institutional, and non-profit, customers can earn incentives for improving performance and installing new energy-saving equipment or by optimizing building or industrial systems with retro-commissioning (RCx) processes.	Allowable for projects that improve energy performance.	L	Y	• Governmental, institutional, and non-profit customers	No	https://www.nipsco.com/energy-efficiency/for-your-business/custom-incentive-program

APPENDIX F: MICROGRID SIZING SPECIFICATIONS

SITE ASSESSMENT

Citilink's bus depot is analyzed for a perspective microgrid via Google Maps. This location is depicted in

. This system would require the use of two areas around the Citilink depot, an open field across from the depot, and an open lot located next to the depot. Also, for this perspective microgrid, area on the roof is analyzed, to provide a total area of 23,500 square meters.

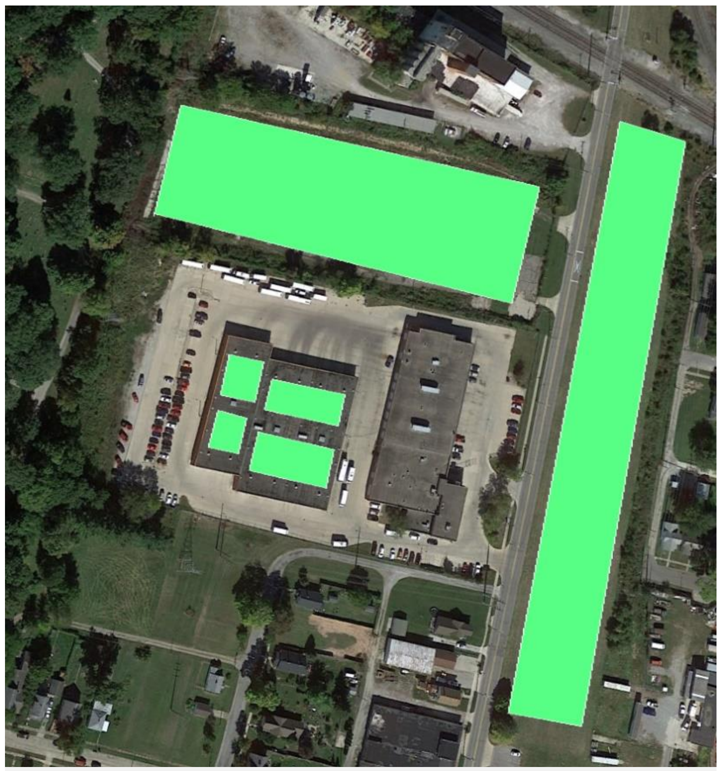

Figure F-1 Citilink Bus Depot with Microgrid Outline

SYSTEM DESIGN

Figure F-3 is used to determine the optimal GCR and tilt angle of the perspective PV array located in the field and open lot. For this calculation land is given a cost of $10,500 (Purdue, n.d.). The x-axis of Figure F-3 shows GCR, the y-axis gives tilt angle, and the z-axis is the net present values of the microgrid. Based on this figure a tilt angle of 25 degrees and a GCR of 0.35 provides the optimal net present value.

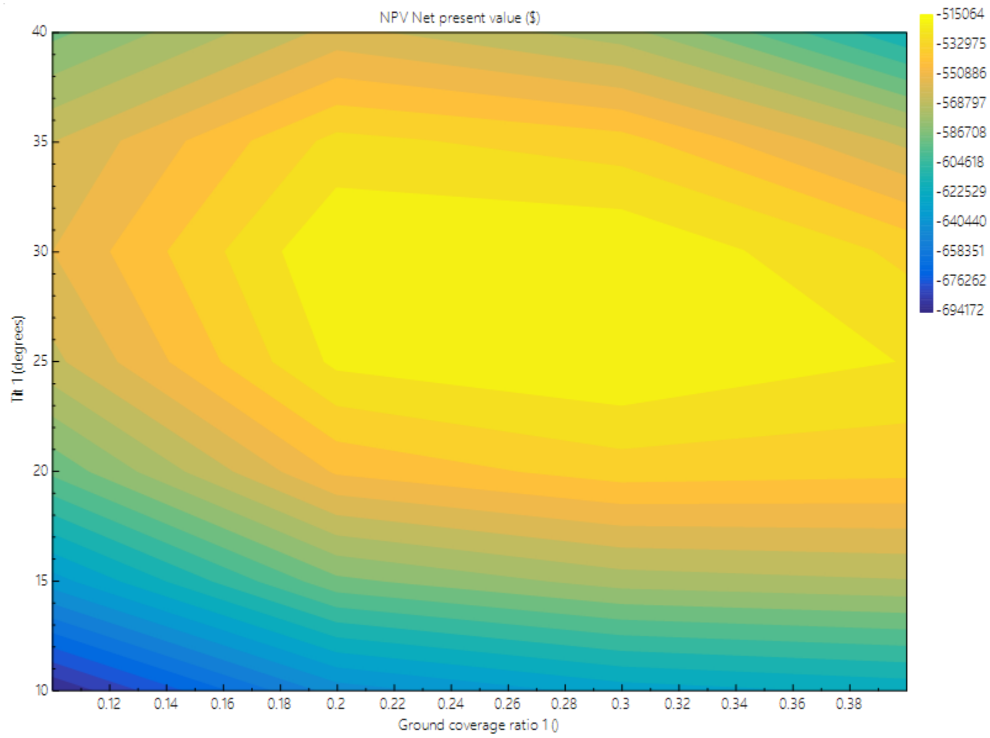

Figure 5 Figure F-3 Net Present Value as a Function of Tilt and GCR

The roof mounted array is simulated with a tilt angle of 0 degrees and a GCR of 0.95,. The array that is place in the field and the open lot have a tilt angle of 25 degrees and a GCR of 0.35,

TABLE F-3 SYSTEM DESIGN PARAMETERS – SPATIAL ANALYSIS

DC Power (MW)	2.0
AC Power (MW)	1.7
Power Ratio	1.2
Area (m^2)	23,500
Battery Power (MW)	0.512
Battery Capacity (MWh)	3.8

. The system will produce 2.0 MW of DC power and 1.7 MW of AC power, with a power ratio of 1.2. The system would require 23,500 square meters to facilitate a PV array of this size and would be accompanied with a 0.512 MW/3.8MWh battery system.

TABLE F-1 SYSTEM DESIGN PARAMETERS – SPATIAL ANALYSIS (ROOF TOP)

Tilt angle (degrees)	0
GCR	0.95

TABLE F-2 SYSTEM DESIGN PARAMETERS – SPATIAL ANALYSIS (FIELD)

Tilt angle (degrees)	25

GCR	0.35

TABLE F-3 SYSTEM DESIGN PARAMETERS – SPATIAL ANALYSIS

DC Power (MW)	2.0
AC Power (MW)	1.7
Power Ratio	1.2
Area (m^2)	23,500
Battery Power (MW)	0.512
Battery Capacity (MWh)	3.8

TABLE F-2 SYSTEM DESIGN PARAMETERS – LOAD BASED DESIGN

DC Power (MW)	3.2
AC Power (MW)	2.7
Power Ratio	1.2
Area (m^2)	14,277
Tilt angle (degrees)	25
GCR	0.35
Battery Power (MW)	.612
Battery Capacity (MWh)	4.4

, which is a system design based on the input load profile, has a DC power of 3.2 MWs and an AC output of 2.7 MWs. The tilt angles and GCR remain the same, but the new area needed is 14,277 square meters. The battery bank for this scenario can output 0.612 MWs and can store 4.4 MWhs of energy.

TABLE F-2 SYSTEM DESIGN PARAMETERS – LOAD BASED DESIGN

DC Power (MW)	3.2
AC Power (MW)	2.7
Power Ratio	1.2
Area (m^2)	14,277
Tilt angle (degrees)	25
GCR	0.35
Battery Power (MW)	.612
Battery Capacity (MWh)	4.4

ELECTRICAL LOAD

The load profile utilized for this analysis is generated via STV's PEER tool. The analysis of the Citilink bus routes indicates an expected peak electrical load during the winter months of about 625 kWs and a minimum power output of about 350 kWs during the summer months, shown in Figure F-3.

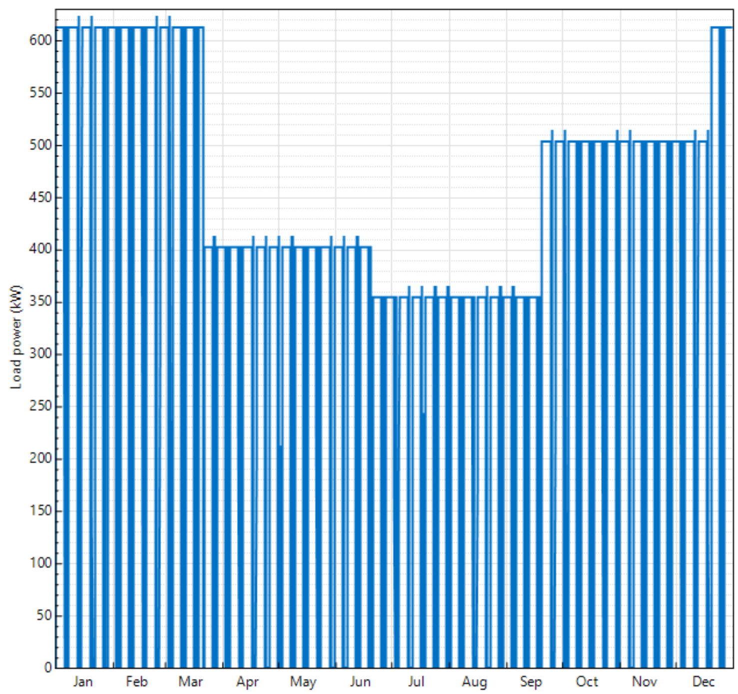

Figure F-4 Citilink BEB Load Profile