Fleet Transition Plan

COTA | MARCH 2024

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1 EXECUTIVE SUMMARY

Purpose of Plan

Sustainability

COTA's mission is to provide transportation solutions that connect people to prosperity through innovation, dedication, and teamwork. As the regional public transit provider for the Greater Columbus area, COTA is responsible for providing sustainable mobility solutions that keep pace with advancements in the transportation sector and meet changing customer expectations for transit service.

In 2022, COTA released its first sustainability plan, which included a greenhouse gas (GHG) inventory and GHG reduction goals. The GHG inventory revealed that 71 percent of COTA's GHG emissions are generated by the bus fleet; thus, a transition to zero-emission fleet vehicles is a crucial step in meeting the agency's emission reduction goals. The 2022 Sustainability Plan also included COTA's first Zero-Emission Transition Plan, with the goal of fully converting the bus fleet to zero-emission buses by 2035 and achieving net zero by 2045.

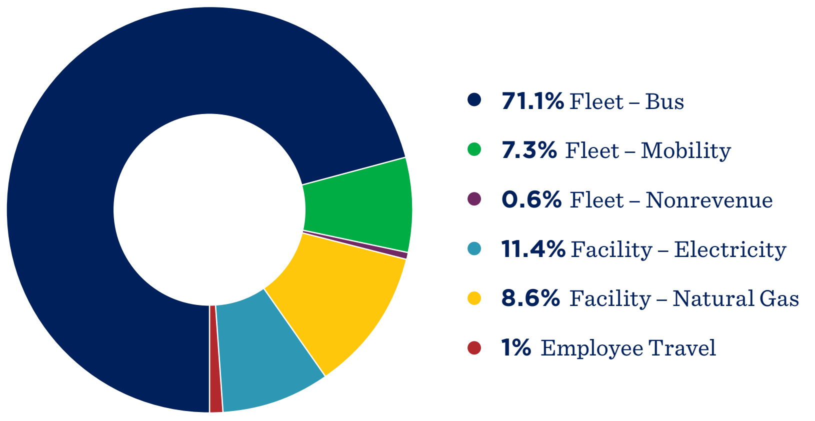


Figure 1: **COTA'S ANNUAL GHG EMISSIONS** (2019)

Since the release of the initial Fleet Transition Plan, COTA has brought **50 battery electric buses** (BEBs) into the fleet (24 operating today, and 26 to be delivered through 2024), installed the **first phases of electric vehicle supply equipment** (EVSE), and developed plans to **expand EVSE at bus garages and on-route.** Additionally, COTA has completed a **hydrogen fuel cell bus feasibility study** and has begun plans to bring hydrogen buses into the fleet. These developments have advanced COTA closer to its 2035 goal and necessitated the update of the Zero-Emission Transition Plan. This updated 2024 Transition Plan aims to capture COTA's various efforts to transition toward cleaner vehicles and provide a framework for COTA's continued transition.

COTA SUSTAINABILITY GOALS

100% *Zero-Emission Bus Fleet by 2035*

NET-ZERO BY 2045

FTA Compliance

In addition to COTA's commitment to sustainability, this plan is also intended to comply with the Federal Transit Administration's (FTA's) Zero-Emission Bus Transition Plan requirements. Below are the six elements required by the FTA, with links to each section in this document that address these requirements:

1. **POLICY AND LEGISLATIVE IMPACTS**

   Consideration of policy and legislation impacting relevant technologies.

   SHOWN IN: **POLICY AND LEGISLATIVE IMPACTS**

2. **FLEET PLAN**

   Demonstration of a long-term fleet management plan with a strategy for how the applicant intends to use the current request for resources and future acquisitions.

   SHOWN IN: **ZERO-EMISSION VEHICLE STRATEGY**

3. **FACILITY AND INFRASTRUCTURE PLAN**

   Evaluation of existing and future facilities and their relationship to the technology transition.

   SHOWN IN: **FACILITIES AND INFRASTRUCTURE PLAN**

4. **FUEL PLAN**

   Description of the partnership of the applicant with the utility or alternative fuel provider.

   SHOWN IN: **INTERNAL AND EXTERNAL ENGAGEMENT**

5. **FUNDING PLAN**

   Overview of the availability of current and future resources to meet costs for the transition and implementation.

   SHOWN IN: **FUNDING PLAN**

6. **WORKFORCE TRANSITION PLAN**

   Examination of the impact of the transition on the applicant's current workforce by identifying skill gaps, training needs, and retraining needs of existing workers. This focuses on supporting the applicant's short-term and long-term needs to operate and maintain zero-emission vehicles while avoiding displacement of the existing workforce.

   SHOWN IN: **WORKFORCE DEVELOPMENT**

COTA's Zero-Emission Bus Strategy

COTA has defined its fleet transition strategy in two phases: a near-term strategy (2024–2027) and a long-term strategy (2028–2035). The near-term strategy captures today's bus service, while the long-term strategy aligns with COTA's future bus service. COTA found it necessary to differentiate between these two time horizons because there are a few significant developments that COTA anticipates will happen in the coming years, including a larger bus fleet, more frequent service, new routes, and potentially a third bus garage. These changes are expected to occur between 2025 and 2028.

Near-Term Strategy (2024–2027)

FLEET: NUMBER OF ZERO-EMISSION BUSES (ZEBS): 75 TO 85

From 2024 to 2027, COTA plans to expand BEB operations and begin integrating hydrogen fuel cell electric buses (FCEBs) into fixed-route bus operations.

70 BATTERY ELECTRIC BUSES

COTA currently operates 24 BEBs and will accept delivery of 26 additional BEBs through 2024. Pending funding availability, COTA plans to procure ten more BEBs in 2024 for 2025 delivery. In 2025, COTA plans to procure ten 60-foot BEBs that would be delivered in 2026. COTA intends to procure BEBs in 2026 as well, but exact quantities have yet to be identified. By 2027, COTA would operate at least 70 BEBs.

5–15 HYDROGEN FUEL CELL ELECTRIC BUSES

Updated route modeling revealed that BEBs do not have the range necessary to operate across all of COTA's routes, even with on-route charging, and that FCEBs are needed on some of COTA's longer routes. COTA plans to procure no less than 5, but not more than 15, FCEBs (quantity will be dependent on funding) that will operate across a variety of routes in COTA's service area. COTA intends to begin operating this initial investment in hydrogen buses by the end of 2026.

Table 1 shows the existing and future fleet composition during the near-term strategy.

Table 1: **EXISTING AND FUTURE FLEET COMPOSITION**

PROCUREMENT YEAR	OPERATIONAL YEAR	BEB	FCEB
Existing		24	–
2022	2024	26	–
2023	2025	–	–
2024[1]	2025	10	–
	2026	–	5–10
2025	2026	10	–
	Total	**70**	**5–10**
	TOTAL ZEBs	**75–85**	

[1] *This procurement schedule anticipates a 12 month lead time for BEBs and a 16 to 24 month lead time for FCEBs.*

INFRASTRUCTURE

UP TO 130 CHARGING STATIONS

To charge the new BEBs, COTA has installed 50 charging stations between its two garages (Phase 1 of COTA's depot charging installation project completed in early 2024). In mid-2024, COTA will begin design of Phase 2 of the depot charging installation project, with plans to install up to 80 additional charging dispensers. The Phase 2 design will be implemented in stages to provide charging capacity and infrastructure ahead of vehicle deliveries, as needed in COTA's existing facilities, well into the long-term phase of the transition plan.

HYDROGEN FUELING

While growing the BEB fleet, COTA plans to procure its first hydrogen FCEBs and install hydrogen fueling infrastructure at McKinley Garage. COTA has completed a hydrogen fuel cell bus feasibility study to develop optimal first steps for the Hydrogen Fuel Cell Bus Program. COTA plans to execute this initial investment in hydrogen buses according to the feasibility study findings.

CONTINUED PLANNING

In addition to the ZEB investments that will come to fruition before 2027, COTA will complete five planning and design efforts to further define the long-term strategy.

1 ZERO-EMISSION ROUTE MODELING UPDATE

COTA is planning to complete updated zero-emission vehicle (ZEV) route modeling between 2025 and 2026. COTA anticipates service changes, new bus rapid transit (BRT), a return to pre-COVID service levels, and potentially expanded service after 2025. All of these variables make it impossible for COTA to model its future service in the present. This updated route modeling will inform what ZEB transitions are possible for the fleet after 2026.

2 ZERO-EMISSION COMPLIANT SCHEDULING

COTA will develop ZEB operation guidelines to indicate the maximum daily ranges and operation times for ZEBs. These guidelines will be used when creating new routes and scheduling bus service, and will help COTA better integrate the technology throughout the long-term strategy.

3 DESIGN FOR DEPOT CHARGING INSTALLATION, PHASES 3 AND 4

After completing Phase 2 design and installation schedules, COTA plans to complete two more phases of depot charger design at both Fields and McKinley Garages. At the time of writing this report, COTA is planning for Phase 3 and Phase 4 to include up to 80 charging dispensers each. Exact dispenser quantities will be determined based on the Zero-Emission Route Modeling Update and service requirements.

4 ON-ROUTE CHARGING DESIGN/CONSTRUCTION

COTA will continue to plan for and design on-route chargers. COTA has determined three ideal locations for on-route chargers and has begun planning and design work for chargers at these locations. COTA plans to utilize depot charging as much as possible before adding on-route charging. On-route chargers are planned to be installed after 2028 and are included as part of the long-term strategy.

5 2027 FLEET TRANSITION PLAN

COTA will update the Fleet Transition Plan by 2027 to include new route modeling, depot charger plans, on-route charger plans, and hydrogen plans. This third transition plan will define BEB and FCEB purchase quantities for the remaining timeline leading up to the 2035 full fleet conversion goal.

Long-Term Strategy (2028–2035)

FLEET: ONE HUNDRED PERCENT ZERO EMISSION BUSES BY 2035

From 2028 to 2035, COTA will focus on transitioning the rest of the bus fleet to ZEVs. COTA plans to operate a mixed fleet with BEBs and FCEBs to meet the 2035 zero-emission fleet goal. Specifics of the long-term strategy will be developed during the near-term strategy, and the 2027 Fleet Transition Plan will include a detailed approach to the long-term vision. Given the many changes anticipated for COTA's service in the next few years, at this time it is not feasible to commit to the exact composition of ZEBs in COTA's 2035 fleet (e.g., 50 percent BEB and 50 percent FCEB, or 75 percent BEB and 25 percent FCEB); however, COTA remains fully committed to a 100 percent ZEB fleet and envisions a mixed fleet. COTA intends to continue purchasing BEBs and FCEBs through the long-term strategy. BEB and FCEB quantities and a procurement schedule would be determined after the 2025–2026 route modeling is completed.

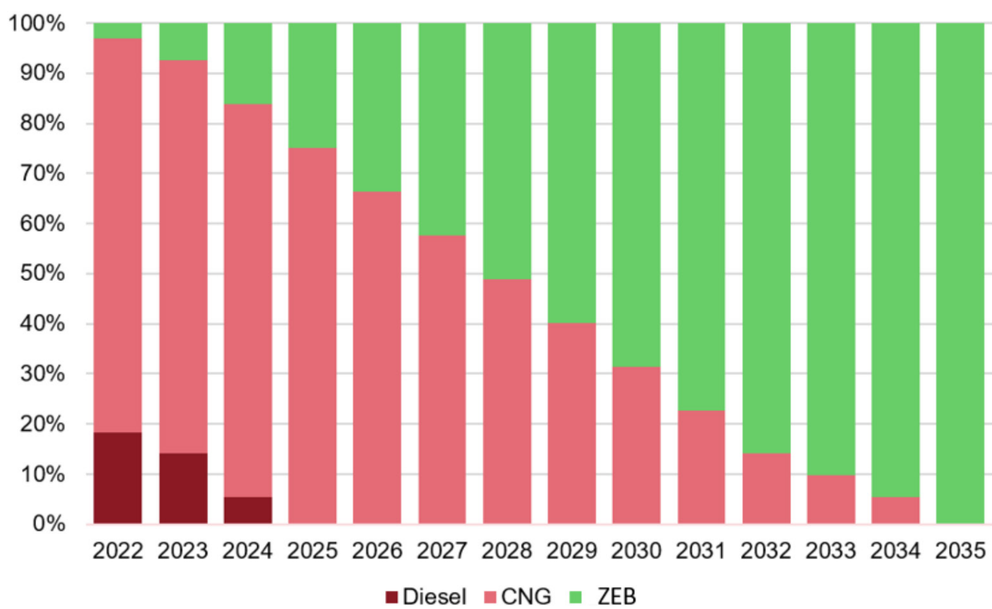
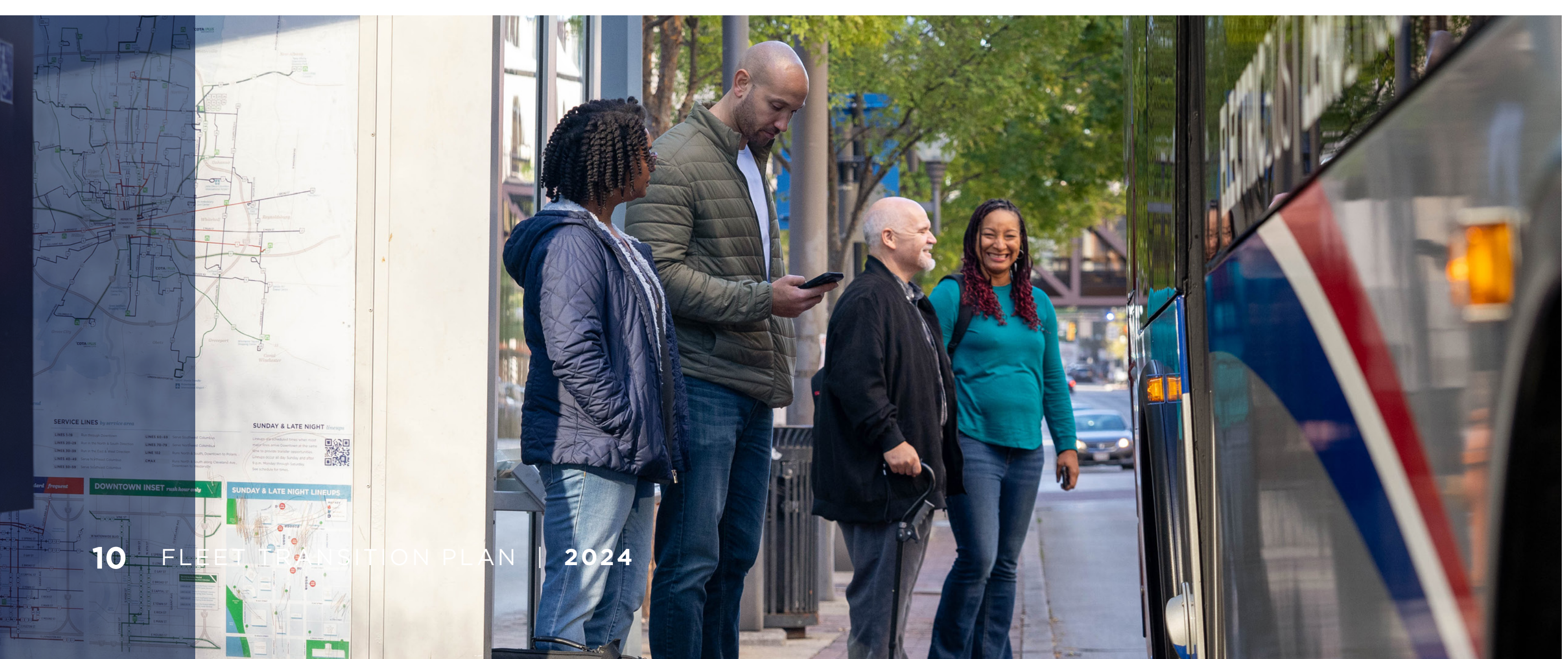


Figure 2: **FLEET COMPOSITION FROM 2022 TO 2035**



INFRASTRUCTURE

FIELDS GARAGE:
100%
Battery Electric

Fields Garage is planned to operate BEBs and compressed natural gas (CNG) buses in the near term, and to transition to 100 percent BEBs by 2035. COTA has installed 10 plug-in charging dispensers (Phase 1), and plans to install an additional 40 dispensers in the near term (Phase 2) and finish the build out with 80 dispensers in the long term (Phases 3 and 4). The final build will have 130 charging dispensers. Due to spatial constraints discovered during the hydrogen feasibility study, COTA does not plan to operate FCEBs out of Fields Garage. COTA plans to utilize CNG at this facility until completing the transition to BEBs.

MCKINLEY GARAGE:
100%
Battery Electric & Hydrogen

McKinley Garage is planned to operate BEBs, FCEBs, and CNG buses in the near term and to transition to 100 percent BEBs and FCEBs in the long term. COTA has installed 40 plug-in charging dispensers (Phase 1), and plans to install an additional 40 dispensers in the near term (Phase 2) and finish the build out with 80 additional dispensers (Phases 3 and 4). The final build will have 160 charging dispensers. COTA plans to install hydrogen fueling at McKinley Garage in the near term and scale up hydrogen fueling as needed in the long term. COTA plans to use CNG at this facility until completing the transition to BEBs in the long term.

NEW FACILITY:
100%
Battery Electric & Hydrogen

Pending the outcome of the LinkUS Initiative, COTA plans to construct a third bus garage to support growing bus operations. COTA intends for this new garage to operate both BEBs and FCEBs. COTA will further define the fuel composition of this garage once future plans are more concrete.

AT LEAST THREE ON-ROUTE CHARGING LOCATIONS

COTA will utilize on-route charging at key locations to improve the range of the BEB fleet once BEBs cannot operate with depot-only charging. All on-route charging will be in the form of pantograph dispensers, each connected to one 300 kilowatt (kW) charging cabinet. COTA is currently planning and designing on-route chargers at the Easton Transit Center (two chargers), Westview Turnaround (two chargers), and Northland Transit Center (one charger). Chargers are anticipated to be available during the long-term strategy, and additional on-route chargers will be added as needed.

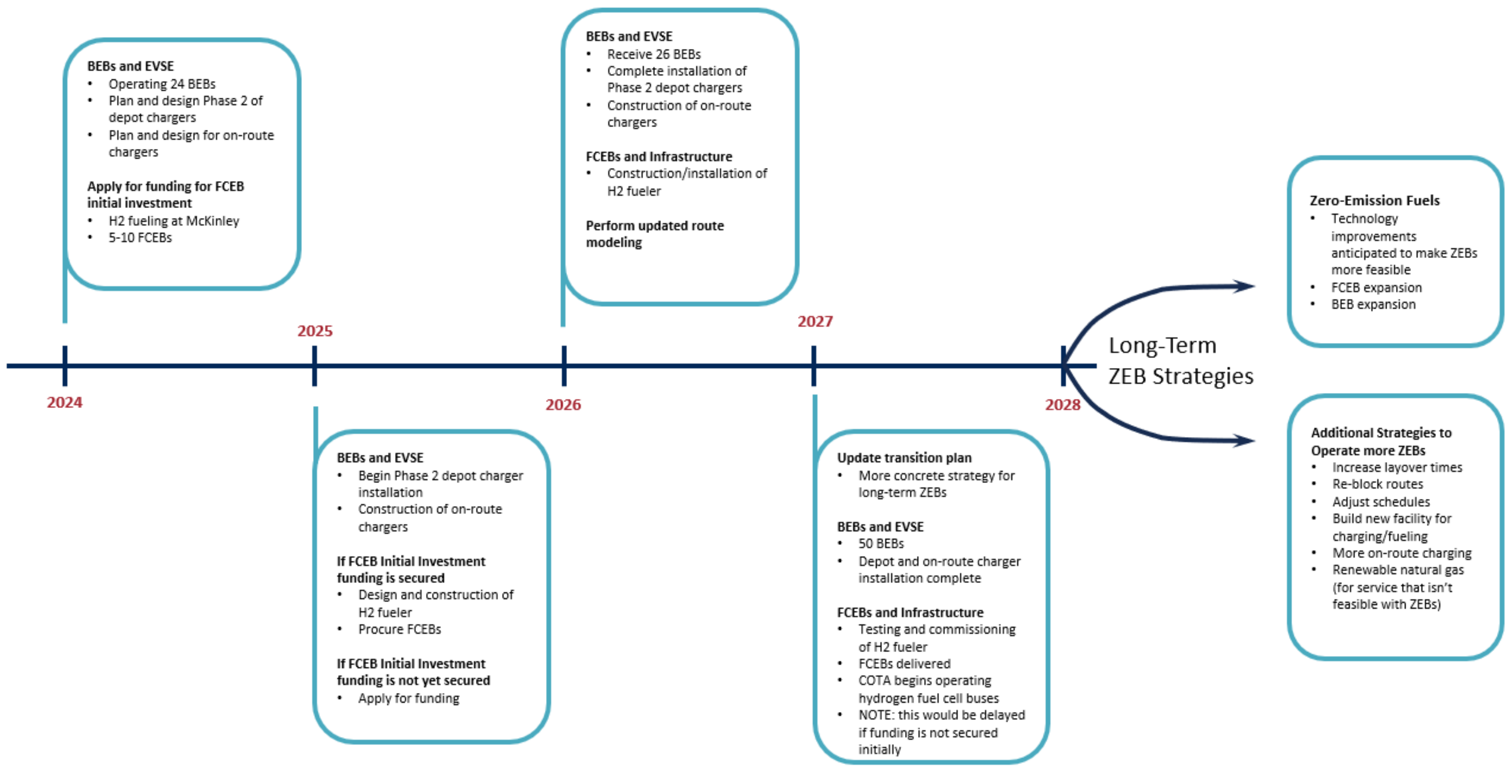


Figure 3: **ZEB TRANSITION TIMELINE**

2 PURPOSE FOR PLAN

COTA is committed to delivering innovative solutions that foster prosperity by connecting individuals. As the primary regional public transit provider for the greater Columbus area, COTA is responsible for delivering sustainable mobility solutions that align with evolving transportation-sector advancements and fulfill shifting customer expectations for transit services.

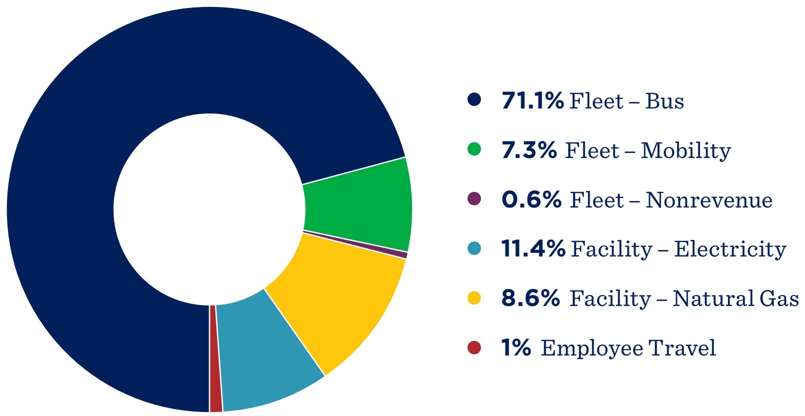


Figure 4: **COTA'S ANNUAL GHG EMISSIONS** (2019)

In 2021, the transportation sector accounted for 29 percent of greenhouse gas (GHG) emissions nationwide. With an increasing societal focus on eliminating emissions, transportation agencies across the nation have recognized the importance of decarbonizing operations. Establishing emission-free transit operations will reduce the transportation sector's contribution to emissions and benefit overall reduction goals. Regional governance, planning, and resources will be needed to transform and expand COTA's existing transit service to provide zero-emission mobility for all of its customers.

COTA's 2022 Sustainability Plan reflects its commitment to zero-emission mobility. The plan introduces a goal to have net-zero GHG and fine particulate matter (PM 2.5) emissions within all operations by 2045. Because COTA's bus fleet generates over 71 percent of its GHG emissions, transitioning to zero-emission fleet vehicles and facility operations is a crucial step in meeting its emission reduction goals. COTA aims to have a 100 percent zero-emission bus fleet by 2035.

CNG

BEB

COTA's journey to zero-emission bus operations began with the introduction of compressed natural gas (CNG) vehicles in 2013. Battery electric buses (BEBs) were added to the vehicle fleet in 2021. Since the release of the 2022 Sustainability Plan, COTA has continued investigating emergent technologies and changing economics for zero-emission fleet vehicles. Advancements in hydrogen fuel cell electric buses (FCEBs), which use hydrogen fuel cells for energy, have expanded the options available for replacing COTA's existing CNG buses with zero-emission vehicles. Incorporating a mix of BEBs and FCEBs into COTA's growing zero-emission fleet will allow the flexibility needed to transition to 100 percent zero-emission bus operations while maintaining and expanding quality service for COTA's customers. Ongoing investigation will help assess the proportion of BEBs and FCEBs needed to meet COTA's service needs. This plan provides an update to COTA's 2022 Zero-Emission Transition Plan, building on various existing initiatives and resources to guide the transition from traditional fossil-fuel usage to emission-free vehicles and facilities.

PART 1

ANALYSIS

3 POLICY AND LEGISLATIVE IMPACTS

3.1 2024 Updates

FTA Low/No Emission Grant Program: COTA received $26.7 million in funding from the Federal Transit Administration's (FTA's) Low/No Emission Grant Program in 2022 to replace 28 diesel vehicles with BEBs. This resulted in 14 BEBs being added to COTA's fleet in 2023. An additional 14 BEBs will enter service in the second and third quarters of 2024. Additionally, COTA ceased purchasing CNG vehicles in 2021, and all diesel vehicles are expected to be retired by the end of 2024.

LinkUS: LinkUS is a partnership between COTA, the City of Columbus, Franklin County, and the Mid-Ohio Regional Planning Commission (MORPC). In November 2024, voters in the COTA service area will decide on a levy to increase COTA's sales tax revenue from 0.5 percent to 1 percent. This half-percent sales tax increase will, in part, help expand and improve COTA's existing transit system and provide funding for LinkUS high-capacity rapid transit projects, transit supportive infrastructure projects, and various other equitable transit-oriented initiatives. LinkUS highlights the connection between mobility, equity, and a reduction in carbon emissions for the region. The initiative is planned to provide at least five high-capacity bus rapid transit (BRT) corridors throughout Central Ohio, with improved bicycle and pedestrian facilities. Two of the five LinkUS rapid transit corridors are currently in the FTA's Capital Investment Grants Program, and a third will enter project development in 2024.

Vision Zero Columbus: In 2023, the City of Columbus completed a 2023–2028 Vision Zero Columbus plan update, which includes strategies to advance the goal of reducing traffic deaths and serious injuries to zero. Strategies within the plan that warrant partnership include updating COTA's safety equipment and developing design standards for BRT and other transit corridor improvements.

Zoning Code Changes: The City of Columbus is also in the process of reforming its zoning code, which has not undergone significant changes in over 70 years. The code update will promote higher-density zoning along more than 60 transportation corridors. This increased urban density will result in an increased demand for transit, impacting COTA service needs in corridor areas.

3.2 Policy and Legislative Impacts from 2022 Plan

COTA INITIATIVES

Sustainability Plan: In the 2021 Sustainability Report and 2022 Sustainability Plan, COTA outlined its commitment to sustainable transit, including achieving the following:

- ***100% low-emission vehicles by 2025***
- ***Net-zero GHG emissions by 2045***
- ***Net-zero PM 2.5 emissions by 2045***

Since 2013, COTA has reduced GHG emissions per vehicle mile by 11 percent and has reduced PM 2.5 emissions per vehicle mile by 73 percent. In October 2021, COTA's board approved the purchase of eight electric buses in 2022, in addition to the two that were already in use. COTA also updated its short-range (5-year) and long-range (30-year) transit plans to meet future demand and identify improvements to bus service and facilities.

Regional Partnerships: COTA's regional partnerships also reflect the agency's commitment to sustainability. COTA is an active partner with MORPC's program to address air quality issues for the region and is actively collaborating with the City of Columbus, MORPC, and Franklin County on the LinkUS mobility initiative. Released in 2020, the LinkUS Mobility Corridors Framework Strategy highlights workforce development strategies as well as streamlined strategies to implement transit infrastructure investments through a standardized, accelerated project development process.

CITY OF COLUMBUS INITIATIVES

Smart City Challenge: In 2016, the City of Columbus competed against 77 cities to win the first-ever United States Department of Transportation (USDOT)-hosted Smart City Challenge. This resulted in $50 million to form the Smart Columbus Initiative, which aims to reinvent transportation and mobility in central Ohio. The program prioritizes innovation and includes considerations for connected, autonomous, and electric vehicle (EV) projects.

Clean Energy Columbus: In November 2020, voters in Columbus voted yes in support of the city moving forward with a 100 percent clean energy aggregation program that is based in Ohio. In 2021 (after legislation passed), the City of Columbus released Clean Energy Columbus, which allows the city the right to contract for clean electricity and positions residents and businesses to become carbon neutral by 2050. The initiative is set to reduce the city's carbon emissions by about 1.2 million metric tons annually.

Climate Action Plan: In 2021, the City of Columbus released a climate action plan with the goal of reaching carbon neutrality by 2050. The transportation section of the plan details goals to increase private zero-emission vehicle (ZEV) adoption through development of an equitable EV charging plan by 2025. In addition, the plan addressed the goal of implementing ZEV fleets (as covered by the Green Fleet Action Plan, 2020) with the targeted goals of 100 percent of municipal light-duty passenger ZEVs by 2030, and 100 percent ZEV fleets by 2050. The City of Columbus' climate action plan also describes the goal of promoting medium- and heavy-duty ZEV adoption, with COTA listed as an implementing partner.

REGIONAL, STATE, AND NATIONAL INITIATIVES

Alternative Fuel Vehicle Acquisition and Fuel Use Requirement

In July 2015, Ohio passed the Alternative Fuel Vehicle Acquisition and Fuel Use Requirement into law, which set a requirement for all newly required state agency vehicles to be capable of using an alternative fuel and mandated that these vehicles must use the relevant alternative fuel if it is available and reasonably priced.

Ohio Department of Transportation (ODOT) Infrastructure Resiliency Plan

In May 2016, the ODOT Infrastructure Resiliency Plan was released to identify the vulnerability of ODOT's transportation infrastructure to climate change effects and extreme weather events, and potential approaches to adapt to these changes. Potential approaches outlined in the plan include specific procedures that focus on emergency transportation operations during extreme weather events.

Climate Change Coalition

In February 2018, the Ohio State University joined a Climate Change Coalition, which is an alliance among leading North American universities that will create a collaborative model to help local communities achieve their climate goals and accelerate the transition to a low-carbon future.

Ohio State University Zero-Emission Vehicles

In 2022, Ohio State University received $26 million from the FTA through fiscal year (FY) 2026 to establish and operate a testing center to support the deployment of zero-emission and low-emission buses. In 2023, Ohio State University's Board of Trustees approved an update to the Campus Master Plan, Framework 3.0. The plan includes transportation and mobility improvements, such as several redesigned campus roadways and potential realignments for Olentangy River Road, Kinnear Road, and State Route 315 (locations that are also referenced for further study by the LinkUS Transit Plans).

Ohio University Sustainability and Climate Action Plan

In April 2021, Ohio University released a Sustainability and Climate Action Plan, with the goal of using the plan as a road map for the next 5 years of progress toward carbon neutrality and the university's climate commitments.

Bipartisan Infrastructure Law (BIL)

In 2022, USDOT announced nearly $1.5 billion in grants funded by the BIL to modernize bus fleets and facilities. This funding supports competitive FTA grant programs such as the Low/No Emission Grant Program and the Grants for Buses and Bus Facilities Program.

UTILITY/ENERGY INITIATIVES

American Electric Power (AEP) Ohio offers financial incentives for the hardware, network services, and installation of eligible Level 2 and direct current fast charging (DCFC) stations. Incentives are available in varying amounts to all nonresidential customers. EV charging stations must be installed at workplaces, government facilities, multi-unit dwellings, or other publicly available charging locations.

AEP joined the National Electric Highway Coalition (NEHC), committing to create a network of DCFC stations connecting major highway systems from the Atlantic to the Pacific coasts of the United States. NEHC utility members agree to ensure efficient and effective fast charging deployment plans that enable long distance EV travel, avoid duplication among coalition utilities, and complement existing corridor DCFC sites.

AEP has plans to achieve net zero carbon dioxide emissions by 2050, with an interim goal to cut emissions 80 percent from 2000 levels by 2030. AEP is investing $8.2 billion in renewables through 2026 and adding approximately 16,000 megawatts of regulated wind and solar through 2030.

Ohio has proven to be a leader in the emerging hydrogen (H2) industry. There are several organizations working toward promoting the production and utilization of hydrogen fuel cell electric vehicles (FCEV) within the region. The Ohio Fuel Cell Coalition was established to bring together industry, academic, and government leaders to strengthen Ohio's fuel cell industry. In addition, the Renewable Hydrogen Fuel Cell Collaborative (RHFCC) was established in 2016 through a collaboration with the Stark Area Regional Transit Authority (SARTA), based in Stark County, Ohio, and the Ohio State University Center for Automotive Research. This organization aims to establish the Midwest as a national leader in the adoption of hydrogen as a fuel and works to encourage the growth of this alternative fuel industry within Ohio and the region.

4 INTERNAL AND EXTERNAL ENGAGEMENT

4.1 2024 Updates

Continued Utility Coordination: In 2022, COTA confirmed that local utility providers can upgrade utility services to provide sufficient capacity to accommodate the full build out of BEBs in COTA's fleet. In 2023, COTA completed the necessary electrical upgrades at both Fields and McKinley Garages. Fields Garage can now accommodate 130 BEB chargers, and McKinley Garage can now accommodate 160 BEB chargers.

Hydrogen Availability: COTA is coordinating with H2 providers in order to find the most suitable H2 partner that will meet the agency's short- and long-term needs. ***See Appendix 2:* Hydrogen Fuel Cell Electric Bus Feasibility Study** for more details on hydrogen availability coordination.

Hydrogen Infrastructure: COTA conducted interviews with six industry leading hydrogen infrastructure providers to stay current on industry knowledge, provider options, and best practices for working with hydrogen vendors. ***See Appendix 2:* Hydrogen Fuel Cell Electric Bus Feasibility Study** for more details on hydrogen infrastructure coordination.

Peer Agency Interviews: COTA also conducted informational interviews with six transit agencies to learn about their hydrogen fuel cell bus programs and gather trends and takeaways to inform COTA's own efforts.

4.2 Engagement Efforts from 2022 Plan

COTA developed an Internal and External Stakeholder Engagement Action Plan to facilitate decision-making and knowledge sharing during the process of introducing new ZEB technology to the complex operation of daily transit service. The goal of COTA's stakeholder engagement plan is to create an environment of transparent and efficient communication and efforts surrounding the ZEB transition. Engaging with stakeholders early and often will mitigate the risk of late-program changes. Throughout the engagement process, findings and stakeholder feedback will be integrated into revising strategies in a responsive and iterative process. This plan represents a suggested framework for communications, and it is expected that the stakeholders involved will adjust the process and meet as needed to account for dynamic operational demands.

This plan was developed based on COTA's existing management structure and available industry research.[2]

[2] *Boren, Sven and Grauers, Anders, "Stakeholder Collaboration Models for Public Transport Procurement of Electric Bus Systems," The International Journal of Sustainability Policy and Practice (January 2019).*

INTERNAL STAKEHOLDER ENGAGEMENT WORKING GROUPS

Conversations with peer agencies have highlighted the significance of interdepartmental communication and collaboration in a successful fleet electrification transition. A clear understanding and agreement throughout the agency in terms of goals, responsibilities, timelines, and standards will support COTA as they navigate new technologies while maintaining a high level of service to the region. The objective of internal stakeholder engagement working groups is to foster collaboration between key partners involved with COTA's ZEB transition, identify crucial components to facilitate decision-making and knowledge sharing, and achieve a transparent level of communication between all internal stakeholders. To encourage sound procurement decisions and iterative learning through the implementation of the ZEB Transition Plan, the following working groups are intended to foster collaboration and efficiency:

Table 2: **WORKING GROUP SUGGESTED MEETING FREQUENCY**

WORKING GROUP	SUGGESTED MEETING FREQUENCY
ZEB Vehicle Procurement	Every other month, shifting to monthly for 3 months leading up to vehicle procurement
ZEB Infrastructure Procurement	Every other month, shifting to monthly for 3 months leading up to vehicle procurement
Operations and Maintenance	Monthly year-round

ZEB Vehicle Procurement and Performance Review

- COTA procures vehicles annually. It is recommended that this group meet every other month throughout the year, shifting to monthly meetings leading up to procurement. This frequency will allow the group to review performance metrics and lessons learned from the previous year and to set expectations leading to negotiations with the original equipment manufacturer (OEM). In addition, this group will work to ensure adequate storage of parts necessary for preventative maintenance of the new buses. This will likely require coordination with the OEM.
- In addition to vehicle procurement coordination responsibilities, a subgroup within this working group will be tasked with evaluating ongoing training practices and the overall workforce development necessary for ZEB transition. To support the deployment of ZEB technologies, it will be necessary to coordinate training efforts to ensure a workforce that safely and effectively maintains ZEBs. This includes, but is not limited to, trainings on ZEB bus systems, basic electric/electronics, and high-voltage safety.

Decisions made will include the following: adjustments as necessary to procurement schedules, purchasing buses, and assigning buses to facilities with capacity and feasible routes for ZEB deployment (in coordination with Service Planning and the ZEB Infrastructure team, detailed below).

Involved Departments and Individuals: include Operations Engineering (Wesley Oliver), Capital Projects (Joe Massey), Supply Management (Joshua Traenkle and Jeff Salyers in Supply Management and Stores), and Finance (Joshua Traenkle and Matt Miller).

ZEB Facilities and Infrastructure Procurement

- Infrastructure is procured in phases but may not be procured regularly. It is recommended this group meet every other month throughout the year, shifting to monthly leading up to vehicle procurement. This will ensure that this working group can coordinate effectively with the ZEB Vehicle Procurement working group to ensure that growth of ZEBs and fueling infrastructure decision points align with the infrastructure phasing outlined in the transition plan to evaluate lessons learned through procurement, design, and implementation of previous phases.

Decisions made will include the following: infrastructure procurement, design, and construction timelines in response to, and in advance of, vehicle procurements. This will require coordination with the planning department and ZEB vehicle procurement working groups to ensure capacity and coverage of routes.

Involved Departments and Individuals: include Operations Engineering (Wesley Oliver), Capital Projects (Joe Massey), Supply Management (Joshua Traenkle and Jeff Salyers in Supply Management and Stores), Finance (Joshua Traenkle and Matt Miller), Andrew Biesterveld, and Facilities (Tim Smith).

Ongoing Review of Operations and Maintenance

- This group is recommended to meet monthly to objectively evaluate operations and maintenance practices. It is recommended that this working group coordinate with the ZEB Vehicle Procurement group as well as the ZEB Infrastructure Procurement group to meet monthly leading up to vehicle and infrastructure procurement.

Decisions made will include the following: routes/tasks on which to operate ZEB vehicles, changes to routing/blocking necessary for range/on-route charging needs of ZEB technology, changes to maintenance practices, updating training and workforce development resources, purchases of relevant training materials, and coordination of workforce development efforts with external stakeholders.

Involved Departments and Individuals: include Human Resources (HR) People and Culture, including, but not limited to – Labor Relations and Safety: Russ Burton; and Labor Relations: Julie Williams. From HR Learning and Development – Instructional Design: Ryan Smith; Training Managers: Steve Perkins, Tyler Willis, Max Camper, Bill Williams, and Marcus Collier. In addition, representatives from Operations Engineering should be involved in this working group.

EXTERNAL STAKEHOLDER ENGAGEMENT

COTA has identified the following external stakeholders as critical partners to ensure the efficient transition to a ZEB fleet. These partners fall into two high-level categories: Power Management, and Maintenance and Training. The Power Management partners will be key in coordinating integration of a new technology into the electrical grid responsibly and economically, while the Maintenance and Training partners will help to ensure that the workforce supporting this deployment is trained for a safe and reliable transition to a new technology. The following list details the expected responsibilities of each external stakeholder as well as details on recommended coordination efforts.

Power Management

Utilities: American Electric Power (AEP) and the Columbus Department of Power (DOP)

- COTA will coordinate with AEP to make upgrades to existing connections at facilities in advance of bus delivery to ensure charging capacity.
- Once the available electrical capacity is dedicated to chargers, COTA will coordinate with DOP to design grid upgrades to provide new power feeds at facilities that will ensure electrical capacity for a growing ZEB fleet.
- COTA's ZEB Infrastructure Procurement working group is expected to work closely with these external stakeholders to ensure timely delivery of services.

Charging Management

- The chosen charging management consultant will coordinate with Operations Engineering, including Telematics and Fleet System Engineering, to develop and monitor a smart charging system for both depot charging and on-route charging.

Charger Manufacturers

- The chosen charger manufacturer will coordinate with Operations Engineering and Facilities to ensure charger/vehicle compatibility and safe operations at charging locations.

Maintenance and Training

Bus Manufacturer

- The ZEB Vehicle Procurement working group will collaborate with New Flyer to define bus delivery timelines and to build contract language supportive of an early-stage deployment of ZEBs. This involves adding language that will support the continuation of workforce training courses and materials. Additionally, a specific maintenance warranty period should be defined to allow sufficient time for new ZEB technicians to become proficient in both performing preventative maintenance and utilizing the manufacturer's warranty.

Training Resources: CTE, Community Colleges, Training Resource Materials Providers

- These stakeholders will engage with the Ongoing Review of Operations and Maintenance working group to collaboratively design and implement workforce development resources, including software for tracking training goals and progress, and establishing training standards and certifications.

5 EXISTING CONDITIONS

Initiated in 2013 with CNG vehicles, COTA's journey towards emission reduction has greatly advanced, with strategies continuously evolving to ensure the agency's goals are met. In its 2022 ZEB Transition Plan, COTA prioritized the procuring of BEBs to reduce operational emissions from the bus fleet. Since then, COTA has made progress in acquiring a substantial number of BEBs and installing the necessary infrastructure to support the operation of these vehicles. Building on this momentum, COTA implemented strategic approaches to replacing aging-out diesel buses with BEBs in the coming years, decommissioning most remaining diesel buses when their replacement year came. COTA's commitment to a 100 percent zero-emission bus fleet has been unwavering, adapting and progressing forward based on lessons learned and advancements in zero-emission bus technology. While the 2022 plan aims to achieve 100 percent EVs by 2035, ongoing evaluations will refine this target based on changing economics, emerging technologies, and EV technology's ability to meet resiliency and business continuity objectives.

At the time of this 2024 ZEB transition update, COTA continues to take significant strides towards achieving its goal of becoming a fully zero-emission fleet, and was awarded a 2022 Low/No Emission Grant by the FTA, in recognition of the agency's commitment to sustainable transportation and to drive implementation efforts forward. Additionally, COTA has procured a total of 50 BEBs and has installed multiple charging stations at Fields Garage (10 charging dispensers) and McKinley Garage (40 charging dispensers).

Looking ahead, COTA has developed a comprehensive charging strategy for the years 2023 to 2027, which takes into consideration both BEB and FCEB technology. To determine the best approach to ZEB implementation, COTA conducted a hydrogen feasibility study in 2023, and the results have played a crucial role in shaping the phased approach COTA will take toward infrastructure, fleet composition, and vehicle acquisition. The 2024 ZEB Transition Plan will outline COTA's near-term (2024 to 2027) and long-term (after 2027) phases, highlighting the most effective way to achieve its zero-emission goals.

6 ZERO-EMISSION VEHICLE MODELING

COTA's 2022 Fleet Transition Plan included modeling for a hypothetical transition from CNG vehicles to BEBs. Since this initial modeling, COTA has completed updated modeling that shows optimal on-route charging locations and use of FCEBs in place of CNG vehicles, and provides a detailed block analysis that shows where BEBs and/or FCEBs could be operated within each block at each facility. These modeling updates help COTA refine its near-term ZEB strategy to create a detailed approach for the exact service each ZEB would provide and to indicate from which garage each ZEB would be based.

6.1 On-Route Charger Modeling

In order to effectively deploy BEBs on COTA's more challenging routes, on-route fast chargers at multiple sites may be required. On-route chargers provide opportunities for BEBs to charge during layovers while out in service instead of returning to the garage when running low on charge. These chargers provide about three times as much power and charge the battery much faster with about 1.5 percent per minute of charge. On-route charging extends the operating range of the vehicle enough to meet the needs of COTA's routes, which will improve the feasibility of transitioning the fixed route bus fleet to 100 percent zero-emission buses.

COTA engaged a team of consultants to analyze a variety of transit centers and COTA properties to evaluate which sites are good candidates for the placement of on-route chargers. During this analysis, the team consulted AEP on electrical capacity at each location, developed schematics from an electrical engineer, performed a route modeling analysis, and met with internal COTA stakeholders from Operations, Engineering, Scheduling, Facilities, and Capital Projects to better understand COTA's bus route network and supporting facilities. This on-route charger location assessment resulted in the recommendation of five sites as prime candidates for on-route fast chargers as detailed in **Table 3** and shown in **Figure 5** below.

Table 3: **ON-ROUTE CHARGER LOCATIONS CANDIDATES**

FACILITY NAME	NUMBER OF ROUTES SERVED	AVERAGE LAYOVER TIME	BLOCKS RELYING ON ON-ROUTE CHARGING	ELECTRICAL CAPACITY (kW)	NUMBER OF ON-ROUTE CHARGERS POSSIBLE
EASTON TRANSIT CENTER	9	14m 40s	51	2,890	6
WESTVIEW TURNAROUND	3	13m 02s	25	1,400	3
NORTHLAND TRANSIT CENTER	1	15m 04s	9	1,860	4
REYNOLDSBURG PARK & RIDE	2	9m 00s	10	6,930	15
NORTH TERMINAL	6	6m 42s	3	5,000	11

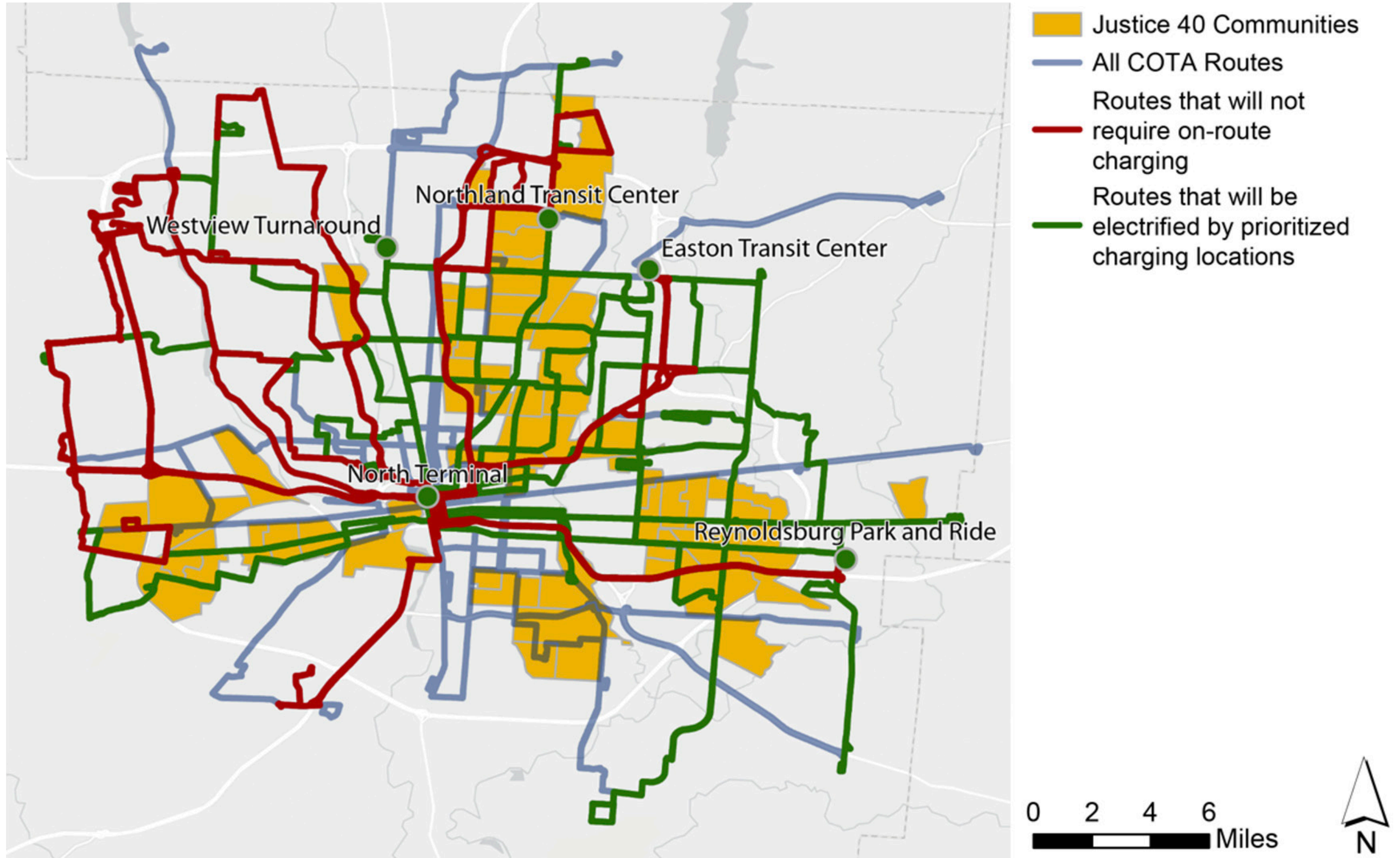


Figure 5: **POTENTIAL SITES FOR ON-ROUTE CHARGING**

Of these five sites, COTA decided to focus first on the top three sites for layover time: Easton Transit Center, Westview Turnaround, and Northland Transit Center. Further information regarding on-route charging plans for these sites can be found in **On-Route Charging.** For complete details on the on-route charging assessment conducted, ***see Appendix 1:* On-Route Charger Location Assessment.**

6.2 Hydrogen Fuel Cell Electric Bus Modeling

As part of the hydrogen fuel cell bus feasibility study, COTA worked with a team of consultants to perform FCEB modeling that depicts what bus service could be operated with FCEBs. COTA performed route modeling to consider "worst-case operating conditions" to ensure that FCEBs could successfully operate in cold winter weather, with full passenger loads, and assuming FCEB end-of-life battery degradation. When considering for worst-case conditions, route modeling showed that 147 out of 223 blocks (66 percent) could be operated with FCEBs, shown as "easy" in **Figure 6.** The remaining 76 blocks were categorized as "medium," indicating that technology improvements, route changes, or a combination of both could make these blocks feasible for FCEB operation. ***See Appendix 2:* Hydrogen Fuel Cell Electric Bus Feasibility Study** for complete details on route modeling.

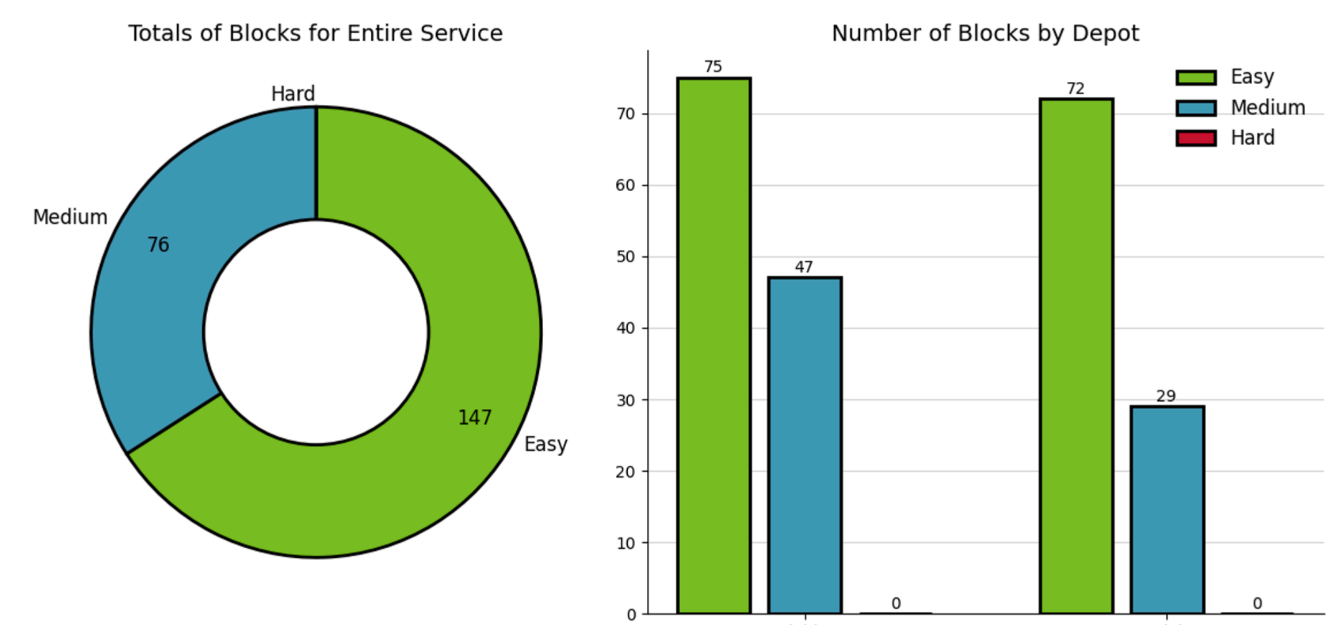


Figure 6: **FCEB BLOCK FEASIBILITY**

6.3 BEB and FCEB Block Analysis

COTA worked with a consultant to determine the maximum quantities of BEBs operated before on-route charging is needed, and the number of blocks BEBs and FCEBs could operate out of each facility.

After determining on-route locations, COTA determined the BEB adoption threshold where depot charging is no longer sufficient and on-route charging would be required. **Table 4** shows the total feasible blocks when considering depot-only BEB charging, three different levels of on-route charging, and FCEB operations. With the current service model, COTA could operate 107 blocks (48 percent of blocks) before on-route charging is needed. It would require 55 BEBs (26 at Fields and 29 at McKinley) to operate these blocks. Once COTA exceeds these bus quantities, on-route charging would be required to continue operating BEBs in this current service model. If service were to significantly change, these thresholds would also change.

Table 4: **BEB AND FCEB BLOCK ANALYSIS RESULTS**

	DEPOT ONLY	SOME ON-ROUTE CHARGING (6 CHARGERS)	MODERATE ON-ROUTE CHARGING (9 CHARGERS)	MAXIMUM ON-ROUTE CHARGING (14 CHARGERS)	FCEB
TOTAL FEASIBLE BLOCKS	107	128	128	145	147
% OF BLOCKS	48%	57%	57%	65%	66%
BEBs NEEDED	55	79	72	88	80
BEBs AT FIELDS	26	45	39	43	-
BEBs AT MCKINLEY	29	34	33	45	80

This analysis also indicated the exact routes and blocks that BEBs and FCEBs could operate from each garage. Overall, COTA could operate some blocks within the following routes with depot-only charging: **blocks 3, 10, 22, 23, and 25.**

COTA could operate all blocks within the following routes with depot-only charging: **blocks 21, 31, 32, 33, 34, 41, 42, 43, 44, 45, 46, 51, 52, 61, 71, 72, 73, 74, and 75.**

Appendix 3: **BEB and FCEB Feasible Blocks by Garage** shows a complete list of the blocks and routes that could be operated with each technology.

PART 2

FLEET TRANSITION PLAN

7 ZERO-EMISSION VEHICLE STRATEGY

7.1 Near-Term Strategy (2024-2027)

NUMBER OF BEBs
70

5-15
FCEBs

H_2
INFRASTRUCTURE

DESIGN FOR UP TO 130 CHARGING STATIONS

PLANNING ADDITIONAL DEPOT CHARGERS AND ON-ROUTE CHARGERS

7.1.1 BATTERY ELECTRIC BUSES

COTA's near-term zero-emission bus strategy focuses heavily on BEBs and begins to integrate FCEBs into the fleet. Forty-eight percent of COTA's blocks can be operated with BEBs that charge at the depot. COTA is first prioritizing depot charging for BEBs, but, like many transit agencies, COTA operates long routes which would require the use of on-route charging if operated with BEBs. COTA plans to maximize BEB operations with depot charging first, then will implement on-route charging in the long-term strategy. COTA can operate up to 55 BEBs and 48 percent of blocks before on-route chargers are required. Once reaching a fleet of 60 BEBs, COTA intends to re-block some service so that all 70 BEBs can operate through COTA's bus network.

Table 5 shows the procurement year and operational year for each order of BEBs in the near-term strategy. COTA will operate 50 BEBs by the end of 2024, plans to operate 60 BEBs by the end of 2025, and plans to operate 70 BEBs by the end of 2026. COTA will continue procuring BEBs in 2026; however, the exact BEB quantities have not yet been determined. COTA aims to continually assess bus service, available charging infrastructure, and ZEB technology to ensure that all BEB procurements have a place within COTA's service and will be successful upon delivery.

Table 5: **BEB PROCUREMENT AND OPERATIONAL SCHEDULE**

PROCUREMENT YEAR	OPERATIONAL YEAR	QUANTITY OF BEBs
2020	2022	10
2022	2023	14
2023	2024	26
2024	2025	10
2025	2026	10
2026	2027	TBD
TOTAL		**70**

COTA has installed 50 depot chargers at its 2 bus garages: 10 chargers at Fields Garage and 40 chargers at McKinley Garage. COTA is looking to design 80 additional depot chargers at both garages in the near-term strategy and to install chargers at the end of the near-term strategy or beginning of the long-term strategy. These chargers are intended to charge the 20 BEBs procured in 2024 and 2025, serve as spare chargers to improve resiliency of the BEB fleet, and charge future BEB purchases (COTA is working toward scaling up bus service to pre-COVID capacity).

COTA has also begun planning for on-route chargers and has identified three optimal locations for on-route chargers: Westview Turnaround, Easton Transit Center, and Northland Transit Center. **Figure 7** shows the location of each of these sites in relation to COTA's two bus garages. The Westview Turnaround is planned to have two on-route pantograph chargers; Easton Transit Center is planned to have two on-route pantograph chargers; and Northland is planned to have one on-route pantograph charger. COTA has begun planning and design work for the three locations and plans to have the on-route chargers completed by the beginning of the long-term strategy (2028).

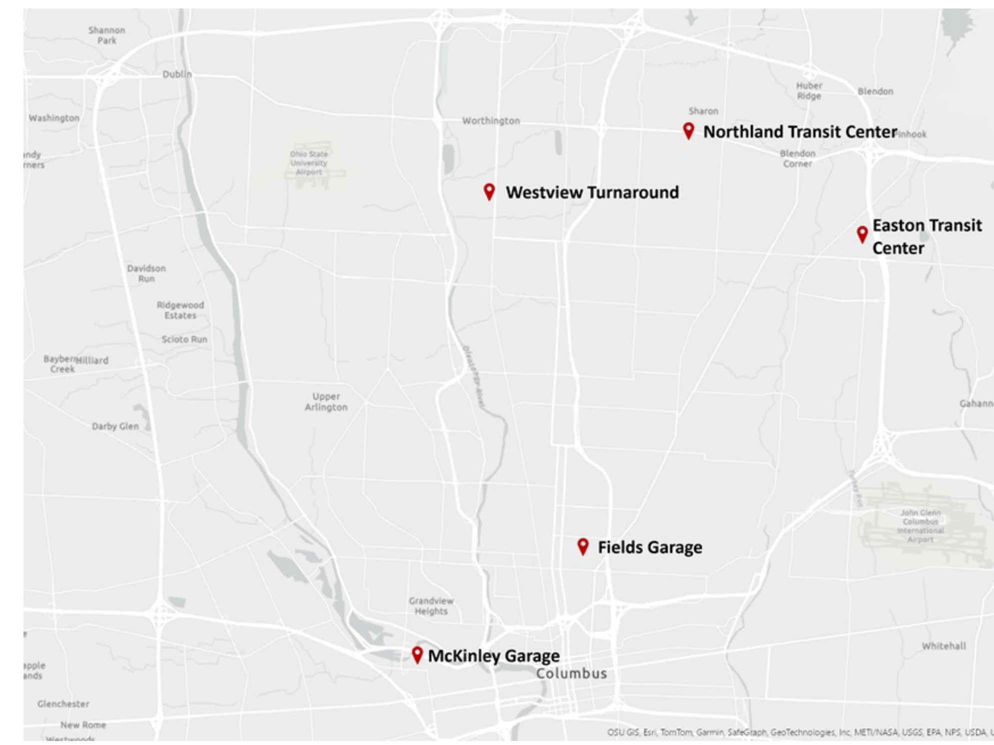


Figure 7: **FUTURE ON-ROUTE CHARGING LOCATIONS**

7.1.2 HYDROGEN FUEL CELL BUSES

COTA completed its hydrogen fuel cell bus feasibility study in 2023 and, from this study, determined that FCEBs would be beneficial to its fleet and developed a strategy on its first steps toward FCEBs.

COTA plans to procure an initial installment of hydrogen fuel cell buses in the near-term strategy. The initial installment for FCEBs would serve as a crucial step towards integrating FCEBs into COTA's bus fleet and meeting COTA's ZEB goals. This initial installment would include 5 to 15 FCEBs (dependent on funding availability) that would be fueled with hydrogen infrastructure at McKinley Garage. Feasibility study findings indicate that McKinley Garage is the ideal facility for hydrogen infrastructure, as it has three areas that could accommodate a hydrogen fueling station. In 2024, COTA will finalize infrastructure type and location and then develop specifications, which will allow COTA to go out to bid for hydrogen fueling infrastructure.

To fund this initiative, COTA will apply for grant funding in 2024, and again in 2025 if the funding is not initially awarded. Assuming that funding is awarded in one of those years, H2 infrastructure and FCEBs would be purchased and FCEBs would begin revenue service in 2026 or 2027.

The purpose of this initial installment is for COTA to gain experience with a smaller number of FCEBs before integrating a larger number of FCEBs into the fleet. It will be important for COTA to focus on FCEB workforce development for operators and bus maintenance specialists to ensure that the workforce is prepared to operate and maintain future FCEBs.

7.1.3 UPDATE ROUTE MODELING

COTA plans to update zero-emission vehicle route modeling in 2025–2026 to accurately capture bus fleet growth, service growth, and zero-emission bus technology advancements.

At the time of writing this plan, COTA is operating a reduced service model that was established during COVID. Like many transit agencies across the United States, COTA is experiencing an operator shortage which prevents the agency from scaling bus service back up to pre-COVID levels. COTA is working toward hiring more operators and intends to scale up service to pre-COVID levels. Additionally, local legislation may pass, which will allow COTA to expand its bus service. If this legislation passes, COTA is looking to expand its bus fleet, implement new BRT routes, and establish a third bus garage.

Significant changes in an agency's bus operations or fleet size indicate the need to re-run zero-emission vehicle modeling. Future BRT service, return to pre-COVID service levels, or possible new service as a result of LinkUS was not reflected in route modeling, as this service does not exist today. A new model would also reflect a larger bus fleet size and potentially new fixed-route services. Lastly, re-running the zero-emission vehicle modeling will account for technology improvements anticipated for both BEBs and FCEBs. This updated route modeling will inform the long term zero-emission bus strategy.

7.1.4 UPDATE TRANSITION PLAN

After updated route modeling is completed to reflect the new service model, COTA will update this Transition Plan to include a more detailed long term zero-emission bus strategy. The long term transition strategy is intended to complete COTA's vehicle transition and operate 100 percent zero-emission buses by 2035.

7.1.5 VEHICLE PROCUREMENT SCHEDULE

Table 6 shows the anticipated procurement schedule for BEBs and FCEBs in the near-term strategy. This table represents the ideal procurement schedule; however, total vehicles may vary depending on the funding available. The FCEB procurements are particularly dependent on new forms of grant funding. FCEB procurement assumes that discretionary grant funding is secured and that COTA can procure the maximum number of FCEBs desired for the initial installment.

Table 6: **ANTICIPATED BEB AND FCEB PROCUREMENT SCHEDULE (NEAR-TERM STRATEGY)**

PROCUREMENT YEAR	OPERATIONAL YEAR	BEB	FCEB
Existing		24	—
2022	2024	26	—
2023	2025	—	—
2024[3]	2025	10	—
	2026	—	5–10
	Total	**60**	**5–10**
	TOTAL ZEBs	**65–75**	

[3] *This procurement schedule anticipates a 12 month lead time for BEBs and a 16 to 24 month lead time for FCEBs.*

7.2 Long-Term Strategy (2028–2035)

BEBs | **FCEBs**

DEPOT CHARGERS | **ON-ROUTE CHARGERS** | **EXPANDED H_2 INFRASTRUCTURE**

COTA's long term zero-emission bus strategy is planned to consist of BEBs and FCEBs. This section describes the overall strategy anticipated in the long term. BEB and FCEB quantities, time frames, and infrastructure specifics would be determined after the updated route modeling, as it is not possible today to know what COTA's future bus fleet will need.

7.2.1 BATTERY ELECTRIC BUSES

COTA intends to continue purchasing BEBs through the long-term strategy. The installation of on-route chargers and additional depot chargers will create opportunity for more blocks to be operated with BEBs. BEB quantities and a procurement schedule would be determined after the 2025–2026 route modeling is completed. COTA aims to continually assess bus service, available charging infrastructure, and ZEB technology to ensure that all BEB procurements have a place within COTA's service and will be successful upon delivery. BEBs procured in the long term will utilize the extensive depot charging infrastructure installed at Fields and McKinley Garages, as well as on-route charging stations.

7.2.2 DEPOT AND ON-ROUTE CHARGING

COTA is planning for the expansion of depot and on-route charging in the near term and, in the long term, will have additional charging installed across multiple locations. COTA will have additional depot chargers at both garages and at least five on-route chargers at three locations. Updated route modeling will inform where new on-route charging stations should be installed, and COTA plans to expand the on-route charging network accordingly in the long term.

7.2.3 HYDROGEN FUEL CELL BUSES

COTA also intends to continue purchasing FCEBs and expand FCEB operations. The initial installment of FCEBs in the near term will help COTA determine the level of investment in FCEBs into the long term. For the long-term FCEB strategy, COTA would expand the hydrogen storage and distribution system at McKinley Garage. This hydrogen infrastructure would serve the initial installment of FCEBs and new FCEBs procured during the long-term strategy. Ideally, this hydrogen fueling system would serve up to 50 FCEBs; however, exact quantities would be determined through the 2025–2026 route modeling.

7.2.4 ADDITIONAL ZEB STRATEGIES

COTA is committed to transitioning the bus fleet to zero-emission vehicles by 2035. Overall, ZEB technology trends indicate that ZEBs in 2030 would have larger ranges and operational hours available than the ZEBs available today. Technology improvements are expected to create more opportunity for ZEB operations in the future.

If ZEB technology does not allow for a full transition in the long term, COTA is exploring various strategies to transition the rest of the fleet. Below are strategies being considered by COTA, which will be discussed and developed as the long-term time horizon draws closer.

Increasing Layover Times: In addition to expanded on-route charging, COTA may increase layover times throughout the BEB network to allow for more charging time. Increasing layover times will provide BEBs with more opportunity to charge throughout the service day, therefore increasing the daily range and operational hours of the BEBs. Increasing layover times also provides operators with longer breaks through their shifts, which could be helpful with operator satisfaction and retention. Updated modeling will inform the usefulness of increasing layover times at specific on-route charging locations.

Re-Blocking: COTA may adjust the fixed route bus network to create blocks more suitable for BEBs or FCEBs. Splitting blocks differently and avoiding blocks that travel long distances for a majority of the day will provide more opportunities for ZEB operations. Additionally, COTA will consider moving blocks and routes between garages if that will help operate more ZEBs.

Third Bus Garage: With success of the LinkUS initiative, COTA's growing fleet and expanding service will likely require a third bus garage. Having a third bus garage will create a new location for depot charging and hydrogen fueling infrastructure, which may improve the ability to operate ZEBs throughout COTA's bus network. Because this would be a new facility rather than a retrofit, COTA could design the garage for BEBs and FCEBs. This would ensure that abundant charging and hydrogen fueling could be available at this garage and, therefore, create more opportunities for ZEB operations.

Alternatives to ZEBs for Achieving Emission Goals: If ZEBs are not feasible even with all other strategies considered, COTA would explore improving the

sourcing of natural gas as a way to reduce emissions until ZEBs become feasible for the entire fleet.

Responsibly sourced gas (RSG) is a term for natural gas that comes from mines that offset GHGs created during the mining process with other sustainable practices. RSG undergoes independent third-party assessment to validate it as RSG. To receive this distinction, companies must demonstrate they are (1) below a certain threshold for methane emissions intensity and using best practices for mitigating it, (2) minimizing community and environmental impacts, and (3) responsibly managing water, waste, and other resources. RSG is not a zero-emission solution; however, it is cleaner than conventional natural gas, gasoline, or diesel.

COTA is also investigating using renewable natural gas (RNG). This gas comes from organic waste material that produces methane, rather than being mined like conventional natural gas. RNG can come from sources such as food waste, landfills, or farms, and would greatly reduce the emissions associated with natural gas use because it would greatly reduce or eliminate the emissions associated with producing the gas. There would still be emissions during the burning of RNG, however, just like with conventional natural gas. Like RSG, RNG is not a zero-emission solution, but it is cleaner than conventional natural gas, gasoline, or diesel.

7.1.1 Timeline

Figure 8 shows a timeline of the fleet transition plan in the near and long term as described in the previous sections.

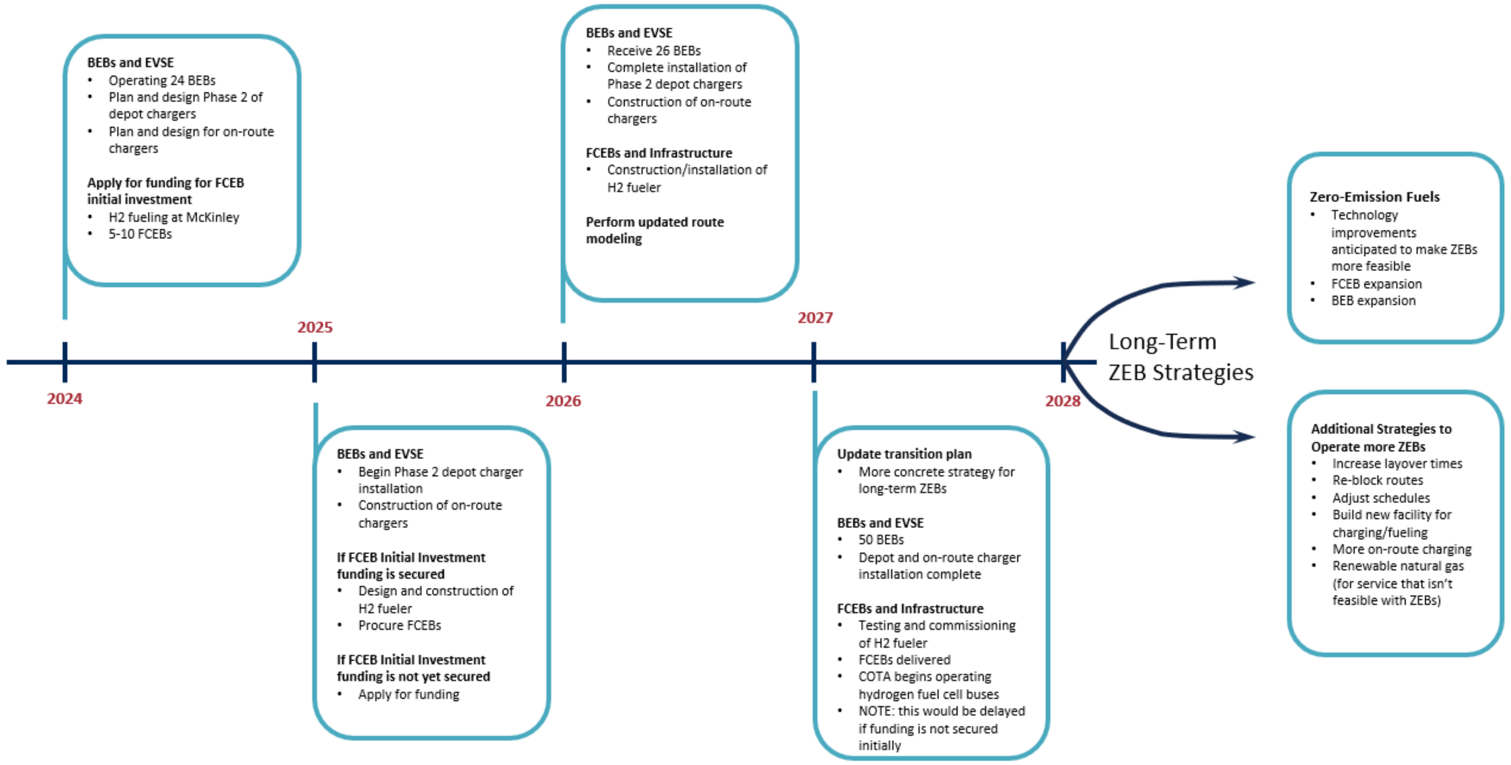


Figure 8: **ZEB TRANSITION TIMELINE**

8 FACILITIES AND INFRASTRUCTURE PLAN

8.1 Fields Garage

Fields Garage is planned to operate CNG buses and BEBs in the near term. During the hydrogen fuel cell electric bus feasibility study, hydrogen was determined to be an operational challenge at Fields Garage and was not considered at this time.

8.1.1 BATTERY ELECTRIC BUS INFRASTRUCTURE

COTA has dedicated resources to install electric vehicle supply equipment (EVSE) at Fields Garage in four phases. By the end of Phase 4, COTA plans to have a maximum of 130 dispensers and 66 charging cabinets at this garage. All charging will be done through plug-in dispensers mounted from the ceilings. Each charging cabinet will power two plug-in dispensers. Buses will utilize smart charging software to charge buses on a schedule, to minimize utility costs. Charger and cabinet installations are shown in **Table 7.** This table shows only the charging infrastructure installed at Fields Garage; each phase will also include charging infrastructure at McKinley Garage. Charging infrastructure at Fields Garage will be installed with the existing bus parking, allowing buses to charge where they normally park. The exact quantity of chargers and dispensers may change depending on BEB needs.

Table 7: **BEB CHARGING AND CABINET INSTALLATIONS AT FIELDS GARAGE ONLY**

	CABINETS INSTALLED	DISPENSERS INSTALLED	TOTAL CABINETS	TOTAL DISPENSERS
FIELDS PHASE 1 (EXISTING)	6	10	6	10
FIELDS PHASE 2	20	40	26	50
FIELDS PHASE 3	20	40	46	90
FIELDS PHASE 4	20	40	66	130
FIELDS TOTAL	**66**	**130**		

8.1.2 HYDROGEN FUEL CELL BUS INFRASTRUCTURE

The hydrogen fuel cell bus feasibility study determined that Fields Garage presents multiple challenges for hydrogen fueling infrastructure, and this garage was not recommended for hydrogen at this time. The location for a hydrogen fueling station at Fields Garage is limited due to its surroundings. Three locations at Fields Garage were considered as possible hydrogen infrastructure locations. Two locations were determined to be infeasible, and the third was deemed to be operationally challenging. The first option was too close to railroad tracks, where a train has previously derailed, causing damage to COTA's property. The second option was deemed possible at the beginning of the study if COTA was able to purchase the land. It was later concluded that purchase of this land was not possible, making this location infeasible. The third option, which is possible but operationally challenging, is located in the employee parking area across the street from the main transit facility. It is possible to install hydrogen fueling infrastructure in this lot, but it is operationally difficult because fueling would be far from all other bus maintenance activities and would require the crossing of a public road at night to fuel. See **Figure 9** for all fueling locations considered.

Figure 9: **FIELDS GARAGE FUELING LOCATION OPTIONS**

8.2 McKinley Garage

8.2.1 BATTERY ELECTRIC BUS INFRASTRUCTURE

COTA has also dedicated resources to install EVSE at McKinley Garage in four phases. McKinley Garage is larger than Fields Garage and is therefore able to operate more EVSE. At the end of Phase 4, COTA plans to have a maximum of 160 dispensers and 80 charging cabinets at McKinley Garage. All charging will be done through plug-in dispensers mounted from the ceilings. Each charging cabinet will power two plug-in dispensers. Buses will utilize smart charging software to charge buses on a schedule, to minimize utility costs. Charger and cabinet installations are shown in **Table 8.** This table shows only the charging infrastructure installed at McKinley Garage; each phase will also include charging infrastructure at Fields Garage. Charging infrastructure at McKinley Garage will be installed with the existing bus parking, allowing buses to charge where they normally park.

Table 8: **BEB CHARGING AND CABINET INSTALLATION AT MCKINLEY GARAGE ONLY**

	CABINETS INSTALLED	DISPENSERS INSTALLED	TOTAL CABINETS	TOTAL DISPENSERS
MCKINLEY PHASE 1 (EXISTING)	20	40	20	40
MCKINLEY PHASE 2	20	40	40	80
MCKINLEY PHASE 3	20	40	60	120
MCKINLEY PHASE 4	20	40	80	160
MCKINLEY TOTAL	**80**	**160**		

8.2.2 HYDROGEN FUEL CELL BUS INFRASTRUCTURE

Following the site evaluation of both Fields and McKinley Garages, McKinley Garage was determined as the most suitable location for a hydrogen storage and distribution system. The McKinley Garage had more space available for H2 infrastructure, while Fields Garage only had room in certain areas. Additionally, the spaces available at McKinley Garage are better aligned with the operational flow of the facility and would not cause large changes in bus fueling patterns.

Figure 10 shows the planned placement of hydrogen fueling infrastructure. This location has been identified as a feasible spot for hydrogen infrastructure because it satisfies 2020 National Fire Protection Association (NFPA) 2 setback requirements and is conveniently located next to existing fueling. Current CNG fueling occurs under a canopy shown to the left of the proposed hydrogen fueling. COTA will conduct planning and design work for this hydrogen fueling station through 2024 and aims to complete construction/installation for the fueling station between 2025 and 2026. Fueling infrastructure is intended to be completed in 2026 to align with the delivery of the FCEBs in 2026.

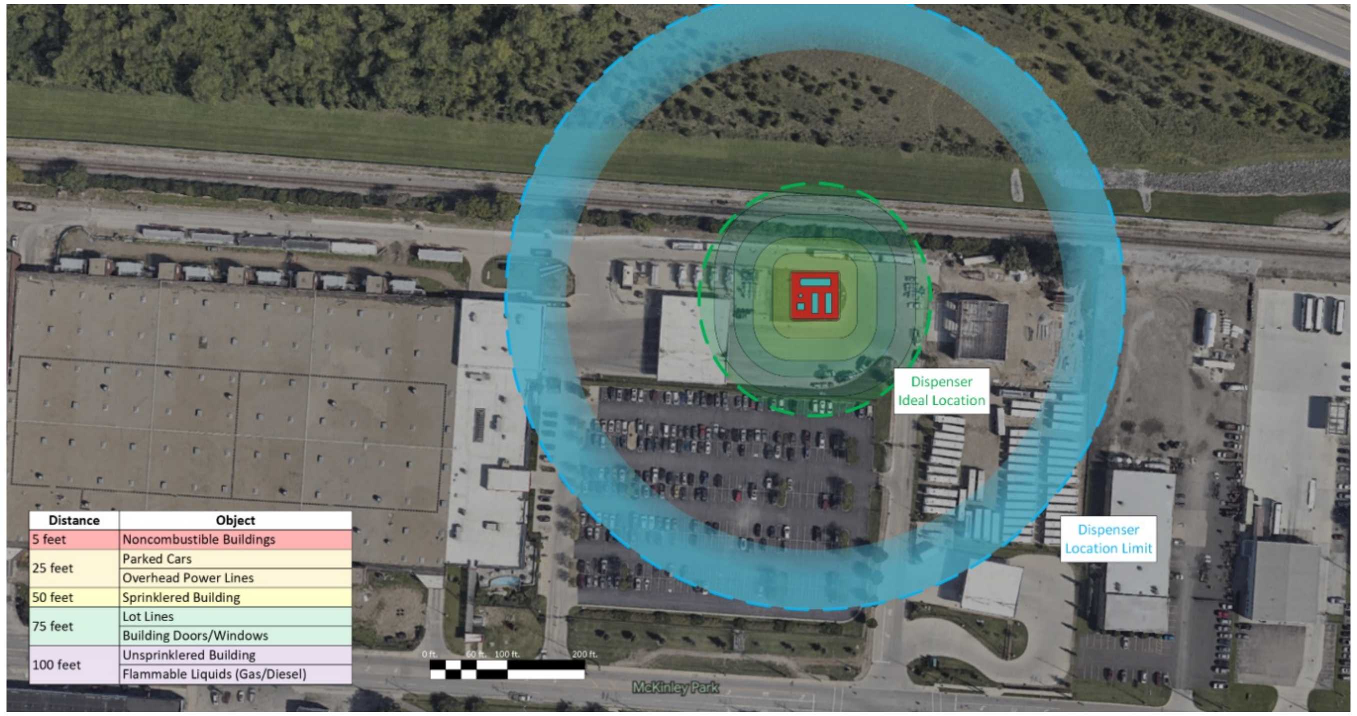


Figure 10: **HYDROGEN FUELING INFRASTRUCTURE PLACEMENT WITH 2020 NFPA 2 SETBACKS — MCKINLEY GARAGE**

8.3 Future Facility Considerations

COTA's fleet growth, anticipated service expansion, and ZEB growth necessitates a third facility in the long term. COTA has conducted preliminary discussions about operating a third facility within the 2028 to 2030 timeframe. COTA intends to pursue the construction of a third facility; however, the feasibility of opening a third facility will depend on funding availability and the outcome of the LinkUS Initiative.

If constructed, the new facility will be built to optimize both EVSE and hydrogen fueling. ZEB infrastructure would ideally be built during the facility's initial construction, as this would be more cost effective and minimize operational disruptions compared to a retrofit. It will also be ideal to coordinate with the utility about power availabilities before selecting a site. This will provide COTA with information on the existing power supply, possible power supply (if upgrading utilities), and costs associated with utility upgrades. If upgrades are needed, it would be preferable to complete utility upgrades prior to constructing ZEB infrastructure on the site.

The 2025–2026 route modeling efforts could help inform multiple aspects of the future facility. Route modeling could determine the level of EVSE and hydrogen fueling that would be ideal for this facility. COTA could determine the number of BEB chargers and sizing of hydrogen fueling infrastructure prior to building the new facility, and dedicate the space needed for this infrastructure. Route modeling can also help determine optimal locations for the facility throughout the Columbus area. A third facility located anywhere within COTA's service area would be helpful for the ZEB transition; however, route modeling could help determine the best placement for the facility if choosing between multiple locations.

Overall, key considerations for COTA when selecting a site and building a new facility are as follows:

1. **Select site based on space available and power availability.**
2. **If choosing between a few sites, consider the route modeling findings to determine optimal charging and hydrogen fueling locations for future ZEBs.**
3. **Construct all EVSE and hydrogen infrastructure needed at the facility during the initial facility build, rather than adding later in phases.**

8.4 On-Route Charging

COTA will utilize on-route charging at key locations to improve the range of the BEB fleet once BEBs cannot operate with depot-only charging. All on-route charging will be in the form of pantograph dispensers, each connected to one 300 kilowatt (kW) charging cabinet. COTA is currently planning and designing on-route chargers at the Easton Transit Center (two chargers), Westview Turnaround (two chargers), and Northland Transit Center (one charger). COTA is also exploring the ability to place additional on-route chargers at or near the Easton Transit Center. Route modeling indicated that up to five chargers at the Easton Transit Center would be beneficial for maximizing BEB feasibility; however, this site has limited space, which may limit the ability to install more than two chargers.

In the current service model, COTA would experience the greatest return on investment if installing nine chargers at four locations: the Easton Transit Center, Westview Turnaround, Northland Transit Center, and North Terminal. This on-route charging configuration would allow COTA to operate 57 percent of blocks with BEBs. **Table 9** shows the ideal number of chargers installed at each location. It should be noted that the on-route charging shown in this section reflects COTA's current bus service model; as its bus service changes, COTA will continue to monitor charging needs and plan around service as it evolves.

Table 9: **OPTIMATE ON-ROUTE CHARGERS INSTALLED BY LOCATION**

LOCATION	NUMBER OF CHARGERS	STATUS
EASTON TRANSIT CENTER	2 to 5	In planning and expected in service by 2026
WESTVIEW TURNAROUND	2	In design and expected in service by 2025
NORTHLAND TRANSIT CENTER	1	In design and expected in service by 2025
NORTH TERMINAL	1	Planning/design not yet started
TOTAL	**6 to 9**	

8.4.1 FUTURE ON-ROUTE CHARGING CONSIDERATIONS

Because COTA plans to scale up bus service for the long-term strategy, it is difficult to predict what locations will be the best candidates for future on-route charging. With 2023 modeling, COTA identified the Reynoldsburg Park and Ride and the Westwoods Park and Ride as two locations that could be beneficial for future on-route charging. These locations may change, depending on 2025–2026 route modeling. COTA will continue to assess BEB charging needs as the BEB fleet grows.

8.5 Resiliency

To enhance resiliency during the ZEB transition, a key consideration for COTA involves maximizing energy backup from the utility. This can be achieved by utilizing the two existing megawatt generators located at Fields and McKinley Garages. The goal is to optimize the use of these generators, with a focus on supporting the anticipated hydrogen station at McKinley Garage. This approach aligns with the overall resiliency framework, which emphasizes the importance of coordinated strategies to strengthen the operational robustness of the ZEB fleet transition.

Several resiliency strategies for consideration are shown below to provide insight into a comprehensive approach to resiliency planning. COTA plans to employ these approaches to mitigate operational disruptions during power outages.

- On-route charging as a short-term solution, allowing buses to reroute and recharge at alternate locations during localized outages.
- Redundant grid sources such as a secondary feeder to enhance energy resiliency, with a focus on substation and distribution feeder redundancies.
- Spare bus utilization for maintaining operational routes, leveraging a reserve fleet of ZEBs, or a mixed fleet.
- Reduced bus services to offer flexibility, allowing for service adjustments based on the severity of the outage.

The integrated strategies above emphasize the need for a multifaceted approach to ensure a resilient ZEB fleet transition within the broader context of transit operations.

9 SAFETY

COTA is utilizing the FTA's Safety and Security Certification of Electric Bus Fleets - Industry Best Practices (Report 0252) to create BEB and EVSE safety certifications. COTA began working with a consultant in November 2023 to develop safety certification standards. The sections below outline the recommended approaches for BEB, EVSE, and FCEB safety at this time. COTA intends to continue refining the safety certifications to meet industry best practices and standard, and COTA will implement further FCEB safety practices upon receiving the first FCEBs. COTA will continue to assess ZEV safety practices and adopt industry standards as they become available.

9.1 BEB Safety Considerations

COTA has developed mitigation and safety practices for staff working with BEBs. COTA will continue to assess BEB safety practices and adopt industry standards as they become available.

Mitigation Practices

Transit operators would begin by familiarizing themselves with the chemistry of the lithium-ion batteries installed on the buses. There are various types of chemistries utilized in the production of lithium-ion batteries, and some are more prone to thermal runaway than others, while others require specific handling procedures and cooling systems.

Safety managers will be aware of the potential fire risks associated with different battery chemistries, the high voltage capacity of the battery packs, and the potential arc flash ranges, in line with NFPA 70E standards.

Technician Safety

Maintenance personnel (technicians) must be trained not only in the diagnosis and repair of BEBs but also in safe working practices related to high voltage and arc flash in accordance with NFPA 70E standards. If signs of an impending issue are observed, first responders will be contacted immediately. In the event of an incident, other vehicles parked near the incident bus should be moved to a safe area, and the incident bus should not be operated under its own power.

COTA will work to avoid charging BEBs while parked in maintenance bays. If a bus must be recharged after mechanical inspections or repairs are conducted, COTA will move the bus out of the facility and use either a portable charger, a stationary built-in charger pedestal, or other charging means. If indoor charging is unavoidable, low-level chargers would be used.

Battery Storage

When storing new, defective, or damaged battery packs, care must be taken as to where these batteries are stored. New battery packs will arrive fully or partially charged, while defective or damaged packs may still contain stranded energy. COTA will identify a storage area away from main buildings and other vehicles. The storage area would preferably permit access for a forklift, be equipped with fire alarms, and have an automatic fire suppression system. As a best practice, lithium-ion batteries would not be stored within facility structures such as maintenance workshops or parts rooms.

9.2 FCEB Safety Considerations

Mitigation Practices

When overseeing an FCEB fleet, it is important to follow guidelines to ensure safety measures are continuously met. The safety considerations listed above for BEBs can also be applied to hydrogen vehicles; however, there are additional parameters unique to the safety of operating and maintaining FCEBs. A critical FCEB safety requirement is to install H2 sensors in all areas where the buses are housed or maintained, including the fueling station, maintenance bays, and bus storage areas. The fueling station must comply with all applicable regulations, from federal to state and local, and must follow ASME[4] B31.12 and Compressed Gas Association (CGA) G-5.4 and G-5.6. NFPA 2, NFPA 30A, and local regulations for setbacks must be adhered to as well.

Under certain criteria, FCEBs are classified as battery electric buses, meaning they must also adhere to high voltage and arc flash precautions outlined by the Occupational Safety and Health Administration (OSHA) and NFPA 70E[5] regarding personal protective equipment (PPE) and de-energized work requirements. If there is a hydrogen leak and an alarm is activated within a facility, employees will be appropriately trained to evacuate the building and follow the safety plan that should be in place. It will be crucial to ensure that staff have a clear understanding of these procedures to prevent avoidable accidents from occurring.

Technician Safety

To ensure the safety of fuelers and technicians, appropriate PPE should be available to protect against serious injury. Additionally, safe battery storage areas should be developed for both new and defective battery packs. Lastly, a safe outdoor storage area will be identified for defective or damaged buses. By following these guidelines, COTA can ensure the safety of everyone involved in the use and maintenance of FCEBs.

9.3 Operational Safety

In addition to learning how to operate from a driving perspective, operators are made aware of the following signs of an impending issue. The following indicators are applicable to both BEBs and FCEBs:

1. **Popping or crackling noises originating from the battery boxes.**
2. **Puffs of smoke, usually whitish in color, emanating from the battery storage boxes.**
3. **The bus fails to power up when first turned on.**

Note that operators should avoid driving through flooded areas such as underpasses if the bus has battery packs mounted low on the vehicle.

Should an operator notice signs of popping noises or smoke while in service, the bus will be evacuated immediately, and first responders will be notified. If possible and safe to do so, the operator should shut off the master switch before leaving the bus. If the bus fails to power up on the first attempt, generally at the depot prior to the first pull-out, the operator will turn off the master switch and immediately notify the maintenance department.

[4] *ASME Code Standards — Standard for Hydrogen Piping and Pipelines (ASME B31.12)*
[5] *NFPA 70E — Standard for Electrical Safety in the Workplace*

10 INFRASTRUCTURE MAINTENANCE

The following section explores strategies for maintaining EVSE and hydrogen systems. At the time of writing this plan, COTA utilizes service agreements with EVSE providers to maintain chargers. COTA has explored options for maintaining chargers, as outlined in the following section. These maintenance considerations are pivotal in ensuring the reliability and longevity of infrastructure supporting COTA's zero-emission initiatives. COTA will continue to evaluate charger maintenance practices throughout the transition plan and adjust roles/responsibilities as needed.

For future hydrogen fueling infrastructure, COTA plans to fully contract out the operation and maintenance of the fueling station to the OEM. It is an industry standard to contract hydrogen station operations and maintenance because hydrogen fueling stations require highly specialized labor which is not effective to develop in-house. COTA does not anticipate altering this operation/maintenance structure at this time but will re-evaluate in the future if infrastructure developments warrant reconsideration.

10.1 OEM Service Agreements

Most charger OEMs offer service agreements when transit agencies purchase an electric vehicle charger. Under these service agreements, the OEM will perform preventative and corrective maintenance for a specified period of time. Service agreements are intended to cover maintenance needs not covered by EVSE warranties. With smaller scale EVSE deployments, the OEM will send a technician to the transit agency for preventative and corrective maintenance. With larger scale EVSE deployments, the OEM may provide a technician to be based either on site or nearby so that more immediate service can be provided.

The key advantage of service agreements is the ease of implementation. It is relatively easy for transit agencies to add a service agreement to an EVSE purchase, and service agreements do not require additional requests for proposal (RFPs), training, or staff. However, because service agreements are a popular option for maintaining EVSE, some transit agencies encounter issues with response times. There is a growing demand for charger maintenance technicians and a limited number of qualified professionals.

10.2 Fully Outsource to Contractor

In this scenario, all warranty maintenance work for EVSE is managed by a local electrical contractor. The contractor would execute warranty maintenance tasks specified by the agency, with oversight provided by the agency itself. Upon completion of the work, the local contractor would submit an invoice. The agency would manage the warranty claim process and collaborate with the EVSE OEMs for reimbursement on the contractor's warranty work.

This outsourcing option offers several advantages, including the specialized expertise of contracted staff in electrical work, potentially leading to quicker repair times. It also reduces the labor burden on COTA's existing staff, allowing them to allocate time to other responsibilities. Training responsibilities for maintenance staff are shifted to the contractor, alleviating COTA's training burden. Moreover, the agency's equipment needs are reduced, as the contractor takes on maintenance equipment responsibilities.

However, there are associated disadvantages to consider. With this option, COTA would bear a cost for contractor services. Implementation requires obtaining documents and manuals from the OEM for proper warranty maintenance practices. Coordination with the OEM for warranty claims adds complexity. Additionally, scheduled site visits for warranty repairs and establishing an arrangement for the contractor to bill back for warranty repairs may pose challenges.

10.3 In-House

The in-house option would require COTA to first begin coordinating with the EVSE OEM to perform maintenance work that may be covered by warranty. If the OEM cannot perform the maintenance, the agency would deploy its staff or contracted staff for the task. The agency would manage the warranty claim and seek potential reimbursement from the EVSE OEM.

Advantages of this option include the OEM performing warranty work, ensuring consistency with existing OEM service agreements and presenting a lower upfront cost. Having onsite staff allows for direct oversight and control over the maintenance program.

However, there are drawbacks to performing maintenance in-house as well. In-house warranty maintenance and working on EVSE require the highest level of staff training, which is historically challenging to obtain from the OEM and can impact repair times without adequately trained staff. Staff would need specialized training in NFPA 70E, related to high voltage equipment, potentially increasing labor demands and requiring new staff positions as the agency's EVSE fleet grows. COTA would also need to purchase maintenance tools and equipment, making this option potentially more expensive in the long term.

10.4 H2 Maintenance

Drawing from industry trends and expert advice, outsourcing all hydrogen system maintenance to the OEM or a qualified third party is COTA's preferred approach. Due to the specialized nature of hydrogen storage and distribution systems, this best practice involves fully outsourcing all preventive, corrective, and warranty maintenance through a service agreement with the OEM or a qualified third party. Peer agencies inform on the reliability and effectiveness of this model for maintaining hydrogen fueling systems, aligning with the industry practices across the United States.

10.5 Key Performance Indicators

COTA intends to track key performance indicators (KPIs) to ensure that charging and hydrogen fueling equipment remains in optimal condition. The implementation of robust KPIs becomes integral for evaluating the functionality and performance of charging infrastructure.

COTA has worked with a contractor to develop COTA's KPI Reporting & Dashboard for the ZEB Program. Listed below are the KPIs that COTA will track and monitor through the Fleet Transition Plan. Once beginning the operation of FCEBs, COTA will add KPIs specific to FCEBs (such as hydrogen fueling time).

1. **ZEB Utilization**
   a. Miles driven (by bus per month)
   b. Days and hours in service
   c. Utilization comparison to CNG fleet
2. **Energy Use**
   a. Per fleet, bus, and route
   b. Compared to temperature
   c. Consumption from HVAC
   d. Average SOC utilization
3. **Efficiency**
   a. Per mile in service
   b. Efficiency comparison to CNG fleet
4. **Operating Cost per Mile**
   a. Cost per mile
   b. Cost comparison to CNG fleet
5. **Maintenance and Availability**
   a. Logged issues
   b. Bus pull-out availability
   c. Maintenance costs per mile by fleet class
6. **Emissions Reductions**
   a. Mileage based
   b. Power plant emissions
   c. Kg CNG reduced
7. **Charger Utilization Performance**
   a. Utility energy consumed
   b. Demand and energy costs
8. **Charger Maintenance and Availability**
   a. Maintenance issues and fault codes tracking
   b. Charger availability

11 FUNDING PLAN

11.1 Capital Costs of Fleet Transition Plan

11.1.1 BATTERY ELECTRIC BUSES AND EVSE

The implementation of new ZEB technology will warrant new capital costs for COTA. This section of the transition plan explains the anticipated capital costs for the near-term transition strategy. The long-term strategy costs will be determined as part of the 2027 Fleet Transition Plan. **Table 10** shows the capital costs for the near-term BEB strategy, including buses and charging stations. Depot charging infrastructure is shown in four phases. Phase 1 was completed in 2024. Phases 2 is planned to be designed during the near term and completed by the beginning of the long-term strategy. Design and construction costs for Phase 2 are anticipated to occur in the near term. COTA is also planning for capital expenditures for on-route chargers to occur in the near term. Much of the BEB capital costs have already been funded through federal grants, local grants, and COTA's internal funding mechanisms. All costs shown below are in 2023 dollars.

Table 10: **NEAR-TERM BEB CAPITAL COSTS (2023 DOLLARS)**

Vehicle Purchases	Price per Unit		Units	Total Cost
40-Foot Battery Electric Buses	$1,187,218		10	$11,872,180
Bus Total				***$11,872,180***
Depot Infrastructure	**Materials**	**Installation**	**Units**	**Cost**
Phase 1	$51,940	$66,502	50	$5,922,100
Phase 2	$51,940	$66,502	80	$9,475,360
Depot Design Costs	$400,000		-	$400,000
Depot Total				***$15,797,460***
On-Route Infrastructure	**Materials**	**Installation**	**Units**	**Cost Estimate**
360 kW Pantograph	$127,500	$396,000	9	$4,711,500
On-Route Charger Design	$471,150		-	$471,150
On-Route Total				**$5,182,650**
Grand Total				***$32,852,290***

This budget assumes COTA's current pricing for a 40-foot BEB, which is $1,187,218, for BEBs procured in 2024. Depot charging ports will be paired with cabinets on a 2:1 ratio. All depot charging is planned to be done with plug-in chargers and charge management software. Depot charging infrastructure estimates are based on COTA's Fleet Electrification Budget. The estimate assumes a per-unit materials cost of about $52,000 and a per-unit installation cost of about $67,000. Each phase assumes the maximum number of chargers are installed; actual charger quantities may vary depending on need. Additionally, there will be a $400,000 design cost that will cover both depots' design needs to implement the necessary infrastructure.

In order for longer routes to be feasible with the BEB purchases, COTA plans to maximize on-route charging opportunities once depot-only charging cannot support the entire BEB fleet. On-route charging will consist of DCFC pantographs for easy charging mid-route. This capital budget assumes that COTA is able to place five chargers at or near the Easton Transit Center, two at the Westview Turnaround, one at the Northland Transit Center, and one at the North Terminal, resulting in a total of nine on-route pantograph chargers. Pantograph costs are based on a representative 360 kW charger, per the recommended charger for on-route locations, and includes the cost of the materials and their installation. Beyond the base pantograph costs, there will likely be additional construction and electric utility-related costs to support implementation of on-route chargers.

11.1.2 HYDROGEN FUEL CELL ELECTRIC BUSES AND INFRASTRUCTURE

Table 11 shows the estimated capital budget for the near term hydrogen costs. These include 15 FCEBs and hydrogen fueling infrastructure.

In 2024, COTA will define the configuration for the hydrogen fueling station at McKinley and determine if the mobile hydrogen fueling configuration or permanent and scalable H2 fueling configuration will be implemented. A 40-foot FCEB is budgeted to cost $1.5 million per bus. FCEBs account for about 90 percent of planned hydrogen-based costs, while the remaining 10 percent ($2.64 million, estimated) comprises purchase of the mobile fueling infrastructure. COTA is currently assessing funding opportunities and planning to submit grant applications to fund the initial investment in hydrogen fuel cell buses. All costs shown below are in 2023 dollars.

Table 11: **NEAR-TERM BEB CAPITAL COSTS (2023 DOLLARS)**

Vehicle Purchases	Units	Unit Cost	Total
40-Foot FCEBs	15	$1,500,000	$22,500,000
Bus Total			***$22,500,000***
H2 Fueling Infrastructure			
Liquid Hydrogen Fueling Station	1	$2,000,000	$2,000,000
Planning and Commissioning	1	$200,000	$200,000
Contingency (20%)	1	$440,000	$440,000
Infrastructure Total			***$2,640,000***
Grand Total			**$25,140,000**

11.2 Funding Strategies

COTA will continue to leverage existing local funding sources and seek additional funds from federal, state, or local grants, as shown in **Table 12.** The BIL, as enacted in the Infrastructure Investment and Jobs Act, authorizes up to $108 billion for public transportation, which is the largest federal investment in public transportation in the nation's history. Part of the BIL funding will be used to increase the funds available through the FTA Low/No Emission Vehicle Grant Program and the FTA Bus and Bus Facilities Grant Program.

Table 12: **POTENTIAL GRANT OPPORTUNITIES**

Type of Agency	Agency	Title	Description
Federal	USDOT	Rebuilding American Infrastructure with Sustainability and Equity (RAISE)	Investment in transportation infrastructure including transit (Competitive).
	FTA	Grants for Buses and Bus Facilities Formula Program (49 USC 5339 a)	Bus procurement and related facilities (Formula).
		Bus and Bus Facilities (49 USC 5339 b)	Bus procurement and related facilities (Competitive).
		Low or No Emission Vehicle (49 USC 5339 c)	Procurement of ZEB and fueling/charging infrastructure.
		Metropolitan and Statewide Planning and Non-Metropolitan Transportation Planning (49 USC 5303)	Planning activities that support economic vitality, increase safety, increase accessibility and mobility, and protect and enhance the environment (Formula).
		Urbanized Area Formula (49 USC 5307)	Transportation-related planning for transit capital and operation (Formula).
		State of Good Repair (49 USC 5337)	Capital assistance for maintenance, replacement, and rehabilitation for bus systems (Formula).
		Flexible Funding Program – Surface Transportation Block Grant (23 USC 133)	Preserve and improve the conditions and performance of surface transportation, including transit (Formula).
		Flexible Funding Program – Congestion Mitigation and Air Quality Program (23 USC 149)	Funding may be used for areas in nonattainment or maintenance of ozone, carbon monoxide, and/or particulate matter. Funds may be used for transit capital expenditures as long as they have an air quality benefit (Formula).
		Human Resources and Training (5314 b)	Human resources and workforce development programs as they apply to public transit activities (Formula).
State	Ohio EPA	Diesel Emission Reduction Act (DERA)	Replace, repower, or retrofit older higher emitting diesel engines with newer diesels or alternative fuel vehicles (Competitive).
		Medium- and Heavy-Duty Emissions Reduction Grants	Grants to replace or repower Class 4–8 trucks and school, shuttle, and public transit buses.
Regional	MORPC	MORPC-Attributable Funding for Transportation	Funding available for transit agencies for public transit improvements. The funds come from the Surface Transportation Block (STB) Grant Program and the Congestion Mitigation and Air Quality (CMAQ) Improvement Program.
Local		Smart Columbus Initiative EV Charger Rebate	Rebate to install EV charging stations and equipment.

12 WORKFORCE DEVELOPMENT

COTA staff worked with its consultant team to develop a workforce development plan as part of the COTA ZEB Transition Plan. This plan was required in order to be eligible to apply for funding from the FTA Low/No Emission Vehicle Grant Program. FTA specified that each agency should examine the impact of the ZEB transition on the 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 to avoid displacement of the existing workforce. In addition, FTA also required each agency to use a minimum of 5 percent of their grant funds to support workforce development and training. COTA will account for the workforce development plan within department operational budgets and ensure the funds are spent per FTA guidelines.

In August 2022, FTA notified COTA that they had been awarded $26.7 million to purchase 28 battery electric buses, 14 depot chargers, and 6 on-route chargers. This award also included $1.34 million in grant funding to be spent on workforce development and training to support the deployment of the 28 electric buses. The total budget for this task, including both federal grant funding and local COTA funding, will be at least $1.67 million. The detailed workforce development budget is shown in **Table 13.** COTA staff worked with the consultant team to develop a plan for executing each of these workforce development activities and programs as detailed below.

Table 13: **FTA LOW/NO AWARD FOR WORKFORCE DEVELOPMENT**

Description	Federal Grant Amount	Local Match Amount	Total Cost
Bus OEM Operator, Maintenance, First Responder Training/Apprentice Program	$356,800	$89,200	$446,000
PPE, Tools, and Equipment/Apprentice Program	$160,000	$40,000	$200,000
Training Aids, Simulators, Components, and Equipment	$720,000	$180,000	$900,000
Center for Transportation and the Environment (CTE) ZEB 101 Training	$32,000	$8,000	$40,000
ZEB Conference	$72,000	$18,000	$90,000
Total	**$1,340,800**	**$335,200**	**$1,676,000**

12.1 Bus OEM Operator, Maintenance, and First Responder Training

COTA staff interviewed bus and charger manufacturers to collect information about their standard training programs and identify any topics that may need more time or detail. COTA conducted peer interviews with transit agencies that have several years of experience operating zero-emission buses in order to develop a best practices memo. Next, COTA interviewed internal staff from various departments to document current training practices and determine if there are any gaps in the curriculum. Finally, COTA interviewed local first responders to document current emergency response practices and plans and determine whether additional training is needed. The information collected should be used to develop a detailed action plan for COTA's ZEB Operator, Maintenance, and First Responder Training.

12.2 BEB and FCEB Training

COTA has worked with a consultant to integrate BEB training for COTA staff and plan for future FCEB training. In the context of training between FCEBs and BEBs, standardized training practices and knowledge applies to both vehicle technologies. However, FCEBs have some distinctive features that require additional training over BEBs. Specifically, a hydrogen bus contains both fuel cell and hydrogen tanks, which necessitate specialized training. Employees responsible for inspecting the H2 tanks must hold a tank inspection certification. Further, specialized training from the fuel cell OEM is critical for employees to perform preventive maintenance, component replacement, and diagnostic procedures.

12.3 Apprenticeship Program

COTA documented the current Apprenticeship Program and identified potential changes to include ZEB training based on the peer interviews conducted in the previous task. In addition, the team interviewed administrative staff from local colleges and trade schools who may be potential partners for an expanded apprenticeship program.

12.4 Equipment and Tools

COTA documented the current equipment and tools used to train operators and maintenance staff, including PPE, tools, training aids, simulators, components, and other training equipment. Based on the peer interviews conducted in the previous task, COTA identified new tools and equipment needed in order to conduct training for ZEBs. The team will also conduct research to identify specialized tools and equipment available on the market for ZEB training purposes.

12.5 CTE ZEB 101 Training

The CTE offers Zero Emission Bus 101 training to help transit agencies prepare for future ZEB deployments and deepen their understanding of the technology and how best to manage it. ZEB 101 is designed to train management, operations, and maintenance staff on the basics of deploying battery and hydrogen fuel cell electric buses. Participants gain the knowledge they need to ask the right questions of bus manufacturers and infrastructure providers. COTA staff attended the CTE ZEB 101 training and then coordinated an internal training session.

12.6 Zero Emission Bus Conference

CTE also hosts an annual Zero Emission Bus Conference which covers key topics in the transition to a zero-emission fleet, such as community advocacy, full depot electrification, and operations management, as well as innovative technology and practice updates. COTA staff attended the conference to expand their knowledge of ZEBs.

12.7 COTA ZEB Workforce Development Team

The team to implement the COTA Workforce Development Plan has been identified and approved. Roles and responsibilities should be documented within the plan. The team's roles and responsibilities are as follows:

EXECUTIVE OVERSIGHT:
Sindy Mondesir and Andy Biesterveld

BUS OEM OPERATOR, MAINTENANCE, FIRST RESPONDER TRAINING:
Sherry Smith

APPRENTICESHIP PROGRAM:
Tracy Spikes

PERSONAL PROTECTIVE EQUIPMENT, TOOLS, AND EQUIPMENT:
Russ Burton / Dan West

TRAINING AIDS, SIMULATORS, COMPONENTS, AND EQUIPMENT:
Sherry Smith

CTE ZEB 101 TRAINING:
Sherry Smith / Joe Massey

COTA is in a good position to leverage both existing and new resources to develop the existing workforce while building the foundation for incoming staff to ensure successful implementation of the ZEB Transition Plan.

ON-ROUTE CHARGER LOCATION ASSESSMENT

EXECUTIVE SUMMARY

The COTA fixed route bus fleet produces 71 percent of COTA's total greenhouse gas (GHG) emissions. The transition of COTA's CNG and diesel bus fleet to zero emission buses is the greatest opportunity to reduce COTA's overall emissions and should be a top priority for the agency. COTA currently has two (2) battery electric buses (BEBs) in operation and has placed orders for 22 more BEBs that will be deployed in 2022 and 2023. Currently, COTA's BEBs have a maximum range of 170 miles and charge overnight using 150 kW depot chargers. COTA will only be able to deploy electric buses on 50% of the service routes with the use of overnight depot charging at the Fields and McKinley Facilities.

On-Route Charging Opportunities

In order to effectively deploy BEBs on COTA's more challenging routes, on-route fast chargers at multiple sites will be required. On-route chargers provide opportunities for BEBs to charge during layovers while out in service instead of returning to the garage when running low on charge. These chargers provide about three times as much power and charge the battery much faster with about 1.5% per minute of charge. On-route charging extends the operating range of the vehicle enough to meet the needs of COTA's routes which will improve the feasibility of transitioning the fixed route bus fleet to 100 percent zero-emission buses. In 2022, COTA applied for funding from the FTA Low or No Emission Vehicle Grant Program and was awarded $26.7 million to purchase 28 BEBs, 14 depot chargers, and 6 on-route chargers. COTA will need to determine where the six on-route chargers will be deployed in order to prepare for the delivery of the 28 electric buses in 2024.

Methodology & Recommendation

COTA engaged a team of consultants to analyze a variety of transit centers and COTA properties to evaluate which sites are good candidates for the placement of on-route chargers. During this analysis, the team consulted AEP on electrical capacity at each location, developed schematics from an electrical engineer, performed a route modeling analysis, and met with internal COTA stakeholders from operations, engineering, scheduling, facilities, and capital projects to better understand COTA's bus route network and supporting facilities. This on-route charger location assessment resulted in the recommendation of five sites as prime candidates for on-route fast chargers as detailed in **Table 1** and shown on a map in **Figure 1.**

Table 1: **ON-ROUTE CHARGER LOCATIONS CANDIDATES**

FACILITY NAME	NUMBER OF ROUTES SERVED	AVERAGE LAYOVER TIME	BLOCKS RELYING ON ON-ROUTE CHARGING	ELECTRICAL CAPACITY (kW)	NUMBER OF ON-ROUTE CHARGERS POSSIBLE
EASTON TRANSIT CENTER	9	14m 40s	51	2,890	6
WESTVIEW TURNAROUND	3	13m 02s	25	1,400	3
NORTHLAND TRANSIT CENTER	1	15m 04s	9	1,860	4
REYNOLDSBURG PARK & RIDE	2	9m 00s	10	6,930	15
NORTH TERMINAL	6	6m 42s	3	5,000	11

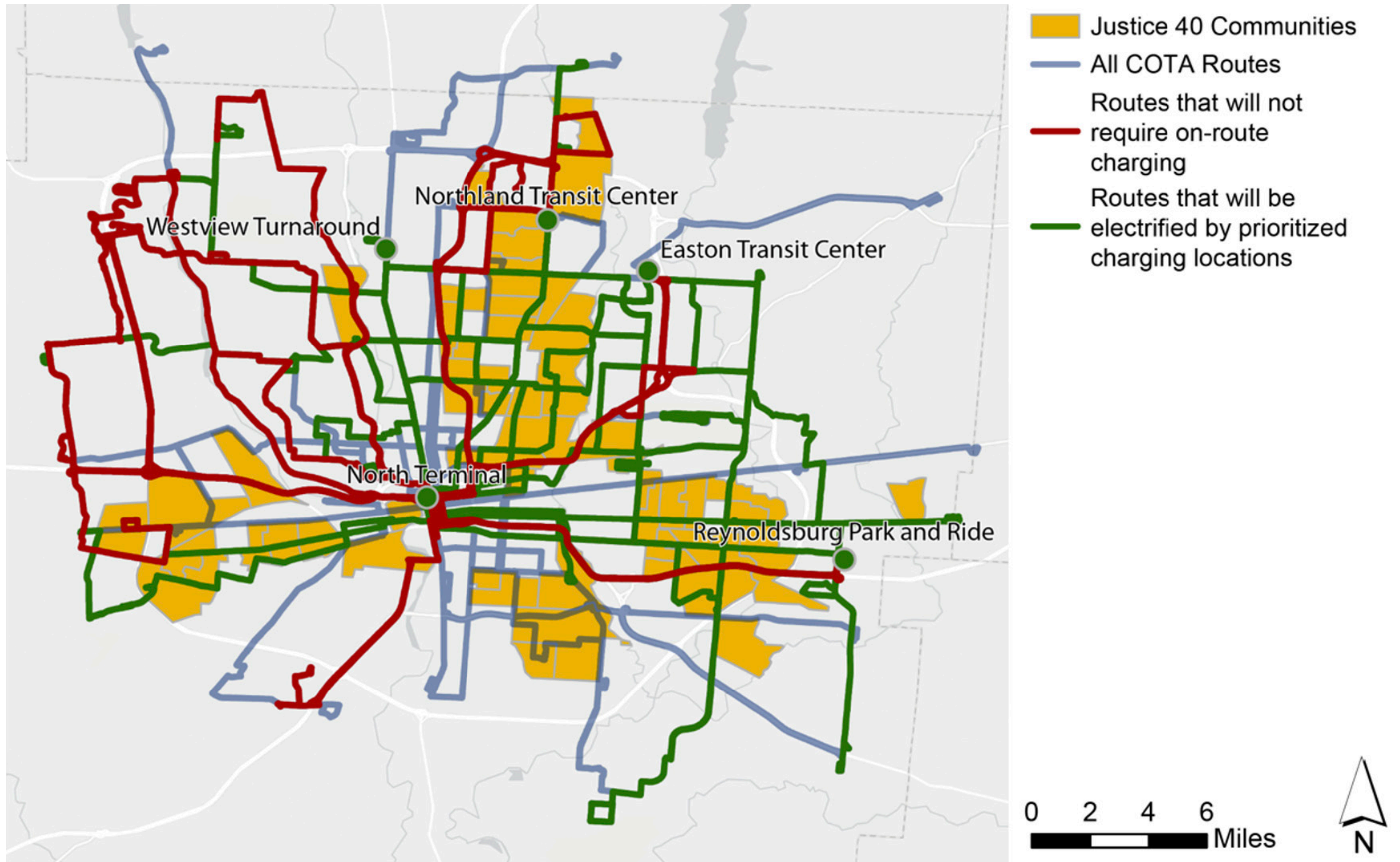


Figure 1: **POTENTIAL SITES FOR ON-ROUTE CHARGING**

Next Steps

There are several analyses and reviews that must be completed before finalizing the locations of the six on-route chargers. The five recommended locations should be reviewed by COTA staff and their consultant team in order to ensure that each site is operationally viable. This may require preliminary design work and further coordination with AEP to confirm electrical capacity. At the same time as the operational review is taking place, the consultant team will also be conducting software-based route modeling that will build upon the route analysis completed earlier in the study.

This software-based route model will use COTA's General Transit Feed Specification (GTFS) data as well as local topography, speed limits, and climate in order to simulate how BEBs will perform in COTA's current operations and local conditions. The outputs of this simulation will include: BEB feasibility by route and block; recommended sites for on-route charging and number of chargers required at each site; charging schedule and charging infrastructure required; daily power demand for each charging site (depot and on-route); and impacts on operations (deadhead miles, hours, fleet size). This modeling effort will provide COTA the critical information required to finalize the locations of the first six on-route chargers. The model outputs will also inform the five-year plan for additional on-route charger deployments beyond the first six chargers.

INTRODUCTION

COTA's mission is to provide solutions that connect people to prosperity through innovation, dedication, and teamwork. Success for COTA is defined as moving people where they want to go, enhancing the economic vitality and growth of the region, and closing social barriers for all communities. Sustainability is at the heart of creating an equitable and inclusive transit system for COTA's diverse customers. COTA advances sustainability practices that conserve resources, protect our workers, and improve the experience of COTA's customers. COTA has set a goal to achieve net-zero greenhouse gas (GHG) emissions by 2045. Achieving net-zero emissions will require transitioning COTA's fleet from fossil fuel powered vehicles to zero-emission vehicles.

Zero-Emission Bus Transition Plan

COTA has started its zero-emission bus (ZEB) transition by deploying two battery electric buses (BEBs) in 2021 and procuring 22 more BEBs that will be deployed within the next 2 years. In addition, COTA has developed a ZEB Transition Plan with the ambitious goal of reaching a 100 percent zero-emission bus fleet by 2035, as shown in the chart below. In 2022, COTA applied for funding from the FTA Low/No Emission Vehicle Grant Program and was awarded $26.7 million to purchase 28 BEBs, 14 depot chargers, and 6 on-route chargers.

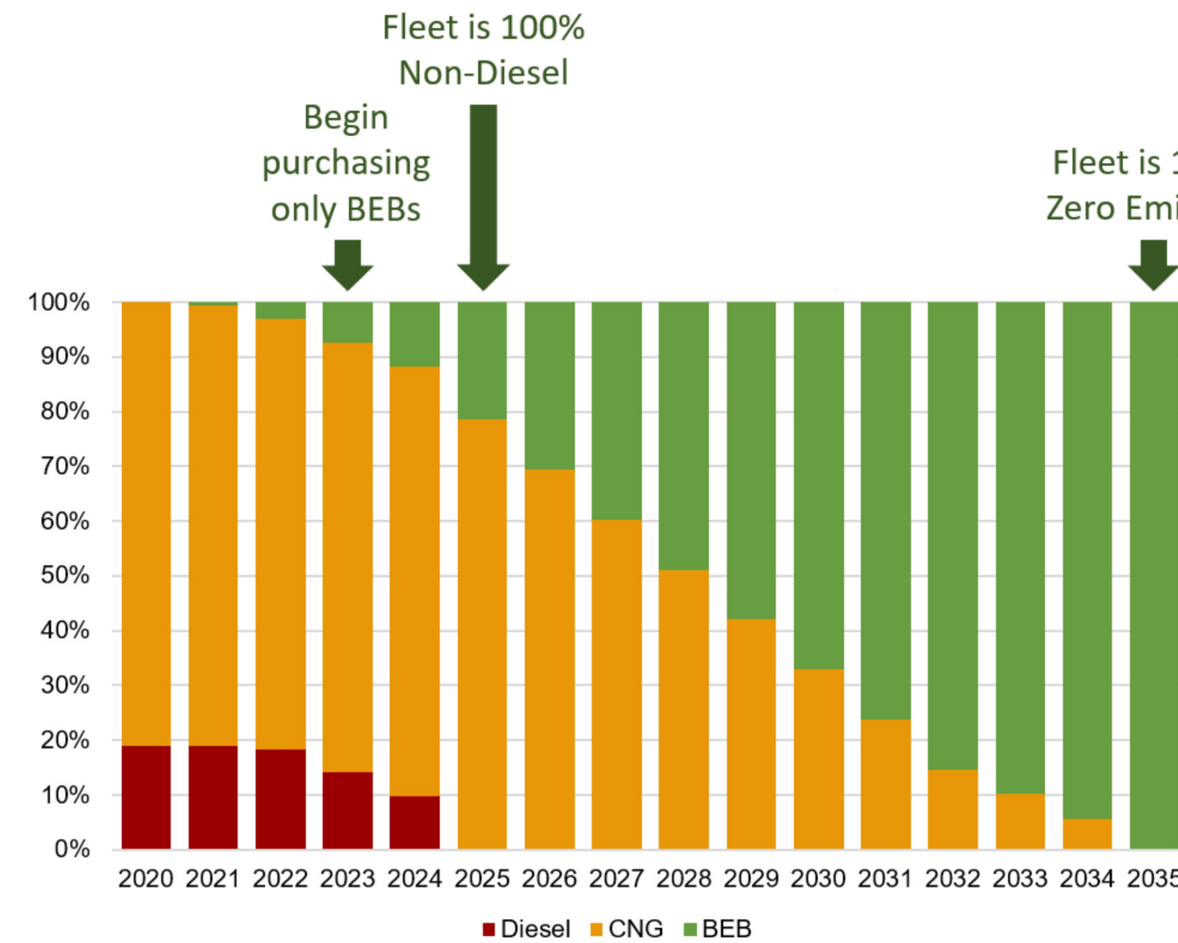


Figure 1: **COTA ZEB TRANSITION PLAN TIMELINE**

Study Purpose

Through the process of developing COTA's ZEB Transition Plan, COTA has engaged a team of consultants to analyze a variety of transit centers and COTA properties to evaluate which sites are good candidates for the placement of on-route chargers. This technical memorandum summarizes the methodology and results of the on-route charger location assessment.

Methodology and Process

COTA PROPERTIES

In early 2022, COTA staff developed a comprehensive list of properties that could be considered for future on-route charger implementation. COTA staff worked with AEP to assess the current electrical capacity at each site. Since upgrading power at a site can be expensive and time consuming, COTA used electrical capacity as a key consideration in determining the viability of each site. **Table 2** shows the sites considered and their respective electrical capacities. Only two sites, Westwoods Park and Ride and Meadow Pond Court (Grove City), were eliminated due to a lack of power at the site.

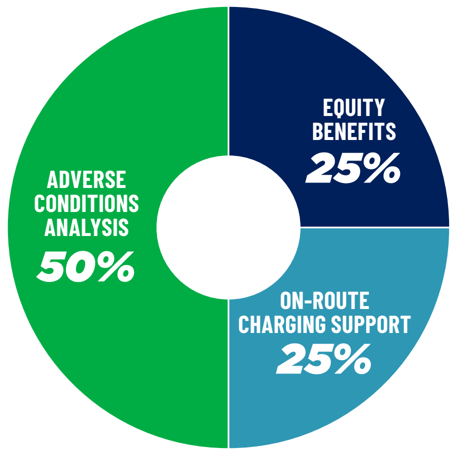
Table 2: **COTA FACILITIES AND ELECTRICAL CAPACITY**

NAME	AREA (ACRES)	CAPACITY AVAILABLE (MVA)	CAPACITY AVAILABLE (kW)	SITE TYPE CAPACITY (KW)
Easton Transit Center	2.9	2.9	2,890	Operation Critical
Northland Transit Center	1.6	1.9	1,860	Operation Critical
Essex Street and Remote	12.0	3.0	3,000	Operation Critical
New Albany Business Park	2.4	6.9	6,900	Operation Critical
Reynoldsburg	3.0	6.9	6,930	Operation Critical
Westwoods Park and Ride	1.0	0.3	300	Operation Critical
Whittier/Seymour	0.3	4.5	4,490	Operation Critical
Fields	10.8	1.4	1,350	Operation Critical
McKinley	27.8	1.6	1,590	Operation Critical
COTA Headquarters	0.2	9.4	9,400	Operation Critical
North Terminal	0.4	5.0	5,000	Operation Critical
Canal Winchester	2.0	N/A	N/A	Operation Critical
Broad and Southhampton	0.3	5.7	5,660	Underutilized Facility
Dublin	0.8	4.6	4,600	Underutilized Facility
Grove City	2.9	4.4	4,400	Underutilized Facility
Whitehall	0.7	2.5	2,510	Underutilized Facility
Main and Weyant	0.2	2.5	2,480	Underutilized Facility
Parsons and Groveport	0.3	3.8	3,800	Underutilized Facility
Westview	1.0	1.4	1,400	Underutilized Facility
Linden Transit Center	0.9	3.2	3,200	Underutilized Facility
Near East Transit Center	0.7	3.2	3,200	Underutilized Facility
Hilliard-Cemetery Road	1.8	3.4	3,400	Underutilized Facility
Livingston and Barnett	2.2	7.0	7,000	Underutilized Facility
Renner Road	2.6	1.5	1,460	Excess Property
Crosswoods	5.5	5.3	5,330	Excess Property
Delawanda	1.0	3.3	3,280	Excess Property
Meadow Pond Court	1.6	0.6	630	Excess Property
Northern Lights	3.0	4.0	4,010	Excess Property
Frebis/Studer	0.3	5.3	5,280	Excess Property

ON-ROUTE CHARGER ANALYSIS METHODOLOGY

Based on available industry information and peer review, along with data from the COTA BEB Pilot Program, battery capacity and range thresholds have been developed to determine which blocks and vehicle tasks are feasible. This analysis takes several key components into consideration, including manufacturers' range claims, characteristics of COTA's individual routes, climate and temperature conditions, opportunities for on-route charging, and battery degradation over time.

This route analysis was based on a point-in-time analysis of COTA's block schedule and vehicle assignments in 2022. The ZEB transition is prioritized from an operations perspective, evaluating all current blocks and vehicle tasks and scoring each based on propensity to be operated using a BEB. The analysis is weighted as follows:



Adverse Conditions Analysis: 50%
Modeling the state-of-charge of each vehicle task in five distinct adverse conditions as well as nominal and strenuous efficiencies.

Equity Benefits: 25%
Quantifying the air quality and emissions impacts a BEB could have on communities of interest (LinkUS).

On-Route Charging Support: 25%
Prioritizing vehicle tasks which layover/terminate at priority on-route charging facilities.

The state of charge (SOC) analysis is designed to account for thresholds of technology ranges, with distance and SOC as the key limiting factors to determine which currently scheduled fixed routes can be transitioned with no other adjustments necessary. This analysis assumes a New Flyer 40-foot vehicle, with the largest battery available (525 kilowatt hours [kWh]), but can be adjusted to account for additional battery sizes. This phase of the route analysis is broken down into two components, the Adverse Conditions Analysis and the Nominal and Strenuous Efficiency Analysis.

State of Charge Analysis

Adverse Conditions Analysis

1. BASELINE CONDITIONS
2. EXTREME WEATHER CONDITIONS
3. BATTERY DEGRADATION: 80% CAPACITY
4. BATTERY DEGRADATION: 70% CAPACITY
5. RIDERSHIP LOAD

Efficiency Analysis

1. NOMINAL CONDITIONS
2. STRENUOUS CONDITIONS

The Adverse Conditions Analysis also examines how vehicle tasks perform under nominal and strenuous vehicle efficiency scenarios. The nominal conditions approach is intended to represent an average day and accounts for moderate temperature conditions and heating, ventilating, and air-conditioning (HVAC) usage, with no passenger overloading. The strenuous conditions approach is intended to represent a hard day for the bus and accounts for more intensive temperature conditions, traffic, hill climbs, and HVAC usage. It is important to note that planning for the "worst case" day may not be practical, but it can be informative in terms of defining the potential limitations of the performance of a ZEB.

ON-ROUTE CHARGER PRIORITIZATION

After identifying the thresholds to determine which routes and blocks would benefit most from on-route charging, the consultant team identified the transit centers, park and rides, and COTA properties these routes and blocks utilized. Of more than 30 COTA-owned facilities reviewed, 7 facilities have been deemed feasible for on-route chargers, as shown in **Table 3.**

Table 3: **POTENTIAL SITES FOR ON-ROUTE CHARGING**

FACILITY NAME	TOTAL BLOCKS SERVED	BLOCKS RELYING ON ON-ROUTE CHARGING	NOTES
EASTON TRANSIT CENTER	65	14m 40s	
WESTVIEW TURNAROUND	25	13m 02s	Omits Route 6, which will no longer terminate at this facility.
NORTHLAND TRANSIT CENTER	9	15m 04s	
REYNOLDSBURG PARK & RIDE	20	9m 00s	
NORTH TERMINAL	8	6m 42s	These three blocks are also served by Easton, Westview, and Reynoldsburg.
MOUND AND 4TH	18	6m 42s	Fourteen blocks are served by stopping at Westview, and the remaining four are solved by layovers at Easton.
RICKENBACKER TRANSIT CENTER	14	6m 42s	
GREYHOUND BUS STATION	–	6m 42s	This may be a good future side for on-route charging of blocks that have layovers at the South Terminal. Blocks and routes not yet assigned.

Several of these sites were eliminated for considerations due to a variety of factors. The intersection of Mound and Fourth was deemed to not be a priority location for this phase of on-route changer deployment because the two routes that have layovers at this location (Route 2 and Route 7) are already served by Westview Turnaround and Easton Transit Center, respectively. The blocks that make up those two routes are solved by the layover time at each of those other locations. There is potential for the Mound and Fourth location to be targeted for future installations of fast chargers to increase the resilience of those two routes. The Greyhound bus station was removed from consideration due to not yet being fully understood in terms of capacity and future uses, as well as not being prepared for charger implementation at this point. Finally, the Rickenbacker Transit Center will not be evaluated as part of this study because a separate project taking place concurrently will evaluate the feasibility of on-route chargers at that transit center.

Figure 2 shows the prioritized charging locations that remain feasible in current conditions.

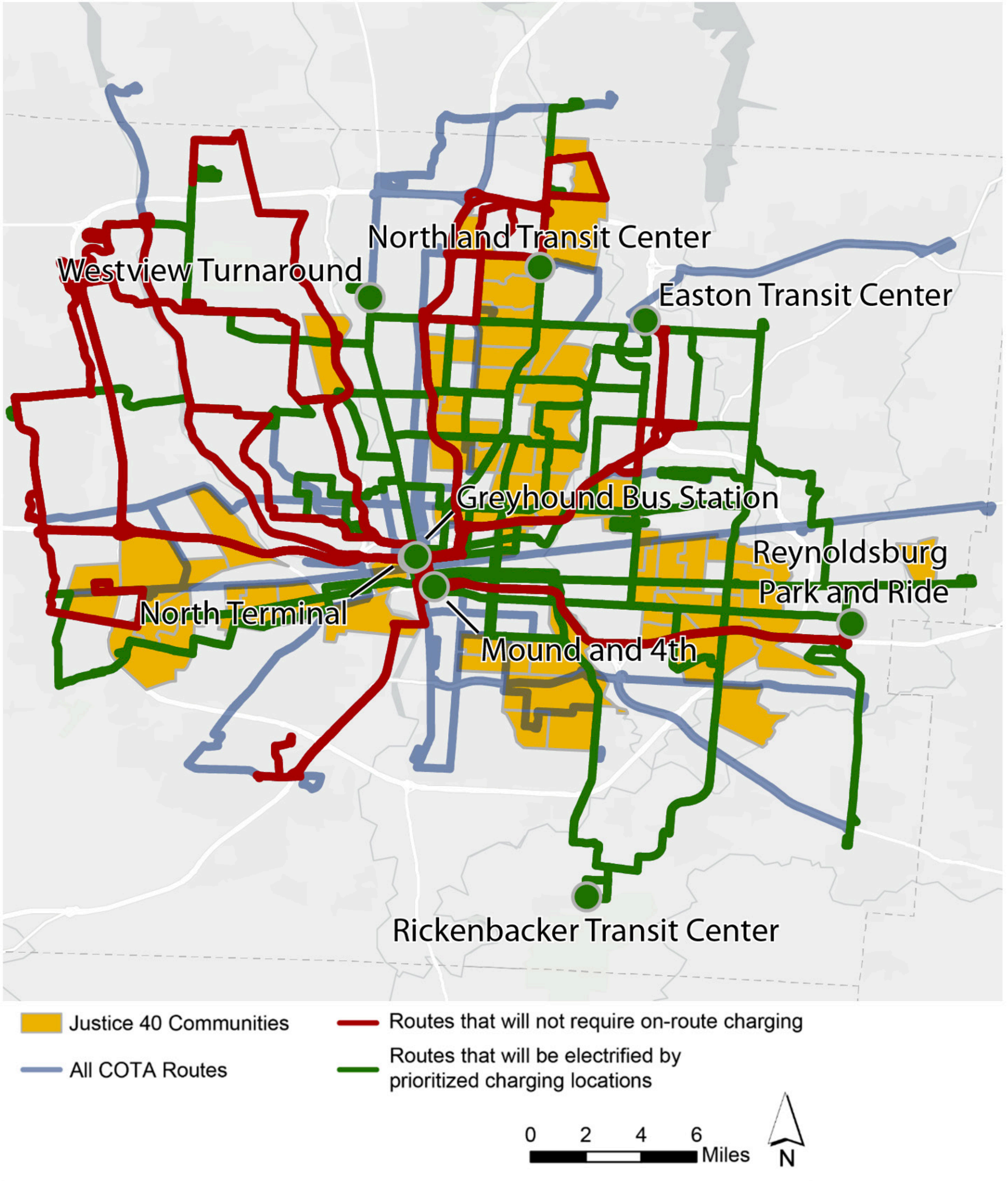


Figure 2: **COTA ROUTES AND FACILITIES BEB PHASING**

On-Route Charger Locations

COTA has conducted a comprehensive assessment of more than 30 COTA-owned facilities within the region for the viability of siting on-route chargers. This analysis included project team site visits to more than 10 locations for further evaluation. Facilities were prioritized by the ease of implementing on-route chargers on site and by the operational impact that on-route chargers at that facility could have in extending the range of future BEBs. Vehicle tasks that terminate or have layovers at these facilities were modeled to have an extended range based on access to an on-route charger and received an increased score. The facilities shown in **Table 4** and **Figure 3** are recommended for further study to confirm feasibility based on preliminary site design.

Table 4: **POTENTIAL SITES FOR ON-ROUTE CHARGING**

FACILITY NAME	NUMBER OF ROUTES SERVED	AVERAGE LAYOVER TIME	BLOCKS RELYING ON ON-ROUTE CHARGING	ELECTRICAL CAPACITY (kW)	NUMBER OF ON-ROUTE CHARGERS POSSIBLE
EASTON TRANSIT CENTER	9	14m 40s	51	2,890	6
WESTVIEW TURNAROUND	3	13m 02s	25	1,400	3
NORTHLAND TRANSIT CENTER	1	15m 04s	9	1,860	4
REYNOLDSBURG PARK & RIDE	2	9m 00s	10	6,930	15
NORTH TERMINAL	6	6m 42s	3	5,000	11

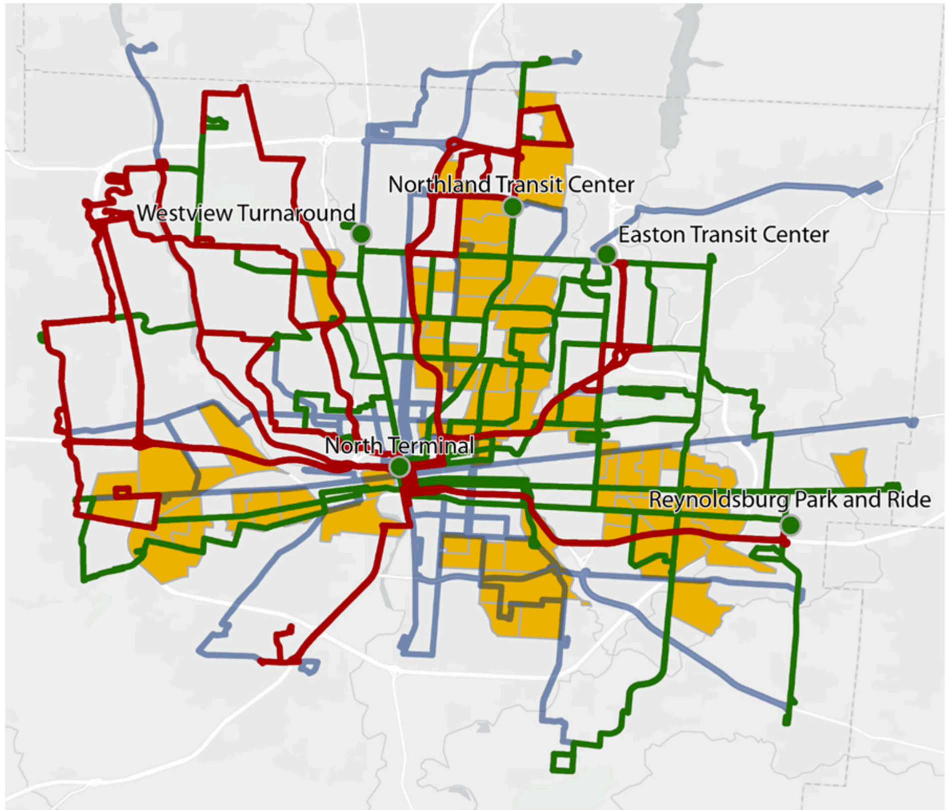


Figure 3: **POTENTIAL SITES FOR ON-ROUTE CHARGING**

EASTON TRANSIT CENTER

Easton Transit Center is a 2.9-acre Park and Ride located at 5260 Transit Drive, Columbus, OH, 43230. According to recent data from AEP, there are 2.89 megavolt-amperes (MVA) (2,890 kW) of electrical capacity available, which could support six 450 kW on-route chargers. Nine routes stop at this transit center (Routes 7, 9, 23, 24, 25, 31, 32, 34, and 44), all of which would benefit from on-route charging. These routes travel through 52 Justice40 census tracts, as shown in **Figure 4.**

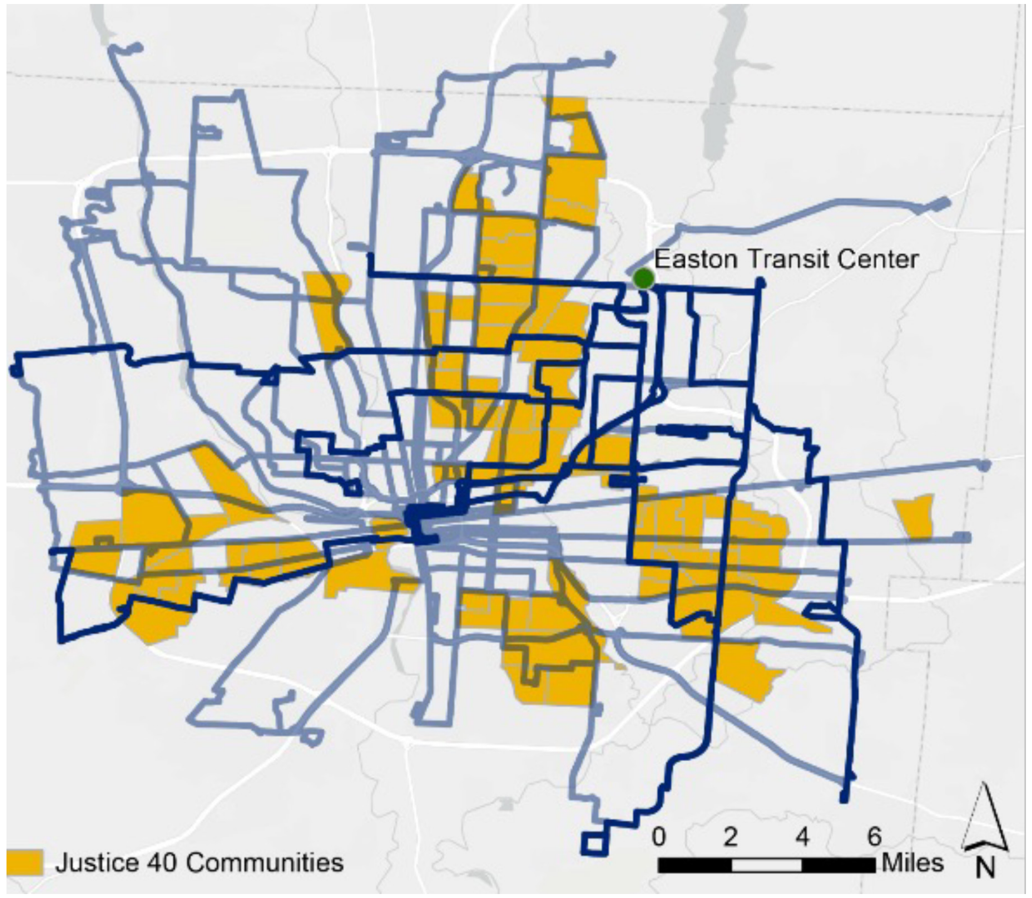
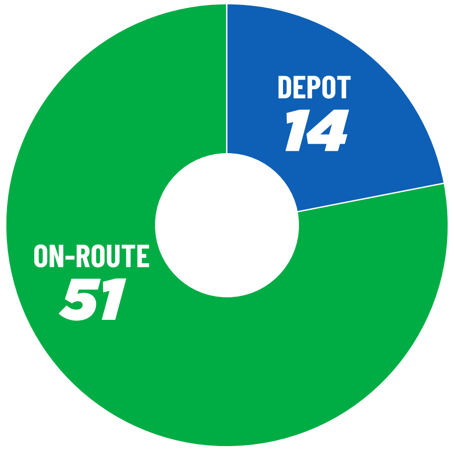


Figure 4: **EASTON TRANSIT CENTER ROUTES AND JUSTICE40 COMMUNITIES**



A total of 65 blocks stop at Easton Transit Center. Of these, 22 percent can be operated by an electric bus with only depot charging, and 78 percent will only be feasible with access to an on-route charger. These results are summarized in **Figure 5.**

Figure 5: **EASTON TRANSIT CENTER BLOCK FEASIBILITY**

Due to the high number of blocks that would benefit from on-route charging at Easton Transit Center, this location is recommended for top prioritization for on-route chargers. **Figure 6** shows the site layout and details. The next step will be to determine the potential locations of on-route chargers and the supporting electrical equipment and infrastructure.

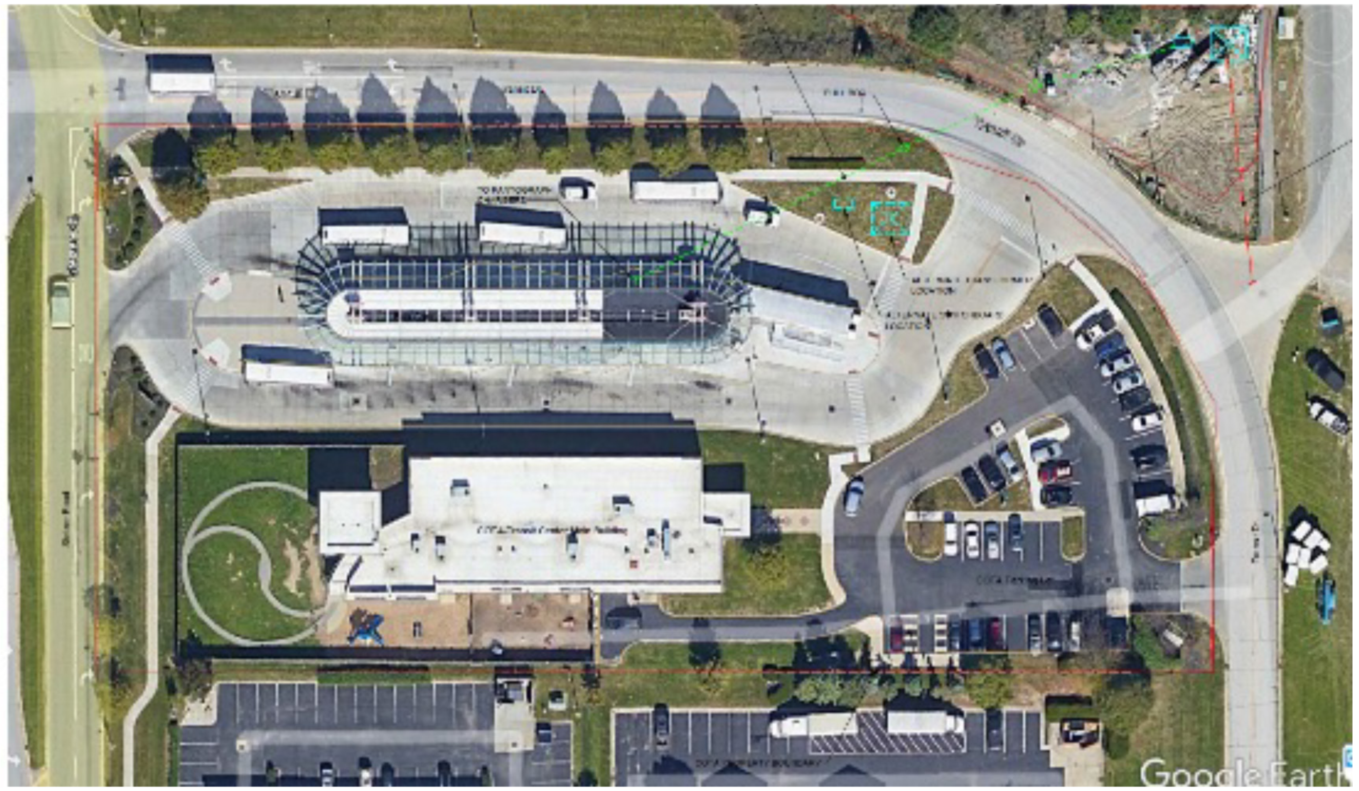


Figure 6: **EASTON TRANSIT CENTER ELECTRIC INFRASTRUCTURE SCHEMATIC AERIAL**

NORTHLAND TRANSIT CENTER

Northland Transit Center is a 1.6-acre Park and Ride located at 5495 Cleveland Avenue, Columbus, OH, 43229. According to recent data from AEP, there is 1.86 MVA (1,860 kW) of electrical capacity available which could support four 450 kW on-route chargers. One route, 101, stops at this transit center since Route 6 service to this location has been discontinued. Route 101 is shown in **Figure 7.** This route travels through 13 Justice40 census tracts.

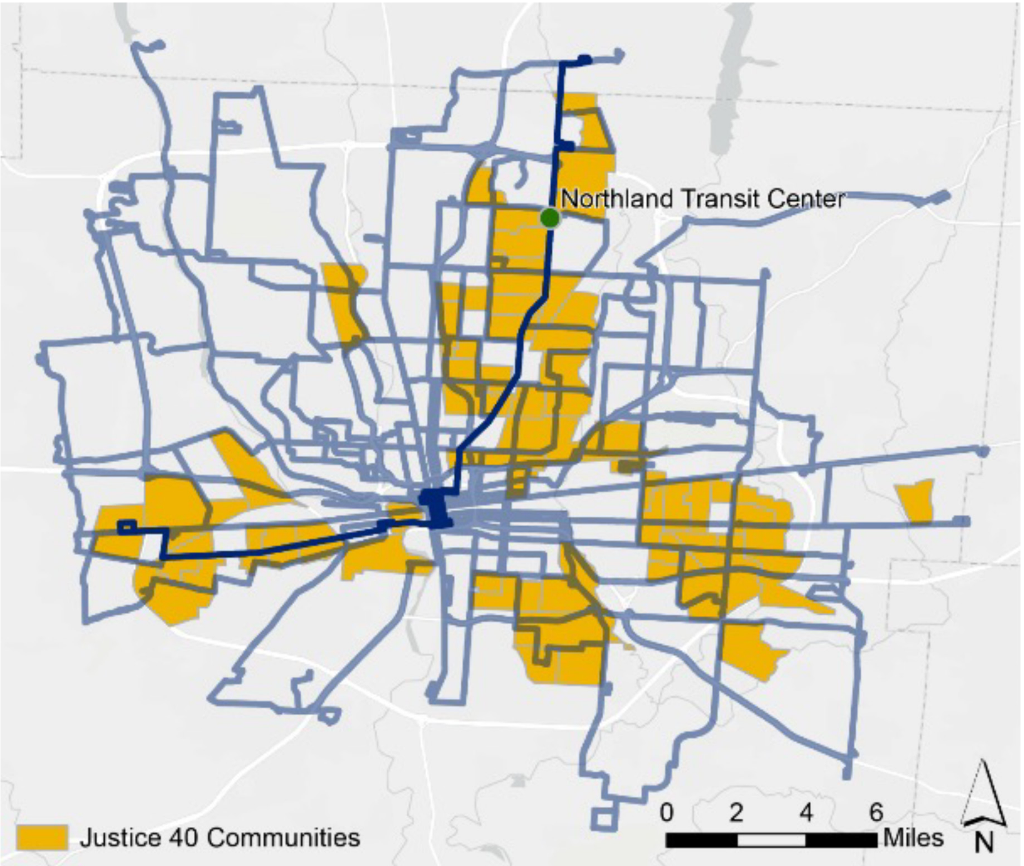


Figure 7: **NORTHLAND TRANSIT CENTER ROUTES AND JUSTICE40 COMMUNITIES**

Nine blocks stop at Northland Transit Center. All of the blocks will only be feasible with access to an on-route charger. These results are summarized in **Figure 8**.

Figure 8: **NORTHLAND TRANSIT CENTER BLOCK FEASIBILITY**

Due to the high number of blocks that would benefit from on-route charging at Northland Transit Center, this location is recommended for further study to confirm feasibility. **Figure 9** shows the site layout and details. The next step will be to determine the potential locations of on-route chargers and the supporting electrical equipment and infrastructure.

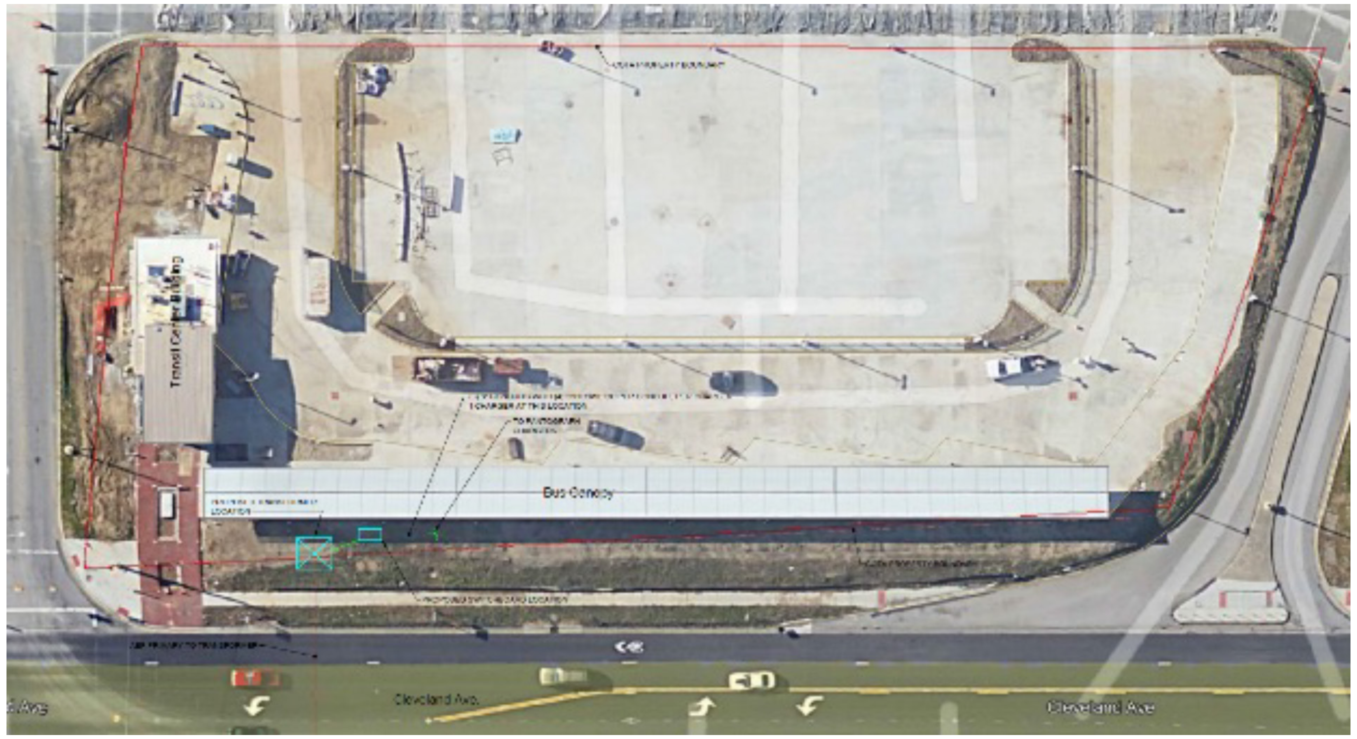


Figure 9: **NORTHLAND TRANSIT CENTER ELECTRIC INFRASTRUCTURE SCHEMATIC AERIAL**

WESTVIEW TURNAROUND

Westview Turnaround is a 1-acre, end-of-line, turnaround station located at 5271 North High Street, Columbus, OH, 43214. According to recent data from AEP, there is 1.4 MVA (1,400 kW) of electrical capacity available which could support three 450 kW on-route chargers. As shown in **Figure 10,** three routes stop at this facility, including Routes 2, 11, and 33. These routes travel through 19 Justice40 census tracts.

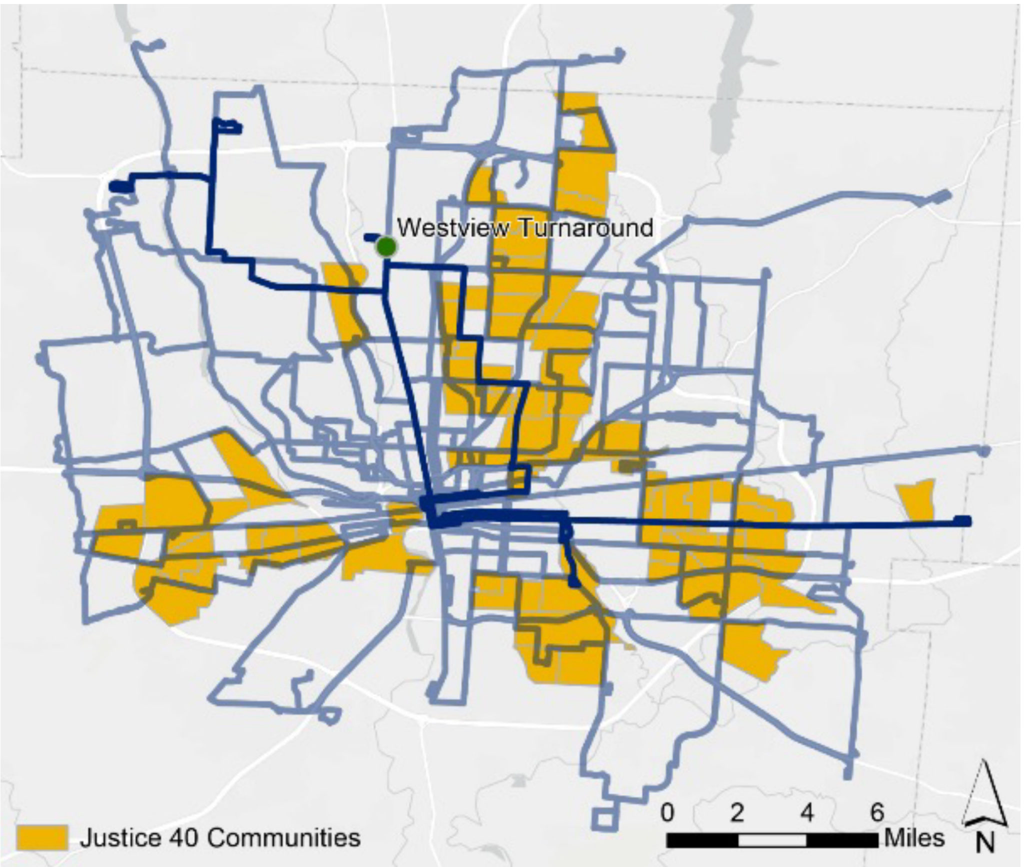


Figure 10: **WESTVIEW TURNAROUND ROUTES AND JUSTICE40 COMMUNITIES**

A total of 25 blocks stop at Westview Turnaround, all of which will only be feasible with access to an on-route charger. These results are summarized in **Figure 11.**

Figure 11: **WESTVIEW TURNAROUND BLOCK FEASIBILITY**

Due to the high number of blocks that would benefit from on-route charging at Westview Turnaround, this location is recommended for further study to confirm feasibility. **Figure 12** shows the site layout and details. The next step will be to determine the potential locations of on-route chargers and the supporting electrical equipment and infrastructure.

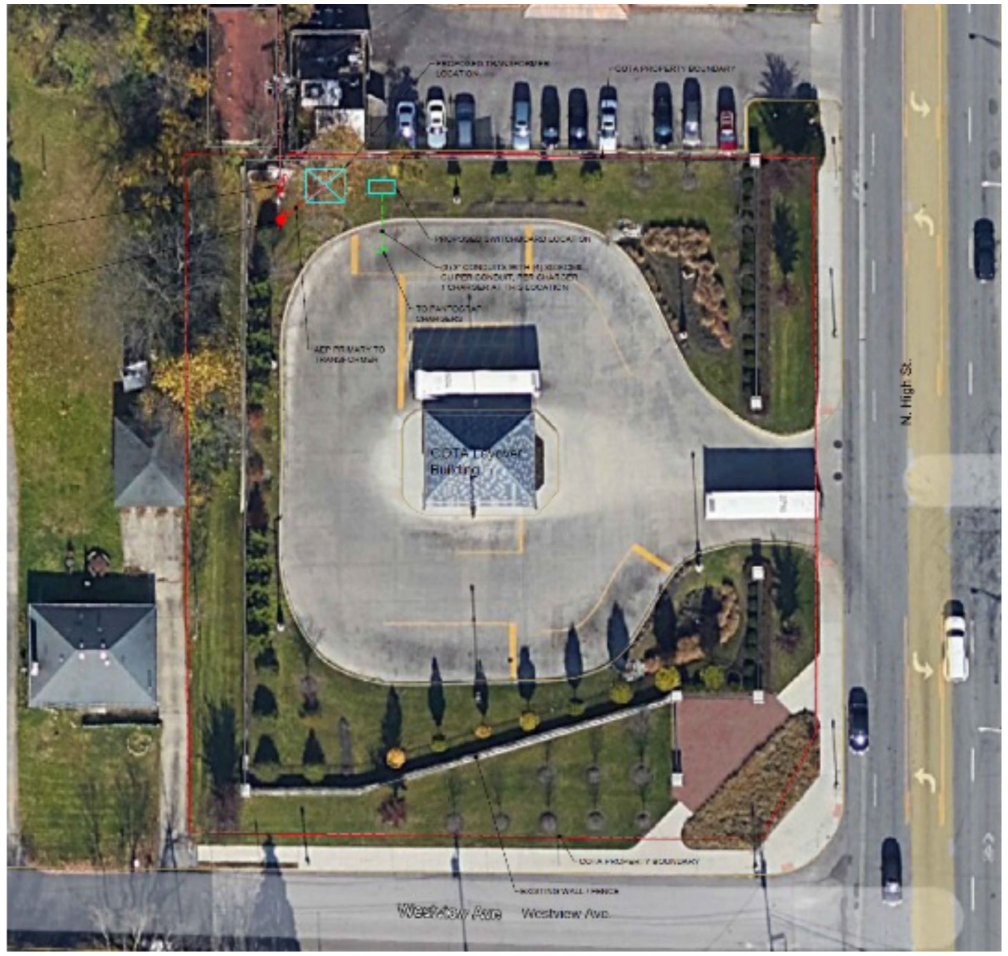


Figure 12: **WESTVIEW TURNAROUND ELECTRIC INFRASTRUCTURE SCHEMATIC AERIAL**

REYNOLDSBURG PARK AND RIDE

Reynoldsburg Park and Ride is a 3-acre transit station located at 2100 Birchview Drive, Reynoldsburg, OH, 43068. According to recent data from AEP, there is 6.93 MVA (6,930 kW) of electrical capacity available which could support fifteen 450 kW on-route chargers. As shown in **Figure 13,** two routes, Routes 1 and 51, stop at this facility. These routes travel through 15 Justice40 census tracts.

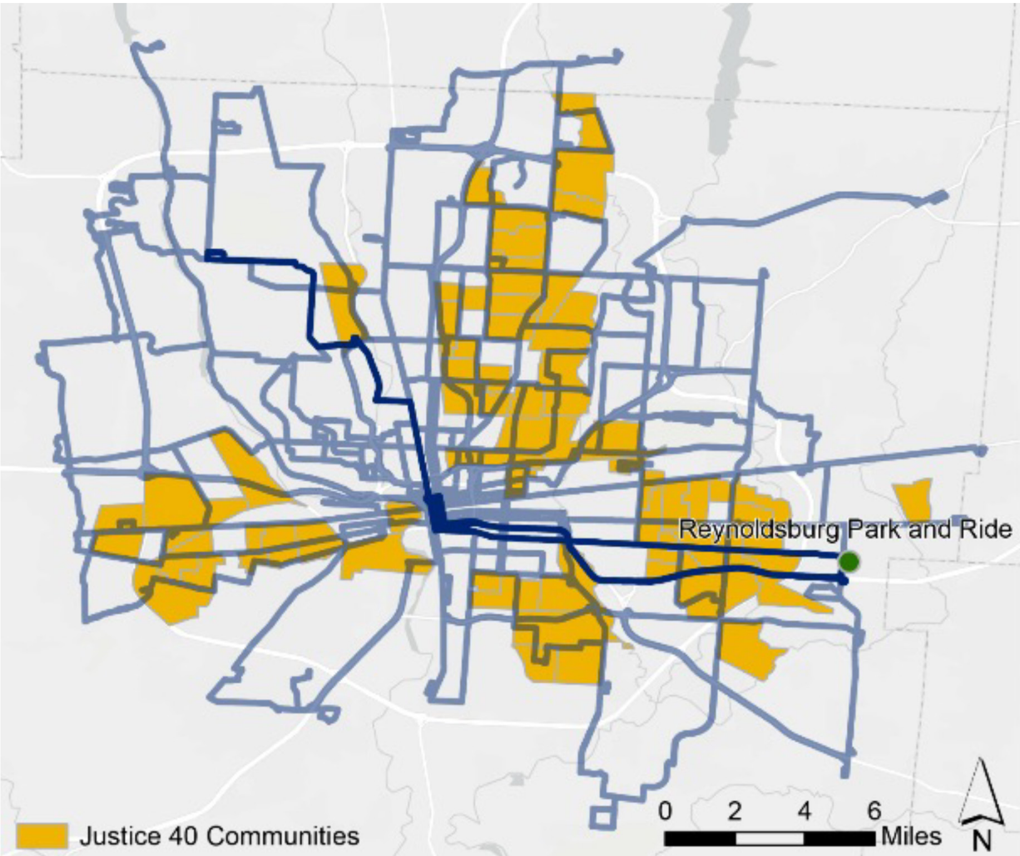
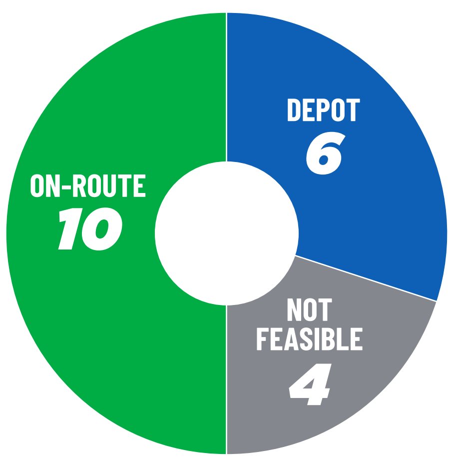


Figure 13: **REYNOLDSBURG PARK AND RIDE ROUTES AND JUSTICE40 COMMUNITIES**



A total of 20 blocks stop at the Reynoldsburg Park and Ride, of which 30 percent can be operated by an electric bus with only depot charging, and 50 percent will only be feasible with access to an on-route charger. The remaining 20 percent will not be feasible even with on-route charging. These results are summarized in **Figure 14.**

Figure 14: **REYNOLDSBURG PARK AND RIDE BLOCK FEASIBILITY**

Due to the high number of blocks that would benefit from on-route charging at Reynoldsburg Park and Ride, this location is recommended for further study to confirm feasibility. **Figure 15** shows the site layout and details. The next step will be to determine the potential locations of on-route chargers and the supporting electrical equipment and infrastructure.

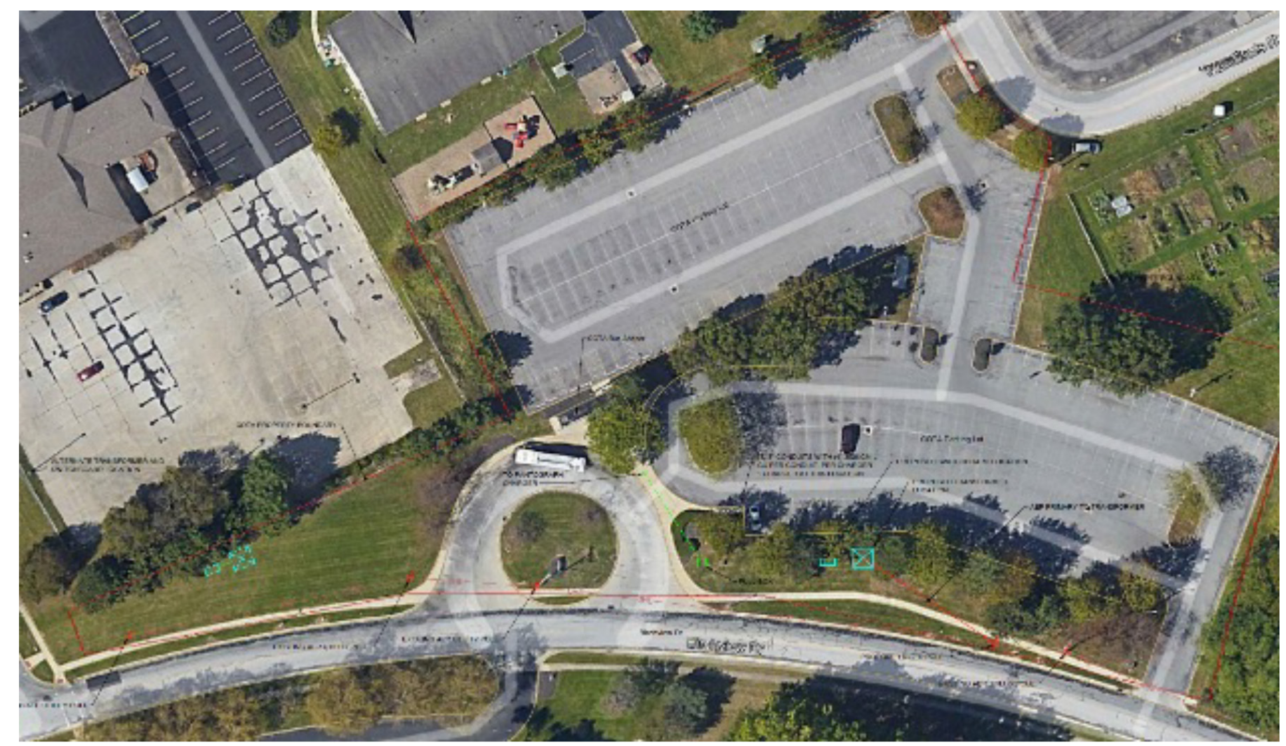


Figure 15: **REYNOLDSBURG PARK AND RIDE ELECTRIC INFRASTRUCTURE SCHEMATIC**

NORTH TERMINAL

North Terminal is a 0.36-acre terminal located at 33 West Spring Street, Columbus, OH, 43215. It is an important operator restroom, but the facility is empty most of the day since it is a rush-hour-only terminal and hub for night line-ups. According to recent data from AEP, there is 5.0 MVA (5,000 kW) of electrical capacity available which could support eleven 450 kW on-route chargers. Two routes stop at this transit center, Routes 52 and 61, as shown in **Figure 16.** These routes travel through three Justice40 census tracts.

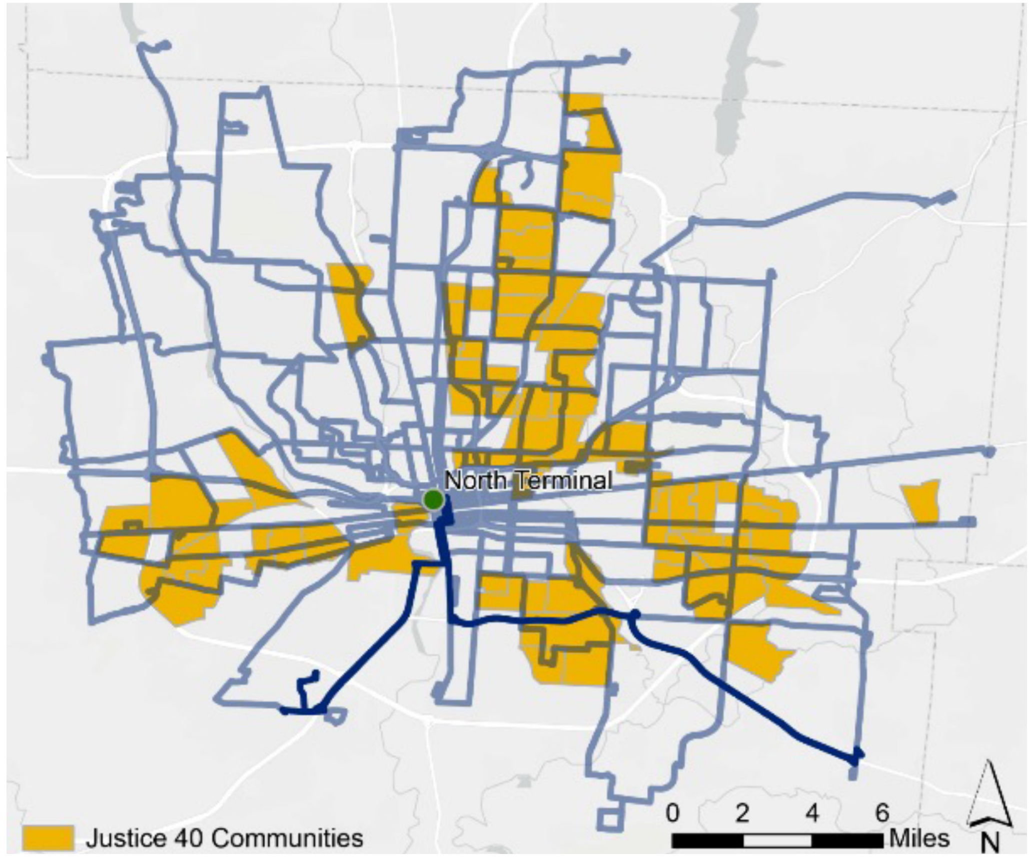
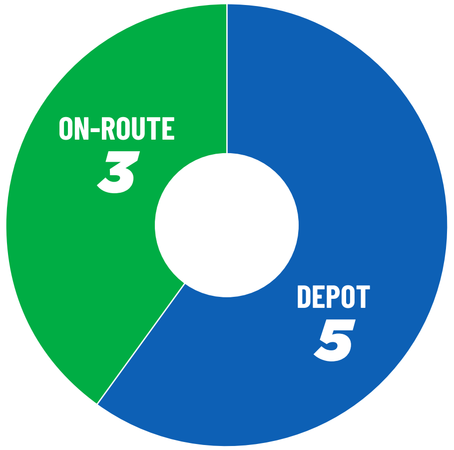


Figure 16: **NORTH TERMINAL ROUTES AND JUSTICE40 COMMUNITIES**



Eight blocks stop at North Terminal, 63 percent of which can be operated by an electric bus with only depot charging, and 37 percent of which will only be feasible with access to an on-route charger. These results are summarized in **Figure 17.**

Figure 17: **NORTH TERMINAL BLOCK FEASIBILITY**

Due to the high number of blocks that would benefit from on-route charging at North Terminal, this location is recommended for further study to confirm feasibility. **Figure 18** shows the site layout and details. The next step will be to determine the potential locations of on-route chargers and the supporting electrical equipment and infrastructure.

Figure 18: **NORTH TERMINAL ELECTRIC INFRASTRUCTURE SCHEMATIC AERIAL**

Next Steps

Several analyses and reviews must be completed before finalizing the locations of the six on-route chargers. The five recommended locations should be reviewed by COTA staff and consultants in order to ensure that each site is operationally viable. This may require preliminary design work and further coordination with AEP to confirm electrical capacity. At the same time the operational review is taking place, the consultant team will be conducting software-based route modeling that will build upon the route analysis completed earlier in the study.

This software-based route model will use COTA's general transit feed specification (GTFS) data as well as local topography, speed limits, and climate in order to simulate how BEBs will perform in COTA's current operations and local conditions. The outputs of this simulation will include BEB feasibility by route and block, recommended sites for on-route charging and number of chargers required at each site, charging schedule and charging infrastructure required, daily power demand for each charging site (depot and on-route), and impacts on operations (deadhead miles, hours, and fleet size). This modeling effort will provide COTA the critical information required in order to finalize the locations of the first six on-route chargers. The model outputs will also inform the 5-year plan for additional on-route charger deployments beyond the first six chargers.

Appendix 2

HYDROGEN FUEL CELL ELECTRIC BUS FEASIBILITY STUDY

EXECUTIVE SUMMARY

The Hydrogen Fuel Cell Electric Bus (FCEB) Feasibility Study aims to provide Central Ohio Transit Authority (COTA) with the necessary tools and strategies to make informed decisions regarding its FCEB program. Currently, COTA operates around 300 buses, including CNG and BEB vehicles, and has two bus facilities. The agency has set a goal to transition its fixed-route fleet to become fully zero-emission by 2035, as outlined in the BEB transition plan developed in 2022.

This document presents the key findings of the hydrogen feasibility study for FCEBs in two parts. The first part describes the data collection and analysis completed by the HDR project team, including a comprehensive technology review, route modeling, peer agency interviews, and hydrogen industry vendor interviews. The second part presents the recommended courses of action, largely encompassing the proposed fleet mix, or long-term plan, and initial investment, or near-term plan. An overview of the site visit conducted by the HDR team in August 2023, which was utilized to develop the proposed fleet mix and hydrogen strategies is provided, highlighting the process taken to determine locations suitable for hydrogen infrastructure between the two garages. The proposed fleet mix is accompanied by hydrogen strategies, and followed by facility plans, contingency fleet considerations, safety guidelines, and capital cost estimates.

- The proposed fleet mix is broken into three zero-emission bus phases, and the hydrogen strategies are offered as near term (2024–2027) and long term (after 2027).
- The proposed ZEB fleet mix for COTA is roughly one-third BEB, one-third FCEB, and the remaining third to be identified in future years.

The feasibility study identifies McKinley Garage as the most suitable location for hydrogen infrastructure, with three potential locations identified - one mobile hydrogen fueling location, one permanent hydrogen fueling location, and a secondary location to consider if either of the other two locations become unavailable.

To ensure safety in the use and maintenance of FCEBs, the second half of the report outlines contingency and safety considerations. Capital costs for the near-term and long-term strategies are also provided, with the near-term capital budget set at a maximum of 15 FCEBs and mobile fueling infrastructure. The long-term strategy's capital cost estimates include 45 FCEBs, assuming that 15 FCEBs are acquired in the near term, bringing the total hydrogen fleet to 60 FCEBs in the long term, as well as the recommended long-term infrastructure.

Overall, the FCEB Feasibility Study provides a comprehensive framework with tools intended to inform the FCEB program. Before the recommended courses of action can begin, the first step is for COTA to work with local authorities to update the NFPA 2 code from the 2020 version to the 2023 version.[6] With the 2020 code

[6] NFPA 2023 Setback Requirements

in place, it is challenging to place mobile hydrogen fueling infrastructure in the recommended location. After updating the NFPA 2 code, the insights, recommendations, and analyses presented in this report may serve as a robust foundation for the agency's strategic planning and future endeavors in zero-emission technology.

Industry Research

The project team conducted extensive industry research and outreach to understand today's hydrogen FCEBs and their deployments in the US transit market.

Hydrogen (H2) is emerging as a sustainable transit fuel due to its zero-carbon emissions when consumed in fuel cells, offering a potential solution for longer transit routes compared to battery electric buses (BEBs). The technology review, provided in Appendix A: Technology Review, offers an overview of hydrogen for transit applications, highlighting its potential benefits and challenges. The team explored different methods for hydrogen generation, with a notable preference for delivered liquid hydrogen due to its cost-effectiveness compared to other delivery methods and infrastructure advantages. The US Department of Energy and Federal Transit Administration is actively supporting the transition to zero-emission vehicles, which is expected to drive down costs as hydrogen infrastructure expands.

Peer agency interviews and insights from industry-leading hydrogen infrastructure providers added valuable real-world perspectives, offering lessons learned and best practices for consideration. The interviews conducted provide valuable insights, emphasizing scalability, planning, and efficient hydrogen station features. The six interviews and their takeaways can be found in Appendix B: Peer Agency Interviews. Additionally, detailed hydrogen vendor interviews are offered in Appendix C: H2 Industry Day Interviews, detailing various hydrogen infrastructure providers, each with different services and considerations, which can support COTA's future project considerations.

Route Modeling

The following section offers HDR's route modeling and analysis on behalf of COTA. Route modeling was performed to determine the feasibility of operating COTA's bus fleet with hydrogen fuel cell electric buses (FCEBs) in place of its existing fleet.

METHODOLOGY AND ASSUMPTIONS

The project team used HDR's internal zero-emission fleet modeling tool (Zero+) to perform route analysis for COTA's fleet. FCEB operation was simulated for COTA's current fixed-route bus operations. The simulated vehicles have onboard storage for 37.5 kg of hydrogen, and it is assumed that 80 percent of that capacity is available for use. The vehicles were simulated using COTA's existing schedule operating out of both Fields and McKinley garages. The simulation takes the route, topography, climate, stop locations, speed limits, and driver behaviors into consideration to provide the most accurate estimate of the energy requirement for each block of work of FCEBs on these routes.

HYDROGEN RESULTS

Route Operations

Figure 2 shows the fuel level of each block over the course of a day. Each line in the figure represents a block where the color of the line changes as the fuel level decreases. The color changes from green to yellow to red as the fuel level drops from 100 percent to 0 percent. If a vehicle were to reach 0 percent the line would be black, and the vehicle would be stranded in real operations. In the simulation, blocks are started at 90 percent fuel level and are split apart if they would drop below 10 percent. When these splits are added they can be seen in the figure as blue boxes.

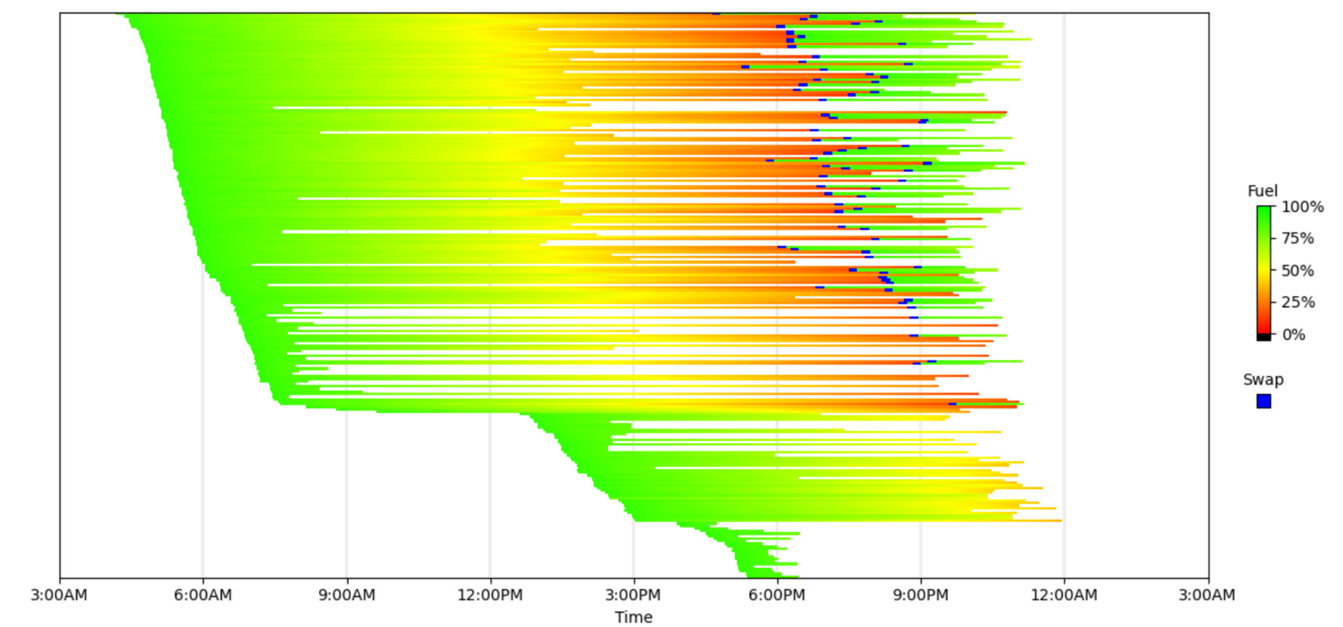


Figure 2: **FUEL LEVELS IN EACH BLOCK DURING A WEEKDAY SERVICE DAY**

As the fuel level heatmap shows, several blocks cannot be operated the same as they are today if they were replaced with FCEBs. If the full 100 percent nameplate capacity of the fuel tanks were available, then these blocks would be operational. However, agencies that have deployed FCEBs have experienced difficulty using more than 80 percent of the stated capacity, which has been incorporated into the simulation model. Additionally, there could be an option to use different vehicles which carry more hydrogen; however, this would require a shift in manufacturers and possibly require larger vehicles. For the purpose of this route modeling, the project team assumed a vehicle which most closely matches COTA's current vehicles.

Out of the 223 weekday blocks only 147 of them can operate without any modifications. The remaining 76 blocks require a single split to fit within the operational capabilities of the hydrogen buses. "Easy" blocks require no modifications, and "Medium" blocks require a single split at some point during the day. There are no "Difficult" blocks in COTA's service, which would be blocks that require more than 1 split or blocks that could not operate at all with the FCEB range limitations due to the maximum distance traveled from the garage. **(Figure 3)**

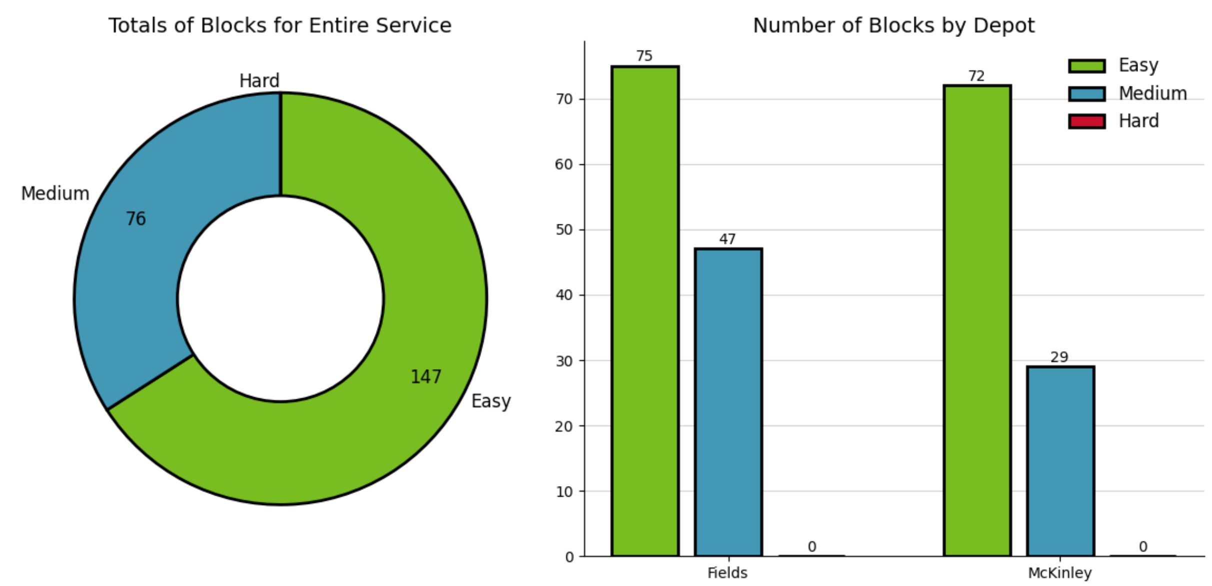


Figure 3: **BLOCKS GROUPED BY LEVEL OF DIFFICULTY FOR FCEB OPERATION**

Figure 4 shows a comparison of operating statistics between FCEB and diesel buses. Splitting blocks apart for FCEB operations introduces additional operational overhead. The simulation splits blocks at trip boundaries to minimize the impact to service, and splits are scheduled so that the new bus replaces the existing bus in the field. This means that the deadhead time spent driving the replacement bus out to the route, and the time spent returning the deplete bus to the garage are both additional deadhead that did not previously exist. The impact that this additional deadhead has on operations is shown both in relative terms to the existing deadhead, and in absolute terms compared to the total service in the following figure.

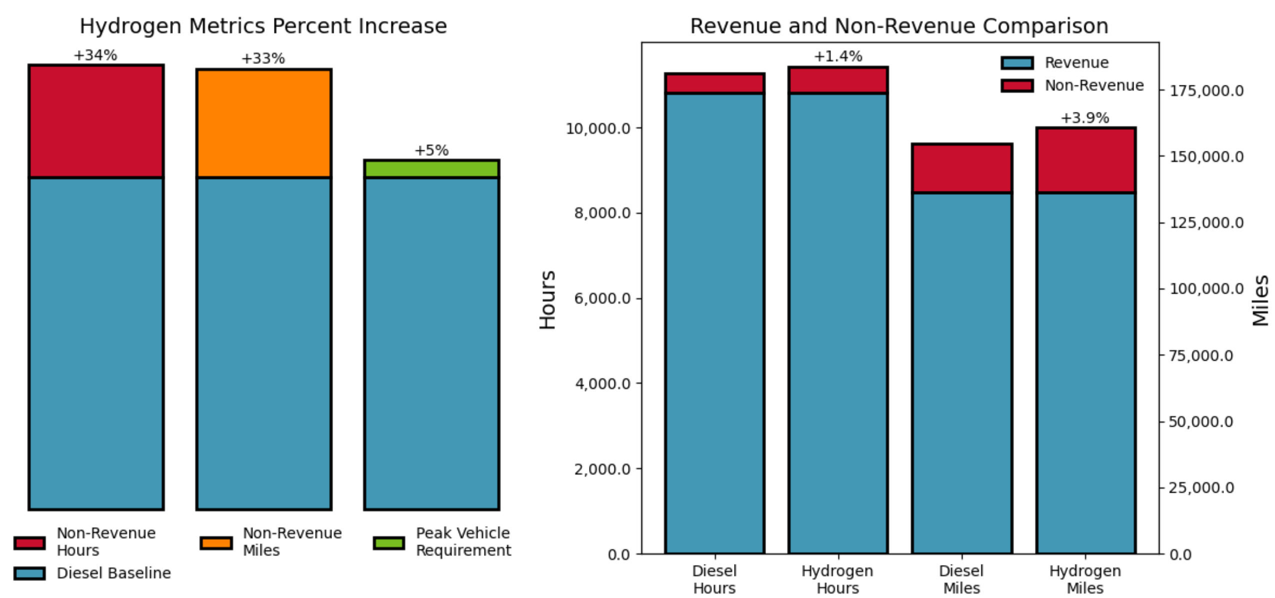


Figure 4: **BLOCKS GROUPED BY LEVEL OF DIFFICULTY FOR FCEB OPERATION**

A full transition to FCEBs would result in increased non-revenue hours and non-revenue miles of 34 percent and 33 percent respectively. The overall impact from a complete conversion to FCEBs on total operating hours and miles is a 3.9 percent increase in miles, and a 1.4 percent increase in operating hours. This simulation model does not optimize the trip boundary where blocks are split based on distance from the garage, but only based on fuel level. A planning exercise should be completed to identify the most ideal locations for inserting these block splits if FCEBs are deployed. An optimized solution may have a lower deadhead. **Table 1** shows a comparison of the weekday statistics for FCEBs and CNG buses.

Table 1: **COMPARISON OF WEEKDAY STATISTICS FOR FCEBS AND DIESEL BUSES**

	Revenue		Non-Revenue		Peak Vehicle Requirement
	Miles	Hours	Miles	Hours	
CNG	27,259.2	2,164.8	3,683.6	90.2	154
Hydrogen	27,259.2	2,164.8	4,888.0	120.7	162

Despite the large number of blocks that need to be split, the impact to the overall fleet size is minimal with only 8 additional active vehicles being needed each day when compared to the existing diesel service. This is because vehicles can be refueled relatively quickly and re-used multiple times throughout the day. For the most part, the same vehicles that operate the morning and evening tripper blocks can also be used as the replacement vehicles for blocks that go beyond the capabilities of the FCEBs at the end of the day.

COMPARISON TO BEB MODELING

Overall, FCEBs are able to operate more blocks than BEBs even with on-route charging for BEBs. All BEB blocks could be operated with FCEBs; there are also additional blocks that are not feasible to operate with BEBs that could be operated with FCEBs. **Figure 5** shows a comparison of BEB and FCEB block feasibility for COTA's existing bus blocks by route. Variables used to produce the modeling outputs for both BEBs and FCEBs are detailed in **Appendix D: Modeling Variables.**

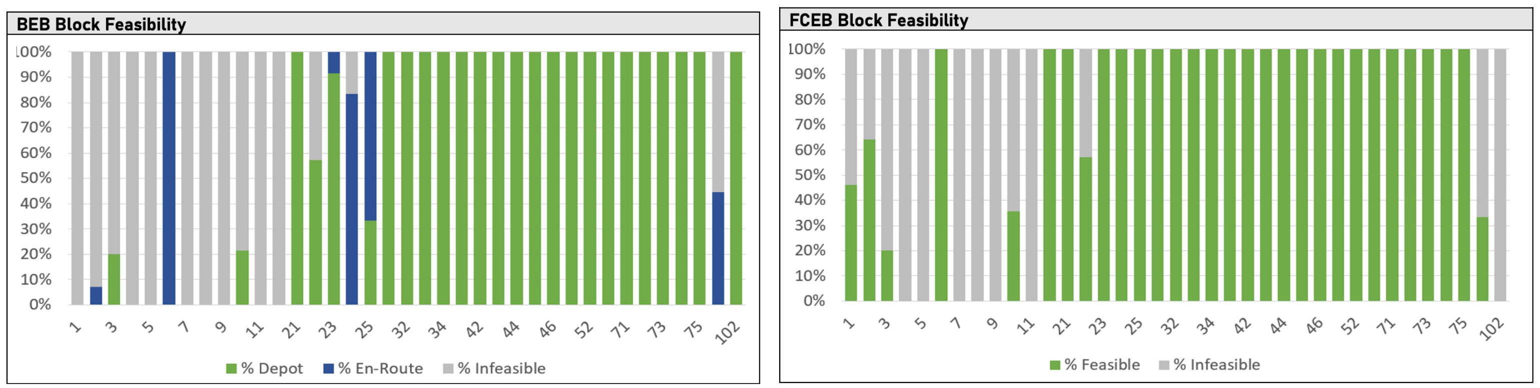


Figure 5: **BEB VS FCEB BLOCK FEASIBILITY BY ROUTE**

When comparing the difficulty of operating each block with ZEBs, FCEBs are able to operate more blocks than BEBs. **Figure 6** shows the difficulty of operating each block with BEBs or FCEBs by categorizing them as “Easy”, “Medium”, or “Hard”. “Easy” blocks are blocks that could be operated with a ZEB without any additional vehicles or changes necessary. “Medium” blocks are blocks which could be operated with a ZEB swapping the vehicle out during the block with another ZEB. A “medium” block could also be re-routed to become an “easy” block to avoid the swap. “Hard” blocks are blocks that would require more than one swap and are not operationally feasible with today’s technology.

About one-third of COTA’s blocks could easily be operated with BEBs, while about two-thirds of COTA’s blocks could easily be operated by FCEBs.

ADDITIONAL MODELING CONSIDERATIONS

In evaluating the fleet’s operational efficiency, an assessment was conducted to determine the percentage of vehicles compatible with a 675 kWh battery bus. Selected charging locations have been strategically identified, including two at Westview and Easton, and one each at Reynoldsburg and North. With the integration of the 675 kWh bus into the on-route model, the block feasibility notably improves, transitioning from 127 out of 226 blocks to 160 out of 226, reflecting an increase from 56 percent to 71 percent.

FUTURE ON-ROUTE OPPORTUNITIES

The implications of incorporating more on-route charging surface several important considerations. To optimize future opportunities, a key aspect involves exploring longer layover times and assessing the current redundancy at layover locations, especially those equipped with more than one charger. Future on-route prospects should factor in COTA’s block schedule, examining the duration of layovers at existing locations. It’s essential to recognize that while additional charging locations may not always be justified, a nuanced approach considers the potential benefits of adjusting timing, possibly necessitating an increase in the number of chargers. Instead of immediately expanding locations, a strategic approach should involve prioritizing the extension of layover times and subsequently evaluating the need for additional chargers at identified locations. Moreover, there is an opportunity to implement layover time for routes stopping at enroute charging locations without dedicated charging schedules. For routes passing by these locations, a consideration is reconfiguring routes to facilitate stops at charging points, particularly for routes with nearby stops within 0.2 miles. Extending layover times emerges as a viable strategy to enhance charging capacity, though it warrants careful assessment of potential charger requirements.

Figure 6: **BEB VS FCEB BLOCK DIFFICULTY**

BEB AND FCEB FEASIBILITY BY FACILITY

In this study, the project team looked at the blocks are operated out of each facility and the feasibility of operating each block with either BEBs or FCEBs. Modeling results shown in **Figure 7,** indicate that each facility had a similar number of BEB Easy and FCEB Easy blocks. The Fields Garage had 38 BEB Easy blocks, 36 FCEB Easy blocks, and 48 blocks that were not easy to operate with either technology. The McKinley Garage had 40 BEB Easy blocks, 31 FCEB Easy blocks, and 30 remaining blocks that were not easy to operate with BEBs or FCEBs. Blocks that were not easy to operate with BEBs or FCEBs were categorized as “Remaining.”

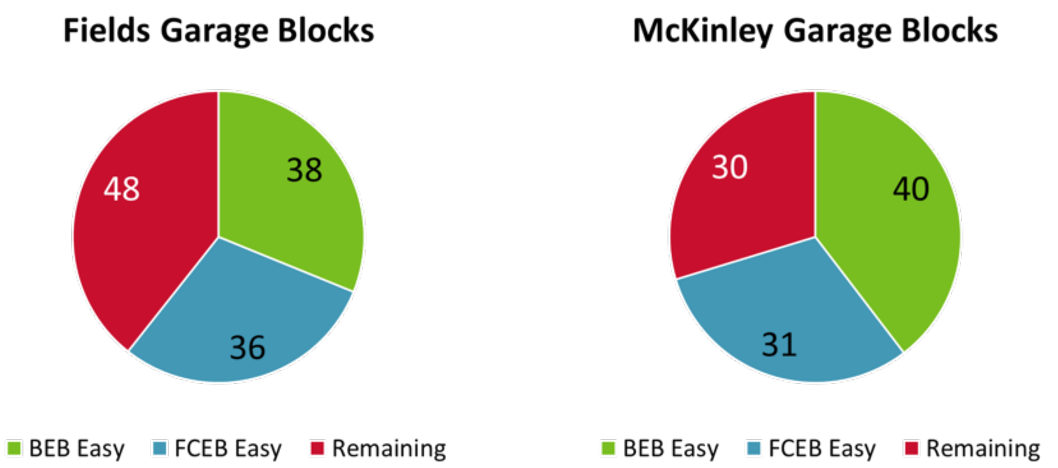


Figure 7: **BLOCK DIFFICULTY BY FACILITY**

It is important to note that the Remaining blocks comprise of COTA's longer blocks. At Fields Garage, Remaining blocks make up almost 57 percent of service miles; at McKinley Garage, Remaining blocks make up 55 percent of service miles **(Figure 8).**

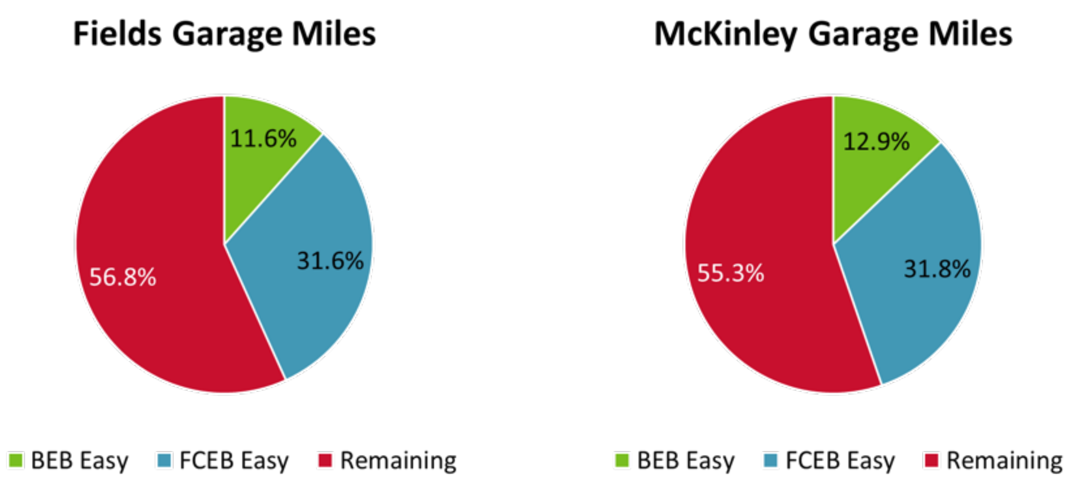


Figure 8: **SERVICE COVERAGE BY FACILITY**

Table 2 shows the specific blocks that are categorized as BEB Hard along with the facility that the block is assigned to. For BEBs, Routes 1, 2, 8, and 10 are the most difficult to operate with BEBs because all blocks within the route are categorized as BEB Hard.

Table 2: **BEB HARD BLOCKS**

ROUTE	FACILITY	NUMBER OF HARD BLOCKS WITHIN ROUTE	ALL BLOCKS CLASSIFIED AS HARD BLOCKS?
1	Fields	14	Y
2	Fields	14	Y
3	McKinley	4	-
4	Fields	4	-
5	McKinley	7	-
7	McKinley	3	-
8	Fields	14	Y
9	McKinley	2	-
10	McKinley	14	Y
11	Fields	4	-
12	McKinley	3	-
21	McKinley	4	-
22	Fields	7	-
23	Fields	8	-
24	Fields	6	-
25	Fields	5	-
32	McKinley	2	-
33	McKinley	4	-
102	Fields	3	-
CMAX	Fields	7	-

Table 3 shows the specific blocks that are categorized as FCEB Hard along with the facility that the block is assigned to. For FCEBs, Route 8 is the most difficult to operate with FCEBs because all blocks within the route are categorized as FCEB Hard.

Table 3: **FCEB HARD BLOCKS**

ROUTE	FACILITY	NUMBER OF HARD BLOCKS WITHIN ROUTE	ALL BLOCKS CLASSIFIED AS HARD BLOCKS?
1	Fields	14	-
2	Fields	14	-
3	McKinley	4	-
4	Fields	3	-
5	McKinley	7	-
7	McKinley	3	-
8	Fields	14	Y
9	McKinley	2	-
10	McKinley	9	-
11	Fields	3	-
22	Fields	7	-
102	Fields	3	-
CMAX	Fields	4	-

KEY TAKEAWAYS

Route modeling shows that more of COTA's existing bus service could be operated with zero-emission vehicles if FCEBs are considered in the fleet. BEBs could operate 78 of the 223 blocks modeled and FCEBs could operate 147 of the 223 blocks modeled. There are 76 blocks which are not easy to operate with BEBs or FCEBs. These remaining blocks could be approached with a few strategies (see **Long-Term Plan**).

When looking at modeling results for Fields and McKinley operations, both facilities could hypothetically house FCEBs. Real-world site conditions would indicate which site is the preferred location and a site visit was conducted to determine the ideal location for the first installment of FCEBs.

Site Visit

After discussing the modeling results with the project team, HDR and COTA determined that a site visit was necessary for this study. HDR conducted a site visit to both COTA operations and maintenance facilities located on Fields Ave and McKinley Ave on August 23, 2023. This site visit provided an opportunity for the HDR project team to further discuss COTA's operations, planned expansions, fleet goals, and hydrogen's place in COTA's fleet.

The primary goals of the site visit were to determine the suitability of Fields Garage and McKinley Garage to house a hydrogen storage and distribution system (utilizing delivered liquid hydrogen) and identify a preferred location for this infrastructure.

GENERAL INFORMATION

COTA is planning for a 20 percent service expansion in the future, which would include some BRT routes. As COTA's fleet continues to grow and more ZEBs are added to the fleet, it is important that resiliency is built into any BEB or FCEB plan. In order to ensure resiliency and back-up, three days of preparation are desired for both FCEB and BEB.

Both facilities are equipped with CNG capabilities, including fueling and defueling. Safety systems for detecting and handling CNG are already in place, as well as a ventilation system designed to meet CNG safety requirements.

At the time of writing this report, COTA has 10 BEBs that operate out of Fields Garage. COTA plans for 14 additional BEBs to be delivered in Q4 2023 and 26 more BEBs to be delivered in 2024. By the end of 2024, it is planned for COTA to have 50 BEBs.

FIELDS GARAGE

BEBs and EVSE

Currently, the existing 10 BEBs are charged with 10 plug-in chargers that are mounted from the ceiling at Fields. The charging cabinets are located in the area adjacent to the bus storage. There are no chargers available in the maintenance bay at the time of writing this report. As the BEB fleet grows, COTA may consider adding a portable BEB charger to one of the maintenance bays.

Ceiling/Roof Considerations

The roof height is 20 feet in the bus storage areas and repair bays. The majority of the electricity infrastructure has already been lowered from the ceiling, but it's necessary to check some conduits running to lights that were not lowered for sealed/explosion rating. Currently, the safety requirements rely on six air movements per hour rather than 18" spacing from the ceiling. As implementation becomes closer, it will be important to investigate whether this is also an option with hydrogen.

Non-Revenue Fleet

The non-revenue fleet, which includes a light-duty fleet of supervisor vehicles, is currently housed inside but there are plans to move them outside. COTA aims to eventually convert the non-revenue fleet to electric vehicles and use Level 2 chargers. However, COTA is waiting until larger electric SUVs are available on the market before transitioning the non-revenue fleet.

H2 Infrastructure Locations

The location for a hydrogen fueling station at Fields Garage is limited due to its surroundings. The facility is bordered on the North and East sides by railway tracks, a main roadway on the South side, and a recycling plant on the West side. Across the road on the South side, there is a large employee parking lot, facilities for the Stops and Zones crew, parking for Access Services vehicles, along with the administration building for Access Services and repair shops for access vans.

HDR considered three locations at Fields Garage as possible hydrogen infrastructure locations.

Option 1 for the location of a hydrogen fueling station was initially proposed in the Northeast triangle formed at the merging point of the east/west and north/south rail lines. However, this area of the facility has a history of hydrocarbon contamination from previous property owners, and remediation had to take place after a train derailment. COTA expressed concerns about building a hydrogen station in such a vulnerable area. Additionally, the train tracks behind the site are curved, and COTA has experienced one derailment in the past. With the exclusion of the triangle area, there is no other viable area on the lot to build a hydrogen station to fuel buses.

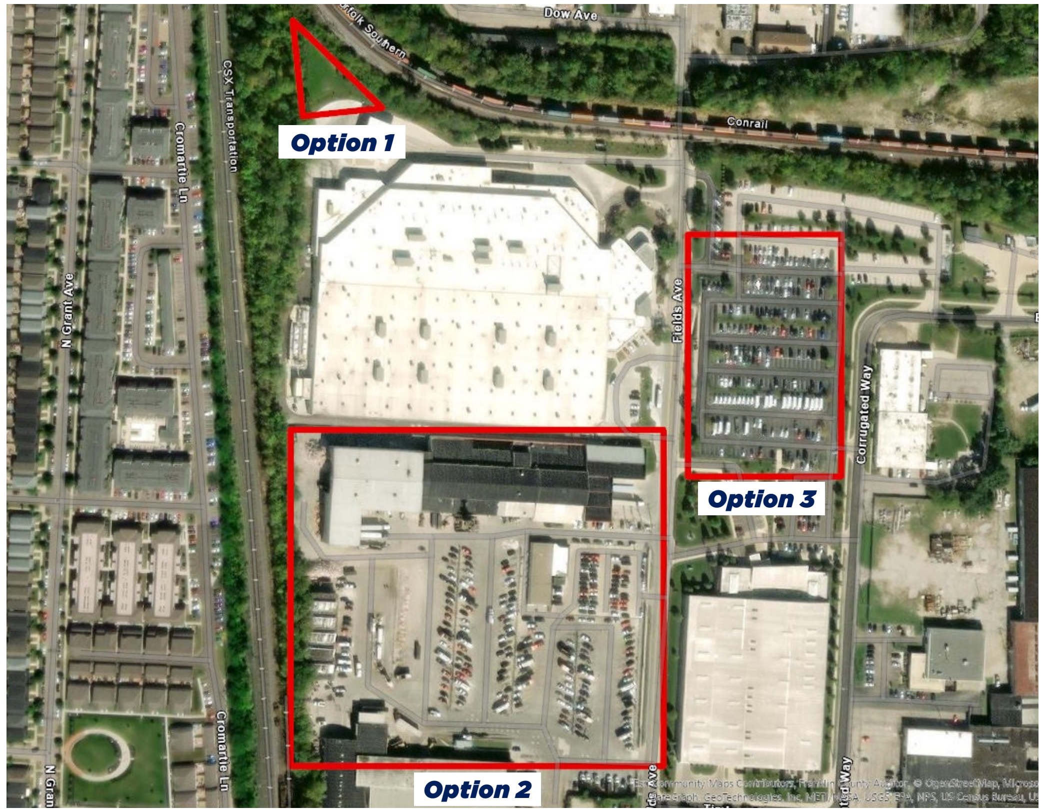


Figure 9: **INFRASTRUCTURE LOCATION OPTIONS AT FIELDS GARAGE**

Option 2 is a possible location but is not feasible unless COTA is able to acquire this land. Rumpke recycling, located next door, might move, and COTA has expressed interest in purchasing that property to expand. This would solve any space problems at this location, but it is uncertain if the recycling plant will move, and if it does, it is also uncertain if the landowner would sell the property to COTA.

Option 3 was also considered, but it presents operational challenges. There is adequate space to build a hydrogen station across the road in the employee parking lot by removing some of the employee parking. While there is enough space to do this, buses would have to drive across the road to fuel and then drive back across the road to be reparked. With buses being fueled during nighttime hours and traversing a public road, there is an increased risk of vehicular accidents with the public.

Gas Detection Sensors and Compliance

NFPA 30A states that in major repair garages, the area within 18 in. of the ceiling is considered a hazardous zone and is designated as Class I, Division 2. Within these areas, all electrical wiring, conduits, junction boxes, and electrical appliances must be either explosion proof or relocated outside the hazard zone.

The facility is fully compliant with methane sensors and meets Ohio requirements for lighter than air combustible gases. For NFPA 30A compliance in major repair garages, the area within 18 inches of the ceiling is considered a hazardous zone and is designated as Class I, Division 2. Within these areas, all electrical wiring, conduits, junction boxes, and electrical appliances must be either explosion proof or relocated outside the hazard zone. Regarding hydrogen sensors, it is currently unknown if the current methane requirements will meet hydrogen requirements. Further research is needed on this item to determine compliance.

Maintenance Bays

The maintenance bays at this facility are 20 feet wide, but it's worth noting that some areas within each bay have an effective width of 18 feet due to the location of the hoist control box and protective bollards. With a reported 15 bus repair bays, the facility is well-suited to maintain approximately 150 40-foot transit buses. However, it's important to keep in mind that the bay width of 20 feet is not optimal for BEBs or FCEBs due to NFPA-70E Arc Flash minimum distance requirements.

MCKINLEY GARAGE

BEBs and EVSE

At this facility there are no BEBs operating yet, however, COTA is in the process of installing EVSE to support future buses. A 2.5MVA transformer is being added to the facility. The installation of overhead charging may present some challenges due to the interior of the facility. Specifically, the ceiling in the bus parking area is only 18 feet high, and the roof beams are only 15 feet from the floor to the bottom of the beam. Additionally, the distance between support columns is 57 feet, with only 5 feet 10 inches between the stalls on either side of the support. The possibility of installing AC/DC charging equipment with bollard protection instead should be investigated. This could eliminate the need for long DC cable runs to the buses.

H2 Infrastructure Locations

With its spacious area, McKinley Garage offers ample square footage for the installation of a hydrogen fueling station. The location provides up to 11,000 square feet of property, giving multiple options for permanent infrastructure. Additionally, COTA has noted that vertical storage tanks could be utilized at this site, which decreases the footprint of H2 infrastructure further and makes spatial constraints less prevalent.

HDR considered three locations at McKinley Garage as possible hydrogen infrastructure locations.

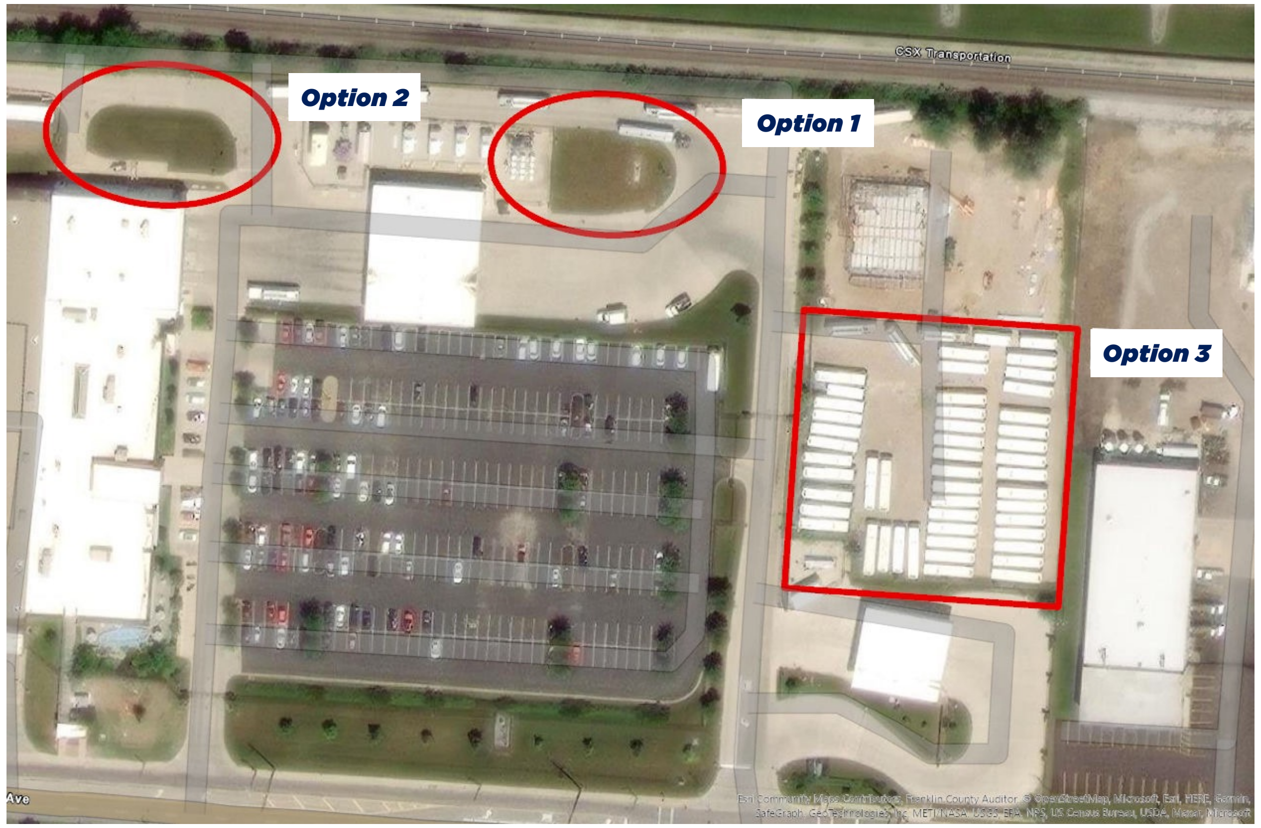


Figure 10: **INFRASTRUCTURE LOCATION OPTIONS AT MCKINLEY GARAGE**

Option 1 is located just east of the current CNG compression station and is deemed a feasible solution. While the proximity may require the installation of a blast wall and the removal of an old diesel tank underground, the distance to the fuel island is between 81 and 150 feet, which is adequate for placement of storage and distribution infrastructure. This means that H2 dispensers could be installed alongside current CNG fueling dispensers. Alternatively, a dispenser could be installed beside the station, with a canopy if required.

Option 2 is also another feasible option, with another area south of CNG fueling currently being used for plant storage. COTA was interested to see if the grassy area next to the building could hold portable or mobile hydrogen infrastructure. This option would allow permanent infrastructure to be built in a different location during the initial investment. However, the proximity may require the installation of a blast wall and moving an air intake on the building.

Option 3 offers a potential solution but is the lowest ranked option. Infrastructure installation at this site would involve taking back some employee parking at the east parking lot to develop a hydrogen-only fuel island. If employee parking becomes an issue, some space could be developed in the retired bus parking area. It should also be noted that this option would require the removal of parking and relocation of inactive buses.

Proposed Fleet Mix and Hydrogen Strategy

Considering route modeling outputs and site visit findings, HDR developed an overall fleet mix recommendation, near-term hydrogen strategy and long-term hydrogen strategy to support COTA's goal of a zero-emission bus fleet. The near-term strategy would be to bring FCEBs into the bus fleet in a smaller first installment between 2024 and 2027. The long-term strategy would be to scale up the FCEB fleet at McKinley Garage after 2027.

31% BEB | **37% FCEB** | **32% REMAINING**

FLEET MIX

As seen across all transit operations, COTA's fleet and routes are everchanging to meet the demands of the community. This fleet mix was created assuming existing blocks and service, but in reality, blocks and service will change periodically. With each installment of ZEBs, it will be important for COTA to carefully plan the blocks that the ZEBs will operate and schedule the ZEBs accordingly. COTA will need to plan for ZEBs to operate shorter blocks or operate blocks where on-route charging or midday refueling is available. COTA may also need to re-block some blocks to become suitable for ZEBs.

Phase I of Zero-Emission Buses: BEBs

COTA is undergoing efforts to add BEBs to the bus fleet and plans to continue adding BEBs to the fleet where it is operationally feasible. According to route modeling and vehicle replacement schedules, COTA can use 55 BEBs to operate BEB Easy blocks and COTA plans to have 60 BEBs in the fleet by 2025. This means that by 2025, COTA will run out of BEB Easy blocks to assign BEBs to and will subsequently need to re-route blocks or start adding FCEBs to the fleet. This fleet mix assumes that COTA is aiming to maintain most existing blocks and chooses to incorporate FCEBs into the fleet. This includes adding relevant en-route charging.

Phase II of Zero-Emission Buses: FCEBs

In 2024, COTA can begin planning for FCEBs so that FCEBs could enter service in 2026–2027. The near-term FCEB strategy would be a smaller initial deployment of FCEBs in 2026–2027 and utilization of a mobile hydrogen station while a permanent station is built at McKinley Garage. Once the permanent hydrogen infrastructure is operational, COTA could scale up the FCEB fleet to operate 31 FCEBs out of McKinley Garage. Current route modeling shows that 31 FCEBs could be operated out of McKinley on FCEB Easy blocks. A secondary option would be to build a permanent hydrogen fueling station that could be scaled up to meet future demands.

Once reaching 31 FCEBs, there are two options to add more FCEBs to the fleet. The first option is for COTA to re-block additional blocks operating from McKinley to operate more FCEBs to this facility. A second option could be to move the mobile hydrogen infrastructure to Fields Garage to start operating FCEBs out of Fields Garage. By re-blocking McKinley blocks or expanding FCEB operations to Fields Garage, COTA could aim to add 50–60 FCEBs to the fleet.

Phase III of Zero-Emission Buses: To Be Determined

While the goal is to operate a fully zero-emission bus fleet, today's technology is not equipped to operate about one third of COTA's blocks unless route modifications are made or ZEB technology advances. This final phase of the zero-emission transition strategy acknowledges this reality and therefore saves this remaining portion for the end of the fleet transition timeline. Listed below are some approaches to this remaining portion of the fleet:

1. Service Changes

It is likely that COTA will have new routes after 2030, and these new routes could be better equipped to operate with ZEBs if planned with ZEBs in mind. COTA could intentionally block service to be conducive for ZEB operation.

2. Additional On-Route Charging

COTA could explore additional on-route charging locations to provide more opportunities for midday charging of BEBs.

3. Additional Vehicles

COTA could purchase additional ZEBs to swap throughout the day on longer routes.

4. Technology Improvements

It is impossible to know exactly how ZEB technology will advance, but given today's demand for EVs, it is probable that the ZEBs of the future will have increased range capabilities. If range capabilities increase, more of COTA's service could be operated with ZEBs.

5. Different Fuel Types

If ZEBs do not appear to be viable in Phase III, COTA could look to low-emission fuels until zero-emission technology is feasible. One option could be to switch CNG buses from being fueled with CNG to being fueled with renewable natural gas (RNG) and/or specify only Cummins near zero CNG engines going forward.

NEAR-TERM HYDROGEN STRATEGY (2024–2027)

5-15 FCEBs | **MOBILE HYDROGEN INFRASTRUCTURE AT MCKINLEY GARAGE**

The initial installment for FCEBs would serve as a crucial step towards integrating FCEBs into COTA's bus fleet and meeting COTA's ZEB goals. This initial installment would include 5–15 (dependent on funding availability) FCEBs that would be fueled with mobile hydrogen infrastructure. To fund this initiative, COTA would need to apply for grant funding in 2024, and again in 2025 if the funding is not initially awarded. Assuming that funding is awarded in one of those years, mobile H2 infrastructure and FCEBs would be purchased and FCEBs would begin revenue service either in 2026 or 2027.

The purpose of this initial installment is for COTA to gain experience with a smaller number of FCEBs before integrating a larger number of FCEBs into the fleet. It will be important for COTA to focus on FCEB workforce development for operators and bus maintenance specialists to ensure that the workforce is prepared to operate and maintain future FCEBs.

The initial installment could also be an opportunity to acquire a mobile hydrogen fueling station that could be used at McKinley, Fields, or a future COTA facility. It is possible for COTA to lease a mobile hydrogen fueling station, however COTA could explore purchasing a mobile station and using this at another facility in the future. Having a mobile station would allow COTA to more easily expand FCEB operations in the long term.

LONG-TERM HYDROGEN STRATEGY (AFTER 2027)

50-60 TOTAL FCEBs | **PERMANENT HYDROGEN INFRASTRUCTURE AT MCKINLEY GARAGE** | **MOBILE HYDROGEN INFRASTRUCTURE AT FIELDS OR NEW FACILITY**

For the long-term FCEB strategy, COTA would install a permanent hydrogen storage and distribution system at McKinley Garage. This hydrogen infrastructure would be built to fuel 40–50 FCEBs. Assuming current blocks and route modeling, COTA could add 31 FCEBs to operate 31 blocks out of McKinley Garage.

Once reaching the milestone of 31 FCEBs at McKinley Garage, there are two options to add more FCEBs to the fleet. The first option is for COTA to re-block additional blocks operating from McKinley to operate more FCEBs from this facility. A second option could be to move the mobile hydrogen infrastructure to Fields Garage to start operating FCEBs out of Fields Garage. By re-blocking McKinley blocks or expanding FCEB operations to Fields Garage, COTA could aim to add 50–60 FCEBs to the fleet.

Facility Plans

MCKINLEY GARAGE SITE OPTIONS

Following the site evaluation of both Fields and McKinley Garages, McKinley Garage was determined as the most suitable location for a hydrogen storage and distribution system. The McKinley Garage had more space available for H2 infrastructure while Fields Garage only had room in certain areas. Additionally, the spaces available at McKinley Garage worked better with the operational flow of the facility.

At McKinley Garage, the team identified three potential locations—one mobile location, one permanent location, and a secondary location to consider for mobile or permanent infrastructure if either of the other two locations become unavailable.

Both 2020 and 2023 setbacks are shown for the three potential locations at McKinley Garage, along with radiuses to indicate the maximum distances allowable between the H2 storage tanks and dispensers in the figures below. While the graphics look similar, it is important to note the different setbacks that are within the green radius. The setbacks within the green radius can present issues, particularly regarding space limitations. As a result of these limitations, the 2020 codes will not work with the mobile infrastructure placements, and although these codes are feasible with the permanent and secondary site locations, working with local authorities to get the codes updated overall is recommended.

How to Interpret Hydrogen Setback Maps (Figures 11–15)

There are multiple setbacks shown in the figures below, along with radiuses to indicate the maximum distances allowable between the H2 storage tanks and dispensers.

H2 equipment is depicted at the center in small specs of blue. Outside these blue specs, there are a few squares which indicate NFPA 2 setbacks. First, there is a red square which shows the setback requirements for noncombustible buildings. After the red square, there are yellow and green squares which show the setback requirements for overhead utilities, combustible construction, parked cars, ordinary combustibles, lot lines, and doors/windows.

The green and blue circles surrounding the NFPA 2 setbacks show the ideal location for fuel dispensers (in green circle) and the maximum distance for fuel dispensers (in blue circle). It is important to place fuel dispensers as close as feasibly possible to hydrogen storage equipment to ensure that H2 maintains the correct temperature and pressure for fueling.

Mobile H2 Infrastructure

This location has been identified as a feasible spot for mobile hydrogen infrastructure. It satisfies the NFPA 2 setback requirements, although this location may require a blast wall and the relocation of an air intake on the northern side of the building closest to the proposed site. This spot is well-suited to the current traffic flow as buses currently pass this area on their way to the existing CNG fueling. Storage tanks and dispensers would be placed on the existing grass patch. The grass patch may need to be paved over. See **Figure 11** below for the mobile infrastructure location with 2020 setbacks and **Figure 12** for the site placement with 2023 setbacks.

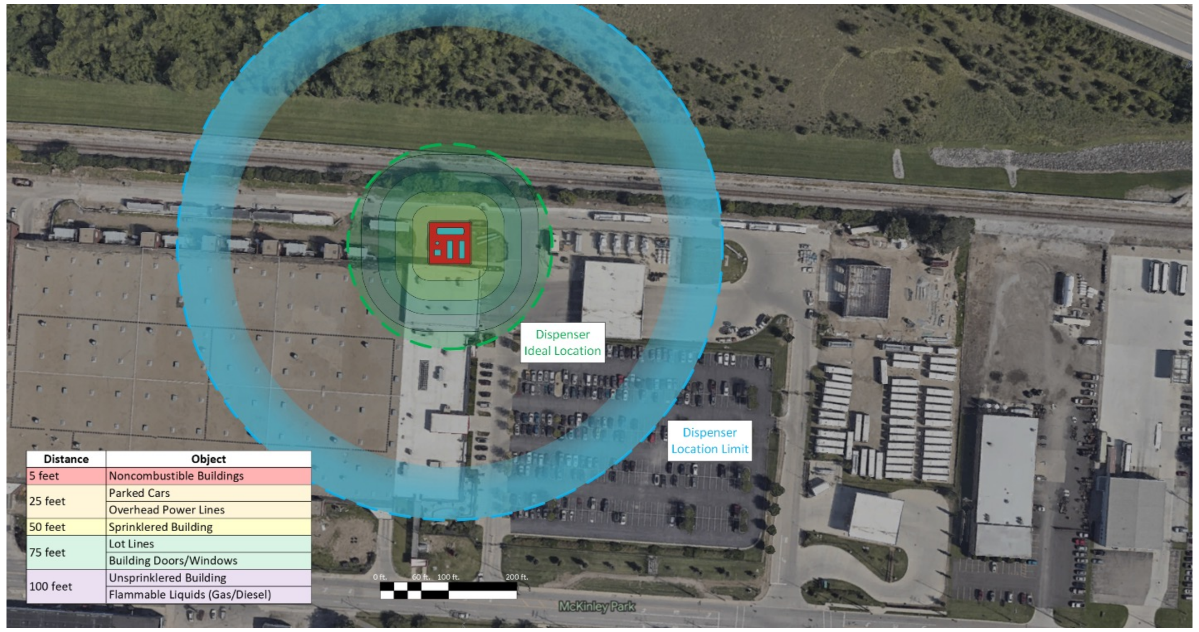


Figure 11: **McKINLEY GARAGE MOBILE H2 INFRASTRUCTURE OPTION 2020 SETBACKS**

Figure 12: **McKINLEY GARAGE MOBILE H2 INFRASTRUCTURE OPTION 2023 SETBACKS**

The preferred location for permanent infrastructure has been chosen because it aligns well with the operational flow of COTA's buses at present. Moreover, it is situated adjacent to its existing compressed natural gas fueling infrastructure, which makes it extremely convenient as there will be no need to reroute buses for overnight fueling. This location is highly centralized, which means everything will be easily accessible in one place. Another reason why this location is preferred is due to the ample space available and the fact that setback considerations aren't as prevalent since it's situated quite far away from most existing buildings. The permanent hydrogen infrastructure location with 2020 setbacks is pictured in **Figure 13** below and **Figure 14** for the site placement with 2023 setbacks.

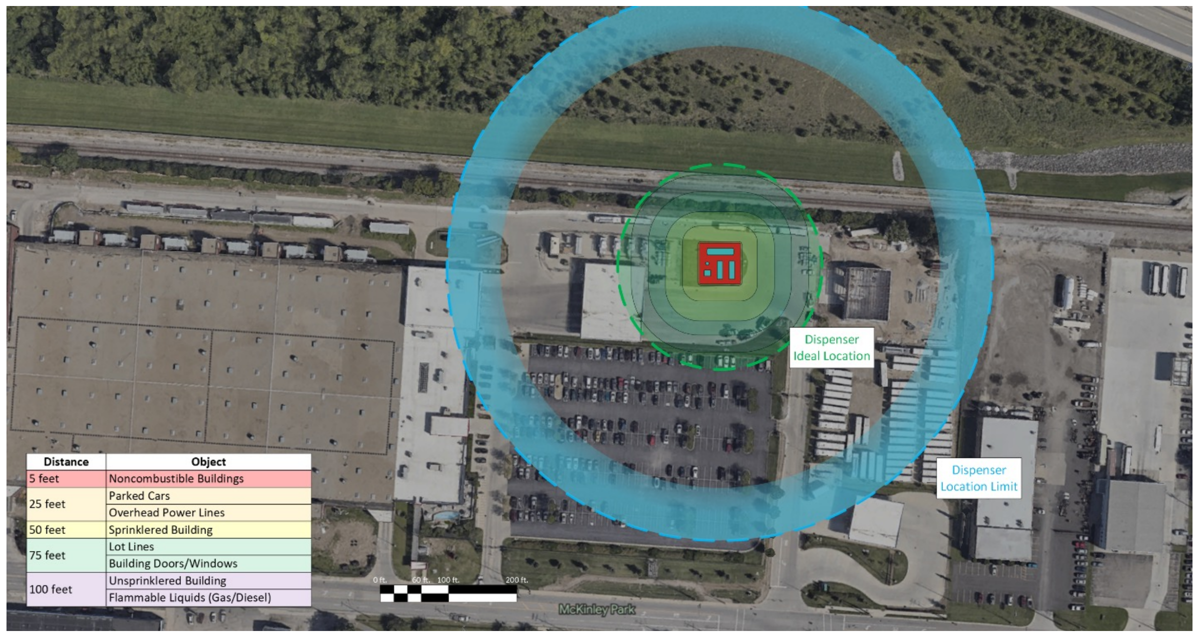


Figure 13: **McKINLEY GARAGE PERMANENT H2 INFRASTRUCTURE OPTION 2020 SETBACKS**

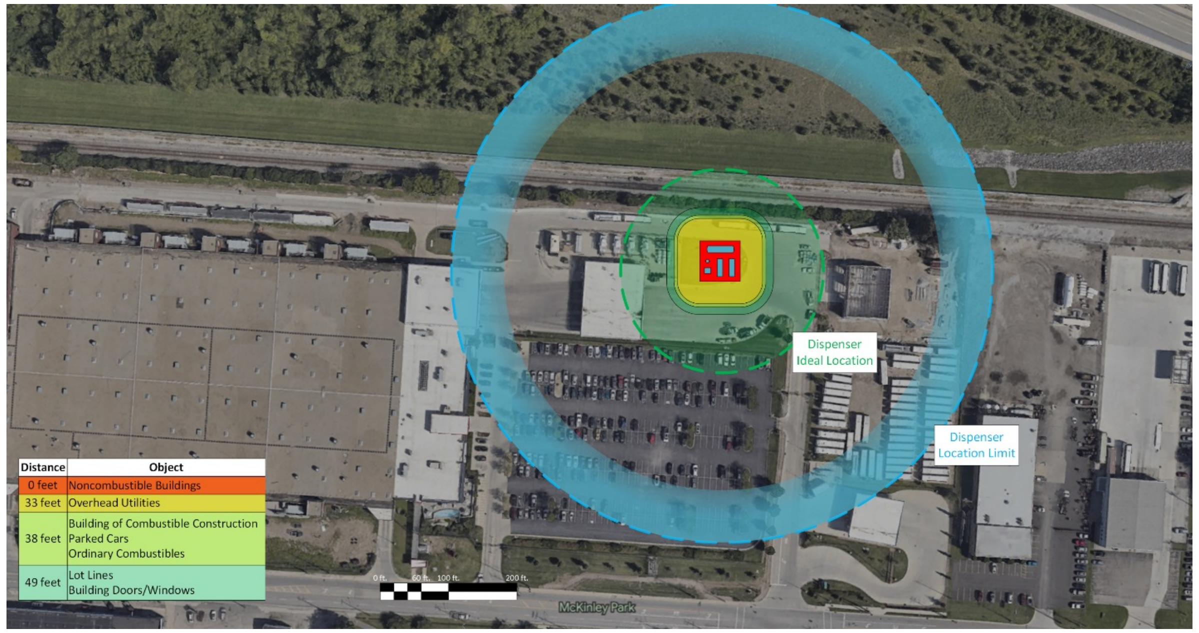


Figure 14: **McKINLEY GARAGE PERMANENT H2 INFRASTRUCTURE OPTION 2023 SETBACKS**

Appendix 2

Secondary Location for H2 Infrastructure

This site currently serves as a space for inactive buses and has ample space if cleared. There is abundant space in this area, which could provide flexibility for the H2 infrastructure design. This was listed as a secondary location rather than preferred site because it is farther away from the current fueling site. This would mean that CNG and H2 will be fueled in different locations, and the buses at this site will have to be moved or sold. Although this option could work, it is not as efficient as the other two locations that were considered. The secondary hydrogen infrastructure site with 2020 setbacks is shown below in **Figure 15** and **Figure 16** for the site placement with 2023 setbacks.

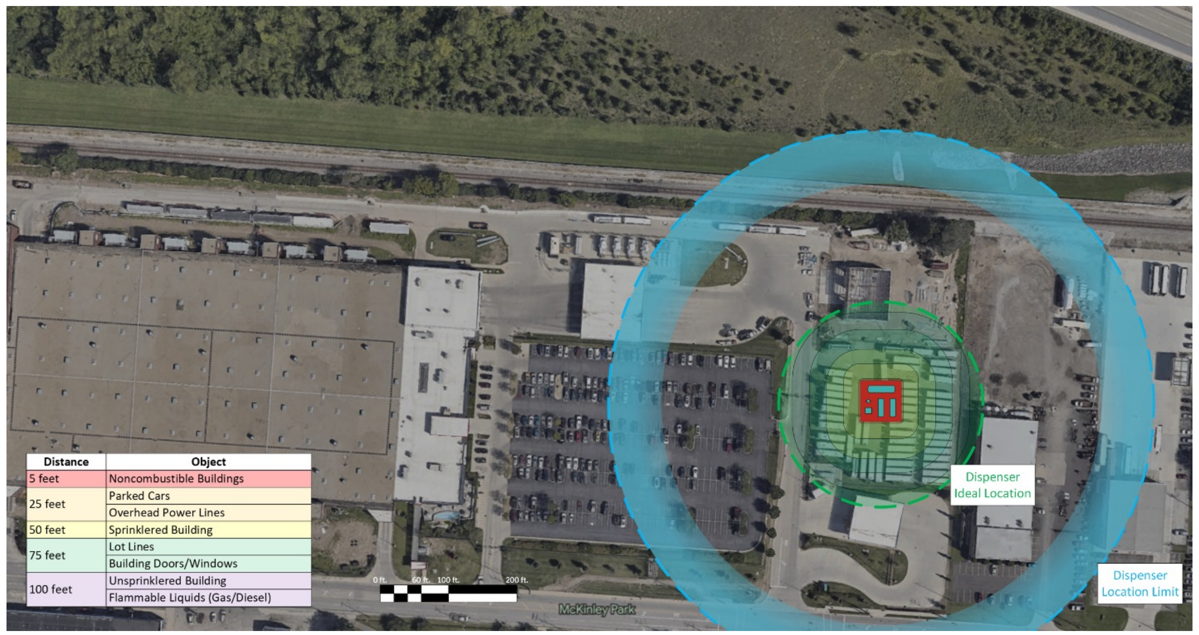


Figure 15: **McKINLEY GARAGE SECONDARY H2 INFRASTRUCTURE OPTION 2020 SETBACKS**

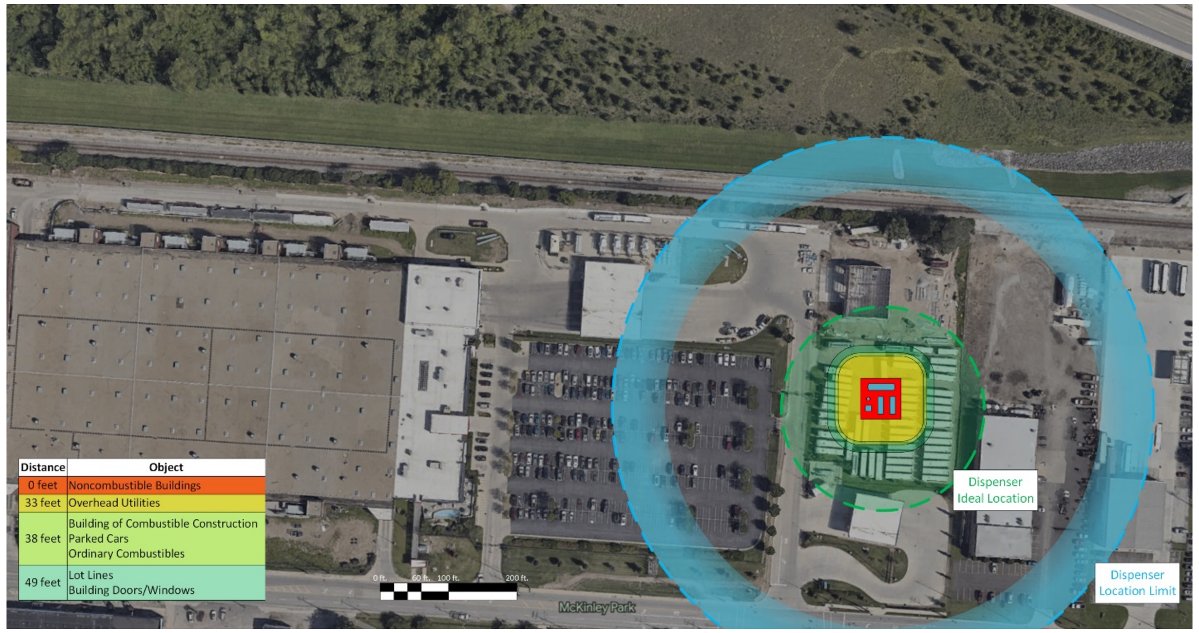


Figure 16: **McKINLEY GARAGE SECONDARY H2 INFRASTRUCTURE OPTION 2023 SETBACKS**

Fleet Contingency Considerations

There are two types of vehicles recognized by the Federal Transit Administration (FTA), active and contingency. The contingency fleet is composed of inactive rolling stock that is reserved or retained for emergencies or other unforeseen and justified activities. These activities could include evacuations during an emergency, crowd control, traffic barriers, loaning to other transit agencies during a justified need, or stand-by replacements for buses in the active fleet during major overhauls or maintenance activities.

It is worth considering what role COTA is responsible for in case of public emergency responses. Additionally, it's recommended to have redundant infrastructure in place for resiliency purposes, such as stand-by or mobile units for emergency production for optimal emergency preparedness.

Revenue rolling stock stockpiled in contingency fleets must meet FTA requirements, their minimum useful life requirements, be properly stored, maintained, and documented in a contingency plan. FTA will permit agencies to include vehicles that have met their minimum useful life in their contingency fleet if an agency is introducing zero-emission vehicles into its fleet. It should be noted that these vehicles are not included in the calculation of the spare ratio. Contingency plans are subject to review during triennial reviews and other FTA oversight reviews.

The recipient should keep a record of information that demonstrates the need for contingency fleet activation, the justification for activation, and the period of activation. The contingency fleet plan should demonstrate that the bus has met its useful life by identifying the year the bus was placed in service, the year and mileage when removed from service, and the useful life of the bus in years and miles. The plan should identify where the buses will be stored, how they will be protected, and list the maintenance activities performed on the bus to ensure they maintain their contingency bus fleet status. It is important to note that the contingency fleet is separate from the spare fleet and is not included in the spare ratio. Any rolling stock not supported by a contingency plan will be considered part of the active fleet.

Safety Considerations

When overseeing a FCEB fleet, it's important to follow guidelines to ensure safety measures are continuously met. A critical FCEB safety requirement is to install H2 sensors in all areas where the buses are housed or maintained, including the fueling station, maintenance bays, and bus storage areas. The fueling station must comply with all applicable regulations, from Federal to State and Local, and follow ASME [7]B31.12, CGA 5.4, and 5.6. NFPA 2, NFPA 30A and Local regulations for setbacks must be adhered to as well.

Under certain criteria, FCEBs are classified as battery electric buses, meaning they must also adhere to High Voltage and Arc Flash precautions outlined by OSHA and NFPA 70 E[8] regarding Personal Protective Equipment (PPE) and deenergized work requirements. If there is a hydrogen leak and the alarm is activated within a facility, employees must be appropriately trained to evacuate the building and follow the safety plan that should be in place. It is crucial to ensure that staff have a clear understanding of these procedures to prevent avoidable accidents from occurring.

[7] *ASME Code Standards — Standard for Hydrogen Piping and Pipelines (ASME B31.12)*
[8] *NFPA 70E — Standard for Electrical Safety in the Workplace*

To ensure the safety of fuelers and technicians, appropriate PPE should be available to protect against "freeze burn". Additionally, safe battery storage areas should be developed for both new and defective battery packs. Lastly, a safe outdoor storage area should be identified for defective or damaged buses. By following these guidelines, COTA can ensure the safety of everyone involved in the use and maintenance of FCEBs.

Capital Costs for Near-Term and Long-Term Hydrogen Strategy

Both the near-term and long-term hydrogen will incur new capital costs. In today's market, the cost of an FCEB is higher than a BEB. The installation of necessary hydrogen storage and distribution equipment will result in additional capital costs for the deployment of FCEBs. This section of the report estimates high-level capital costs for the implementation of the near-term and long-term hydrogen bus strategy. This does not include the cost of delivered hydrogen, operation/maintenance of FCEBs or infrastructure, or workforce development needs. These cost estimates are intended for capital planning purposes and aim to inform future grant applications. Costs are assumed in 2023 dollars and do not include inflation.

NEAR-TERM STRATEGY

Table 4 shows a capital budget for the near-term hydrogen strategy, which includes a maximum of 15 FCEBs and mobile fueling infrastructure. The buses account for the highest capital cost, estimated to be $1.2 million per 40-foot bus. The mobile fueling infrastructure is estimated to be about $2 million; this cost was obtained during the Industry Research phase of this feasibility study. Mobile or temporary H2 infrastructure is in high demand throughout the US for transit applications, and it should be noted that costs for this unit could increase due to demand. This capital cost estimate assumed that COTA would purchase a mobile H2 fueler, however it is also possible to rent these units. Monthly rental of a mobile H2 fueler is estimated at $15,000 to $20,000 per month in 2023. This cost was also obtained during the Industry Research phase of this feasibility study.

Planning and commissioning is assumed to account for 10 percent of infrastructure cost. While the mobile unit will not include design or construction costs, the mobile unit may still need to undergo some site planning and station commissioning. Lastly, a 20 percent contingency was assumed for the infrastructure portions of the near-term hydrogen strategy.

Table 4: **NEAR TERM HYDROGEN STRATEGY—CAPITAL COSTS**

	Quantity	Approximate Cost	Total
Buses	15	$1,200,000	$18,000,000
Mobile H2 Infrastructure	1	$2,000,000	$2,000,000
Planning and Commissioning	1	$200,000	$200,000
Contingency	1	$440,000	$440,000
Total			$20,640,000

LONG-TERM STRATEGY

Table 5 shows the estimated capital costs for the long-term hydrogen strategy. This estimate includes 45 FCEBs and assumes that 15 FCEBs are acquired in the near term; this brings the total hydrogen fleet to 60 FCEBs in the long term.

Infrastructure costs were estimated using HDR's Hydrogen Toolkit Modeling tool. **Table 6** shows the infrastructure needed and the estimated costs to build a permanent H2 system that could fuel up to 60 FCEBs. A 60 FCEB system was assumed in to provide flexibility in the location of the mobile fueling infrastructure. While infrastructure costs are similar between the mobile and permanent unit, it is important to note that the permanent unit has the capacity to fuel up to 60 FCEBs while the mobile unit could fuel a maximum of 10 FCEBs. Unlike the mobile infrastructure, the permanent infrastructure will require design and construction. Industry trends show that the planning, design, construction, and commissioning costs are similar to cost of the permanent H2 infrastructure. This estimate assumed planning, design, construction, and commissioning costs to be 110 percent of the infrastructure costs.

Table 5: **LONG-TERM HYDROGEN STRATEGY—CAPITAL COSTS**

	Quantity	Approximate Cost	Total
Buses	45	$1,200,000	$54,000,000
Permanent H2 Infrastructure	1	$2,207,584	$2,207,584
Planning / Design / Construction / Commissioning	1	$2,428,342	$2,428,342
Contingency	1	$927,185	$927,185
Infrastructure Total			$4,635,926
Bus Total			$60,000,000
Grand Total			**$59,563,112**

Table 6: **HYDROGEN INFRASTRUCTURE FOR LONG-TERM STRATEGY**

Item	Size	Approximate Cost
Liquid Storage	4814.4 kg	$529,584
Cryogenic Pump	100 kg/hr.	$458,000
Vaporizer	100 kg/hr.	$150,000
Station Module	100 kg/hr.	$1,000,000
Hydrogen Dispenser	100 kg/hr.	$70,000
Total		$2,207,584

Appendix 3 BEB AND FCEB FEASIBLE BLOCKS BY GARAGE

Route & Garage		Scenario					Total Blocks	Notes
Fields	McKinley	Depot Only	Enroute (6 chargers)	Enroute (9 chargers)	Enroute (14 chargers)	FCEB		
1	-	0	0	0	3	6	13	7 blocks not feasible with any scenario; 10 to 37 more miles of FCEB range would make remaing blocks feasible.
2	-	0	1	1	2	9	14	5 blocks not feasible with any scenario; 7 more miles of FCEB range would make remaing blocks feasible.
-	3	1	1	1	1	1	5	4 blocks not feasible with any scenario; 39 to 59 more miles of FCEB range would make remaing blocks feasible.
4	-	0	0	0	0	0	4	4 blocks not feasible with any scenario; 35 to 73 more miles of FCEB range would make remaing blocks feasible.
-	5	0	0	0	0	0	7	7 blocks not feasible with any scenario; 35 to 73 more miles of FCEB range would make remaing blocks feasible.
-	6	0	4	4	4	4	4	-
-	7	0	0	0	4	0	5	1 block not feasible with any scenario; additional layover time at Easton would make remaining block feasible
8	-	0	0	0	0	0	13	13 blocks not feasible with any scenario; 13 to 45 more miles of FCEB range would make remaing blocks feasible.
-	9	0	0	0	4	0	4	-
-	10	3	3	3	4	5	14	9 blocks not feasible with any scenario; 12 to 37 more miles of FCEB range would make remaing blocks feasible.
11	-	0	0	0	0	0	3	3 blocks not feasible with any scenario; 37 more miles of FCEB range would make remaing blocks feasible.
-	12	0	0	0	3	3	3	-
-	21	6	6	6	6	6	6	-
22	-	8	8	8	8	8	14	6 blocks not feasible with any scenario; 44 to 64 more miles of FCEB range would make remaing blocks feasible.
23	-	11	12	12	12	12	12	-
24	-	0	5	5	6	6	6	-
25	-	3	9	9	9	9	9	-
-	31	6	6	6	6	6	6	-
-	32	6	6	6	6	6	6	-
-	33	8	8	8	8	8	8	-
34	-	12	12	12	12	12	12	-
41	-	2	2	2	2	2	2	-
42	-	2	2	2	2	2	2	-
43	-	4	4	4	4	4	4	-
-	44	2	2	2	2	2	2	-
-	45	4	4	4	4	4	4	-
-	46	2	2	2	2	2	2	-
-	51	5	5	5	5	5	5	-
-	52	4	4	4	4	4	4	-
-	61	4	4	4	4	4	4	-
-	71	2	2	2	2	2	2	-
-	72	2	2	2	2	2	2	-
-	73	6	6	6	6	6	6	-
74	-	2	2	2	2	2	2	-
-	75	2	2	2	2	2	2	-
CMAX	-	0	4	4	4	3	9	5 blocks not feasible with any scenario; 23 to 56 more miles of FCEB range would make remaing blocks feasible.
102	-	0	0	0	0	0	3	3 blocks not feasible with any scenario; 40 to 60 more miles of FCEB range would make remaing blocks feasible.
Total feasible blocks		107	128	128	145	147	223	67 blocks infeasible
% of Blocks		48%	57%	57%	65%	66%	100%	30% infeasible
BEBs needed		55	79	72	88	80	-	
BEBs @ Fields		26	45	39	43	-	-	
BEBs @ McKinley		29	34	33	45	80	-	-

Appendix 4

ACRONYMS AND ABBREVIATIONS

AEP	American Electric Power: Ohio Power Company
APTA	American Public Transportation Association
ASE	National Institute for Automotive Service Excellence
ASME	American Society of Mechanical Engineers
BEB	Battery Electric Bus
BESS	Battery Energy Storage System(s)
BIL	Bipartisan Infrastructure Law
BRT	Bus Rapid Transit
CGA	Compressed Gas Association
CNG	Compressed Natural Gas
CO2e	Carbon Dioxide Equivalent
COTA	Central Ohio Transit Authority
CSU	Cleveland State University
CTE	Center for Transportation and the Environment
DCFC	Direct Current Fast Charging
DERA	Diesel Emissions Reduction Act
DOP	City of Columbus Department of Power
E/E	Electrical/Electronics
EPA	Environmental Protection Agency
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FCEB	Fuel Cell Electric Bus (Hydrogen)
FCEV	Fuel Cell Electric Vehicle
FTA	Federal Transit Administration
FY	Fiscal Year
GHG	Greenhouse Gases
GTFS	General Transit Feed Specification
H2	Hydrogen
HVAC	Heating, Ventilating, and Air-Conditioning
KPI	Key Performance Indicator
kW	Kilowatt(s)
KWH	Kilowatt Hour
MORPC	Mid-Ohio Regional Planning Commission
MVA	Megavolt-Ampere(s)
MW	Mega Watt
NEHC	National Electric Highway Coalition
NFPA	National Fire Protection Association
ODOT	Ohio Department of Transportation