



CAPE FEAR PUBLIC TRANSPORTATION AUTHORITY

Zero Emission Fleet Transition Plan

Wave Transit



9/8/2023



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Agency Overview

In 1974, the Wilmington Transit Authority (WTA) was created and tasked with providing public transportation for the City of Wilmington. In 2002, WTA adopted a new name, Wave, as well as a new logo and updated color scheme. The change welcomed in a new vision for the public transportation system. In 2003, due to rapid growth and increasing traffic congestion, the City of Wilmington and the County of New Hanover entered into a new agreement. With this agreement, the city and county merged WTA with the New Hanover Transportation Services to form the Wilmington/New Hanover Transportation Agency (WNHTA). This agreement merged the respective organizations for one year, in order to provide oversight of both agencies under one public transportation authority. In July of 2004, the WNHTA, the WTA, and NHTS were dissolved, and a new transportation authority was created. The merged entity officially became the Cape Fear Public Transportation Authority but kept the name Wave Transit.

In 2011, Wave Transit restructured all fixed routes in the region. The new routes were based on a modern transfer facility, Forden Station, which is centrally located within the service area. Expanded service required additional infrastructure, and a 36,000 square foot Wave Transit Operations Center was built to house a maintenance shop, bus garage, fueling station, and serve as the epicenter of service operation. The Operations Center opened in June 2015. The most recent improvement was Padgett Station, a downtown multimodal transportation center which replaced an open-air transfer point on 2nd St. in January 2020.¹

Fixed Route Service

Wave Transit currently operates 13 fixed routes Monday through Friday: 12 routes operate seven days per week, the University of North Carolina Wilmington (UNCW) shuttle operates on weekdays during the academic year, and the Port City Trolley operates Monday through Saturday. During the winter, the Port City Trolley has reduced hours and route extents. The full system map can be seen in **Appendix A: Wave System Service Maps**.

Port City Trolley

In June 2018, Wave Transit concluded their five-year Short Range Transit Plan, which concluded with recommendations for a revised Downtown Trolley Program. In 2018, two route alignments for the Downtown Trolley were piloted to the community. Both alignments reflected coverage beyond the Central Business District to surrounding districts. Increased coverage and connectivity between the five downtown districts – *Central Business District, North Waterfront, Brooklyn Arts, Castle Street and South Front* – was a priority as expressed by the public and the Downtown Trolley Focus Group through our planning effort. The pilot route received most favorably was launched on October 15, 2018, as the permanent Trolley route.

The Trolley had a new route, and now it needed a new name. The Wilmington community chose the name, Port City Trolley, through a community naming contest that received over 300 suggestions. Fresh branding and a logo were developed by UNCW Graphic Design students, making the Port City Trolley a truly local effort. The route for the Port City Trolley is shown in **Appendix A: Wave System Service Maps**.

¹ <https://www.wavetransit.com/mission-and-history>



UNCW Shuttle

The UNCW Shuttle was initially implemented in 1997 to transport UNCW students who live within one mile of the campus to the University. Today, the shuttle transports students and employees throughout campus and surrounding areas. UNCW Shuttle service helps decrease traffic and makes movement within the campus safer and more efficient, as well as decrease the need for additional surface parking at the university. Prior to the COVID-19 pandemic, UNCW and Wave Transit offered Park and Ride services to a designated, off-campus Park and Ride location across College Road at the intersections of Hurst & Hoggard. Park and Ride shuttle services were suspended for the 2020-2021 academic year. Students and employees of UNCW are eligible to ride the UNCW Shuttle and all Wave Transit buses at no cost by simply showing a valid student or employee UNSea card.² The UNCW Shuttle holiday schedule is dependent on the academic calendar, as service is only provided when classes are in session. The route for the UNCW Shuttle is shown in **Appendix A: Wave System Service Maps**.

Paratransit

Dial-a-Ride Transportation (DART)

Wave Transit operates a DART program that provides ADA accessible van service for individuals with disabilities that are unable to travel by fixed route bus. This service utilizes vans specially equipped with a wheelchair lift and restraints for wheelchairs, so each van can accommodate passengers who use wheelchairs and semi-ambulatory passengers. DART provides curb-to-curb, origin to destination service in New Hanover County, Northern Brunswick County, and Carolina Beach within 3/4 of a mile of any fixed route. The service is available Monday through Saturday from 6am to 9pm and Sunday from 9am to 6pm.

Stakeholder Engagement

To inform Wave Transit's fleet transition strategies, a series of interviews with stakeholders were conducted to gather information on existing programs and policies at the state, regional, and local levels, current Low/No Emissions Fleet Plans, proposed infrastructure and implementation timelines, and potential funding opportunities. The interviews included discussions of the "art of the possible," which will ultimately align Wave Transit's fleet transition with what others are currently planning and executing. As the region continues to explore the transition to zero emissions, it will be critical that these key stakeholders have continued dialogue and communication regarding infrastructure and power needs.

New Hanover County

Representatives from New Hanover County mentioned that the county has not made a commitment to a specific zero emission alternative fuel yet, but has indicated that they will likely select battery electric as the primary technology and have begun discussions around switching to hybrid within the next two years. When discussing their carbon reduction goals, they mentioned a 25% reduction goal which will be established in their 5-year plan. With the infrastructure to handle high and medium voltage, the staff are well trained with low voltage and are prepared for a hybrid conversion beginning on July 1, 2023.

² <https://www.wavetransit.com/seahawk-shuttle-schedule/>



Transdev

Transdev performs the maintenance on both the fixed route and paratransit vehicles. The maintenance of the facilities is handled by Wave Transit. Transdev currently employs six mechanics, but they have capacity to add one additional mechanic. According to Transdev, they have reached out to local colleges, but have not had any success recruiting. All of the drivers are full-time and receive annual training and on as-needed basis. They currently use Trapeze to monitor their operation activities.

City of Wilmington

The City of Wilmington has started planning for a zero-emissions fleet transition through the initiation of a Fleet Transition Study. The city does not plan on creating a timeline for integrating a zero emissions fleet until the completion of the Fleet Transition Study in 2024. The city does not have any EVs within their current fleet. They do have some charging stations in public parking decks that were installed as part of the VW settlement. In 2009, Wilmington performed its first Greenhouse Gas (GHG) emission inventory which established a GHG emission baseline. The overall goal is for the city to reduce GHG emissions resulting from municipal operations by 58 percent by 2050. By 2035, the city plans to have 50 percent of its fleet be zero emission vehicles and 100 percent by 2050.

Wilmington MPO

The MPO does not currently have any existing policies associated with the zero-emission fleet; however, they did mention that their next Metropolitan Transportation Plan (MTP) will include something. Within the MPO area, Wave Transit is the only transit agency who has initiated the transition process. Funding for current facilities is obtained through discretionary funding, Transportation Alternatives Set Aside, and local or regional money.



Zero Emission Transition Plan

The Federal Transit Administration introduced a new requirement that any federal grant application for projects related to zero emission vehicles must include a Zero Emission Transition Plan. Therefore, the FTA requires a Zero Emission Transition Plan from each transit agency that applies to the FTA Low or No Emission Grant Program and the FTA Bus and Bus Facilities Grant Program for zero emission projects. The Zero Emission Transition Plan must include the following six elements:

1. **Policy & Legislative Impacts:** Consideration of policy and legislation impacting relevant technologies.
2. **Fleet Transition 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.
3. **Facility & Infrastructure Plan:** Evaluation of existing and future facilities and their relationship to the technology transition.
4. **Utility & Fuel Partnerships:** Description of the partnership of the applicant with the utility or alternative fuel provider.
5. **Funding Plan:** Address the availability of current and future resources to meet costs for the transition and implementation.
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 the 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.

This Zero Emission Fleet Transition Plan is a roadmap for Wave Transit to bring battery electric vehicles into the transit fleet. Wave Transit's service has a variety of challenges that make a 100% zero emission fleet infeasible today; however, there are a variety of ways that Wave Transit can reduce fleet emissions and slowly move toward a zero emissions future. Fixed route bus service could operate partially with BEVs and partially with CNG vehicles, and paratransit service could be operated with almost all BEVs. Shuttle service and trolley service are more difficult to transition; however, as technology advances, there could be better opportunities to transition these fleets in the future. In the interim, Wave Transit could further explore CNG as a low emission fuel.

Internal support, local support, and grant support will be essential to realize the vision of transitioning the fleet to zero emission vehicles. A transition toward BEVs will result in additional capital costs to build new infrastructure and purchase more expensive, but cleaner vehicles. This plan should serve as a mechanism to guide Wave Transit through their first BEV deployment and secure funding to make a cleaner transit fleet possible for New Hanover County.



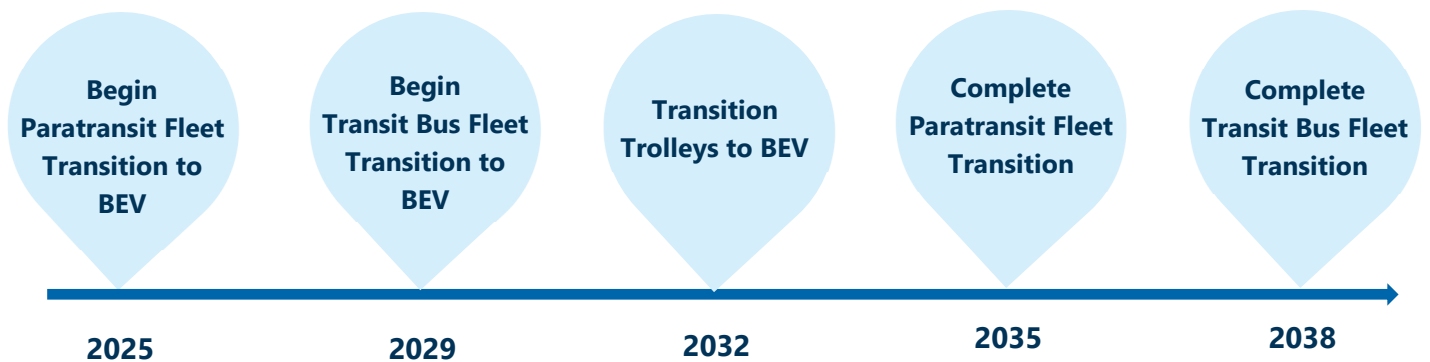
Fleet Transition Overview

Wave Transit’s proposed fleet transition could include fixed-route transit, trolley, UNCW shuttle, and paratransit fleets and may be comprised of a mix of compressed natural gas (CNG) and battery electric vehicles (BEVs). The agency could begin the transition in 2025 with the purchase of CNG shuttles, CNG transit buses, and battery electric paratransit vehicles; the transition of the fixed-route fleet to battery electric could begin in 2029, and trolleys could be replaced with battery electric at the end of their useful lives in 2032.

Wave Transit’s proposed fleet transition would be a phased approach, allowing the agency to gain experience with BEVs and let the technology continue to develop. The transition could begin with the purchase of (15) paratransit vehicles and (6) transit buses; this first phase of the fleet transition only electrifies the vehicles that can complete their service without the need for vehicle swaps mid-day. It is expected that by 2028 battery technology will have advanced enough for paratransit vehicles to meet existing service range requirements, so the transition of the remaining (9) paratransit vehicles will continue according to the fleet replacement schedule. The same is true for fixed route transit buses, so the transition of the remaining (14) transit buses will be replaced according to the fleet replacement schedule.

The UNCW shuttle fleet is currently a mix of CNG and gasoline vehicles; this fleet will transition to 100% low emissions with an entirely CNG shuttle fleet. The remainder of Wave Transit’s fleet will be converted to zero emissions with battery electric vehicles. The paratransit fleet will charge overnight at the O&M Facility using 48A Level 2 chargers, and the fixed route buses will charge at the O&M Facility overnight using plug-in DC Fast Chargers (DCFCs) and either overhead pantograph or wireless inductive DCFCs at Forden Station and Padgett Station. The trolleys will charge overnight at the O&M Facility using plug-in DCFCs. In the future, Wave Transit may be able to convert the UNCW shuttle fleet to battery electric in the future once the market for battery electric shuttles matures and battery technology improves to meet or exceed shuttle service range requirements. Wave Transit’s paratransit fleet and fixed-route fleets will be 100% zero emissions by 2035 and 2038, respectively.

The graphic below shows key milestones of Wave Transit’s proposed fleet transition plan; this approach allows Wave to achieve a 100% low or no emission fleet on a realistic timeline and does not require the early retirement of any existing fleet vehicles. The agency could begin the transition in 2025, but future implementation years may shift if unforeseen circumstances arise such as supply chain shortages or delays in funding appropriation.



Policy & Legislation Impacts

State of North Carolina

The following summary was taken from Zero Emission Vehicle (ZEV) Plan.³ In 2018, N.C. Governor Roy Cooper signed *Executive Order No. 80, North Carolina's Commitment to Address Greenhouse Gas Emissions and Transition to a Clean Energy Economy (EO 80)*, setting the state on a path to reduce greenhouse gas emissions by 40% from 2005 levels by 2050. The order also set a goal of at least 80,000 registered zero-emission vehicles, or ZEVs, in North Carolina by 2025. In addition to working with other state agencies to achieve the emission reduction goals, EO 80 directed the N.C. Department of Transportation (NCDOT) to lead an effort and work with the N.C. Department of Environmental Quality (NCDEQ) to develop a Zero Emission Vehicle (ZEV) Plan for the state.

In 2019, NCDOT published the NC ZEV Plan Version 1.0, which identifies 20 recommendations encompassing four areas to support ZEV adoption:

- **Education** – Educate across a variety of topics such as pricing and affordability, vehicle range per charge, charging costs and options, and availability of vehicles and charging. Education and marketing efforts will be aimed at reaching the public and will include automobile dealerships and fleet owner/operators.
- **Convenience** – Increase ease of charging and comfort in the overall electric vehicle network to alleviate concerns regarding range per charge and replacement of traditional internal combustion engines.
- **Affordability** – Reduce upfront costs through potential financial incentives and help develop a used-car market to provide a more appealing range of vehicle types at more prices.
- **Policy** – Establish policies that promote electric vehicle adoption and revise or remove those that inhibit adoption. State alliances and coalitions may also encourage continued investment.

Since the original plan was published in 2019, the state has made significant movement forward on many ZEV initiatives. Those advances include:

- A 220 percent increase in the number of registered EVs (Battery and Plug-in Hybrid) in North Carolina from less than 13,000 in 2018 when EO 80 was signed, to more than 40,000 in March 2022.
- Investment in six electric school buses, 11 electric transit buses and \$3.4 million in charging infrastructure using the Volkswagen settlement funds. The final tranche of \$67.9 million in Volkswagen funding is scheduled to begin in early 2022 and will prioritize electric vehicle replacements.
- Signing of the Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding on July 13, 2020.
- The addition of 41 ZEVs in the state motor fleet. The state has also ordered over 500 hybrid vehicles in 2021 as part of the NC Motor Fleet ZEV Plan.
- The announcement in 2021 that the British-based company Arrival had selected Charlotte as the site of its second electric vehicle micro factory in the United States. The company plans to create more than 250 jobs. Arrival also announced it will establish a high voltage battery module assembly plant, adding 150 new jobs.

³ <https://www.ncdot.gov/initiatives-policies/environmental/climate-change/Documents/nc-zev-plan.pdf>



- Toyota announced plans to build its first North American battery manufacturing plant for a new generation of vehicles in Randolph County, creating at least 1,750 jobs and investing \$1.29 billion.
- The addition of Climate Change Policy advisors in the NCDOT and the North Carolina Governor's office. The advisors will focus on emission reductions in the transportation sector.

This progress report for the 2019 North Carolina ZEV Plan summarizes the status of transportation electrification in North Carolina and sets the stage for the next phase of work. The next phase will involve the development of the North Carolina Clean Transportation Plan (NCCTP), as outlined in Cooper's January 2022 Executive Order No. 246 (EO 246). For context, the phrase "economy-wide" refers to emissions from all sources.

In addition to instructing NCDOT to develop the NCCTP, EO 246 builds upon EO 80 and outlines two primary goals:

- Reduce economy-wide greenhouse gas emissions to at least 50% below 2005 levels by 2030 and achieve net-zero emissions no later than 2050.
- Increase the total number of registered zero-emission vehicles in North Carolina to at least 1.25 million by 2030. EO 246 also established a goal that by 2050 zero-emission vehicles will comprise 50% of all in-state vehicle sales.

In addition to the initiatives outlined above, on October 25, 2022, Governor Roy Cooper signed Executive Order No. 271: Growing North Carolina's Zero-Emission Vehicle Market.⁴ The executive order directs the North Carolina Department of Environmental Quality (DEQ) to work with stakeholders to propose to the Environmental Management Commission an Advanced Clean Trucks (ACT) program that would ensure zero-emission trucks and buses are available for purchase in the state. ACT would require manufacturers to sell an increasing percentage of ZEVs over time while providing flexibility through credits, trading and other features as segments of the market grow at different speeds. The sales targets would also drive investment in other zero-emission technologies, including charging and fueling infrastructure, while bolstering North Carolina's competitiveness in seeing billions of dollars in federal funding for clean energy development.⁵

City of Wilmington

The following summary was taken from the City of Wilmington Ad Hoc Clean Energy Task Force Report.⁶ In March 2020, City Council established the Ad Hoc Clean Energy Policy Task Force (the Task Force). Comprised of a diverse group of volunteer citizens, the Task Force has provided a community-wide perspective in setting ambitious and achievable clean energy goals for the City of Wilmington.

The purpose/charter of the task force is to advise the mayor and city council, conduct research, study best practices within North Carolina and nationally, and make recommendations on matters related to:

- Adopting a clean energy policy for municipal operations, including a goal for 2050
- Reducing the city's reliance and use of fossil fuels in building & fleet operations
- Promoting clean energy and reducing harmful energy-related environmental impacts
- Creating a socially equitable strategy that benefits all residents

⁴ <https://governor.nc.gov/media/3457/open>

⁵ <https://governor.nc.gov/news/press-releases/2022/10/25/governor-cooper-signs-executive-order-grow-north-carolinas-clean-energy-economy-supporting-market>

⁶ <https://www.wilmingtonnc.gov/home/showpublisheddocument/12728/637469093347530000>



- Providing strategies on how to educate Wilmington residents on clean energy

The Task Force’s clean energy goal recommendations are provided below in **Table 1**. The recommendations align with goals of North Carolina Clean Energy Plan established by Executive Order No. 80⁷, with Duke Energy’s Net-Zero Carbon Emissions by 2050 goal⁸, the Mayors For 100% Clean Energy by 2050 initiative, and aligns with the tenants of the Paris Climate Agreement of 2015.

Table 1. Clean Energy Goals

	2035	2050
City of Wilmington	Transition from fossil fuel powered municipal operations to 50% clean energy and electrify 50% of the city's vehicle fleet.	Transition from fossil fuel powered municipal operations to 100% clean energy, and electrify 100% of the city's vehicle fleet**
Community Wide	The City of Wilmington will collaborate with other governments, the private sector, and residents in achieving aligned clean energy and equity goals as well as advocating for programs and policies at the state, regional, and/or federal level that aid in achieving the transition to clean energy.	

With adoption of a resolution committing to these clean energy goals, the City of Wilmington will be one of 19 other local governments within the State of North Carolina to commit to clean and renewable energy for the future.

⁷ <https://files.nc.gov/ncdeq/climate-change/EO80--NC-s-Commitment-to-Address-Climate-Change---Transition-to-a-Clean-Energy-Economy.pdf>

⁸ <https://news.duke-energy.com/releases/duke-energy-aims-to-achieve-net-zero-carbon-emissions-by-2050>



Fleet Transition Plan

The proposed fleet transition plan reflects the preferred course of action strategy for each fleet type. The preferred courses of action were determined by considering the technology options available and findings from the route modeling analysis. HDR and Wave Transit worked collaboratively to form a near-term and long-term strategy to integrate low and no emission vehicles into the fleet. Complete details on the route modeling performed and transition scenarios considered can be found in the appendices of this report.

Zero Emission Vehicles & Fueling Options

Battery Electric Vehicles

Transit agencies across the globe seeking to reduce GHG emissions are adopting alternative vehicle technologies to replace internal combustion engine (ICE) buses as the vehicles reach the end of their useful life. Battery electric vehicles (BEVs) are the most common zero-emission vehicle in today's market. These vehicles produce no air pollutants or emissions during the operation of the vehicle, thus why they are referred to as zero-emission vehicles. BEVs store power in battery packs that is converted to kinetic energy as a bus moves. BEVs also recuperate a percentage of battery life through regenerative braking – the preservation of kinetic energy that occurs when BEVs idle and/or decelerate. Charging infrastructure for BEVs can be located inside or outside of bus depots or maintenance facilities as well as in locations along established bus routes using either overhead or inductive (wireless) chargers. Charge time can vary from minutes to hours depending on the charging technology deployed. BEVs have a limited operational range compared to conventional buses, and the distance they can travel per charge is impacted by elevation, route profile, ambient temperature, and driver habits. While on-route charging infrastructure extends the operational range of BEVs, it is not always enough to provide BEVs with the same operational range as ICE buses.

CNG and Renewable CNG

Compressed natural gas (CNG) is a commonly used fuel in public transit operations. CNG vehicles are known to be low emission vehicles because they produce far fewer air pollutants compared to gasoline or diesel. CNG vehicles do, however, produce greenhouse gas (GHG) emissions during both the production of the fuel and the burning of the fuel.

Renewable CNG (also known as RNG) is a biogas which is fully interchangeable with conventional CNG. The biogas used to produce RNG comes from a variety of sources, including landfills, wastewater treatment plants, livestock farms, food production facilities, and organic waste management operations. The production of renewable CNG results in fewer GHGs than conventional CNG which makes RNG a more sustainable alternative. While it produces fewer emissions than conventional CNG, renewable CNG is still classified as a low-emission fuel. Renewable CNG can be used to reduce fleet emissions without making significant infrastructural changes. RNG is ideal for agencies that already have CNG vehicles, have additional capacity for more CNG vehicles, and receive CNG deliveries (rather than getting CNG directly from a pipeline).

Energy Modeling & Analysis

Understanding energy consumption is a key component of fleet transition planning as it informs the choice of vehicle technology, infrastructure requirements, finances, and fleet replacement strategies. The modeling effort evaluated Wave Transit's fixed route service, trolley service, paratransit service,



and UNCW shuttle service. Modeling assumed a worst-case-scenario day where the vehicles were at full seated capacity and ambient temperature of 30°F. Below are the key findings for each type of service.

Fixed Route Service

Fixed route bus service could not be feasibly operated with BEVs if only using depot charging. If using on-route charging and depot charging, BEVs were feasible for six blocks on routes 101, 103, 104, and 108. BEVs would be feasible if buses were swapped throughout the day as batteries depleted, but this approach is inefficient and not recommended.

A full BEB transition with today's technology would require substantial changes to fixed route service; because of this, the project team looked for opportunities to incorporate a smaller number of ZEVs into Wave Transit's fleet in the near-term. The team identified six fixed route vehicles that could be replaced with electric equivalents. These six vehicles could operate blocks on routes 101, 103, 104, and 108. These vehicles would be charged with one on-route charger at Forden Station and six depot chargers for overnight charging. This phased transition approach would allow Wave Transit to gain experience operating ZEVs and would utilize a site (Forden Station) which already has adequate power availability for EVSE. This scenario would not require the purchase of additional vehicles and would create minimal increases in non-revenue miles and non-revenue hours. There would be very slight increases in non-revenue miles and hours due to the required layovers of ZEVs at Forden Station for on-route charging. This scenario would require the purchase of vehicles that are more expensive than ICE equivalents and require the purchase of depot and on-route charging stations, which both create additional capital costs. Wave Transit could look to federal programs, such as the FTA Low/No Emissions Program or Bus/Bus Facilities Program to support some of the costs of infrastructure upgrades and the additional cost of a BEV. With adequate grant support, the increased capital costs of this scenario could be mitigated or offset. Overall, this scenario would allow Wave Transit to gain experience with ZEVs, slowly integrate technology, and minimize capital costs associated with bringing ZEVs into a fleet.

Trolley Service

Trolley service could not be feasibly operated with BEVs. Even with on-route charging, the vehicle would need to be swapped during the day to complete service.

Route modeling showed the trolley service to be infeasible to operate with BEVs. The project team determined it was most appropriate to delay a transition to battery electric trolley buses until technology has advanced. Presently the battery electric trolley market is small, but as the market continues to grow, it is possible that a vehicle in the future would be able to operate the Downtown Trolley service without major service modifications or cost increases. Once there is a BEV that meets the Downtown Trolley's service needs, Wave Transit could re-evaluate the use of BEVs for trolley service.

Paratransit Service

Paratransit service showed the highest feasibility for BEV operations. 15 of the 20 vehicles could complete service with BEV technology as it is available today. The remaining five vehicles could complete service if they were swapped mid-day or brought back to the garage for mid-day charging. On-route charging is not feasible for paratransit vehicles because the electric equivalents of Wave's paratransit vehicles do not have the ability to accept a fast charge.



The project team determined that the paratransit fleet could be transitioned to BEVs using a phased approach. With today's BEV capabilities, 15 of the 20 active paratransit vehicles can complete service on a worst-case day using Level 2 depot chargers only. Wave Transit could replace up to 15 vehicles with BEVs and install one charger per vehicle at the O&M facility. The remaining five paratransit vehicles could be transitioned in the future dependent on battery technology improvements. Improvements in battery storage capacity or improvements in fast charging speeds would make the remaining five paratransit vehicles more viable for electrification. The near-term focus could be on the 15 vehicles possible to electrify today, and the long-term focus could be on the last five vehicles.

UNCW Shuttle Service

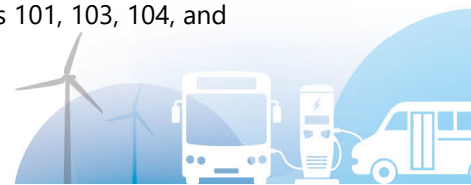
Shuttle service could not be feasibly operated with BEV technology as it is available today, and this form of service showed the lowest feasibility of the four services modeled. On-route charging locations were difficult to determine because there was not a consistent layover location for the shuttle buses. Even if there was a good location for on-route charging, there would still be many swaps required. Eight of the buses would need to be swapped twice during a service day, and one bus would need to be swapped once. The substantial increase in non-revenue miles, increased vehicle needs, and challenges with on-route charging make shuttle service infeasible for electrification with today's technology.

Because battery electric vehicles were shown to be operationally infeasible for shuttle service, Wave Transit could consider a low-emission alternative such as CNG or renewable CNG. A portion of the shuttle fleet is already CNG powered, and Wave Transit could look to transition the remaining vehicles to CNG. This would reduce the emissions of the shuttle fleet, and if Wave Transit wanted to further reduce emissions, the agency could look into sources of renewable CNG for the shuttles. To implement this strategy, Wave Transit would need confirmation that existing CNG infrastructure can support additional vehicles. The agency may need to plan for additional fueling sites, increased compression for fast fill, and possibly additional service employees to fuel vehicles. Upgrades to CNG infrastructure would create capital costs that would not exist if no fleet changes were made. Wave Transit could look to grant funding to upgrade infrastructure to accommodate more CNG vehicles; the FTA Low/No Emissions Program has funding for low emissions vehicles (such as CNG) which has historically been underutilized. This funding supports projects to expand the use of low-emission fuels as an interim strategy before implementing no-emission technologies. Wave Transit could look to this grant program or others to help fund costs to convert shuttle service to fully CNG vehicles. In summary, this scenario presents an opportunity for Wave Transit to reduce emissions within the shuttle fleet without significant changes to service or infrastructure.

Fleet Transition Strategy

Wave Transit may take a phased approach to transitioning the fleet to battery electric. This transition could begin in 2025 with an initial deployment of five paratransit vehicles that would be supported by five 48A Level 2 chargers. The paratransit fleet may expand to include an additional 19 BEVs according to the replacement schedule in **Figure 1**. Each vehicle would have a dedicated Level 2 charger that would be installed at the O&M Facility in the same year the vehicles enter service; the paratransit fleet would be 100% battery electric in 2035.

The fixed-route fleet may begin to transition in 2029 with four transit battery electric buses that would be supported by one 150kW DCFC and four 60kW DCFCs at the O&M Facility, and four 300kW DCFCs on-route at Forden Station. These four vehicles would operate blocks on Routes 101, 103, 104, and



108; these blocks can all be completed using depot and on-route charging only, without the need for a bus swap or an increase in active fleet size. The next four transit buses would enter service in 2030 and be supported by one additional 300kW DCFC at Forden Station and three 300kW DCFCs at Padgett Station.

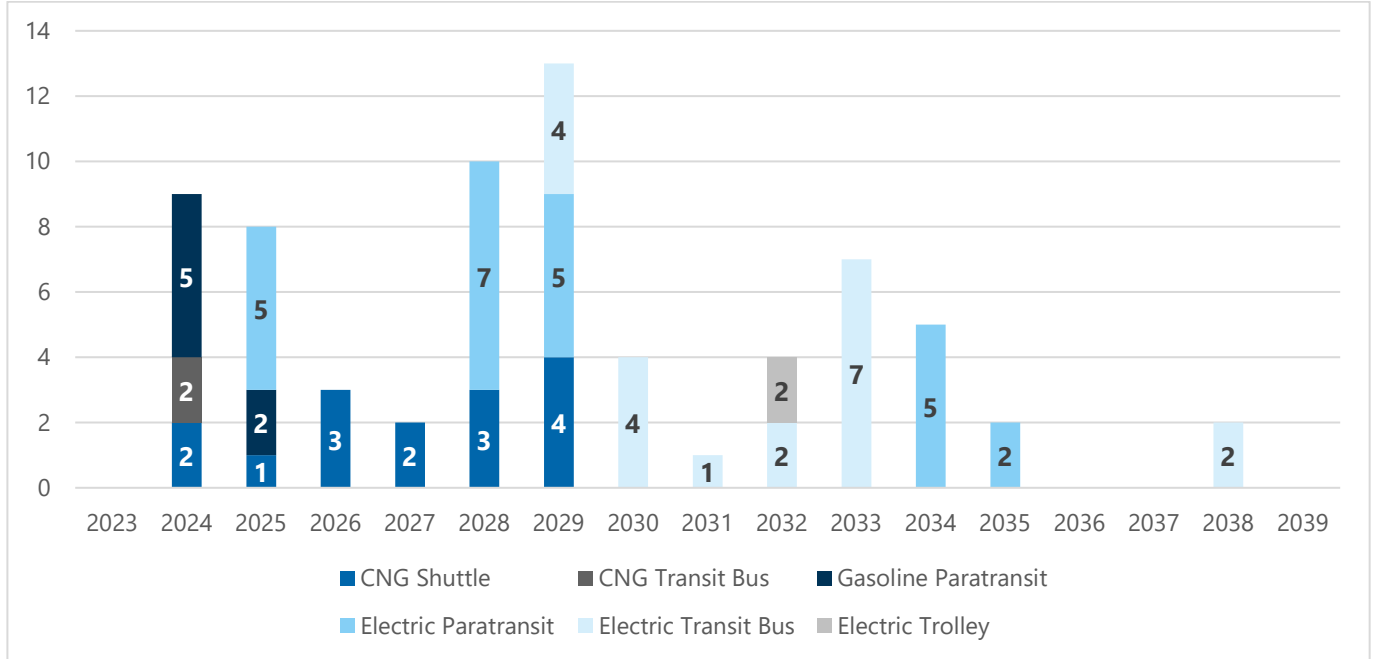


Figure 1. Vehicle Replacement Schedule by Fuel Type

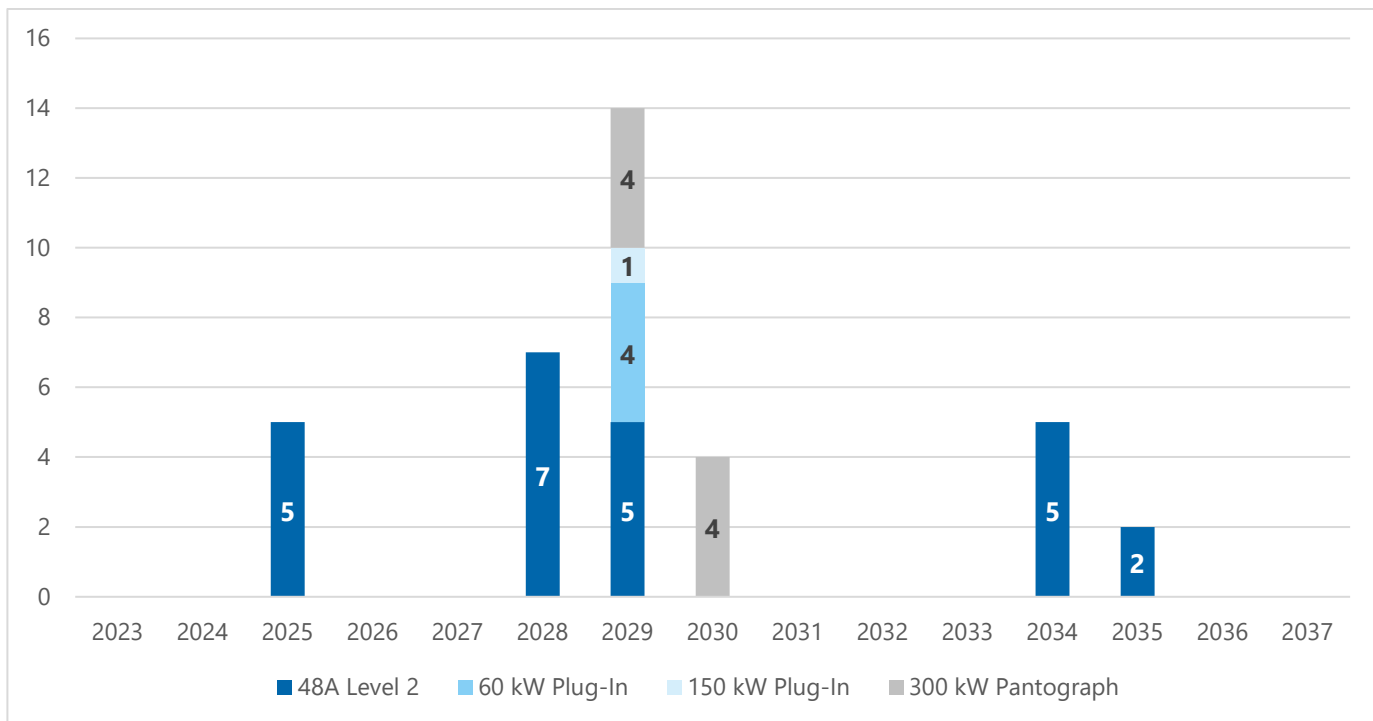


Figure 2. Charger Installation Schedule



Facility & Infrastructure Plan

Existing Conditions

Wave Transit Operations and Maintenance Facility

Wave Transit's only operations and maintenance facility is located at 1480 Castle Hayne Road in Wilmington, NC. This facility has four drive through maintenance bays, parts and tool storage, CNG slow fill stations, one CNG quick fill lane, two diesel fuel pumps, one bus wash lane, temporary service parking and is currently home to 38 fixed-route vehicles, 24 paratransit vehicles, and 3 vanpools. All vehicles are operated and maintained at this facility with Wave Transit employees operating paratransit services and Transdev employees operating fixed route services and maintenance of all vehicles.

Paratransit vehicles (red), shuttles (yellow), fixed-route buses and trolley (blue), and non-revenue vehicles (purple) are parked along the edges of the property as shown in **Figure 3**. All buses enter and exit through a single driveway off Castle Hayne Road. The bus wash, CNG quick fill, and diesel lanes are centrally located in the facility's yard, and CNG slow fill stations are located alongside fixed-route parking. Revenue vehicles returning from service are parked in the service temporary parking area (green) until they are serviced and parked for the night.

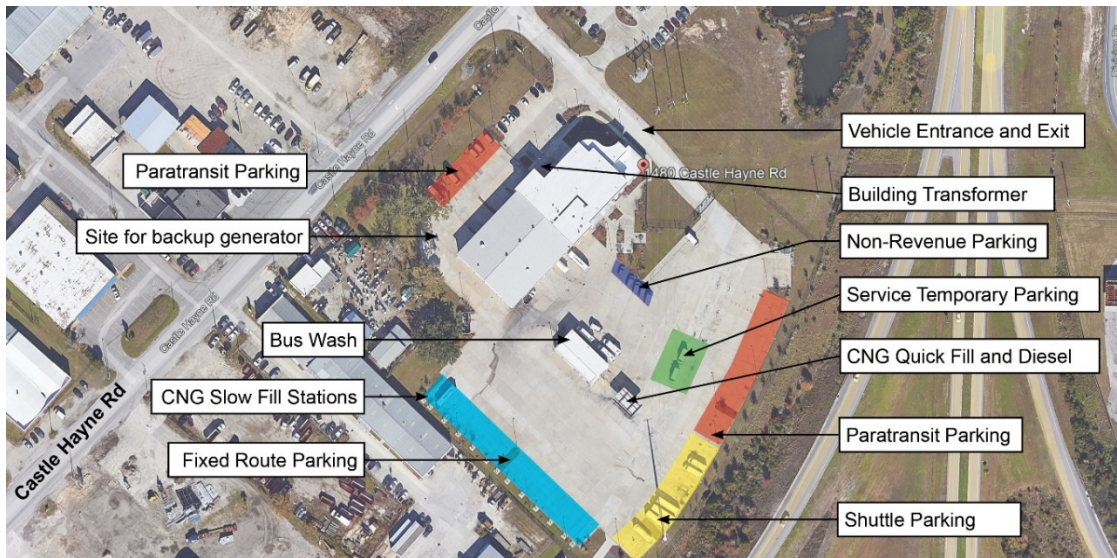


Figure 3. Wave Transit Operations and Maintenance Facility Aerial View

The CNG compression station located in the far south corner of the yard near the compressors and diesel storage tanks as shown in **Figure 4** draws three phase power that comes from Castle Haynes Road as well. In addition to the existing infrastructure, Wave Transit is currently planning to install a 400 kW backup generator near the compressor station as well as a 250 kW backup generator for the facility along the front parking area.



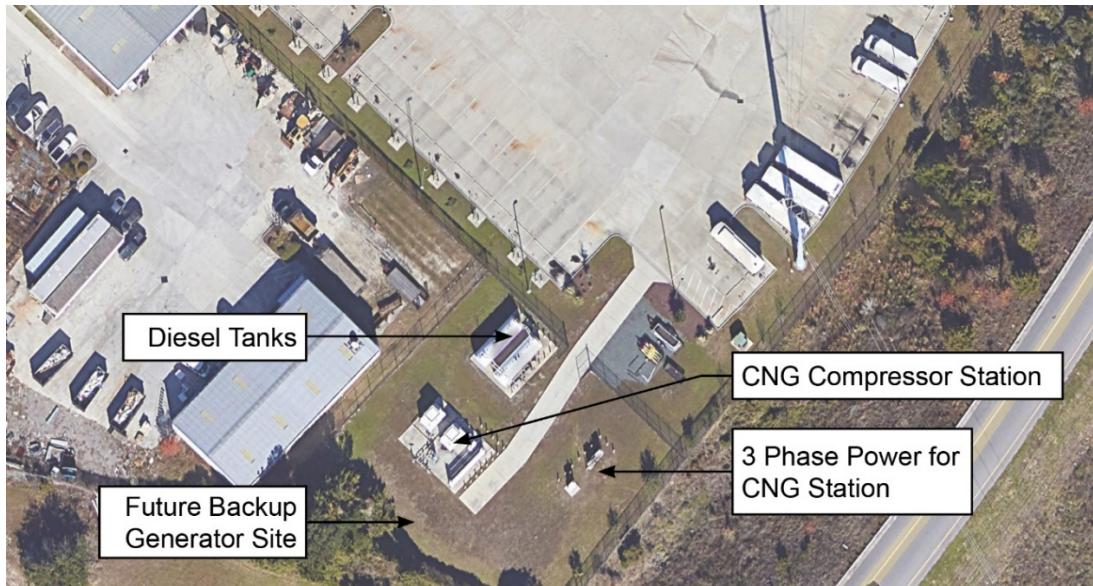


Figure 4. Wave Transit Operations and Maintenance Facility Aerial View

Electric Vehicle Charging Infrastructure

Wave Transit Operations and Maintenance Facility

Wave Transit does not currently have any chargers installed at the O&M facility but would ideally install chargers behind each vehicle along the curb line. These would be protected by bollards and eliminate the need for any changes to the current parking configuration to accommodate the transition to BEVs.

Forden Station

Currently, buses enter Forden Station from Hunters Trail and park in a sawtooth pattern with all routes having a designated boarding and alighting location. Existing canopies used to provide riders with shelter from the elements could serve a dual purpose of supporting overhead pantograph-style charging or existing layover lanes could be used to support in-ground wireless inductive charging. The location of the building's existing utility transformer is identified in **Figure 5** and power appears to come from Hunters Trail.





Figure 5. Forden Station Aerial View

Padgett Station

Buses enter Padgett Station from N 3rd Street and park nose-to-tail with all routes having designated lanes for passenger boarding and alighting. The building's existing transformer is located on the north edge of the property as shown in **Figure 6** with power appearing to come from Campbell Street. This facility is a historic building site which would require additional approvals to obtain permits for construction and infrastructure installation. If allowed, overhead pantograph-style chargers could be attached to and supported by the existing canopy structure. If architectural requirements don't allow for pantographs to be installed, existing layover lanes could be used to support in-ground wireless inductive charging as an alternative that allows for "hidden" infrastructure.





Figure 6. Padgett Station Aerial View



Utility & Fuel Partnerships

The electrical and hydrogen fuel support required at each facility was determined and reviewed with consideration to local utilities. This includes the expected demand for each facility, intended sourcing of the fuel, and potential rate structures.

Coordination with Electric Utility

The project team met with representatives from Duke Energy, and based on that conversation, Duke Energy mentioned that they do not have a fleet electric vehicle (EV) rate, although they did say they have a time of use rate with standard fees. Currently, Duke Energy has limited programs to support infrastructure capital costs.

The project team was able to confirm about 1 MW of power available at both Forden Station and Padgett Station; however, it would be important for Wave Transit to remain engaged with Duke Energy if pursuing the installation of on-route charging at either site.

The scheduling of power delivery upgrades would follow the below timeline once the application for new services is received:

- 2 months for programing and review of request with site visit
- 3 months for utility design
- 12 months for transformer purchase and delivery
- 3 months for constructions and energizing the transformer.

Solar power is a possible sell back, but the amount of energy able to be sold back is capped at the amount of energy used. Duke Energy would not be providing multiple energy feeds per site, but instead, most items would be single substations. Wave Transit would have to remain in contact with Duke Energy during this timeline to ensure power remains available.

Power Supply at Wave Transit O&M Facility

Duke Energy has confirmed that there is currently up to 1 MW of excess capacity at the O&M Facility that could be used to support charging infrastructure. The required infrastructure would draw up to approximately 750 kW of power, so no additional utility infrastructure would be required to accommodate vehicle charging at this location.

Power Supply at Forden Station

Duke Energy has confirmed that there is currently up to 1 MW of excess capacity at Forden Station that could be used to support charging infrastructure. The required charging infrastructure would draw up to 1.5 MW of power, so additional utility infrastructure would be required to accommodate vehicle charging at this location. Wave Transit would need to coordinate required utility upgrades with Duke Energy prior to the installation of charging infrastructure at this location.

Power Supply at Padgett Station

Duke Energy has confirmed that there is currently up to 1 MW of excess capacity at Padgett Station that could be used to support charging infrastructure. The required infrastructure would only draw up to 900kW of power, so no additional utility infrastructure would be required to accommodate vehicle charging at this location.



Financial Analysis & Funding Plan

This section describes an analysis conducted to determine the budgetary requirements associated with Wave’s proposed fleet transition, including both capital and ongoing operations and maintenance (O&M) costs. The analysis was used to determine a high-level total cost of ownership over the 17-year period from 2023 through 2040, based on today’s dollars (2023 \$).

Analysis Methods

Two scenarios were evaluated for this financial analysis. First, a baseline scenario was modeled to establish the forecasted total cost of ownership for Wave’s current fleet through the year 2040. This entails maintaining and replacing existing fleet vehicles with similar makes, models, and fuel types according to the fleet replacement schedule shown above in **Figure 1**. Next, a transition scenario was evaluated to determine the total capital and O&M costs associated with an alternative fuel fleet transition over the same timeframe. This scenario also follows the replacement schedule shown in **Figure 10**.

Capital Expenditures

The capital expenditures associated with fleet ownership include both vehicle and charger purchases, charger installations, and any power upgrades needed to support the new charging infrastructure. **Table 2** summarizes the assumptions made to determine the capital costs associated with Wave’s proposed transition to an all-AFV fleet. The costs shown below, in 2023 dollars, are based on reported MSRPs, where available, and industry averages for similar vehicle and fuel types.

Table 2. Capital Cost Assumptions

Vehicle Type	#	Unit Cost (2023 \$)	Vehicle/Charger Type	#	Unit Cost (2023 \$)
BASELINE SCENARIO			TRANSITION SCENARIO		
Existing Fleet Vehicles			Alternative Fuel Vehicles		
Gillig Diesel Transit Bus	3	\$460,000	Gillig Battery Electric Transit Bus	20	\$950,000
Gillig Hybrid Transit Bus	2	\$765,000	Hometown 28’ Villager Electric	2	\$560,000
Gillig CNG Transit Bus	15	\$520,000	Landi Renzo Ford E-450 Econoline	15	\$460,000
Hometown CNG Trolley	2	\$460,000	US Hybrid Ford Transit T-350 DRW	24	\$290,000
Ford Diesel Shuttle	7	\$175,000	<i>Gillig CNG Transit Bus (initial rep.)</i>	2	\$520,000
Ford CNG Shuttle	8	\$460,000	<i>Ford Gasoline Paratransit (initial rep.)</i>	7	\$100,000
Ford Gasoline Paratransit	24	\$100,000	Charging Infrastructure		
			48A Level 2 Charger	24	\$10,500
			60 kW DC Fast Charger	4	\$96,500
			150 kW DC Fast Charger	1	\$210,000
			300 kW Pantograph Charger	8	\$950,000
			<i>Power Upgrades (one-time cost)</i>	1	\$250,000



Vehicle Purchases

Research and trends in the AFV market were reviewed to forecast future market conditions and costs for ICE vehicles and AFVs. An annual inflation rate of 3 percent was assumed for all costs, consistent with trends in the consumer price index (CPI) as reported by the U.S. Bureau of Labor Statistics. AFV purchase prices were then discounted at a rate of 5 percent per year until 'price parity', the point at which the purchase prices for ICE vehicles and AFVs are equal, was reached in about six years. This is consistent with forecasts from Bloomberg NEF (BNEF) for battery pack prices, which are expected to drop by up to 10 percent annually before reaching a critical threshold of \$60 per kilowatt-hour (kWh).⁹

Note that this analysis does not account for any financial incentives or support that may be pursued to help fund new vehicle purchases and charger installations, such as the Federal Transit Administration's (FTA) Low-No Grant Program and Bus and Bus Facilities grants. The FTA provides 80 percent of project funding through these programs; the remaining 20 percent is matched locally. The Internal Revenue Service's (IRS) Commercial Clean Vehicle Credit can also be leveraged to reduce capital costs. This credit can fund up to \$7,500 per vehicle purchase for vehicles with GVWRs under 14,000 pounds and up to \$40,000 per vehicle purchase for vehicles with GVWRs above 14,000 pounds.¹⁰

Charging Infrastructure

Wave's charging strategy includes a combination of 48A Level 2 chargers, 60kW and 150kW DC Fast Chargers (DCFC), and 300kW on-route pantograph chargers. Purchase and installation costs for each charger typically account for about 40 and 60 percent of the total costs shown above in **Table 2**, respectively. For example, the purchase and installation costs for a 60 kW DCFC were estimated at \$38,000 (39.4 percent) and \$58,500 (60.6 percent). The charger costs assumed here are based on industry averages for new charging infrastructure and discussions with original equipment manufacturers (OEM). Power upgrades will also be needed to support on-route charging at Forden Station; based on discussions with various local utilities, it is expected that these upgrades will incur a one-time cost of \$250,000.

All infrastructure costs were raised by the same 3 percent annual inflation rate used to project vehicle purchase prices. Like the assumptions for vehicle purchases, no incentives were included in the analysis of charger costs. However, federal funding is available for clean infrastructure projects that support AFV fleet transitions through sources such as the U.S. Department of Transportation's (USDOT) RAISE Discretionary Grant program. This funding can be leveraged to reduce the capital costs associated with Wave's fleet transition.

Ongoing Expenditures

The ongoing expenditures associated with fleet ownership include fueling and routine maintenance. **Table 3** summarizes the assumptions made to inform this analysis of ongoing O&M costs. The costs shown here, reported in 2023 dollars, are based on average fuel prices in the state of North Carolina, local energy rate structures obtained from Duke Energy, and real-world experience from other transit agencies maintaining ICE, CNG, and electric buses.

⁹ <https://about.bnef.com/blog/the-ev-price-gap-narrows/>

¹⁰ <https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit>



Table 3. Ongoing O&M Cost Assumptions

Fuel Type	Unit	Unit Cost (2023 \$)	Fuel Type	Unit	Unit Cost (2023 \$)
FUELING COSTS			MAINTENANCE COSTS		
Gasoline	\$/gal.	\$3.45	Gasoline	\$/mi.	\$0.88
Diesel	\$/gal.	\$3.68	Diesel	\$/mi.	\$0.88
CNG	\$/GGE	\$2.35	CNG	\$/mi.	\$0.41
Electricity (Energy)	\$/kWh	\$0.0464	Electricity	\$/mi.	\$0.64
Electricity (On-Peak Demand)	\$/kW	\$20.89			
Electricity (Off-Peak Demand)	\$/kW	\$1.05			

Fueling & Electricity

Statewide average fuel costs, as reported by the U.S. Department of Energy’s (DOE) Alternative Fuels Data Center (AFDC), were used in lieu of data on actual fuel expenditures for Wave’s current fleet. In June 2023, the average costs per gallon for gasoline and diesel in North Carolina were \$3.45 and \$3.68, respectively, and the average cost per gasoline gallon equivalent (GGE) of CNG was \$2.35. To forecast future fueling costs, these values were increased or decreased annually based on projections from the U.S. Energy Information Administration’s (EIA) Annual Energy Outlook 2023.¹¹

Electricity rates were based on the Large General Service (Time-of-Use) structure provided by Duke Energy, which applies to nonresidential customers whose demand exceeds 1,000 kW. The on-peak and off-peak rates shown in **Table 3** were applied to 1,200 kW and 850 kW of demand, respectively, based on simultaneous use of all the 300 kW on-route pantograph chargers (on-peak) and depot chargers (off-peak). All utility costs were also increased or decreased annually through 2040 based on forecasts from the EIA.

Routine Maintenance

Average per-mile maintenance costs for ICE, CNG, and electric buses were obtained from the National Renewable Energy Laboratory (NREL) and the real-world experience of other transit agencies. Research from NREL indicates average maintenance costs of \$0.88 per mile for ICE buses and \$0.64 per mile for BEBs, including both scheduled and unscheduled maintenance.¹² The cost differential between BEB and CNG bus maintenance experienced by Foothill Transit was applied to NREL’s value for BEBs to calculate a per-mile maintenance cost for CNG buses of \$0.41 per mile.¹³ A standard inflation rate of 3 percent per year was applied to all maintenance costs through 2040.

Analysis Results

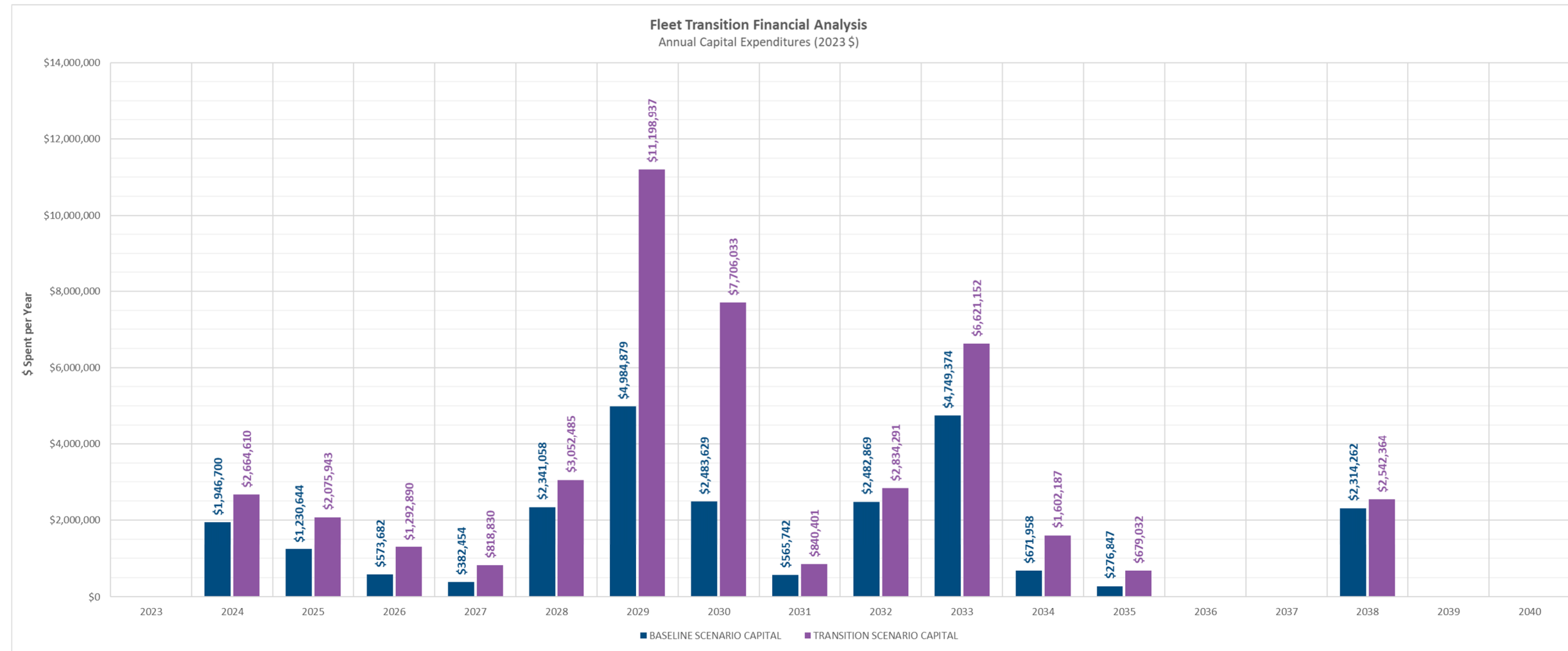
The results of this analysis are summarized by expenditure type in **Figure 7** through **Figure 9**. Trends in total cost of ownership under each scenario are then summarized in **Figure 10** and **Table 4**. The results shown here all encompass the 17-year analysis period from 2023 through 2040.

¹¹ <https://www.eia.gov/outlooks/aeo/data/browser>

¹² https://afdc.energy.gov/files/u/publication/financial_analysis_be_transit_buses.pdf

¹³ <https://www.nrel.gov/docs/fy21osti/80022.pdf>

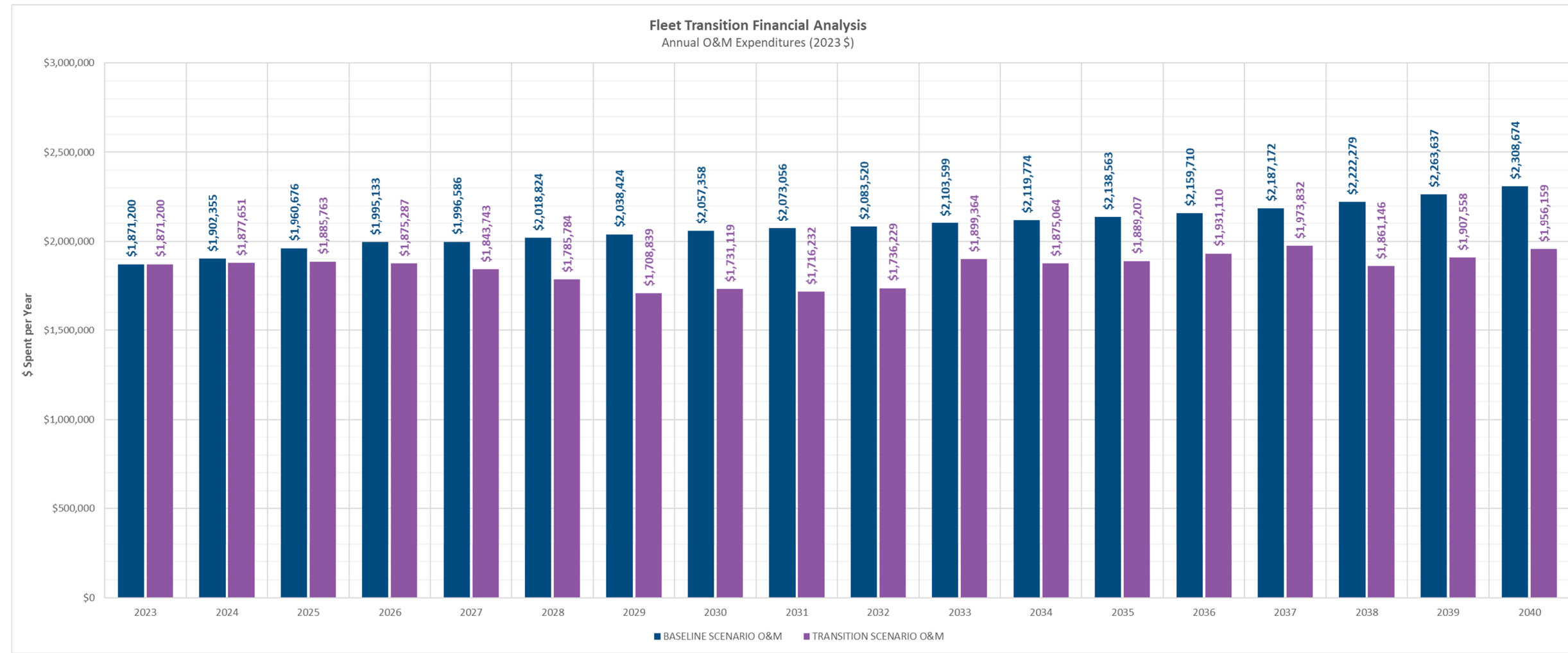




Expenditure Type	Annual Capital Expenditures (2023 \$)																	
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
BASELINE SCENARIO																		
# of Vehicle Purchases	0	9	8	3	2	10	13	4	1	4	7	5	2	0	0	2	0	0
\$ per Year (Vehicles)	\$0	\$1,946,700	\$1,230,644	\$573,682	\$382,454	\$2,341,058	\$4,984,879	\$2,483,629	\$565,742	\$2,482,869	\$4,749,374	\$671,958	\$276,847	\$0	\$0	\$2,314,262	\$0	\$0
Total Capital \$ per Year	\$0	\$1,946,700	\$1,230,644	\$573,682	\$382,454	\$2,341,058	\$4,984,879	\$2,483,629	\$565,742	\$2,482,869	\$4,749,374	\$671,958	\$276,847	\$0	\$0	\$2,314,262	\$0	\$0
Cumulative Capital \$ Spent	\$0	\$1,946,700	\$3,177,344	\$3,751,026	\$4,133,480	\$6,474,538	\$11,459,417	\$13,943,046	\$14,508,788	\$16,991,657	\$21,741,031	\$22,412,990	\$22,689,836	\$22,689,836	\$22,689,836	\$25,004,099	\$25,004,099	\$25,004,099
TRANSITION SCENARIO																		
# of Vehicle Purchases	0	9	8	3	2	10	13	4	1	4	7	5	2	0	0	2	0	0
# of Charger Purchases	0	0	5	0	0	7	14	4	0	0	0	5	2	0	0	0	0	0
\$ per Year (Vehicles)	\$0	\$2,407,110	\$2,020,245	\$1,292,890	\$818,830	\$2,969,760	\$6,041,906	\$3,168,635	\$840,401	\$2,834,291	\$6,621,152	\$1,531,632	\$649,963	\$0	\$0	\$2,542,364	\$0	\$0
\$ per Year (Chargers)	\$0	\$257,500	\$55,697	\$0	\$0	\$82,725	\$5,157,031	\$4,537,399	\$0	\$0	\$0	\$70,556	\$29,069	\$0	\$0	\$0	\$0	\$0
Total Capital \$ per Year	\$0	\$2,664,610	\$2,075,943	\$1,292,890	\$818,830	\$3,052,485	\$11,198,937	\$7,706,033	\$840,401	\$2,834,291	\$6,621,152	\$1,602,187	\$679,032	\$0	\$0	\$2,542,364	\$0	\$0
Cumulative Capital \$ Spent	\$0	\$2,664,610	\$4,740,553	\$6,033,443	\$6,852,273	\$9,904,757	\$21,103,695	\$28,809,728	\$29,650,129	\$32,484,420	\$39,105,572	\$40,707,760	\$41,386,792	\$41,386,792	\$41,386,792	\$43,929,156	\$43,929,156	\$43,929,156

Figure 7. Summary of Capital Expenditures by Year

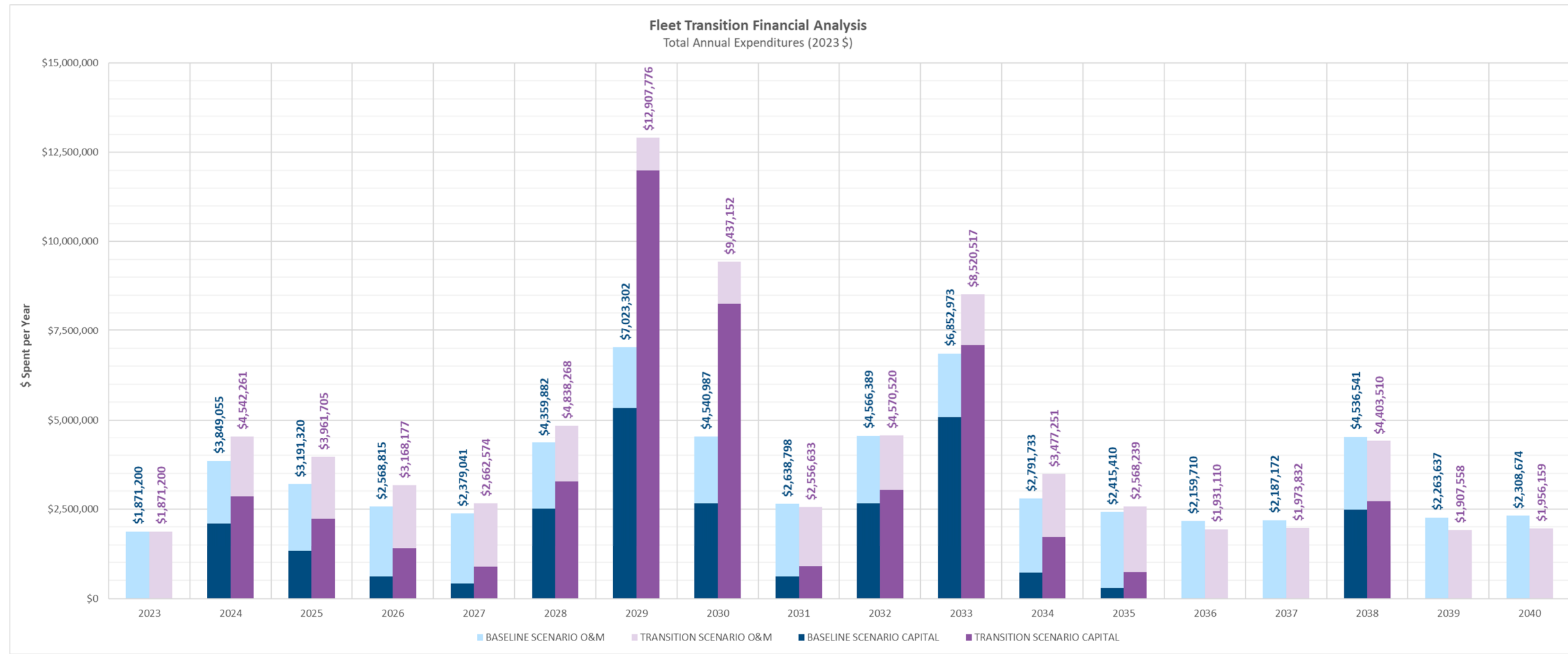




Expenditure Type	Annual O&M Expenditures (2023 \$)																	
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
BASELINE SCENARIO																		
\$ per Year (Maintenance)	\$994,270	\$1,024,098	\$1,054,821	\$1,086,465	\$1,119,059	\$1,152,631	\$1,187,210	\$1,222,826	\$1,259,511	\$1,297,296	\$1,336,215	\$1,376,302	\$1,417,591	\$1,460,118	\$1,503,922	\$1,549,040	\$1,595,511	\$1,643,376
\$ per Year (Fueling)	\$876,930	\$878,257	\$905,855	\$908,668	\$877,527	\$866,193	\$851,214	\$834,532	\$813,545	\$786,224	\$767,384	\$743,473	\$720,972	\$699,591	\$683,250	\$673,239	\$668,126	\$665,298
Total O&M \$ per Year	\$1,871,200	\$1,902,355	\$1,960,676	\$1,995,133	\$1,996,586	\$2,018,824	\$2,038,424	\$2,057,358	\$2,073,056	\$2,083,520	\$2,103,599	\$2,119,774	\$2,138,563	\$2,159,710	\$2,187,172	\$2,222,279	\$2,263,637	\$2,308,674
Cumulative O&M \$ Spent	\$1,871,200	\$3,773,555	\$5,734,231	\$7,729,364	\$9,725,950	\$11,744,774	\$13,783,197	\$15,840,555	\$17,913,611	\$19,997,131	\$22,100,730	\$24,220,505	\$26,359,068	\$28,518,778	\$30,705,949	\$32,928,228	\$35,191,865	\$37,500,539
TRANSITION SCENARIO																		
\$ per Year (Fueling - Current Vehicles)	\$876,930	\$861,729	\$844,802	\$818,256	\$768,950	\$680,280	\$492,868	\$371,233	\$331,247	\$256,423	\$151,661	\$105,153	\$84,224	\$81,945	\$80,248	\$0	\$0	\$0
\$ per Year (Fueling - New Vehicles)	\$0	\$10,980	\$23,861	\$39,977	\$48,234	\$76,069	\$130,814	\$156,333	\$156,690	\$173,309	\$227,703	\$230,585	\$231,608	\$230,734	\$228,744	\$240,428	\$240,364	\$241,094
\$ per Year (Maintenance - Current Vehicles)	\$994,270	\$988,231	\$936,062	\$907,068	\$895,088	\$785,088	\$576,656	\$485,038	\$465,399	\$402,006	\$265,295	\$175,225	\$140,094	\$144,297	\$148,626	\$0	\$0	\$0
\$ per Year (Maintenance - New Vehicles)	\$0	\$16,710	\$78,538	\$107,486	\$128,971	\$238,346	\$466,502	\$650,514	\$694,895	\$836,491	\$1,186,706	\$1,293,601	\$1,361,782	\$1,402,635	\$1,444,714	\$1,549,217	\$1,595,694	\$1,643,565
\$ per Year (Maintenance - Charging Infrastructure)	\$0	\$0	\$2,500	\$2,500	\$2,500	\$6,000	\$42,000	\$68,000	\$68,000	\$68,000	\$68,000	\$70,500	\$71,500	\$71,500	\$71,500	\$71,500	\$71,500	\$71,500
Total O&M \$ per Year	\$1,871,200	\$1,877,651	\$1,885,763	\$1,875,287	\$1,843,743	\$1,785,784	\$1,708,839	\$1,731,119	\$1,716,232	\$1,736,229	\$1,899,364	\$1,875,064	\$1,889,207	\$1,931,110	\$1,973,832	\$1,861,146	\$1,907,558	\$1,956,159
Cumulative O&M \$ Spent	\$1,871,200	\$3,748,851	\$5,634,613	\$7,509,900	\$9,353,644	\$11,139,427	\$12,848,267	\$14,579,385	\$16,295,617	\$18,031,846	\$19,931,211	\$21,806,274	\$23,695,481	\$25,626,592	\$27,600,424	\$29,461,570	\$31,369,127	\$33,325,286

Figure 8. Summary of O&M Expenditures by Year





Expenditure Type	Total Annual Expenditures (2023 \$)																	
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
BASELINE SCENARIO																		
Total Capital \$ per Year	\$0	\$1,946,700	\$1,230,644	\$573,682	\$382,454	\$2,341,058	\$4,984,879	\$2,483,629	\$565,742	\$2,482,869	\$4,749,374	\$671,958	\$276,847	\$0	\$0	\$2,314,262	\$0	\$0
Total O&M \$ per Year	\$1,871,200	\$1,902,355	\$1,960,676	\$1,995,133	\$1,996,586	\$2,018,824	\$2,038,424	\$2,057,358	\$2,073,056	\$2,083,520	\$2,103,599	\$2,119,774	\$2,138,563	\$2,159,710	\$2,187,172	\$2,222,279	\$2,263,637	\$2,308,674
Total Baseline \$ per Year	\$1,871,200	\$3,849,055	\$3,191,320	\$2,568,815	\$2,379,041	\$4,359,882	\$7,023,302	\$4,540,987	\$2,638,798	\$4,566,389	\$6,852,973	\$2,791,733	\$2,415,410	\$2,159,710	\$2,187,172	\$4,536,541	\$2,263,637	\$2,308,674
Cumulative Baseline \$ Spent	\$1,871,200	\$5,720,255	\$8,911,575	\$11,480,389	\$13,859,430	\$18,219,312	\$25,242,614	\$29,783,601	\$32,422,399	\$36,988,788	\$43,841,762	\$46,633,495	\$49,048,904	\$51,208,614	\$53,395,786	\$57,932,327	\$60,195,964	\$62,504,638
TRANSITION SCENARIO																		
Total Capital \$ per Year	\$0	\$2,664,610	\$2,075,943	\$1,292,890	\$818,830	\$3,052,485	\$11,198,937	\$7,706,033	\$840,401	\$2,834,291	\$6,621,152	\$1,602,187	\$679,032	\$0	\$0	\$2,542,364	\$0	\$0
Total O&M \$ per Year	\$1,871,200	\$1,877,651	\$1,885,763	\$1,875,287	\$1,843,743	\$1,785,784	\$1,708,839	\$1,731,119	\$1,716,232	\$1,736,229	\$1,899,364	\$1,875,064	\$1,889,207	\$1,931,110	\$1,973,832	\$1,861,146	\$1,907,558	\$1,956,159
Total Transition \$ per Year	\$1,871,200	\$4,542,261	\$3,961,705	\$3,168,177	\$2,662,574	\$4,838,268	\$12,907,776	\$9,437,152	\$2,556,633	\$4,570,520	\$8,520,517	\$3,477,251	\$2,568,239	\$1,931,110	\$1,973,832	\$4,403,510	\$1,907,558	\$1,956,159
Cumulative Transition \$ Spent	\$1,871,200	\$6,413,461	\$10,375,166	\$13,543,343	\$16,205,916	\$21,044,185	\$33,951,961	\$43,389,113	\$45,945,746	\$50,516,267	\$59,036,783	\$62,514,034	\$65,082,273	\$67,013,384	\$68,987,216	\$73,390,726	\$75,298,284	\$77,254,443

Figure 9. Summary of Total Expenditures by Year



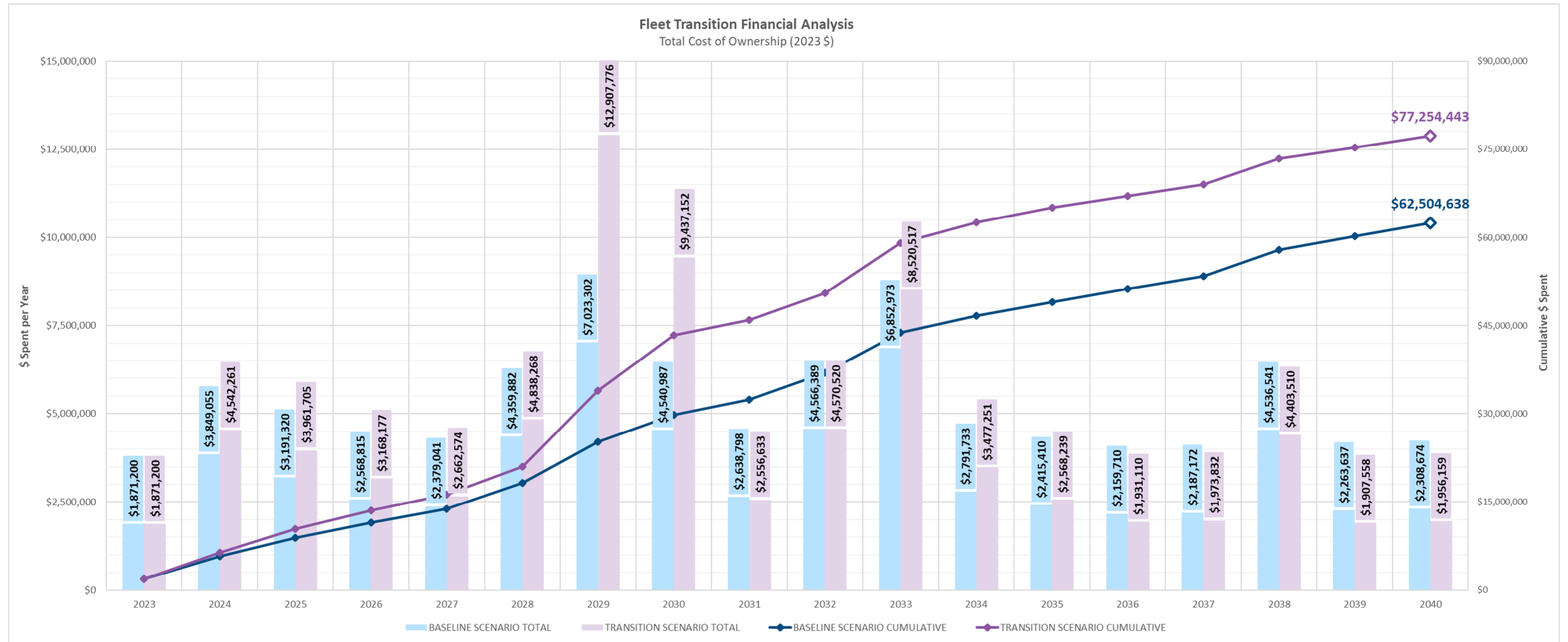


Figure 10. Forecasted Total Cost of Ownership



Table 4. Total Cost of Ownership Breakdown

Expenditure Type	Annual Expenditures (2023 \$)																		Fleet Totals (2023-2040)
	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	
BASELINE SCENARIO																			
# of Vehicle Purchases	0	9	8	3	2	10	13	4	1	4	7	5	2	0	0	2	0	0	70
\$ per Year (Vehicles)	\$0	\$1,946,700	\$1,230,644	\$573,682	\$382,454	\$2,341,058	\$4,984,879	\$2,483,629	\$565,742	\$2,482,869	\$4,749,374	\$671,958	\$276,847	\$0	\$0	\$2,314,262	\$0	\$0	\$25,004,099
Total Capital \$ per Year	\$0	\$1,946,700	\$1,230,644	\$573,682	\$382,454	\$2,341,058	\$4,984,879	\$2,483,629	\$565,742	\$2,482,869	\$4,749,374	\$671,958	\$276,847	\$0	\$0	\$2,314,262	\$0	\$0	\$25,004,099
\$ per Year (Maintenance)	\$994,270	\$1,024,098	\$1,054,821	\$1,086,465	\$1,119,059	\$1,152,631	\$1,187,210	\$1,222,826	\$1,259,511	\$1,297,296	\$1,336,215	\$1,376,302	\$1,417,591	\$1,460,118	\$1,503,922	\$1,549,040	\$1,595,511	\$1,643,376	\$23,280,261
\$ per Year (Fueling)	\$876,930	\$878,257	\$905,855	\$908,668	\$877,527	\$866,193	\$851,214	\$834,532	\$813,545	\$786,224	\$767,384	\$743,473	\$720,972	\$699,591	\$683,250	\$673,239	\$668,126	\$665,298	\$14,220,278
Total O&M \$ per Year	\$1,871,200	\$1,902,355	\$1,960,676	\$1,995,133	\$1,996,586	\$2,018,824	\$2,038,424	\$2,057,358	\$2,073,056	\$2,083,520	\$2,103,599	\$2,119,774	\$2,138,563	\$2,159,710	\$2,187,172	\$2,222,279	\$2,263,637	\$2,308,674	\$37,500,539
Total Baseline \$ per Year	\$1,871,200	\$3,849,055	\$3,191,320	\$2,568,815	\$2,379,041	\$4,359,882	\$7,023,302	\$4,540,987	\$2,638,798	\$4,566,389	\$6,852,973	\$2,791,733	\$2,415,410	\$2,159,710	\$2,187,172	\$4,536,541	\$2,263,637	\$2,308,674	\$62,504,638
TRANSITION SCENARIO																			
# of Vehicle Purchases	0	9	8	3	2	10	13	4	1	4	7	5	2	0	0	2	0	0	70
# of Charger Purchases	0	0	5	0	0	7	14	4	0	0	0	5	2	0	0	0	0	0	37
\$ per Year (Vehicles)	\$0	\$2,407,110	\$2,020,245	\$1,292,890	\$818,830	\$2,969,760	\$6,041,906	\$3,168,635	\$840,401	\$2,834,291	\$6,621,152	\$1,531,632	\$649,963	\$0	\$0	\$2,542,364	\$0	\$0	\$33,739,180
\$ per Year (Chargers)	\$0	\$257,500	\$55,697	\$0	\$0	\$82,725	\$5,157,031	\$4,537,399	\$0	\$0	\$0	\$70,556	\$29,069	\$0	\$0	\$0	\$0	\$0	\$10,189,976
Total Capital \$ per Year	\$0	\$2,664,610	\$2,075,943	\$1,292,890	\$818,830	\$3,052,485	\$11,198,937	\$7,706,033	\$840,401	\$2,834,291	\$6,621,152	\$1,602,187	\$679,032	\$0	\$0	\$2,542,364	\$0	\$0	\$43,929,156
\$ per Year (Fueling - Current Vehicles)	\$876,930	\$861,729	\$844,802	\$818,256	\$768,950	\$680,280	\$492,868	\$371,233	\$331,247	\$256,423	\$151,661	\$105,153	\$84,224	\$81,945	\$80,248	\$0	\$0	\$0	\$6,805,950
\$ per Year (Fueling - New Vehicles)	\$0	\$10,980	\$23,861	\$39,977	\$48,234	\$76,069	\$130,814	\$156,333	\$156,690	\$173,309	\$227,703	\$230,585	\$231,608	\$230,734	\$228,744	\$240,428	\$240,364	\$241,094	\$2,687,527
\$ per Year (Maintenance - Current Vehicles)	\$994,270	\$988,231	\$936,062	\$907,068	\$895,088	\$785,088	\$576,656	\$485,038	\$465,399	\$402,006	\$265,295	\$175,225	\$140,094	\$144,297	\$148,626	\$0	\$0	\$0	\$8,308,444
\$ per Year (Maintenance - New Vehicles)	\$0	\$16,710	\$78,538	\$107,486	\$128,971	\$238,346	\$466,502	\$650,514	\$694,895	\$836,491	\$1,186,706	\$1,293,601	\$1,361,782	\$1,402,635	\$1,444,714	\$1,549,217	\$1,595,694	\$1,643,565	\$14,696,366
\$ per Year (Maintenance - Charging Infrastructure)	\$0	\$0	\$2,500	\$2,500	\$2,500	\$6,000	\$42,000	\$68,000	\$68,000	\$68,000	\$68,000	\$70,500	\$71,500	\$71,500	\$71,500	\$71,500	\$71,500	\$71,500	\$827,000
Total O&M \$ per Year	\$1,871,200	\$1,877,651	\$1,885,763	\$1,875,287	\$1,843,743	\$1,785,784	\$1,708,839	\$1,731,119	\$1,716,232	\$1,736,229	\$1,899,364	\$1,875,064	\$1,889,207	\$1,931,110	\$1,973,832	\$1,861,146	\$1,907,558	\$1,956,159	\$33,325,286
Total Transition \$ per Year	\$1,871,200	\$4,542,261	\$3,961,705	\$3,168,177	\$2,662,574	\$4,838,268	\$12,907,776	\$9,437,152	\$2,556,633	\$4,570,520	\$8,520,517	\$3,477,251	\$2,568,239	\$1,931,110	\$1,973,832	\$4,403,510	\$1,907,558	\$1,956,159	\$77,254,443



Based on this analysis, the total cost of ownership for a transitioned fleet is about \$77.25M, versus an estimated cost of \$62.5M to maintain the current fleet. This \$14.75M difference will create the need for Wave to increase the fleet budget by nearly 25 percent over the next 17 years. The largest single-year expenditures—largely driven by vehicle purchases—are seen in 2029, 2030, and 2033. Multiple BEB purchases would be made in these years that would otherwise be ICE or buses at lower costs; for example, 7 BEB purchases scheduled for 2033 are estimated to cost \$6.6M, while purchasing 7 CNG buses in that year would cost \$4.75M. Many shuttles and paratransit vehicles are also scheduled for replacement in 2029, adding just over \$1M in capital needs for that year. Annual fueling costs decrease greatly, however, from a current value estimated at about \$850,000 to just \$240,000 in 2040 once the fleet has been fully transitioned. Future maintenance costs are shown to be nearly identical at \$1.64M per year; though BEBs are cheaper to maintain than Wave’s current diesel-fueled buses, they are more expensive to maintain than the existing CNG buses.



Workforce Transition Plan

A key aspect of adding electric vehicles to a fleet is preserving the current workforce and providing a pathway to equip staff with the necessary skills to support the successful deployment and maintenance of BEVs. If pursued, it will be important to update existing training to include BEVs and emphasize the ways that the existing workforce can support the transition toward BEVs.

Wave Transit does not currently perform any vehicle maintenance internally, but the agency would work with their contractor to ensure there is no displacement of current maintenance workforce as a result of adding ZEVs to the fleet; this could be done through inclusion of a full workforce transition plan in contract language for maintenance provider(s). If Wave Transit were to bring maintenance functions in-house in the future, the developed training program would be consistent with concepts outlined in this section.

To assist agencies with an examination of the impact of transition to a zero emission fleet on the current workforce, the Federal Transit Administration (FTA) issued information on a Zero Emission Fleet Transition Plan Workforce Evaluation Tool. In this tool agencies will find seven major questions that they are recommended to examine, including:

1. Identify Skills, Training, & Credentials
2. Assess Skills of Current Workforce
3. Identify Skills Gaps
4. Develop Zero Emission Vehicle Transition Workforce Training Program
5. Engage Current Workforce in Planning
6. Incorporate Strategies to Avoid Workforce Displacement
7. Identify Funding for Training Program

Training Program Development

Wave Transit would request that their contractor provide contracted employees with a comprehensive ZEV curriculum, and if one does not exist, Wave Transit could work with the contractor to develop one. Having a high-quality training program would entail coordination with internal and external resources, including the following groups:

- Vehicle and charger OEM training curriculum purchased as part of new rolling stock procurements.
- Vehicle sub-system/sub-component OEM training curriculum.
- Partnership with local first responding agencies.
- Collaboration with transit agencies with operational zero emission fleets and in-house training programs.
- Membership through training consortiums like National Transit Institute.
- Participation in transit associations like American Public Transportation Association, Center for Transportation and the Environment, and Zero Emissions Bus Resource Alliance.

Training Curriculum

Battery electric vehicles require some additional knowledge and skills to operate and maintain the vehicles. One major difference between ICE vehicles and BEVs is that BEVs contain high voltage batteries, which requires all maintenance technicians to be certified to work on high voltage systems.



At a more general level, relevant staff would need to be familiar with the new BEVs and complete vehicle familiarization training. These trainings are typically offered by the OEMs and completing these trainings is standard practice when introducing new vehicles at most transit agencies.

Wave Transit would work closely with the selected contractor to ensure adequate training practices for all contracted staff working with Wave Transit's BEVs. Wave Transit would also work with the contractor to ensure accordance with the Electronic and Electrical Safety Program with guidance from the National Fire Protection Agency (NFPA 70E), Occupational Safety and Health Administration, OEMs, and industry best practices. The sections below outline training for operators and maintenance technicians to work with ZEVs safely and effectively. These concepts can be used to inform the training program managed by Wave Transit's contractor.

Operators

Operators need to complete driver trainings to learn how to efficiently drive the vehicles, become familiar with the sub-systems within the vehicle, and understand high voltage safety. Because of the regenerative braking systems within BEVs, operators should drive BEVs differently than diesel or gasoline vehicles. It is important that operators learn to utilize the regenerative braking system to maximize battery efficiency; the way that an electric vehicle is driven can impact the range. It is expected that operators would complete additional training hours to operate buses effectively and learn procedures for pulling the BEVs into stalls where they would be charged. Operators also need to be familiar with the following sub-systems within a BEV: cameras, windows, doors, fire suppression, and fire detection. Lastly, it is important that operators understand safety procedures with the BEVs. High voltage safety is most applicable to BEV operators, and additional training should be performed if the operators are the staff tasked with plugging in the BEVs at the depot or pulling into any future on-route charging spots.

Maintenance Technicians

In regard to the buses, maintenance staff would also need to undergo additional trainings to work with new BEVs. This staff would need to complete vehicle familiarization trainings that explain how the BEV propulsion system works. Once understanding how the propulsion system works, maintenance staff would learn how to perform preventative maintenance, diagnose problems, and complete repairs. Maintenance staff that work with the BEVs would need to obtain high voltage certifications. Lastly, maintenance staff would need to learn proper use and inspection of PPE for BEV maintenance and Lock-Out-Tag-Out (LOTO) procedures for BEVs.

Another element that should be considered alongside BEVs is the electric vehicle supply equipment (EVSE) which power the BEVs. It would be important to work with the EVSE OEM to define preventative maintenance practices and develop a system for diagnosing issues and repairing EVSE. There are multiple types of EVSE (plug in, pantographs, and inductive chargers), and it would be important for Wave Transit to work with the contractor to ensure that trainings cover the correct charging types.

Training Program Implementation

Wave Transit would work closely with contractors to ensure current technical training programs are up to date, moving forward from older systems and making sure newer systems are adequately integrated into the program. The selected contractor would be expected to provide a training program which includes a comprehensive curriculum on all vehicle systems and subsystems. Through the selected contractor's program, Wave Transit would review all maintenance department training to make sure



employees are provided with specialized training that encompasses current information about new and existing equipment, including modern electronic and mechanical vehicle systems, OEM changes that impact maintenance practices, and refresher training if necessary.

Wave Transit would encourage the selected contractor to identify maintenance management and front-line supervisors for Safety Orientation Training and Maintenance Department training sessions. The following are organizations which offer programs and supplemental professional development events intended to promote workplace safety: Federal Emergency Management Agency (FEMA) National Incident Response Training, Maintenance Program and Process Benchmarking, and National Transit Institute’s Transit Trainers Workshops.

Initially, the selected contractor would identify and develop a core group of subject matter experts to serve as ZEV fleet specialists to Wave Transit. This approach would proactively develop qualified fleet specialists through hands-on experience and learning. As the zero emission fleet grows, more mechanics would complete zero emission maintenance training under the contractor.

Workforce Right-Sizing

As Wave Transit may add BEVs to the fleet, the agency would work closely with the selected contractor to evaluate staffing needs based on overall fleet growth and maintenance needs. Wave Transit would approve additional positions as determined by the contractor’s maintenance staffing guidelines and fleet needs. It is not anticipated that new positions would be needed when adding a few BEVs to the fleet; however, if Wave Transit added a significant number of BEVs and EVSE to their operations, it could become necessary to create new positions. Staffing needs should be evaluated on a rolling basis and Wave Transit should work collaboratively with the selected contractor to ensure that the workforce is the correct size for Wave Transit’s fleet.

Funding Opportunities

The anticipated cost of workforce training would likely fluctuate in response to the adoption of BEVs. Suggested contractor funding is anticipated to come from several sources including procurement, existing funding sources used for training, and federal and local funding shares.

While the cost of the training is one item to consider, the labor cost to train vehicle maintenance personnel is anticipated to be high. As highlighted by the International Transportation Learning Center, the following costs should be considered when budgeting for workforce training:

- Classroom training hours
- Instructor hours (instruction and preparation)
- Instructor hourly wages and benefits
- Instructor costs per class
- Instructor cost per trainee
- On the job training hours
- Mentor hours
- Mentor hourly cost
- Mentor cost per trainee
- Facilities cost
- Training materials/mock-ups/software/simulation cost

Wave Transit would work closely with the contractor to identify funding sources for worker training and re-training and utilize the training funding offered through federal grants to support the agency’s zero emission workforce training costs. Wave Transit could work to secure funding for zero emissions vehicle maintenance and operation training on behalf of the contractor, including, but not limited to, the 5% workforce development requirement of FTA’s Low or No Emissions Grant.



Conclusion & Next Steps

This Zero Emission Fleet Transition Plan may serve as a roadmap for Wave Transit to bring battery electric vehicles into the transit fleet. This study included route modeling of Wave Transit's service, infrastructure and facility analysis, utility coordination, cost analysis, stakeholder outreach, and a phased fleet transition strategy. This ZEB Transition Strategy also meets the federal requirements to apply for FTA funding, including:

1. Policy & Legislative Impacts
2. Fleet Transition Plan
3. Facility & Infrastructure Plan
4. Utility & Fuel Partnerships
5. Funding Plan
6. Workforce Transition Plan

Wave Transit's service has a variety of challenges that make a 100% zero emission fleet infeasible today; however, there are a variety of ways that Wave Transit can reduce fleet emissions and slowly move toward a zero emission future. Fixed route bus service could operate partially with BEVs and partially with CNG vehicles, and paratransit service could be operated with almost all BEVs. Shuttle service and trolley service are more difficult to transition; however, as technology advances, there could be better opportunities to transition these fleets in the future. In the interim, Wave Transit could further explore CNG as a low emission fuel.

Internal support, local support, and grant support would be essential to realize the vision of transitioning the fleet to zero emission vehicles. A transition toward BEVs could result in additional capital costs to build new infrastructure and purchase more expensive, but cleaner vehicles. This plan may serve as a mechanism to guide Wave Transit through their first BEV deployment and secure funding to make a cleaner transit fleet possible for New Hanover County.



Appendix A: Wave System Service Maps



Figure 11: Port City Trolley Route





Figure 12: UNCW Shuttle Service Routes



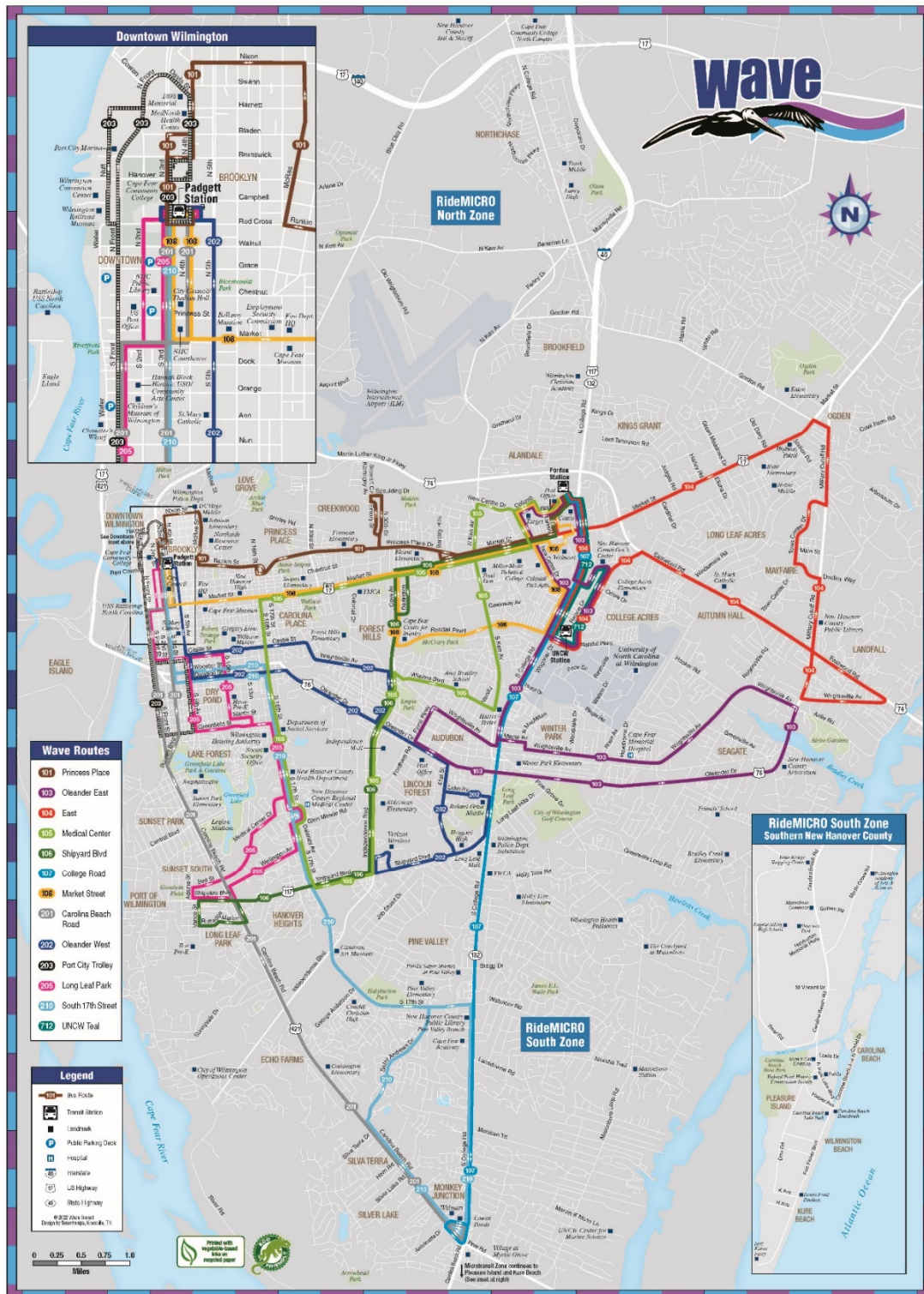


Figure 13: Wave System Map



Appendix B: Energy Modeling & Analysis

Transitioning a fleet to zero emission buses (ZEBs) introduces new technology and requirements into day-to-day operations. Successful fleet transitions consider operational requirements, market conditions, available power, infrastructure demands, and associated costs. This section provides detailed modeling results to inform near-term and long-term transition strategies. Modeling efforts included battery electric buses (BEBs) with both depot and on-route charging options.

Fleet Data Evaluation

The first step in exploring alternative fuel vehicles is to evaluate the current routes and fleet vehicles used to provide service. This evaluation began by collecting and reviewing all available background documents and data relevant to the study. Key data included:

- Operator blocks for weekdays and weekends
- Block-type and bus-type assignments
- General Transit Feed Specifications (GTFS) data for transit blocks on weekdays and weekends
- Ridership data by route or block for typical weekdays and weekends
- Operations information including revenue and deadhead hours and miles
- Fleet Replacement Plan

All data collected and reviewed feeds the modeling effort and analysis that follows.

Energy Consumption Analysis

Fixed Route

Understanding energy consumption is a key component of fleet transition planning, as it informs the choice of vehicle technology, infrastructure requirements, finances, and fleet replacement strategies. HDR's proprietary Zero+ modeling tool provides a comprehensive understanding of the potential impacts zero emission bus (ZEB) technology may have on Wave Transit's existing service. **Figure 14** shows the Zero+ Model inputs, outputs, and process. Energy consumption is impacted by several factors, including slope and grade of the bus routes, number of vehicle stops, anticipated roadway traffic, and ambient temperature. The Zero+ model also analyzes variables known to impact lifetime vehicle performance like: energy density, battery degradation, operating environment, heating, air conditioning, and auxiliary power loads, and the lifecycle of bus batteries and hydrogen fuel cells. The model is fed by GTFS data, GIS data, and vehicle profile assumptions to create an accurate energy consumption profile unique to Wave Transit's existing service. In sum, Zero+ results include many data variables, yielding the most accurate results possible to influence strong, effective decision making.

The Zero+ model results, combined with discussions with agency staff, provide the basis upon which the preferred refueling strategy would be determined. For a battery electric bus (BEB) scenario, this modeling evaluated whether the optimal charging strategy is depot charging only, a mix of depot and on-route charging, or on-route charging only, and identifies potential strategies that best complement Wave Transit's service and fleet plans. Simulations were performed at the granular level, so that the strategy can inform individual vehicles, routes, and blocks as well as the full Wave Transit fleet. Examining each vehicle individually drives decisions for the right technology at the system, depot,



route, and block levels. This analysis balances impacts to operations, overall fleet size, and infrastructure requirements and ultimately provides Wave Transit with the information to make a data-driven determination of the preferred BEB transitional technologies and deployment pace.

By using this data and applying existing Wave Transit service information, the Zero+ tool produced a heat map showing the vehicle state of charge (SOC) throughout the day on any given route block. Modeling details which blocks and routes could perform within currently available BEB vehicle range capabilities, as well as forecasts at what point in each route BEB range is exceeded. This insight provides clear data for planning operational adjustments and fleet demands to maintain service levels and maximize BEB utilization, while also highlighting changes that may affect riders and recommending tactics to avoid or mitigate these impacts.

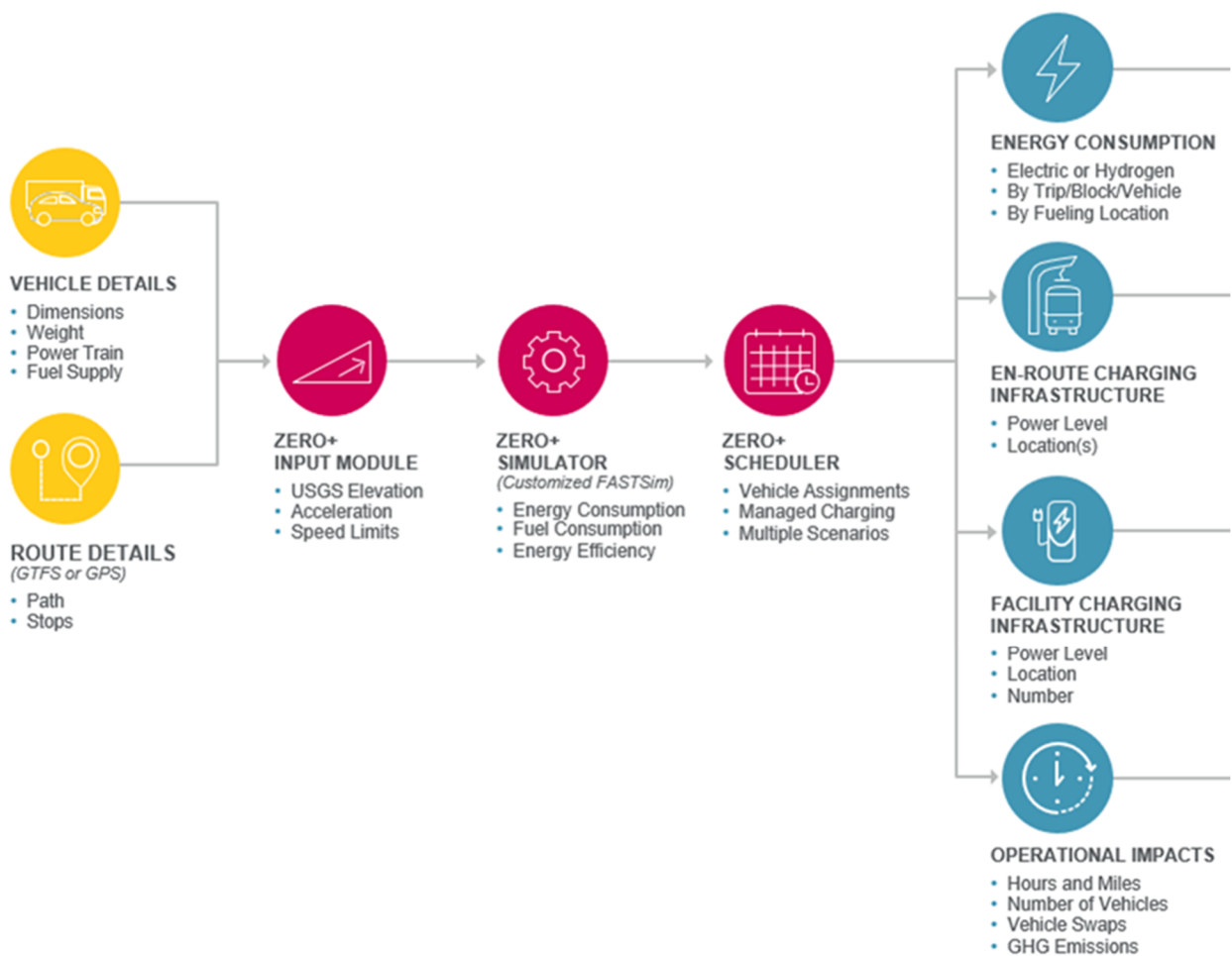


Figure 14. Zero+ Model Inputs, Outputs, and Process

Scenarios Modeled

Based on the evaluation and collection of data described above, a baseline scenario is simulated of current Wave Transit fixed route service. This validates both the data provided and the functionality of



the model by comparing simulation results to observed Wave Transit existing operations. This validation provides confidence that the simulations of BEB scenarios are not missing critical data points that influence the transition. BEB scenarios simulated include two alternatives: BEBs with depot charging only, and BEBs with both depot and on-route charging.

Battery Electric Bus – Depot Charging Only

Depot charging only was modeled first to establish a baseline feasibility. This scenario allows the Zero+ Model to identify which existing service blocks can be electrified without an increase in peak vehicle requirements, the need for on-route charging, or the need for schedule modifications to achieve the same level of service. By electing a depot-only charging profile, the model calculates what staff, vehicle, and service modifications would be needed to maintain the current level of service.

Simulation Assumptions

To develop a model relevant for Wave Transit’s fleet and operations, a set of assumptions and variables were identified. This simulation modeled fixed route services with transit buses, a 28’ trolley, and 32’ cutaways; the cutaways used for UNCW Shuttle service have a different operational profile than transit buses and trolleys, so they were modeled independently. Not all vehicle original equipment manufacturers (OEMs) will meet the same specification, so when Wave Transit procures vehicles for the transition it is crucial that the agency ensure vehicle procurements meet or exceed this minimum specification.

Table 5. Depot Charging Only Zero+ Model Inputs

Variable	Input		
Vehicle Type	28’ Trolley	32’ Cutaway	Transit Bus
Nameplate Battery Capacity	224 kWh	160 kWh	490 kWh
End-of-Life Battery Health	80% (Maximum Battery Degradation)		
Energy Reserve	20%		
Heating	Electric Heater		
Ambient Temperature	30°F (Coldest Day, 10 th percentile)		
Passenger Capacity	100% seated capacity		
Maximum Charging Power	150 kW	50 kW	150 kW



Simulation Results: Fixed Route Transit and Trolley Service with Depot Charging Only

Key Takeaways:

- Revenue Hours and Miles remain the same
- Non-Revenue Miles: **97% increase**
- Non-Revenue Hours: **98% increase**
- Peak Vehicle Requirement: **94% increase**
- Increase from 15 to 29 buses
- Increase from 1 to 2 trolleys
- Every block must be swapped at least once during the day
- Most transit buses would require one swap per day
- Trolley service would require 2 swaps per day

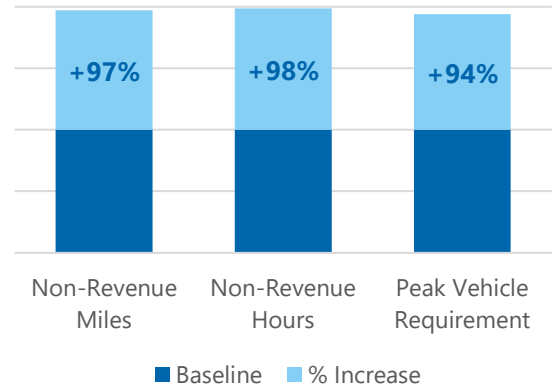


Figure 16 shows the vehicle battery SOC plot for each block. Each block is represented by a line on the chart with the color of the line corresponding to the SOC of the vehicle. The color changes from green to yellow to red as the SOC drops from 100 to 0 percent. Bus swaps shown in blue are introduced only between trips to minimize service impacts.

Figure 15. Fixed Route Transit & Trolley Service Depot Charging Only Model Outputs

Bus swaps are also inserted in locations to guarantee the minimum SOC does not dip below the required 20 percent reserve capacity, including the energy needed to return the vehicle to the depot when a swap is needed. Whenever a vehicle is swapped out, it is replaced with a BEB that has a fully charged battery. Swapping buses is only helpful when the bus either stays near the depot all day or returns within a close distance to the depot at multiple points throughout the day. If a block is scheduled to travel a long distance in one direction away from the depot, then there is no opportunity for a swap. **Figure 16** shows that all vehicles are able to complete existing service with the introduction of bus swaps, but adding bus swaps would require an increase in both fleet size and non-revenue hours and miles.



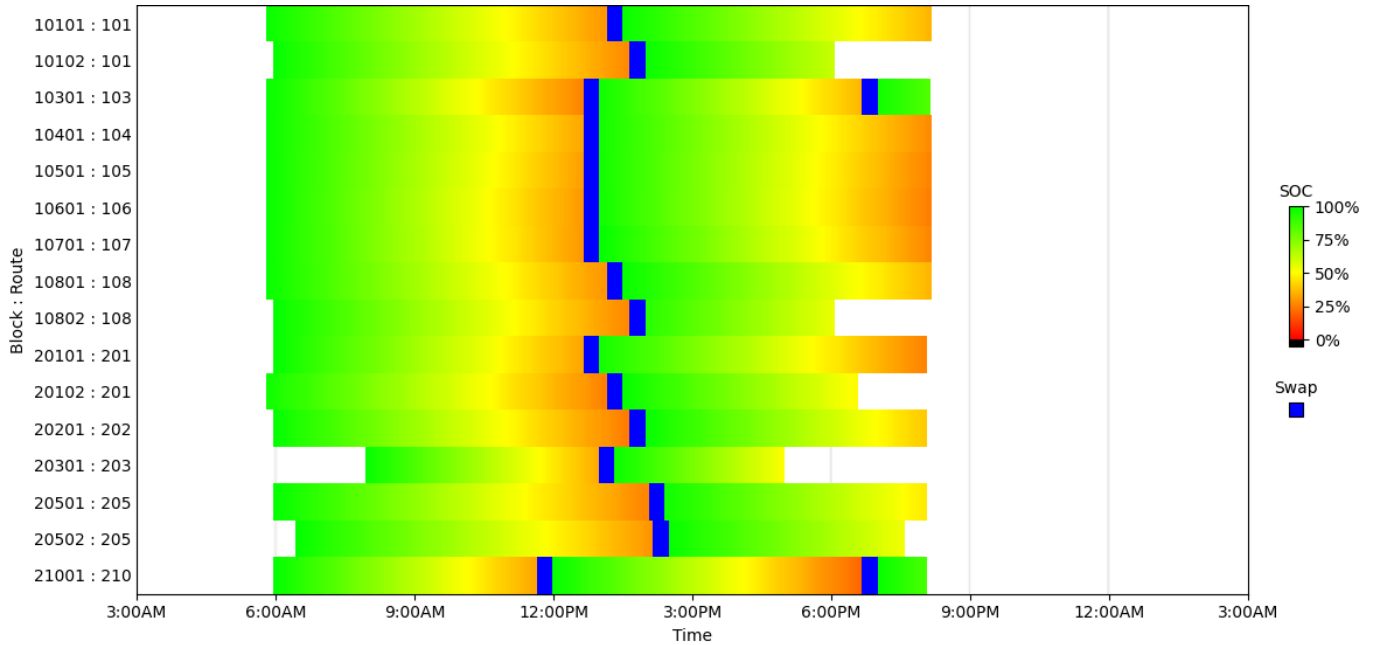


Figure 16. Fixed Route Transit and Trolley Depot Charging Only Weekday Block SOC Heatmap

Power Requirements

The power demand for charging buses and trolleys fluctuates throughout the day as shown in **Figure 17** with a peak demand of 450 kW. The O&M facility would use at most 12,331 kWh of energy over the course of the day for charging buses and trolleys; these energy requirements reflect the worst-case daily energy requirements, meaning the maximum energy that would be required during weekday service with cold weather (10th percentile ambient temperatures) and end-of-life battery capacity (80% of nameplate capacity). This places an upper limit on the energy requirements for beginning discussions with Duke Energy, who has confirmed there is 1 MW of excess capacity at the O&M facility, as well as begin planning for resiliency with backup power solutions.



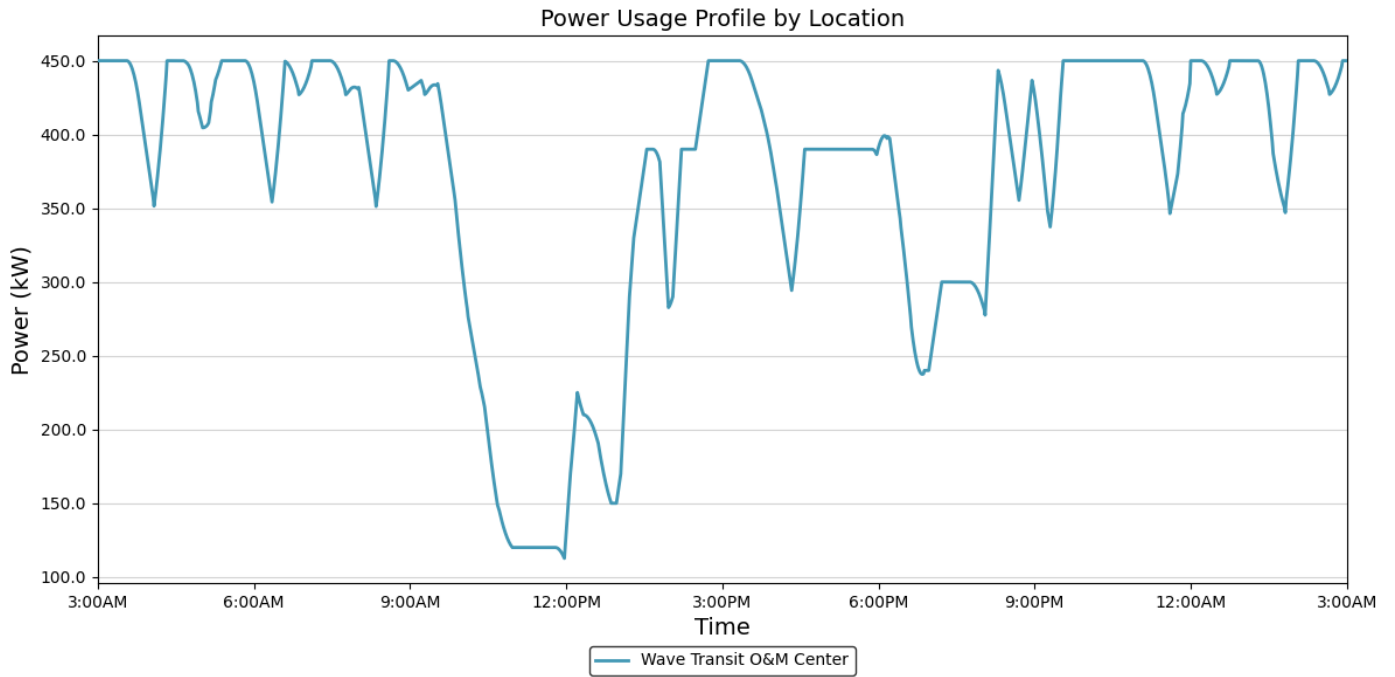


Figure 17. Fixed Route Transit & Trolley Service Depot Charging Only Daily Power Demand Profile at the O&M Facility (kW)

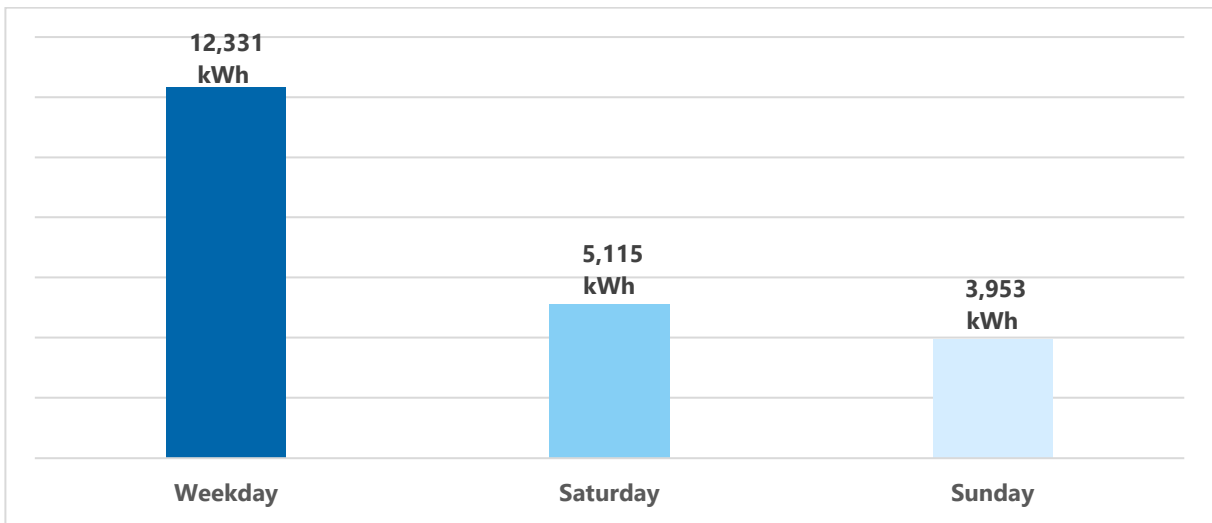


Figure 18. Fixed Route and Trolley Service Depot Charging Only Daily Energy Requirements (kWh)



Simulation Results: UNCW Shuttle Service with Depot Charging Only

Key Takeaways:

- Revenue Hours and Miles remain the same
- Non-Revenue Miles: **291% increase**
- Non-Revenue Hours: **287% increase**
- Peak Vehicle Requirement: **111% increase**
- Increase from 9 to 19 shuttles
- Every block must be swapped at least twice during the day
- Most shuttles would require three swaps per day

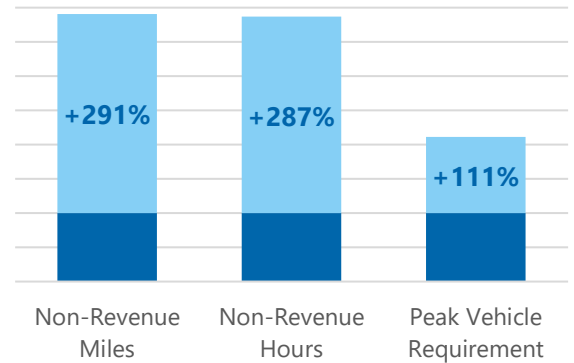


Figure 19. UNCW Shuttle Service Depot Charging Only Model Outputs

Figure 20 shows the vehicle battery SOC plot for each block. Each block is represented by a line on the chart with the color of the line corresponding to the SOC of the vehicle. The color changes from green to yellow to red as the SOC drops from 100 to 0 percent. Bus swaps shown in blue are introduced only between trips to minimize service impacts.

Bus swaps are also inserted in locations to guarantee the minimum SOC does not dip below the required 20 percent reserve capacity, including the energy needed to return the vehicle to the depot when a swap is needed. Whenever a vehicle is swapped out, it is replaced with a BEB that has a fully charged battery. Swapping buses is only helpful when the bus either stays near the depot all day or returns within a close distance to the depot at multiple points throughout the day. If a block is scheduled to travel a long distance in one direction away from the depot, then there is no opportunity for a swap. This model highlights that vehicles are not capable of completing a significant portion of currently scheduled blocks; operating UNCW Shuttle service with depot-only charging would introduce major operational impacts.



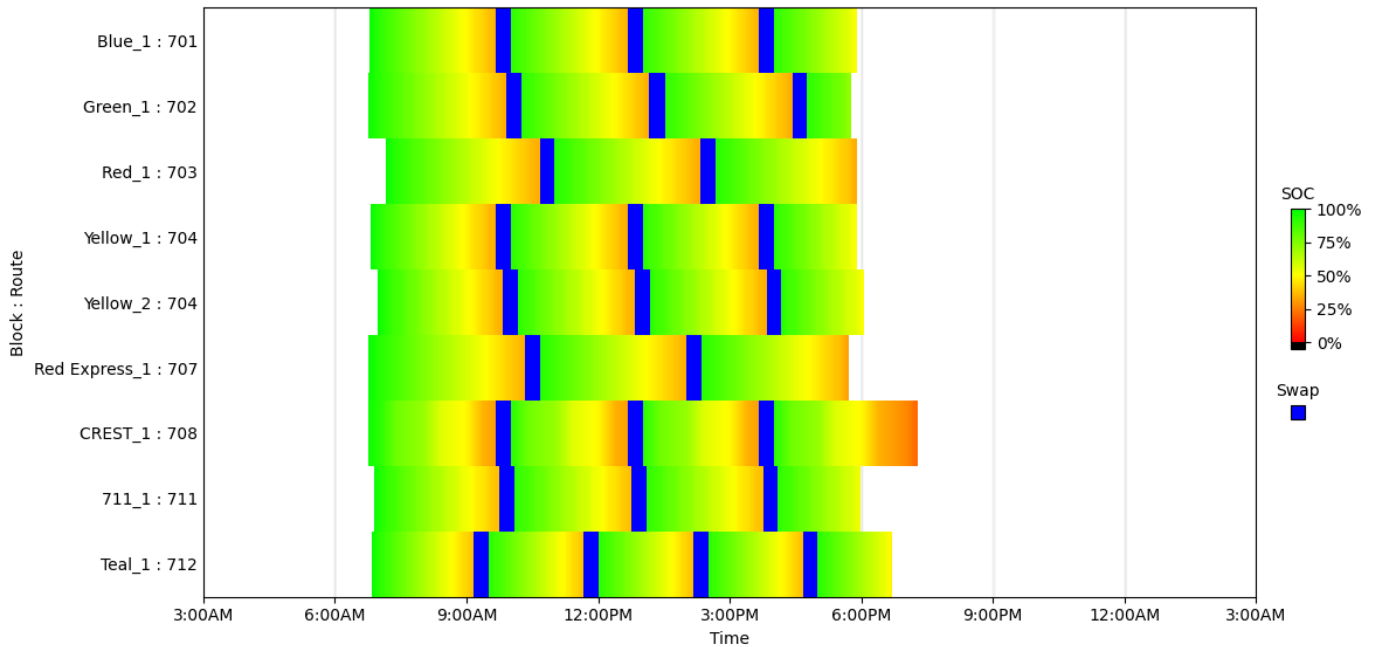


Figure 20. UNCW Shuttle Service Depot-Only Charging Weekday Block SOC Heatmap

Power Requirements

The UNCW Shuttle Service only operates on weekdays, requiring 3,390 kWh per day to charge the entire shuttle fleet using depot-only charging. The power demand for charging shuttles fluctuates throughout the day as shown in **Figure 21** with an optimized peak demand of 465 kW occurring just before noon at the O&M Facility; if all buses were to be charged simultaneously, the peak load would increase to 600 kW. The power demand profile shows that most of the charging occurs during the day and not overnight, allowing buses to be re-used multiple times throughout the day. If the charging was pushed to overnight instead of being spread throughout the day, even more vehicles would be required to maintain the same level of service.



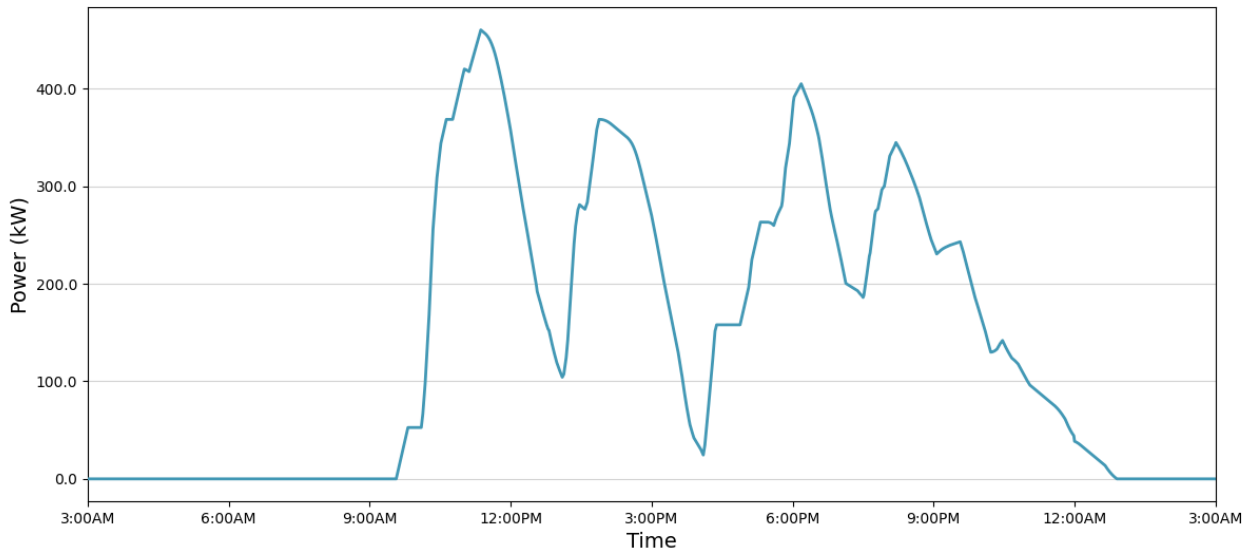


Figure 21. UNCW Shuttle Service Depot-Only Charging Daily Power Demand Profile at the O&M Facility (kW)

Battery Electric Bus – Depot and On-Route Charging

On-route charging is an enhancement that can greatly improve the feasibility of BEBs in many situations. This is particularly helpful with circulatory routes where the same on-route charger can be used by a vehicle multiple times throughout the day. The on-route charging infrastructure is ideally located at places, such as transit centers, where buses operating on multiple routes all have scheduled layover time. On-route charging is capable of greatly extending the range of a BEB and facilitating a one-to-one replacement of CNG vehicles when the routes are conducive to this charging strategy.

Simulation Assumptions

The simulation assumptions for modeling service with both depot and on-route chargers shown in **Table 6** are similar to the assumptions for modeling depot charging only, but an input for on-route charging power is added. The battery electric trolley modeled does not support overhead pantograph on route charging at this time, so there is no value provided in the table.

Table 6. Depot & On-Route Charging Zero+ Model Inputs

Variable	Input		
Vehicle Type	Trolley	32' Cutaway	Transit Bus
Nameplate Battery Capacity	224 kWh	160 kWh	490 kWh
End-of-Life Battery Health	80% (Maximum Battery Degradation)		
Energy Reserve	20%		
Heating	Electric Heater		
Ambient Temperature	30°F (Coldest Day, 10 th percentile)		
Passenger Capacity	100% seated capacity		
Maximum Charging Power at Depot	150 kW	50 kW	150 kW



Variable	Input		
Maximum Charging Power On-Route	-	50 kW	300 kW

On-Route Charger Locations

Layover times in the existing schedule were used to identify the most ideal locations for on-route chargers. There were two transit centers identified as good candidates for on-route charging; Forden Station and Padgett Station both have significant layover time to facilitate charging. Many vehicles have concurrent layovers at each of these locations, so several chargers would be needed to serve the fleet. UNCW Shuttle service modeling also identified Leutze Hall as a potential location for on-route charging, but this would require significant service modification to increase layover times.

Forden Station

Forden Station is located at 505 Cando Street in Wilmington, NC. Routes 101, 103, 104, 105, 106, 107, and 108 serve this transit center with a combined 27 hours of layover time on an average weekday. The UNCW Shuttle Teal Route also has a layover at this location.



Figure 22. Forden Station Aerial View



Padgett Station

Padgett Station is located at 520 North 3rd Street in Wilmington, NC. Routes 101, 108, 201, 202, 203 (Port City Trolley), 205, and 210 service this transit center with a combined 13 and a half hours of layover time on an average weekday.



Figure 23. Padgett Station Aerial View



Leutze Hall

Leutze Hall is located at 671 Racine Drive in Wilmington, NC, within the University of North Carolina Wilmington (UNCW) campus. This is the location with the most scheduled layover time for shuttle service, but there is no consistent layover location for all shuttles.



Figure 24. Leutze Hall Aerial View



Simulation Results: Fixed Route Transit and Trolley Service with Depot and On-Route Charging

Key takeaways:

- Revenue Hours and Miles remain the same
- Non-Revenue Miles: **49% increase**
- Non-Revenue Hours: **50% increase**
- Peak Vehicle Requirement: **50% increase**
- Increase 16 from to 24 buses
- 10 blocks would require one swap per day

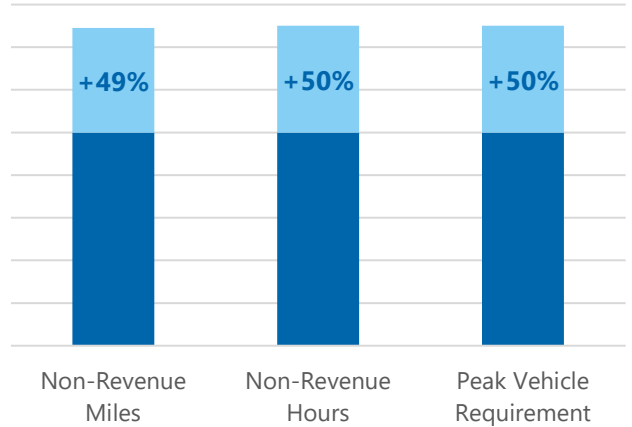


Figure 25. Fixed Route Transit and Trolley Service Depot and On-Route Charging Model Outputs

The vehicle battery SOC plot shown in **Figure 26** illustrates the SOC for each block during weekday service when both depot and on-route chargers are used. Weekend service was also modeled, but fleet and charging requirements are driven by weekday service when operational demand is the greatest.

Bus swaps shown in blue are also inserted in locations to guarantee the minimum SOC does not dip below the 20% reserve capacity, including the energy needed to return the vehicle to the depot when a swap is required. By introducing on-route charging, the number of bus swaps required on a weekday is significantly reduced from 18 to 10. 6 blocks on routes 101, 103, 104, and 108 can be converted to BEBs at a one-to-one ratio with the addition of on-route charging, all of which layover at Forden Station.

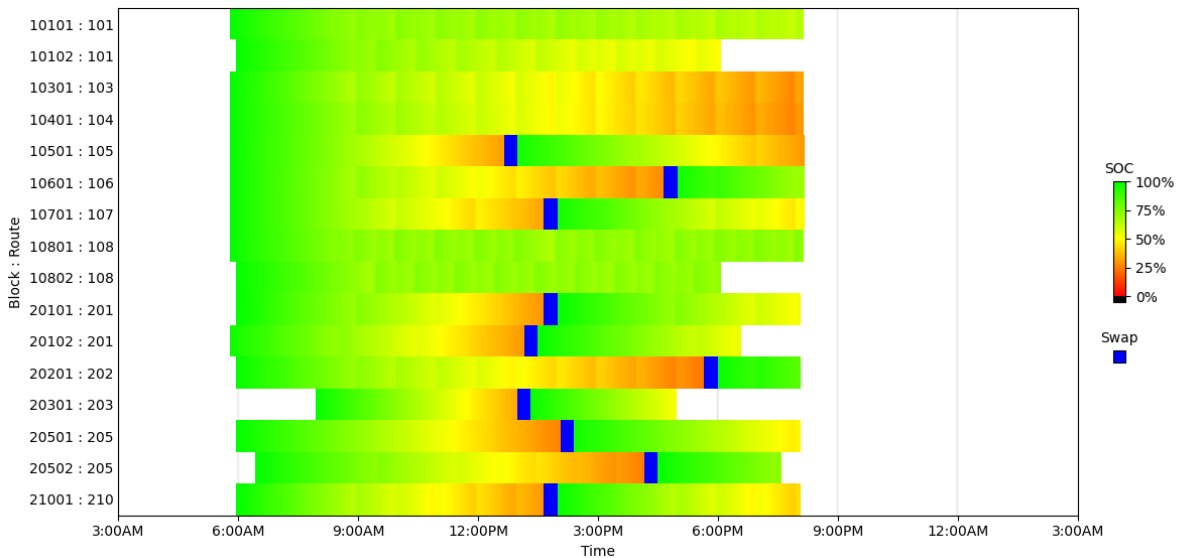


Figure 26. Fixed Route Transit and Trolley Service Depot and On-Route Charging Weekday Block SOC Heatmap



Power Requirements

By introducing on-route charging, the O&M Facility would require less power. The total weekly energy would decrease from 70,723 kWh to 35,037 kWh, and the facility peak power load would decrease from 450 kW to 390 kW. Although less power would be required when on-route chargers are introduced, new power requirements are added to the on-route charging locations. Forden Station would experience a peak demand of 1.5 MW, and Padgett Station would experience a peak demand of 0.9 MW. Duke Energy has confirmed that up to 1 MW of power is currently available at each site, meaning additional infrastructure would be required at Forden Station to support the required peak power load.

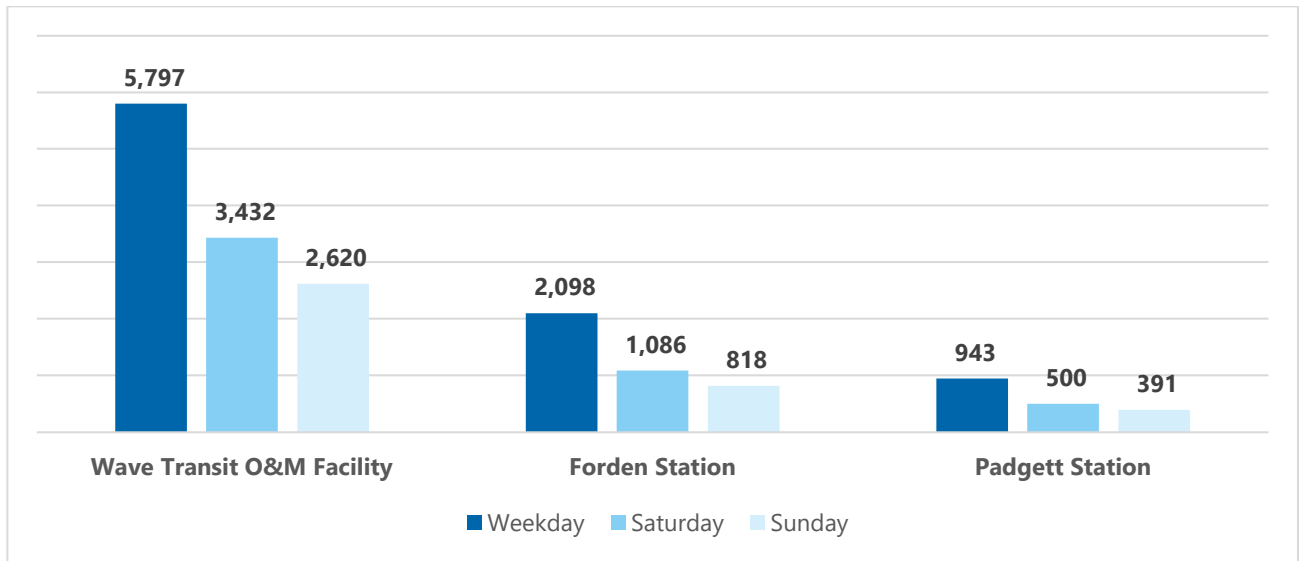


Figure 27. Fixed Route Transit & Trolley Service Daily Energy Requirements by Location (kWh)

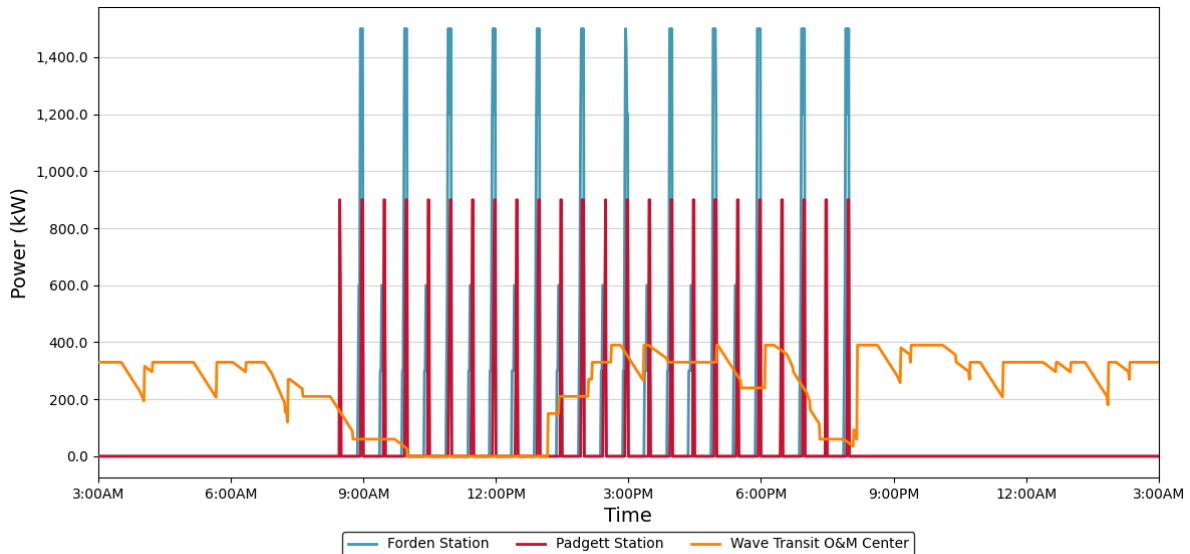


Figure 28. Fixed Route Transit & Trolley Service Depot and On-Route Charging Peak Power Demand by Location



Simulation Results: UNCW Shuttle Service with Depot and On-Route Charging

Key takeaways:

- Revenue Hours and Miles remain the same
- Non-Revenue Miles: **243% increase**
- Non-Revenue Hours: **246% increase**
- Peak Vehicle Requirement: **111% increase**
- Increase from 9 to 19 buses
- All but one block must be swapped at least twice during the day

Even with on-route charging introduced, the UNCW Shuttle Service is not feasible with today’s vehicle and battery technology. All blocks require bus swaps, and most blocks would require 3 swaps each day to maintain the same level of service. The shuttle fleet size would need to more than double to maintain the same level of service. The vehicle battery SOC plot shown in **Figure 30** illustrates the SOC for each block during weekday service when both depot and on-route chargers are used with bus swaps shown in blue.

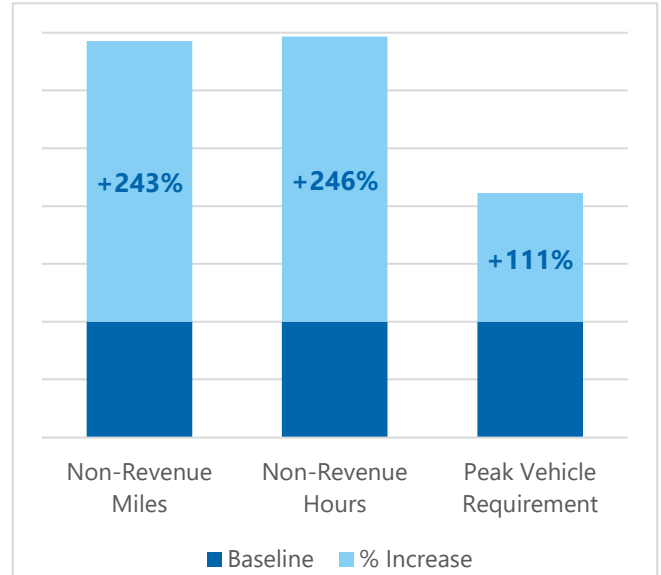


Figure 29. UNCW Shuttle Service Depot and On-Route Charging Model Outputs

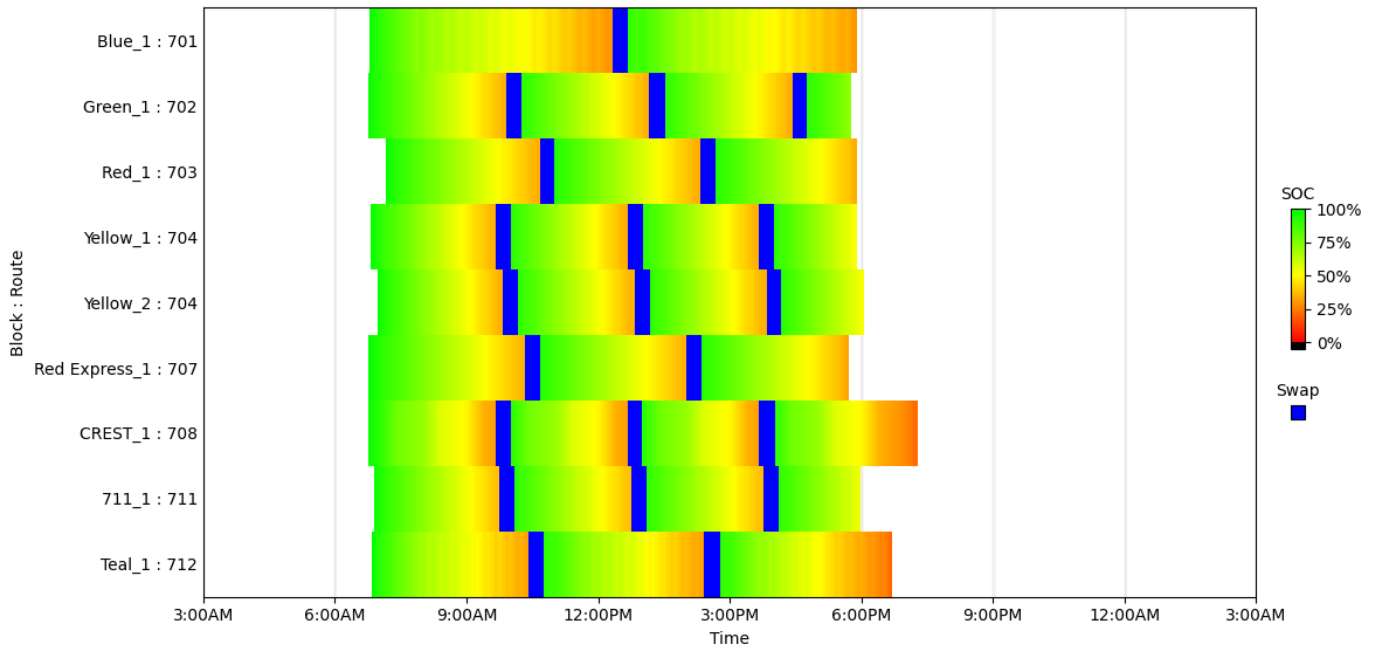


Figure 30. UNCW Shuttle Service Depot and On-Route Charging Weekday Block SOC Heatmap



Paratransit

Wave Transit paratransit services were modeled separately from fixed route services due to the available data types. The modeling effort for Wave Transit's paratransit fleet is based on operating data provided by the agency, as well as battery and charging specifications of BEB equivalents. Existing paratransit vehicle average daily miles and hours were considered in the modeling, derived from provided monthly vehicle data. The total energy consumption of the BEB fleet is computed using the average-case vehicles to forecast overall site energy and fleet size impacts.

To protect the life of the BEBs' batteries and avoid range anxiety, a minimum state of charge (SOC) of 20% and a maximum SOC of 90% to protect the life of the battery is assumed. These assumptions are reflected in the analysis by assuming a usable battery capacity equal to 70% of the vehicle's nameplate battery capacity. The use of accessory equipment like wheelchair lifts can also impact the energy consumption, but the impacts are difficult to predict. Accessory equipment does not typically significantly impact energy consumption, but to account for unknown additional energy requirements a 10% energy consumption buffer was added to the daily energy needs of each vehicle that is equipped with a wheelchair lift.

If the daily amount of energy required exceeds the available energy for that vehicle type, then the cases for an increase in fleet size or mid-day fast charging are considered. These additional cases facilitate protecting the vehicle's health while avoiding interruptions to normal operations. Three scenarios were considered: a base scenario, a scenario reflecting an expanded BEB fleet, and a scenario where the fleet is not expanded but mid-day recharging is supported.

Model Inputs

This energy modeling effort was conducted to understand the feasibility of fleet operations using BEBs and to forecast the magnitude of infrastructure needed to support a transition to a BEB fleet. The modeling has been based on National Transit Data (NTD) operating data for January 2023 provided to support the effort and the battery and charging specifications of each BEB equivalent identified in **Table 7**. Existing paratransit vehicle average and maximum daily miles and hours derived from provided monthly vehicle data were considered in the modeling; January data is assumed to be representative of monthly data throughout the year because there is no significant seasonal variation between months. The total energy consumption of the EV fleet is computed using both the average and worst-case vehicles, which allows overall site energy and fleet size impacts to be more accurately predicted.

The fleet was modeled iteratively to compare fleet feasibility with the different BEBs available in **Table 7**. When comparing models on an average day, some vehicles could replace most of the existing fleet with 1-to-1 replacements, but only the US Hybrid Ford Transit T-350HD could replace all 20 vehicles without an increase in fleet size. On a worst-case day, there were no BEB equivalents that could replace all vehicles one-to-one without service modifications.



Table 7. Modeled EV Specifications

BEB Vehicle Make/Model	Nameplate Battery Capacity (kWh)	Efficiency (kWh/mile)	Useable Battery Capacity (kWh)	Maximum Charger Power (kW)
Lightning Electric 350HD 80	80	0.57	72.0	80
Lightning Electric 350HD 120	120	0.71	108.0	80
GreenPower AV Star	118	0.79	106.2	61
GreenPower EV Star	118	0.77	106.2	61
Sunset Vans Electric Low Floor Minibus	75	0.38	67.5	100
US Hybrid Ford Transit T-350HD DRW	180	0.86	162.0	80

The standard operation off hours included a one-hour safety buffer on both ends, for a total of 8 hours available for vehicle charging Monday through Friday. This buffer does not only provide a grace period for connecting any given vehicle to their charger, but also considers the change in charge rate that occurs as a battery reaches full charge.

If the daily amount of energy required exceeds the available energy for that vehicle type, then the case for an increase in fleet size is considered; this additional case facilitates protecting the vehicle’s health while avoiding interruptions to normal operations.



Table 8. Paratransit Fleet Modeling Inputs – Average Day

Vehicle Number	Vehicle Make/Model	Jan 2023 Total	Jan 2023 Revenue Miles	Jan 2023 Total	Days in Service	Daily Total Miles	Daily Revenue Miles	Daily Hours
2905	Ford E350 Starcraft	1,823	1,622	151	20	91	81	7.6
2805	Ford E350 Starcraft	2,040	1,756	166	23	89	76	7.2
2901	Ford E350 Starcraft	2,315	1,960	194	27	86	73	7.2
2206	Ford Champion	246	219	21	3	82	73	7.2
2904	Ford E350 Starcraft	1,804	1,507	159	22	82	69	7.2
2506	Ford Champion	866	748	80	11	79	68	7.2
2806	Ford E350 Starcraft	2,656	2,195	233	33	80	67	7.1
2802	Ford E350 Starcraft	1,943	1,595	172	25	78	64	6.9
2801	Ford E350 Starcraft	2,876	2,435	233	34	85	72	6.8
2501	Ford Champion	403	336	34	5	81	67	6.8
2504	Ford Champion	905	772	80	12	75	64	6.7
2902	Ford E350 Starcraft	2,840	2,317	221	34	84	68	6.5
2502	Ford Champion	1,883	1,540	149	23	82	67	6.5
2804	Ford E350 Starcraft	1,730	1,419	150	23	75	62	6.5
2903	Ford E350 Starcraft	2,341	1,931	198	31	76	62	6.4
2503	Ford Champion	1,914	1,547	167	26	74	60	6.4
2203	Ford Champion	441	375	38	6	74	63	6.3
2803	Ford E350 Starcraft	1,463	1,224	117	19	77	64	6.2
2201	Ford Champion	983	816	79	13	76	63	6.1
2505	Ford Champion	17	5	1	1	17	5	1.3

The maximum miles traveled in a single shift in January was 155 miles; when using 155 miles in the model as the worst-case scenarios, no vehicles can be replaced without significantly increasing the fleet size and charging infrastructure sizing. The maximum mileage vehicles can travel without service modifications was found to be 105 miles. January 2023 audit data was used to determine that at most 5 vehicles exceeded 105 miles in a single day.

Wave Transit has 8 full-time drivers assumed to operate on an 8-hour shift, and 12 part-time drivers assumed to operate on a 6-hour shift. Vehicle data was sorted from greatest to least average daily hours; the 5 greatest values were assigned a maximum daily mileage of 155 miles, and the 8 greatest values were assumed to be operated by full-time drivers on 8-hour shifts. A shift length of 6 hours for part-time drivers is assumed for the remaining 12 vehicles. In most vehicles operating part time, the average daily hours exceeded the 6-hour shift length. If the average daily hours exceeded shift length, maximum daily hours were assumed to be equal to average daily hours.

Table 9 shows a breakdown of paratransit service trips relative to the average trip length of 80 miles and the 105-mile maximum range of battery electric cutaways. In January, there were two days where 5 vehicles exceeded 105 miles, four days where 4 vehicles exceeded 105 miles, 5 days where 3 vehicles exceeded 105 miles, 5 days where 2 vehicles exceeded 105 miles, and 7 days where 1 vehicle exceeded



105 miles. For the purpose of modeling a worst-case scenario, it was assumed that in a given day 5 vehicles would exceed 105 miles in a single shift.

Table 9. January 2023 Paratransit Audit Data Summary

Minimum Daily Miles Traveled	17	
Average Daily Miles Traveled	80	
Maximum Daily Miles	155	
	Trip Count	Percentage of Total
Trips Less than 80 Miles	207	49.8%
Trips Between 80 Miles and 105 Miles	151	36.3%
Trips Greater Than 105 Miles	58	13.9%
Total Trips	416	100%

Model Results

Wave Transit’s paratransit fleet can complete routes on an average day without any increase in required fleet size or the use of DC Fast Chargers (DCFCs) depending on the replacement vehicle. The fleet was modeled iteratively to compare fleet feasibility with the different BEBs available in **Table 9** above. On a worst-case day, 25% of vehicles cannot complete their service on a single charge without fleet or service modifications. Two alternate scenarios were modeled, where either the fleet size increases or vehicles are brought back to the O&M facility for charging mid-day.

Baseline Scenario

First, a baseline scenario was modeled to identify the number of vehicles and chargers required to support a BEB fleet based on current operating characteristics. **Table 10** shows which vehicles can complete service on a worst-case day and which cannot. This model illuminated challenges with some BEBs’ ability to complete the service required of them on a single charge as shown in the Average Day Feasibility and Worst-Case Day Feasibility columns below.

Table 10. Baseline Scenario Model Results

Vehicle Number	Average Miles	Maximum Miles	Shift Length	Shifts	Average Day Feasibility	Worst Case Day Feasibility
2905	91	155.0	8.00	1	Feasible	Infeasible
2805	89	155.0	8.00	1	Feasible	Infeasible
2901	86	155.0	8.00	1	Feasible	Infeasible
2206	82	155.0	8.00	1	Feasible	Infeasible
2904	82	155.0	8.00	1	Feasible	Infeasible
2506	79	105.0	8.00	1	Feasible	Feasible
2806	80	105.0	8.00	1	Feasible	Feasible
2802	78	105.0	8.00	1	Feasible	Feasible
2801	85	105.0	6.00	1	Feasible	Feasible



Vehicle Number	Average Miles	Maximum Miles	Shift Length	Shifts	Average Day Feasibility	Worst Case Day Feasibility
2501	81	105.0	6.00	1	Feasible	Feasible
2504	75	105.0	6.00	1	Feasible	Feasible
2902	84	105.0	6.00	1	Feasible	Feasible
2502	82	105.0	6.00	1	Feasible	Feasible
2804	75	105.0	6.00	1	Feasible	Feasible
2903	76	105.0	6.00	1	Feasible	Feasible
2503	74	105.0	6.00	1	Feasible	Feasible
2203	74	105.0	6.00	1	Feasible	Feasible
2803	77	105.0	6.00	1	Feasible	Feasible
2201	76	105.0	6.00	1	Feasible	Feasible
2505	17	105.0	6.00	1	Feasible	Feasible

The five vehicles reaching the maximum 155 miles per day experienced battery capacity utilization challenges, leading to the need for an increased fleet size to facilitate bus swaps or mid-day recharging at the O&M Facility. Without these accommodations, these vehicles would not be able to complete their service.

Expanded Fleet Scenario

This model scenario assumes that all vehicles that were feasible on a worst-case day remain unchanged, but the five vehicles that could not meet service requirements are assumed to be swapped on-street with a fully charged vehicle to finish service. When daily mileage exceeds the range capability of the BEB, the model will add an additional vehicle to the fleet. Vehicles would remain on the street until their battery reaches 20% SOC and then would be swapped with a fully charged bus for the remainder of service. To accommodate bus swaps, the fleet would need to increase by 5 vehicles, one for each vehicle reaching the maximum daily miles. **Table 11** indicates the *minimum* infrastructure that would be needed to maintain service and, in practice, the fleet may be charged by higher powered chargers.



Table 11. Expanded Fleet Scenario Analysis

Make & Model	Daily Maximum Miles	BEB Fleet Size	Minimum Charger Level and Output	Peak Load (kW)	Maximum Daily Energy Consumption (kWh)	Hours to Full Charge
US Hybrid Ford Transit T-350HD	155	6	48A Level 2	69.0	751.0	11.15
US Hybrid Ford Transit T-350HD	155	4	32A Level 2	30.7	475.4	10.32
US Hybrid Ford Transit T-350HD	105	3	32A Level 2	23.0	349.0	10.18
US Hybrid Ford Transit T-350HD	105	11	30A Level 2	79.2	1,229.4	10.37
US Hybrid Ford Transit T-350HD	105	1	15A Level 2	3.6	34.1	2.96

Mid-Day Recharging Scenario

To identify the infrastructure needs of a BEB fleet supported by mid-day charging, another scenario was modeled where the overall fleet size does not change from the current fleet, but some vehicles are brought back to the O&M Facility during the day to recharge. Similar to the expanded fleet scenario, only 5 vehicles would need to be brought back for midday charging to complete service. In the model, this is reflected by splitting shifts for the 5 vehicles with a maximum mileage of 155; one 8-hour shift is broken into two 4-hour shifts, and drivers would return to the O&M Facility to recharge in the middle of their shift. When splitting these shifts in half, all 5 vehicles can complete service at maximum mileage without the need for additional vehicles.

Table 12 indicates the *minimum* infrastructure that would be needed to maintain service and, in practice, the fleet may be charged by higher powered chargers.

Table 12. Mid-Day Recharging Scenario Analysis

Make & Model	Daily Maximum Miles	BEB Fleet Size	Minimum Charger Level and Output	Peak Load (kW)	Maximum Daily Energy Consumption (kWh)	Hours to Full Charge
US Hybrid Ford Transit T-350HD	155	5	50 kW DCFC	250.0	320.1	2.64
US Hybrid Ford Transit T-350HD	105	3	32A Level 2	23.0	349.0	10.18
US Hybrid Ford Transit T-350HD	105	11	30A Level 2	79.2	1,229.4	10.37
US Hybrid Ford Transit T-350HD	105	1	15A Level 2	3.6	34.1	2.96



Appendix C: Course of Action Strategies

The project team and Wave Transit utilized the existing conditions, policy/legislative impacts, route modeling, infrastructure requirements, and stakeholder engagement to create possible transition strategies for the fixed route, shuttle, trolley, and paratransit fleets. This section will review the multiple scenarios that were assessed for each fleet type and provide further details about each transition strategy selected.

Fixed Route

The project team looked at three scenarios for fixed route service: a full transition to ZEVs, a partial transition to ZEVs, and a delayed transition to ZEVs. As shown earlier in this report, the project team determined that a phased transition with six ZEVs would best fit the agency's needs at this time. All scenarios are outlined here and could be revisited if Wave Transit wanted to shift direction.

Full Transition to ZEVs: Completing a full transition to ZEVs for Wave Transit's fixed route service would require multiple changes and result in multiple impacts to service and facilities. Because vehicles cannot be replaced one-to-one, transitioning the fleet would require additional vehicles, increases in operating miles, and increases in operating hours. Wave Transit would have to increase the fixed route fleet from 16 to 24 vehicles, install three on-route chargers, and install 24 depot chargers. All of these would incur additional capital costs. Additionally, Wave Transit would need to plan for 10 blocks requiring one bus swap per day, a 49% increase in non-revenue miles, and a 50% increase in non-revenue hours. Wave Transit would need to prepare sites for additional energy demand as well as mitigate parking impacts at their bus yard to accommodate for EVSE. Overall, a full transition requires significant service changes, additional capital costs, and results in some operational impacts.

Phased Transition with 6 ZEVs: Because a full transition required many changes, the project team looked for opportunities to incorporate a smaller number of ZEVs into Wave Transit's fleet in the near-term. The team identified six fixed route vehicles that could be replaced with electric equivalents. These six vehicles could operate blocks on routes 101, 103, 104, and 108. These vehicles would be charged with one on-route charger at Forden Station and six depot chargers for overnight charging. This phased transition approach would allow Wave Transit to gain experience operating ZEVs and would utilize a site (Forden Station) which already has adequate power availability for EVSE. This scenario would not require the purchase of additional vehicles and would create minimal increases in non-revenue miles and non-revenue hours. There would be very slight increases in non-revenue miles and hours due to the required layovers of ZEVs at Forden Station for on-route charging. This scenario would require the purchase of vehicles that are more expensive than ICE equivalents and require the purchase of depot and on-route charging stations, which both create additional capital costs. With adequate grant support, the increased capital costs of this scenario could be mitigated or offset. Overall, this scenario would allow Wave Transit to gain experience with ZEVs, slowly integrate technology, and minimize capital costs associated with bringing ZEVs into a fleet.

Delayed Transition with Renewable CNG: The last scenario considered was delaying a ZEV transition and utilizing renewable CNG in the interim. Eighteen of the 21 fixed route buses are already CNG powered and three are diesel powered; the three diesel buses could be replaced with CNG buses



once they are ready to be retired. CNG offers reduced environmental impacts compared to diesel and gasoline, but CNG production still produces greenhouse gas emissions. Renewable CNG is CNG that is sourced sustainably and therefore minimizes or eliminates the emissions associated with CNG production. This scenario would require additional effort to determine a renewable CNG source and secure the fuel needed for Wave Transit's fleet. Renewable CNG could be used in the interim, and when ZEVs are able to be a one-to-one replacement for Wave Transit's fleet, the agency could re-evaluate ZEVs. The primary benefits of this scenario would be minimal operational changes with some environmental improvements; however, this scenario fails to incorporate ZEVs in the near-term and would not provide Wave Transit with any ZEV experience for fixed route service.

UNCW Shuttle Service

The project team looked at three scenarios for UNCW Shuttle Service: a full transition to ZEVs, a full transition to CNG, and a delayed transition to ZEVs. The project team determined that a transition to CNG would be the best course of action for Wave Transit at this time. All scenarios are outlined in this section and could be revisited if Wave Transit wanted to shift direction.

Full Transition to ZEVs: Completing a full transition to ZEVs for Wave Transit's shuttle service would require significant changes and result in multiple impacts to service and facilities; this scenario has been deemed operationally infeasible with today's technology. This scenario would require an increase from 9 to 19 vehicles, a 243% increase in non-revenue miles, and a 246% increase in non-revenue hours. Even with on-route charging, all but one block would need to be swapped twice in one service day. The UNCW Shuttle Service is not feasible with today's vehicle and battery technology and implementing a full transition would pose a significant capital cost while simultaneously creating operational inefficiencies.

Full Transition to CNG or Renewable CNG: Because battery electric vehicles were shown to be operationally infeasible for shuttle service, Wave Transit could consider a low-emission alternative such as CNG or renewable CNG. A portion of the shuttle fleet is already CNG powered and Wave Transit could look to transition the remaining vehicles to CNG. This would reduce the emissions of the shuttle fleet, and if Wave Transit wanted to further reduce emissions, the agency could look into sources of renewable CNG for the shuttles. Based on findings from the site visit, it appears that Wave Transit has adequate CNG infrastructure to accommodate for additional CNG vehicles. In summary, this scenario presents an opportunity for Wave Transit to reduce emissions within the shuttle fleet without significant changes to service or infrastructure.

Delayed Transition to ZEVs: This is a "business as usual" approach that entails no changes to the shuttle service at this time. The intent of this scenario is to wait until technology advances and ZEVs can operate shuttle service without significant modifications or operational impacts. The disadvantage to this approach is that there would be no environmental improvements within the shuttle fleet, and that Wave Transit would not be able to utilize the federal funding available to support low and no emissions fleet upgrades in the near-term.



Trolley

The project team looked at three scenarios for trolley service: a transition to ZEVs, a transition to CNG, and delaying a transition to ZEVs. The project team determined that delayed transition would be the best course of action for trolley at this time. All scenarios are outlined in this section and could be revisited if Wave Transit wanted to shift direction.

Full Transition to ZEVs: To fully operate trolley service with ZEVs, Wave Transit would need to purchase an additional trolley vehicle and install an on-route charger. Even with on-route charging the vehicle would need to be swapped during the day. The on-route charger would need to be inductive because there is only one battery electric trolley vehicle available in today's market with limited fast charging capabilities. The vehicle can only accept plug in or wireless charging (not pantograph charging), and charge speeds are lower for this vehicle compared to fixed route transit buses. It should be noted that wireless charging is generally the most expensive charging option (when comparing one wireless charger to one pantograph charger or one plug in charger); these charging specifications would result in additional capital costs for Wave Transit. It is not operationally efficient to operate trolley service with today's ZEVs, and this scenario yields the highest capital costs of the three scenarios explored for trolley service.

Full Transition to CNG or Renewable CNG: The second transition scenario analyzed for the trolley service was a transition to a CNG vehicle, which could also use renewable CNG. This would lower emissions for the trolley and utilize existing CNG infrastructure. The Downtown Trolley service is a small element of Wave Transit's services, and it may not be worth the time and cost to focus on changing one vehicle to CNG when larger impacts could be made in other areas of the fleet.

Delayed Transition to ZEVs: The downtown trolley is a small part of Wave Transit's service and the logistics and funding needed to change the fuel type outweighs the small environmental improvements of a transition. For this reason, the preferred approach is to delay a transition to a ZEV until the vehicles have the capacity to replace the trolley at a one-to-one ratio. Presently the battery electric trolley market is small, but as the market continues to grow, it is possible that a vehicle in the future would be able to operate the Downtown Trolley service without major modifications or cost increases. Once there is a ZEV that meets the Downtown Trolley's service needs, Wave Transit could re-evaluate the use of ZEVs for trolley service.

Paratransit

The project team looked at three scenarios for paratransit service: a full transition to ZEVs, a phased transition to ZEVs, and a transition to CNG. The project team determined that a phased transition to ZEVs with a maximum of 15 ZEVs would be the best course of action for Wave Transit at this time. All scenarios are outlined in this section and could be revisited if Wave Transit wanted to shift direction.

Full Transition to ZEVs: Compared to all other service, paratransit service is most favorable for ZEV operation today. As shown in route modeling, five of the 20 paratransit vehicles would require mid-day charging on a worst-case-scenario day and the remaining 15 could operate service with depot-only charging. Wave Transit could fully transition the paratransit fleet to ZEVs and plan for on-route charging for five vehicles. To implement this transition, Wave Transit would need to plan for



increased capital costs for an on-route charging station and for the additional cost of a ZEV compared to an ICE vehicle.

Phased Transition with 15 ZEVs: This was deemed to be the optimal paratransit scenario because it provides a mostly zero-emission paratransit fleet while reducing capital costs associated with a full transition. Because 15 paratransit vehicles can operate as ZEVs with a one-to-one replacement, this scenario removes the need for an on-route charging station and opts to leave five paratransit vehicles as gasoline powered vehicles. The primary advantages to this approach are the ability for staff to gain experience with ZEVs, lower infrastructure costs compared to a full transition, lower emissions compared to the existing fleet, and utilize charging at the bus depot where adequate power is already available. In this scenario, it will be important to consider staff training and passenger education. Like with all ZEVs, staff will need to be trained to maintain a fleet of electric paratransit vehicles and operators trained to drive the vehicle efficiently. Specific to paratransit service, Wave Transit would need to consider passenger education especially for passengers who are visually impaired or blind. ZEVs are much quieter than their ICE counterparts and outreach may be needed to ensure all riders are familiar with the new vehicles and able to access them conveniently. It should also be noted that the electric cutaway vehicle market is not as developed as the full size transit bus market, meaning that more cutaway options could become available to Wave Transit in the coming years. The future cutaway vehicles could have improved ranges which could allow for Wave Transit to fully operate paratransit service with ZEVs using depot charging.

Full Transition to CNG or Renewable CNG: The last transition scenario analyzed for the paratransit fleet was a transition to CNG vehicles. Vehicles could also use renewable CNG. Transitioning from gasoline to CNG would lower emissions for the paratransit fleet and utilize existing CNG infrastructure. While CNG is feasible, the ZEV scenario was selected because the ZEV scenario offers a zero-emission solution while the CNG solution is only low emission.

