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City of Lawrence Zero-Emission Bus Fleet Transition Study

Submitted by:

Center for Transportation and the Environment

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Executive Summary

Project Overview

The City of Lawrence ("the City", "Lawrence") engaged the Center for Transportation and the Environment (CTE) to perform a zero-emission bus (ZEB) transition study to provide a recommendation and an overall approach for the City to transition its Fixed-Route and Demand Response fleets to 100% zero-emission by 2035. The result of this study is intended to inform the City of the estimated costs, benefits, constraints, and risks of the transition to a zero-emission fleet and to guide future planning and decision making. The *Zero-Emission Bus Fleet Transition Study* report summarizes the transition analysis results, which considers both battery electric buses (BEBs) and hydrogen fuel cell-electric buses (FCEBs) for the Fixed-Route fleet. For the Demand Response fleet, battery electric technology was considered. CTE worked closely with the City staff throughout the project to develop an approach, define assumptions, and confirm the results.

Project Goals

The primary goals of this project were to assess the feasibility of transitioning the entirety of the City's Fixed-Route and Demand Response bus fleets to zero-emission technology by 2035 and to understand technology options, transition timelines, and relevant costs. Within the scope of the plan, CTE estimated capital and operational costs, planned project phases and timelines, and determined infrastructure requirements necessary to adopt ZEB fleet vehicles throughout the transition period, 2024-2035. In addition, the results of this study provide the City of Lawrence with a Zero-Emission Transition Plan that meets the Federal Transit Agency's (FTA) requirements for Low-No grant applications, ensuring the City is positioned to pursue future FTA funding.

Transition Scenarios

<u>Fixed Route</u>
The approach for the fixed route study is based on an analysis of three ZEB technology scenarios compared to a baseline scenario:

- Baseline Scenario (current technology)
- Scenario 1: BEB Depot-Only Charged Fleet
- Scenario 2: BEB Depot and On-Route Charged Fleet
- Scenario 3: Mixed BEB Depot-Only Charged and FCEB fleet

To accurately forecast transit service feasibility for each of these zero-emission technologies, CTE assessed the block feasibility of the City's current service schedules. If the block energy requirement exceeds the usable onboard storage capacity of the vehicle, the block is considered infeasible. If the block energy requirement does not exceed the usable onboard storage capacity, the block is considered to be feasible. Although not a zero-emission scenario, this study includes a baseline scenario that is used to compare the cost of a ZEB transition to a “business-as-usual” case. The baseline case is used to assess the cost of the transition to the different ZEB scenarios.

The **Baseline Fleet Scenario** was developed to project bus procurement costs if the City did not change its current vehicle procurement plan. The City’s Baseline fleet consists of diesel and hybrid buses, as well as the existing battery electric buses the City currently operates. The total cost of ownership for the Baseline scenario, which includes capital costs for bus procurement and infrastructure and operating costs for fuel and maintenance, over the transition period is estimated at nearly $29 million, which is less than the other three scenarios analyzed.

The **BEB Depot-Charge Only Fleet Scenario (Scenario 1)** was developed to analyze transition to a fleet consisting entirely of battery electric buses that can meet transit service range requirements. Fleets consisting of BEBs that only charge at a bus yard or depot may not be able to meet the current range requirements of all routes. As a result, transit agencies may not achieve a 100% ZEB transition, or may need to consider alternatives such as on-route charging, hydrogen fuel cell buses, or reblocking transit service to incorporate mid-day depot charging. According to CTE’s modeling, overnight depot-charged BEBs cannot complete all current City of Lawrence fixed-route blocks, even with assumed technology advancements, by the City‘s 2035 zero-emission fleet goal. The total cost of ownership for this scenario, which achieves a 90% ZEB fleet, is estimated at $46 million for the transition period.

The **BEB Depot and On-Route Charge Fleet Scenario (Scenario 2)** was developed to analyze transition to a fleet consisting entirely of battery electric buses, augmenting depot charging with on-route charging to allow range-limited BEBs to meet transit service requirements. As a result, the City can achieve a 100% ZEB transition under this scenario. The total cost of ownership for this scenario is estimated at $55 million for the transition period.

The **Mixed Fleet Scenario (Scenario 3)** was developed to analyze transition to a fleet consisting of both battery electric buses and fuel cell electric buses. The range of FCEBs is far greater the BEBs and can be used on blocks where depot-charged BEBs are not feasible. In the Mixed Fleet scenario, the total cost of ownership is estimated at $57 million.

The project team conducted a series of analyses to understand the projected total costs of ownership of the transition for the City‘s fixed route fleet. The summary of these assessments is displayed in the total cost of ownership summary graphic below, in Figure 1**.**

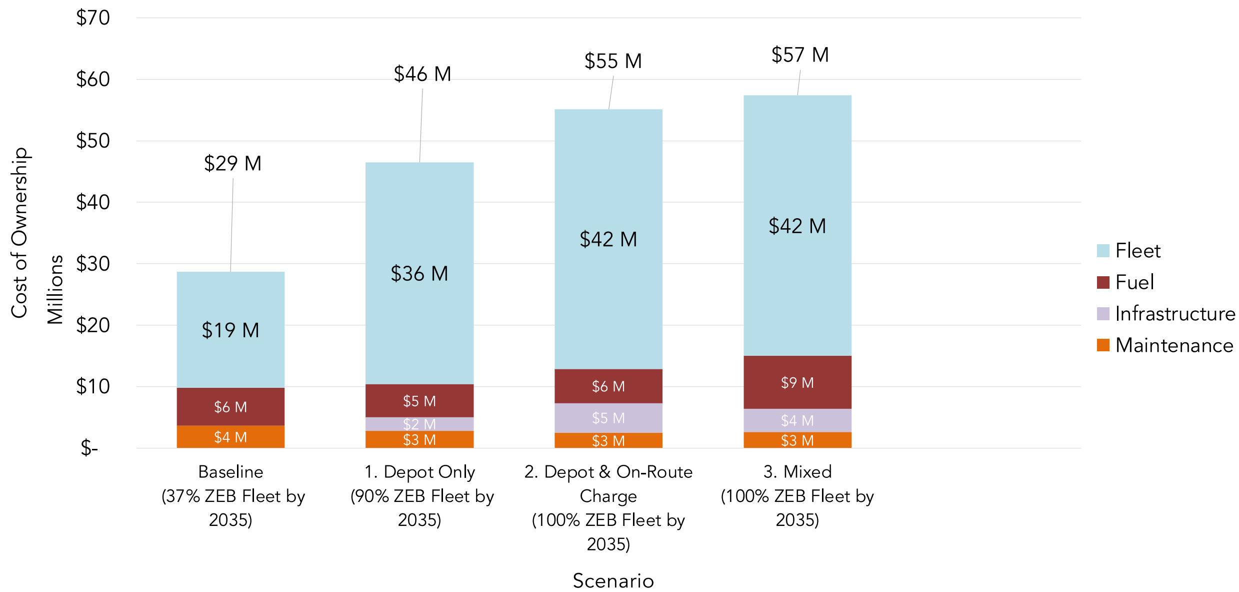

Figure 1. Fixed Route TCO Costs – All Scenarios

Demand Response

There are currently no on-route charged or hydrogen fuel cell demand response vehicles on the market. There are significant challenges to overcome before these options are commercially available. Therefore, the analysis for the City's Demand Response fleet is based on one ZEB technology scenario compared to a baseline scenario:

- Baseline (current technology)
- BEB Depot-Only Charged Fleet

The project team conducted a series of analyses to understand the projected total costs of ownership of the transition for the City's Demand Response fleet. The summary of those assessments is displayed in the total cost of ownership summary graphics below, in Figure 2.

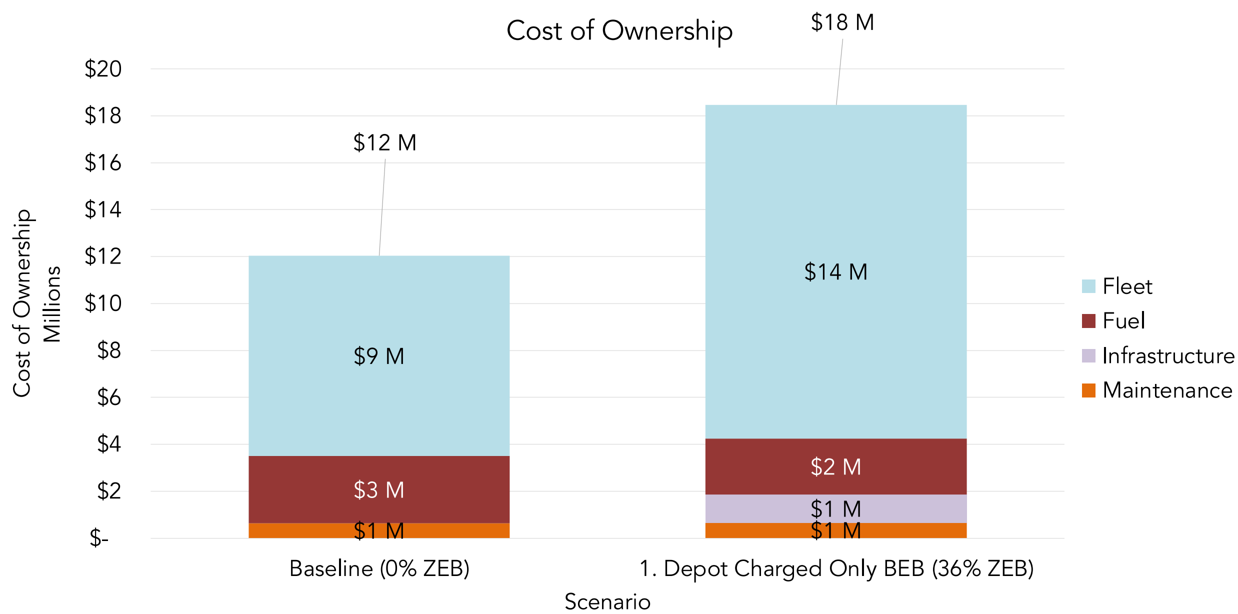

Figure 2. Demand Response TCO Costs - All Scenarios

Overall, ZEB technologies are in a period of rapid development and change, and all available options will require significant investment in facilities and infrastructure. The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. As Lawrence continues to transition to a zero-emissions fleet, it will be important to consider and plan for operational adjustments around operations, maintenance, planning and scheduling, administration, and customer sentiment.

Introduction

Lawrence, Kansas is a diverse and multifaceted city that provides many of the amenities of a large metropolitan area, while still maintaining a strong sense of community. Located in Northeast Kansas, Lawrence is just 45 minutes west of Kansas City, and 30 minutes east of Topeka, the state capital. Lawrence offers a rich and fascinating history, a wide range of exciting cultural experiences, and nationally recognized educational institutions.

The City of Lawrence engaged the Center for Transportation and the Environment (CTE) to perform a zero-emission bus (ZEB) transition study to provide a recommendation and an overall approach for the City to transition its Fixed-Route and Demand Response fleets to 100% zero-emission by 2035 or sooner. CTE was supported by NV5 in completing this analysis.

Zero-emission technologies considered in this study include BEBs, FCEBs, and associated refueling infrastructure. BEBs and FCEBs have similar electric drive systems that feature a traction motor powered by a battery. The primary differences between BEBs and FCEBs are the respective amount of battery storage and the method by which the batteries are recharged. The electric drive components and energy source for a BEB and FCEB as compared to an internalc combustion bus are illustrated in Figure 3.

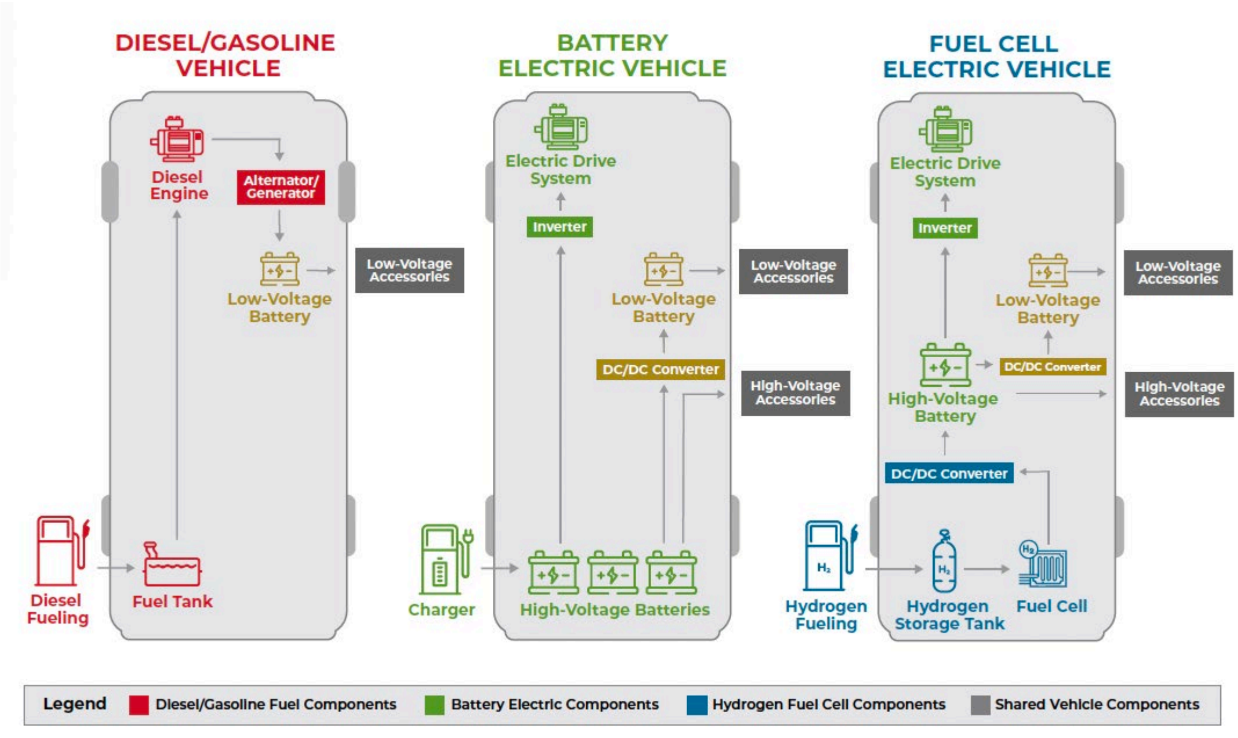

Figure 3. Schematic of ZEB Technologies

There are considerations and limitations associated with each technology. One of the primary limitations of BEBs is overall energy storage capacity. Although BEBs are approximately four times more efficient than diesel vehicles, the total amount of energy that can be stored on board without adding excessive weight is still less than diesel. That means that using current technology, the overall BEB range on one charge is less than the range of a diesel vehicle on one tank of fuel. Range limitations can be mitigated by the use of the appropriate charging technologies and strategies, and this is a very important element in the planning for any BEB deployment, especially when considering a full fleet transition. Furthermore, battery and charging technologies are changing at a rapid pace. The trends toward higher battery energy densities and increasingly sophisticated software-based charge management methodologies are expected to improve the range of BEBs to levels more comparable with traditional diesel vehicles over time. Regardless of which battery technology or chemistry is utilized, all high-voltage vehicle batteries in the market today degrade over time. Therefore, the impact on performance over time and associated battery warranties should be reviewed to optimize operations and further reduce risk.

Limitations also exist for FCEB deployments. Since battery technology is also utilized in FCEBs, there are similar concerns with degradation and end-of-life performance that also exist for BEBs. Current FCEBs do have a range that is longer than BEBs and more similar to traditional diesel or CNG buses, so theoretically, there will be less operational risk due to fueling strategies when incorporating FCEBs into a fleet. However, both the upfront cost of FCEB vehicles and the cost of fuel are currently higher than with their BEB counterparts (hydrogen vs. electricity).

This analysis reflects the state of technology at the time that it was prepared, however, the transition to a full zero-emission bus fleet is expected to take many years to complete. Throughout the City's transition period, the state of technology development, costs, regulatory environment, service requirements, and supply chain will all evolve, requiring the City to reassess and update this Plan to ensure that the City continues to meet its mission in the most effective and efficient way possible.

Transition Planning Methodology

This analysis was completed using CTE's Transition Planning Methodology, which is a complete set of analyses used to inform agencies in converting their fleets to zero-emission. The methodology consists of data collection, analysis and assessment stages; these stages are sequential and build upon findings in previous steps.

Steps specific to this study are outlined below:

1. Planning and Initiation
2. Service Assessment
3. Fleet Assessment
4. Fuel Assessment
5. Maintenance Assessment
6. Facilities/Infrastructure Assessment
7. Total Cost of Ownership Assessment

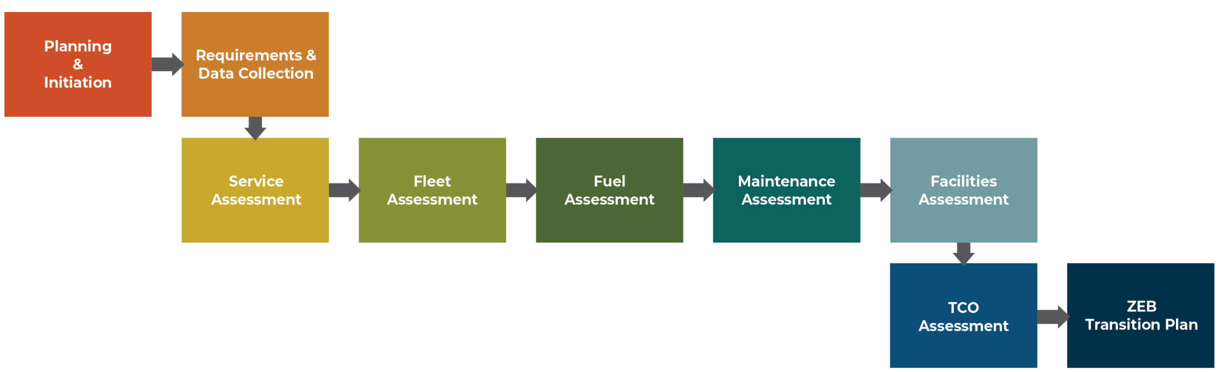

Figure 4. ZEB Transition Study Methodology

Fixed Route Analysis

Service Assessment

The Service Assessment analyzes the feasibility of maintaining Lawrence's transit service with battery electric and hydrogen fuel cell electric buses. The key component of the Service Assessment is the Block Analysis, which analyzes BEB feasible range under varying conditions as compared to block service requirements. The energy needed to complete a block is compared to the available energy for the model bus type that is planned for the block. If the model bus's available energy exceeds the block's required energy, then that block is considered feasible for that ZEB type. In the event a block is not initially feasible, the Service Assessment also yields a timeline for when blocks become achievable for zero-emission buses as technology is expected to improve. This information is used to inform a schedule for ZEB procurements in the Fleet Assessment and fuel consumption volumes in the Fuel Assessment.

Bus efficiency and range are primarily impacted by a number of variables including the route operating profile (e.g., mileage including deadhead, dwell time, acceleration, speed over distance, traffic conditions, etc.), topography (e.g., grades), climate (e.g., ambient temperature and relating HVAC usage), driver behavior (i.,e., acceleration and deceleration), and operational conditions (e.g., passenger loads and auxiliary loads). As such, the efficiency and range of a given ZEB model can vary dramatically from one route to another and from one agency to another. Therefore, it is critical to determine efficiency and range estimates that are based on an accurate representation of the City's operating conditions. Through previous and current projects with Lawrence, CTE had collected performance data on the BEBs currently in operation. This data was used to calibrate CTE's models, resulting in a more accurate prediction of expected ZEB performance across all of the City's routes. Efficiency values that were obtained through previous modeling based on the collected route data of the City's routes alongside real deployment data from BEB performance were used to determine the amount of energy required for each of Lawrence's blocks.

The Service Assessment determines the percentage of Lawrence's blocks that will be achievable in a given year, considering the energy demand of the blocks and the battery capacity of the buses. The analysis also considers an assumed battery capacity improvement factor of five percent every two years. This improvement in battery capacity increases the estimated range of the buses over time, which gradually increases the percentage of blocks that are achievable by 2035. This process was conducted for the fixed service blocks.

Nominal load conditions assume average passenger loading and a moderate temperature over the course of the day, which places marginal demands on the motor and the heating, ventilation, and air conditioning (HVAC) system. Strenuous load conditions assume high or maximum passenger loading and near-maximum output of the HVAC system. These strenuous loading conditions represent a plausible loading scenario to establish an outer bound for the analysis. It is important to note that this is not a "worst case" scenario, as the worst case is difficult to define. The City should be aware that performance will degrade in the event conditions exceed the defined strenuous conditions used for the analysis. This nominal/strenuous approach offers a range of operating efficiencies, measured in kilowatt-hour/mile (kWh/mi), to use for estimating annual energy consumption (nominal) or planning maximum daily energy consumption (strenuous). Strenuous operating conditions were utilized for each of Lawrence's service blocks to determine feasibility.

Service Assessment Assumptions

CTE uses a set of assumptions to guide the service assessment. The assumptions for the service assessment are as follows:

- Research suggests that battery density for electric vehicles has improved by an average of 5% each year[1]. For the purposes of this study, CTE assumed a more conservative 5% improvement to energy storage every two years.
- For FCEBs, improvements in hydrogen storage capabilities are expected to occur over the course of the transition period. As a result, CTE assumed a 5% improvement in range for FCEBs every two years.
- Projected battery capacity was based on the assumption that useable battery capacity is 80% of nameplate capacity with 10% degradation, effectively 72% of nameplate capacity, effectively representing an approximation of average battery capacity over the expected life of the batteries. At the time of the development of this report, multiple BEB manufacturers are moving towards allowing a larger percentage of the battery (greater than 80%) to be available for use; however, the 72% represents a conservative assumption of available battery capacity at the mid-life of a battery.
- While routes and block schedules are unlikely to remain the same over the course of the transition period, this projection assumes the blocks will retain a similar structure to what is in place today. Despite changes over time, this analysis assumes blocks will maintain a similar distribution of distance, relative speeds, and elevation changes by covering similar locations within the city and using similar roads to get to these destinations. This core assumption affects energy use estimates as well as block achievability in each year.
- The City's current 25', 30', and 35' buses are assumed to be replaced with 35' BEBs for transition plan purposes. 40' ICE buses are assumed to be replaced with 40' BEBs.
- BEBs are assumed to be overnight depot-charged to assess initial block feasibility.

Table 1. Service Assessment Battery Capacity and Efficiency Assumptions

Bus Size (ft)	2024 Nameplate Battery Capacity (kWh)	Assumed Usable Battery Capacity (kWh)	Strenuous Efficiency (kWh/mi)	References
35	588	423	2.9	Capacity: Available Capacity in the Market Efficiency: CTE Aux Estimate
40	686	493	3.2	Capacity: Lawrence's existing BEB fleet Efficiency: Lawrence BEB KPI Data

It should be noted that BEB range is negatively impacted by battery degradation over time. A BEB may be placed in service on a given block with beginning-of-life batteries; however, it may not be able to complete the entire block at some point in the future before the batteries are at end-of-life (typically considered 80% of usable battery capacity). Conceptually, older buses can be moved to shorter, less demanding blocks and newer

[1] https://arpa-e.energy.gov/technologies/publications/long-range-low-cost-electric-vehicles-enabled-robust-energy-storage

buses can be assigned to longer, more demanding blocks. The City can rotate the fleet to meet the demand assuming there is a steady procurement of BEBs each year to match service requirements. This could also be said for FCEBs, although the impact of degradation is assumed to be less.

Service Assessment Results

The results of the service assessment were used to determine if/when a full transition to BEBs for the City's fixed route blocks may be feasible within the identified transition period. Figure 5 shows the BEB feasibility for the City's 25', 30, and 35' blocks over the transition period with the assumption that the vehicles on these blocks would all be replaced with a 35' BEB. Two blocks (11%) remain infeasible by the end of the transition period if 2035. Figure 6 shows the BEBs feasibility for the City's 40' blocks over the transition period with 40' BEBs. Five blocks (20%) remain infeasible by 2035.

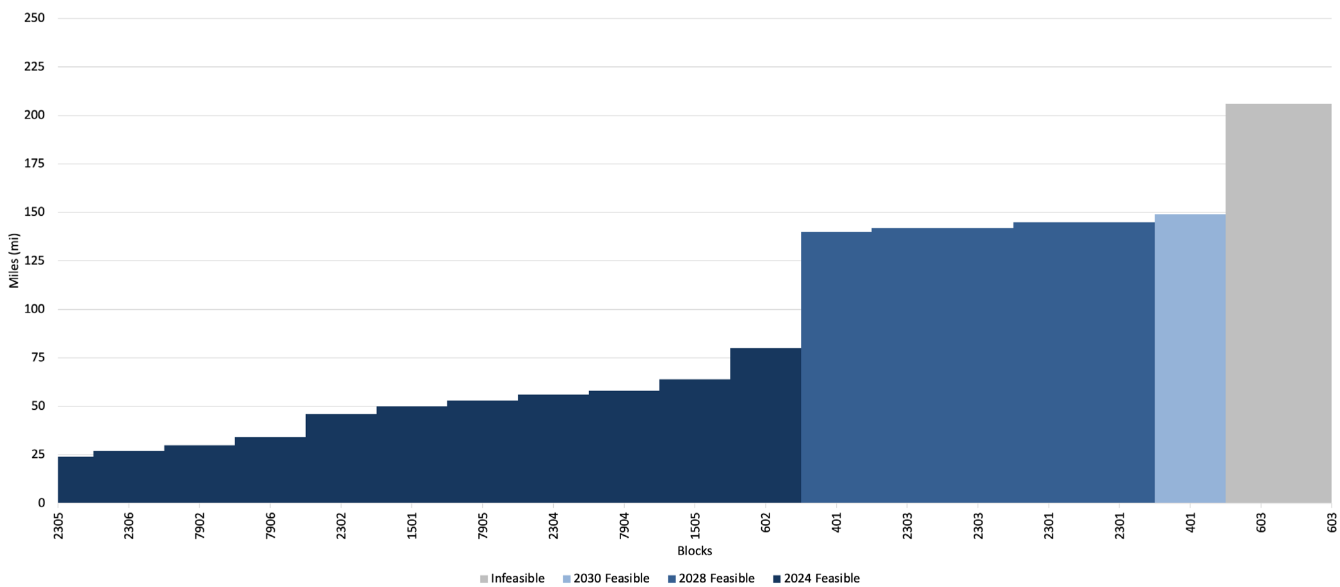

Figure 5. 25', 30', 35' Fixed Route Block Feasibility

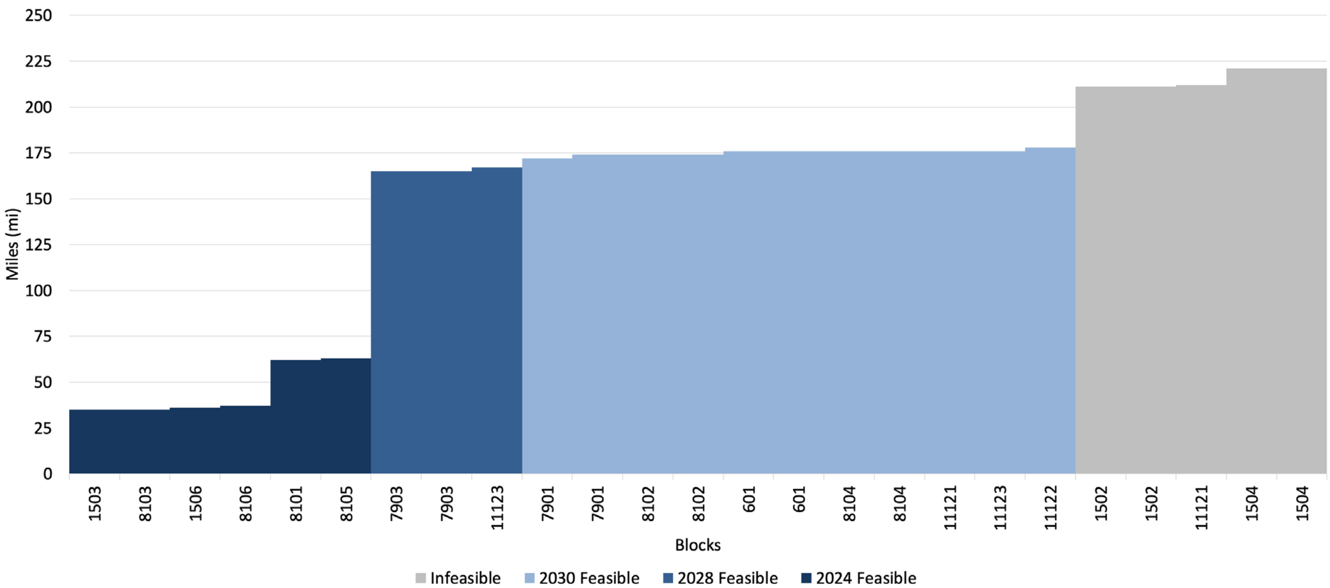

Figure 6. 40' Fixed Route Block Feasibility

The results show that a transition of the fixed route fleet to zero-emissions sooner than 2035 would require on-route charging, midday charging at the depot, or assigning two BEBs to infeasible blocks, each of which implies changes to present-day service and operations. Additionally, fuel cell electric vehicles could also increase block feasibility. For transition plan purposes, the project team decided to analyze on-route charging and FCEBs. The remainder of the analysis will analyze three scenarios compared to the baseline:

- Baseline Scenario (current technology)
- Scenario 1 : BEB Depot-Only Charged Fleet
- Scenario 2 : BEB Depot and On-Route Charged Fleet
- Scenario 3 : Mixed BEB and FCEB fleet

Fleet Assessment

Once the Service Assessment was completed, the City's current fleet replacement schedule was used to project bus replacement timelines for the existing fleet, as well as the subsequent replacements of ZEBs at the end of their service lives. Results from the Service Assessment are integrated with the City's current fleet replacement plan and purchase schedule to produce two main outputs:

1) A projected bus replacement timeline through the end of the transition period (2035); and
2) The annual and total capital costs of those replacements.

Fleet Assessment Assumptions

Specific assumptions were used for this analysis, based on input from the City. Assumptions include:

- For the vehicle costs, an annual inflation rate of 4% applied through 2026, and 2% applied through 2035, based on historical Producer Price Index (PPI) for transportation equipment and bus bodies.
- 2024 new vehicle cost assumptions for the different vehicle types assessed in the analysis can be seen in Table 2.
- Additional ZEB technology (other than Lawrence's known ZEB procurements in 2025) was not assumed to be procured until 2028, to allow time to acquire funding and install infrastructure.
- 25', 30', and 35' vehicles are replaced with 35' zero-emission vehicles. 40' vehicles are replaced with 40' zero-emission vehicles.
- When vehicles are up for replacement, if the results of the service assessment determine there are no feasible blocks for zero emission replacement, the City and the project team determined guidelines for replacement in attempts to avoid the purchase of new ICE vehicles. The City also intends to follow these replacement guidelines for the current Baseline fleet.
    - Expiring vehicles will be refurbished and placed into service for 3 years if there are no feasible blocks available for respective bus assignments at the time of replacement.
    - After 3 years, expiring refurbished vehicles will be replaced with used Kansas University (KU) 40' diesel vehicles for another 3 years, if there are still no blocks feasible with a ZEB.
    - After 3 years of operating with used KU 40' diesel buses, expiring KU 40' vehicles will be replaced with used 40' diesel vehicles for an additional 5 years, if there are still no blocks feasible with a ZEB.

Table 2. Cost Estimates for Fleet Assessment

Vehicle	Cost	Source
Diesel 35'	$559,146	Average of 35' Diesel Options from WA State Contract
Diesel 40'	$565,246	Average of 40' Diesel Options from WA State Contract
Electric Cutaway	$408,675	Lawrence Optimal Cutaway Procurement (2024 Procurement)
Electric 35'	$1,159,247	Assuming 20K reduction from 40ft pricing
Electric 40'	$1,179,247	Lawrence Phoenix Contract (2024 Procurement)
On-Route Electric 35'	$1,249,247	Electric 35' cost + 90K additional cost for pantograph rails or inductive charging onboard receiver
On-Route Electric 40'	$1,269,247	Electric 40' cost + 90K additional cost for pantograph rails or inductive charging onboard receiver
Used Diesel 40'	$75,000	Lawrence Estimated Cost
Fuel Cell Cutaway	$450,000	Fenton Mobility Ford E-Transit (US Hybrid/Ideanomics Upfit)
Fuel Cell 35'	$1,305,000	35' not available on the market, assuming same price as 40ft

Fuel Cell 40’	$1,305,000	Average of 40’ FCEB Options from State Contracts in 2024

Conventional wisdom dictates that the costs of BEBs will decrease over time due to higher production volume and competition from new vendors entering the market. While initially this was true, costs appear to have stabilized and begun to increase again in recent years. However, it should also be noted that OEMs have added more battery storage over the same time period. FCEB prices are expected to decrease over time as vehicle orders increase; however, CTE does not currently have an adequate basis to reduce the costs over time for the purchase of FCEBs.

Fleet Assessment Results

Baseline Scenario

In this scenario, vehicles are procured based on the City’s planned procurements and replacement assumptions. If an ICE vehicle is up for replacement, the vehicle will be refurbished and placed into service for 3 years. After three years, the refurbished vehicle will be replaced with KU 40’ diesel vehicles for another 3 years. At the end of those three years, the vehicle will be replaced with a used 40’ diesel vehicle for 5 years.

The fleet composition for the Baseline Scenario is shown in Figure 7. The vehicle capital costs incurred without transitioning to a zero-emission fleet are shown in Figure 8. Costs associated with acquiring used KU vehicles and refurbishing of existing vehicles are assumed to be maintenance costs and will be accounted for in the Maintenance Assessment.

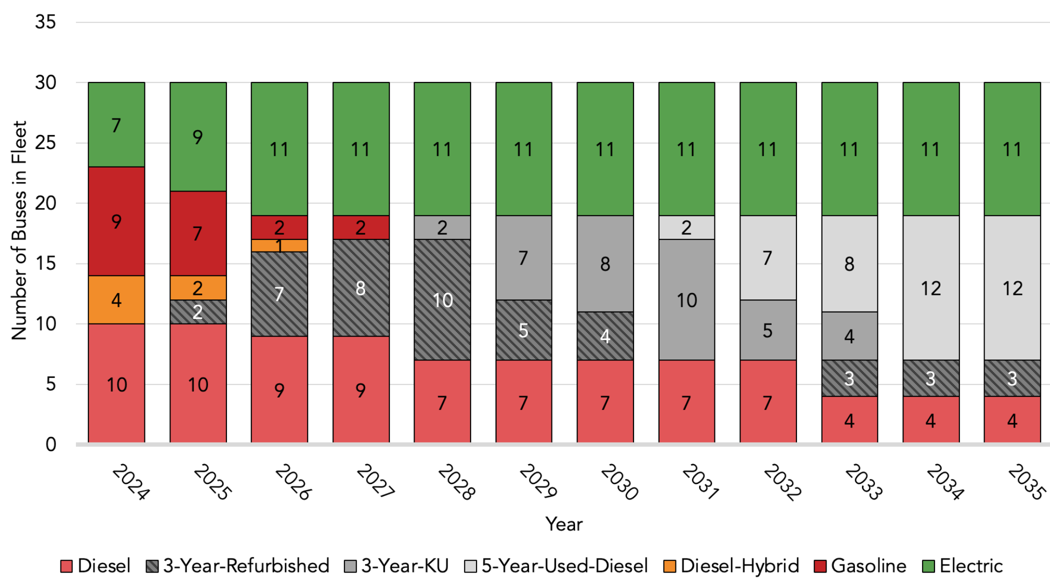

Figure 7. Fixed Route Fleet Composition - Baseline

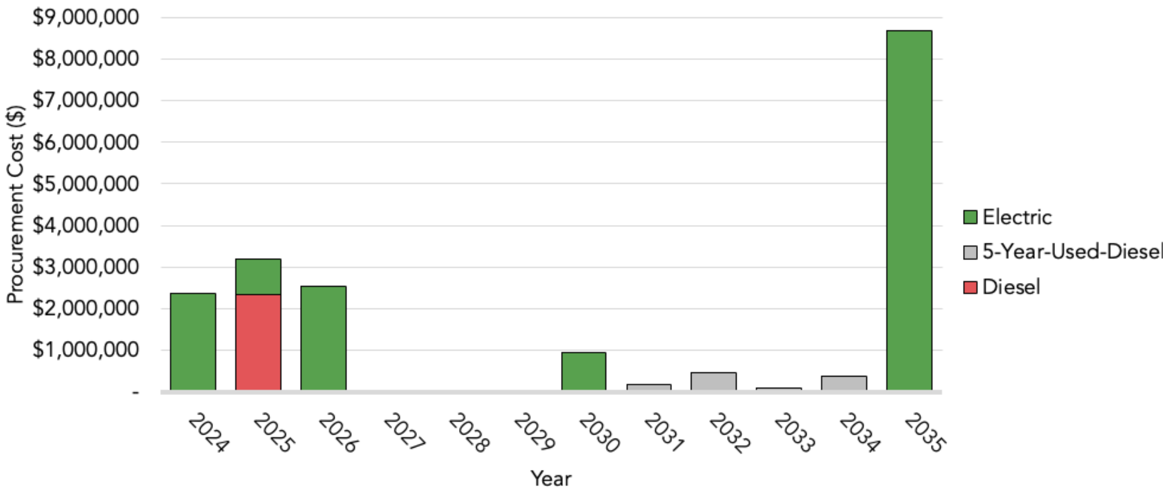

Figure 8. Fixed Route Annual Fleet Procurement Costs - Baseline

BEB Depot-Charge Only Fleet Scenario (Scenario 1)

The fleet composition for Scenario 1 is shown in Figure 9. For this scenario, Lawrence's ICE vehicles are replaced with overnight, depot-charged BEBs based on block feasibility. If the block is infeasible at the scheduled year of replacement for a vehicle, the vehicle is assumed to be refurbished for three years. Block achievability is reassessed at the end of those three years. If blocks are achievable with BEBs, vehicles will be replaced by overnight, depot-charged BEB. If not, vehicles will be replaced with KU 40' diesel vehicles for three years. Block achievability is reassessed again at the end of those three years. If blocks are feasible with BEBs, ICE buses are replaced by overnight, depot-charged BEBs. If not, ICE buses are replaced with a used 40' diesel vehicle for five years. Additional ZEB technology is not assumed to be procured until 2028, to allow the City enough time to fund and procure the necessary infrastructure to support additional zero emission vehicles.

The vehicle capital costs incurred for Scenario 1 are shown in Figure 10. Costs associated with acquiring used KU vehicles and refurbishment of existing vehicles are assumed to be maintenance costs and will be accounted for in the Maintenance Assessment.

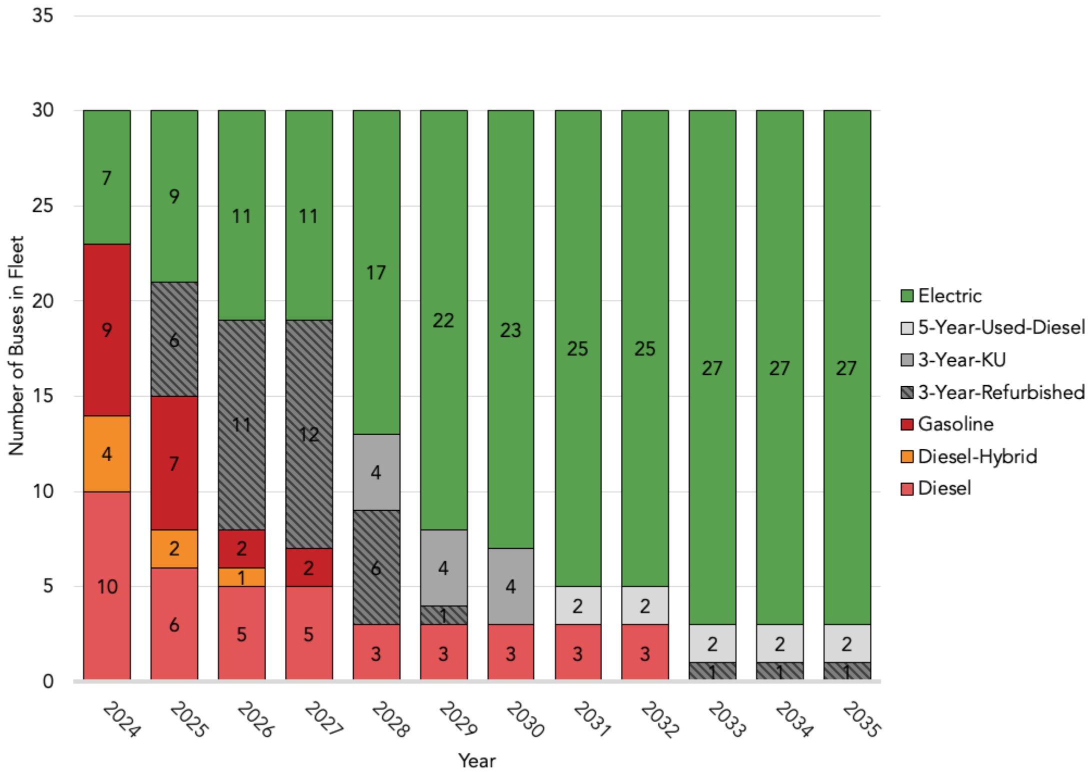

Figure 9. Fixed Route Fleet Composition - Scenario 1

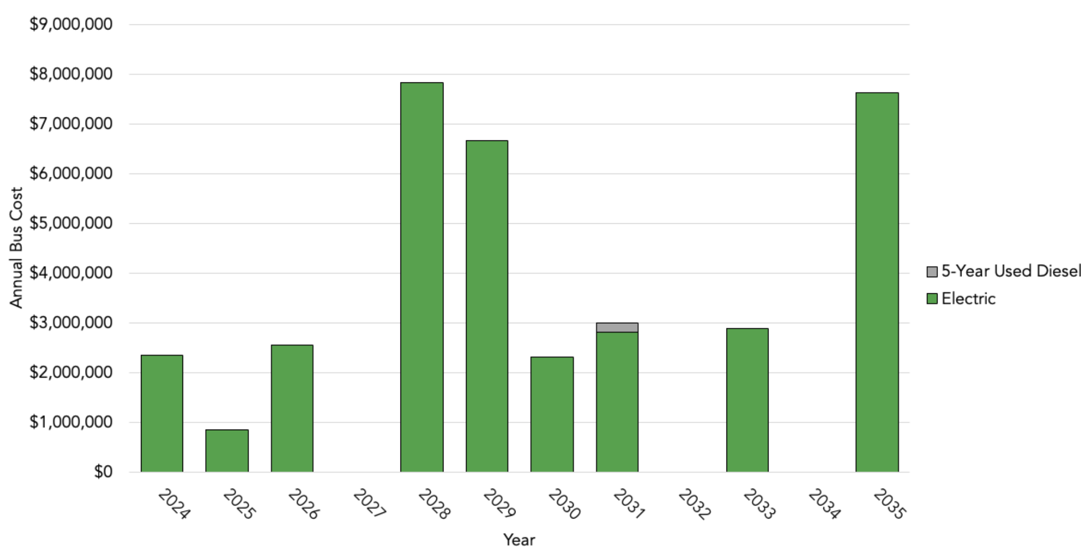

Figure 10. Fixed Route Annual Fleet Procurement Costs – Scenario 1

BEB Depot and On-Route Charge Fleet Scenario (Scenario 2)

The fleet composition for Scenario 2 is shown in Figure 11. For this scenario, an overnight depot-charged BEB is deployed in place of an ICE bus if the vehicle's block is feasible with BEBs. Starting in 2030, an on-route charged BEB is deployed in place of an ICE bus if the vehicle's block is infeasible with an overnight depot-charged BEB. Additional ZEB technology is not assumed to be procured until 2028, to allow the City enough time to fund and procure the necessary infrastructure to support additional zero-emission vehicles. The vehicle capital costs incurred for Scenario 2 are shown in Figure 12. Costs associated with acquiring used KU vehicles and refurbishing existing vehicles are assumed to be maintenance costs and will be accounted for in the Maintenance Assessment.

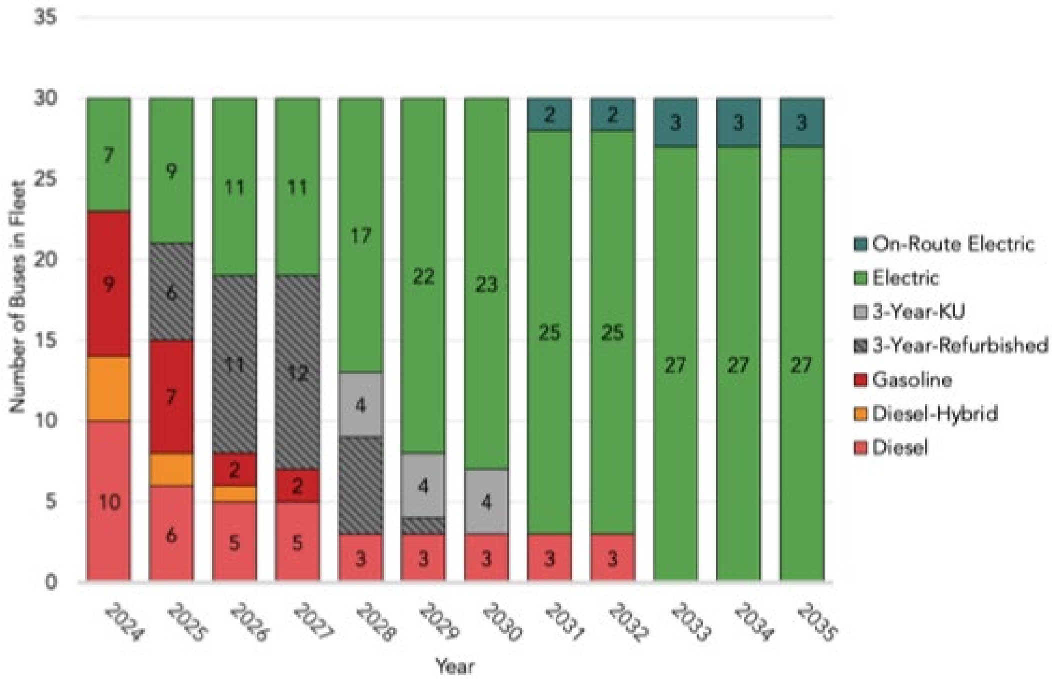

Figure 11. Fixed Route Fleet Composition – Scenario 2

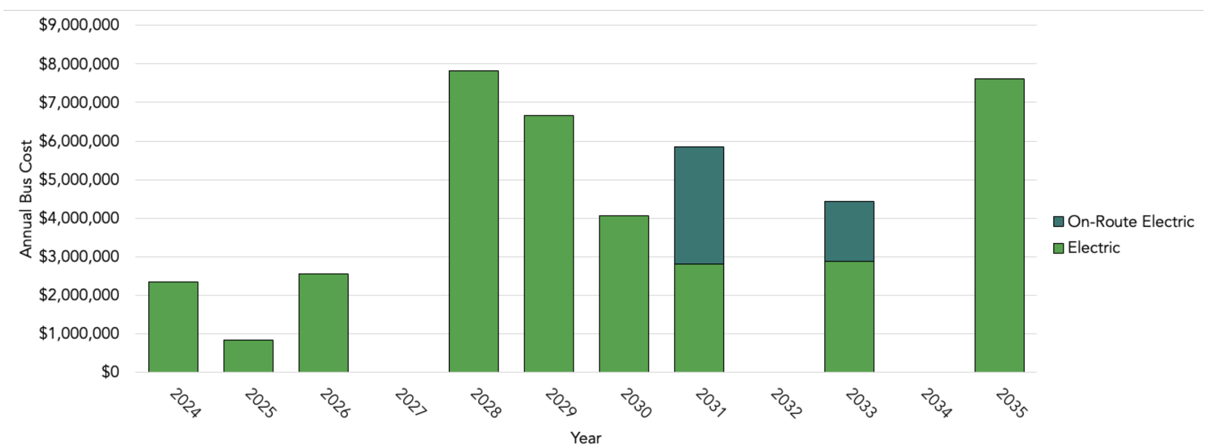

Figure 12. Fixed Route Annual Fleet Procurement Costs – Scenario 2

Mixed Fleet Scenario (Scenario 3)

The fleet composition for Scenario 3 is shown in Figure 13. For this scenario, a depot-charged BEB is deployed in place of an ICE bus if the vehicle's block is feasible. An FCEB is deployed in place of an ICE bus if the vehicle's block is infeasible with a depot-charged BEB. Additional ZEB technology is not assumed to be procured until 2028, to allow the City enough time to fund and procure the necessary infrastructure to support additional zero-emission vehicles. The vehicle capital costs incurred for Scenario 3 are shown in Figure 14. Costs associated with acquiring used KU vehicles and refurbishing existing vehicles are assumed to be maintenance costs and will be accounted for in the Maintenance Assessment.

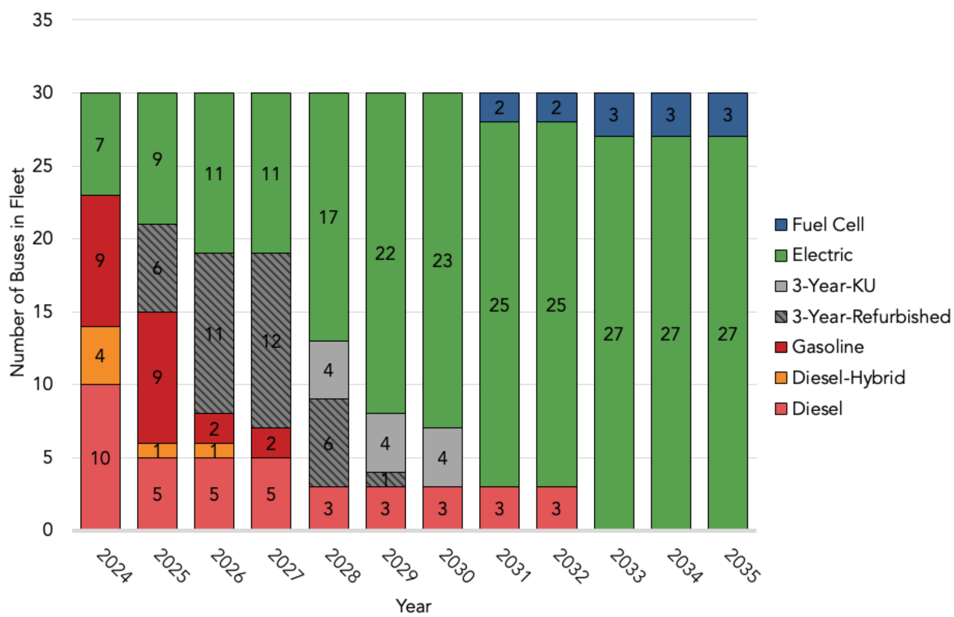

Figure 13. Fixed Route Fleet Composition – Scenario 3

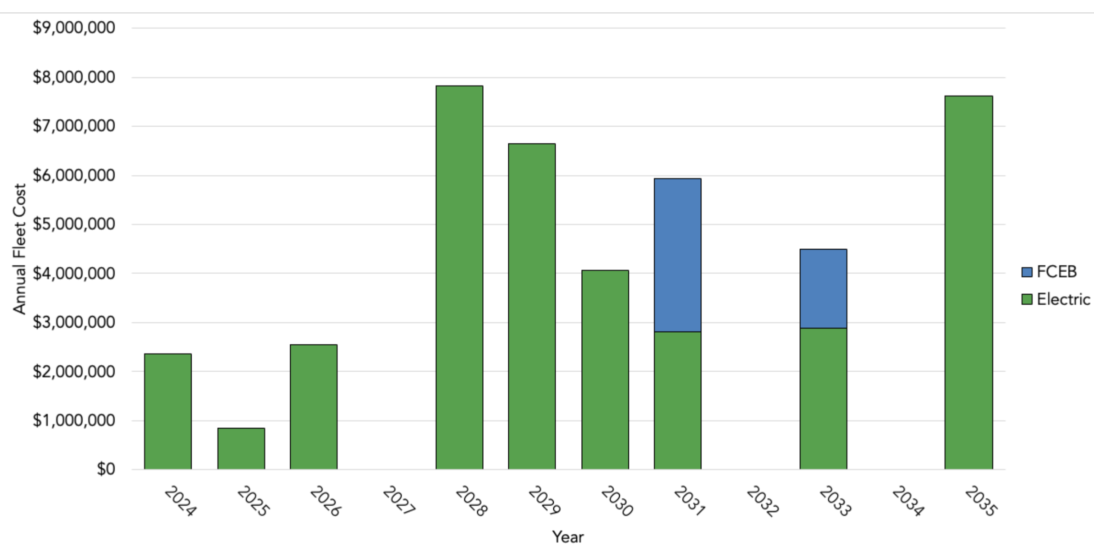

Figure 14. Fixed Route Annual Fleet Procurement Costs – Scenario 3

Figure 15 and Table 3 show a comparison of the cumulative vehicle capital procurement costs of each scenario throughout the transition period.

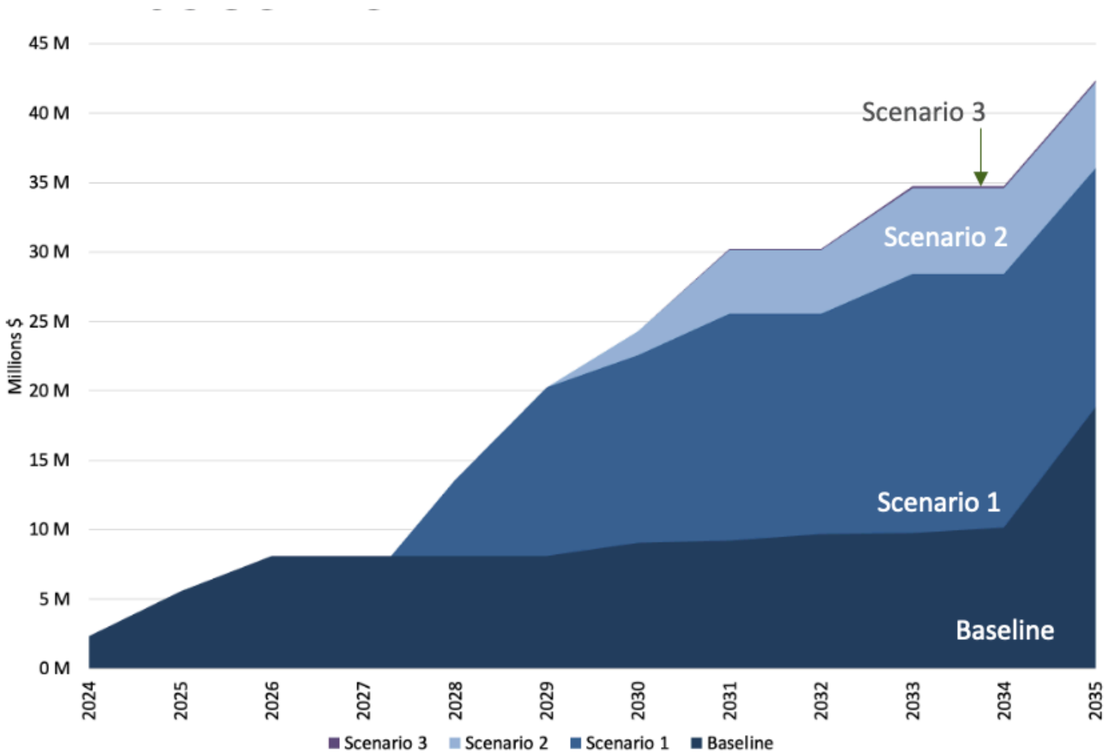

Figure 15. Fixed Route Cumulative Fleet Costs for All Scenarios – Graphic Form

Table 3. Fixed Route Cumulative Fleet Costs for All Scenarios - Tabular Form

Costs	Baseline	ZEB Scenario 1 (BEB Depot)	ZEB Scenario 2 (BEB Depot & On-Route)	ZEB Scenario 3 (BEB Depot & FCEB)
Cumulative ($)	$18.8M	$36.1M	$42.2M	$42.4M
Incremental over Baseline ($)		+$17.2M	+$23.4M	+$23.5M
% ZEB Fleet by 2035	37%	90%	100%	100%

Fuel Assessment

The Fuel Assessment estimates fuel consumption and annual fuel costs for each propulsion technology (i.e., gasoline, diesel-hybrid, diesel, electric, and hydrogen) studied in the relevant scenario. CTE completed this analysis for each of the zero-emission fleet transition scenarios and the baseline scenario. The analysis produced estimates of the fuel costs for each projected fleet composition through the transition period.

The terms “fuel” and “energy” are used interchangeably in this analysis, as ZEB technologies do not require traditional fossil fuels. For clarity, in the case of BEBs, “fuel” is electricity, and related costs include energy, demand, and other utility charges. The primary source of energy for a BEB comes from the local electrical grid. Utility companies typically charge separate rates for total electrical energy used and the maximum electrical demand on a monthly basis. As more buses and chargers are added to a system, both the energy used and the demand increase. Utility rates may also vary throughout the day (i.e., time-of-use rates) and throughout the year (i.e., seasonal rates); this makes electricity costs highly variable.

FCEBs are more similar to CNG or diesel vehicles, as they are fueled by gaseous or liquid hydrogen fuel. In addition to the cost of the fuel itself. Operations and maintenance costs to maintain fueling infrastructure are built into the Fuel Assessment.

Fuel Assessment Assumptions

Specific assumptions were used for the Fuel Assessment, based on input from the City. Assumptions include:

- Fuel Consumption
  - Annual mileage and fuel use estimates by fleet and fuel type are constant throughout the transition period.
  - For Lawrence’s existing fleet, annual fuel consumption estimates are based on 2024 recorded service data. Annual BEB (1.9 kWh/mi) and FCEB (8 mi/kg) fuel consumption estimates are calculated from 2024 recorded mileage data and nominal fuel efficiencies, based on Lawrence KPI data and CTE estimates.
- Fuel Costs
  - All costs are based on 2024 dollars with EIA inflation for transportation fuels projected through the end of the transition period.
  - ICE
    - Diesel and Diesel Hybrid: $3.13 per gallon, based on 2024 Lawrence data
    - Gasoline: $2.72 per gallon, based on 2024 Lawrence data
  - Hydrogen
    - $30 per kilogram, estimate based on regional off-site, trucked-in gaseous hydrogen current costs. Hydrogen costs are highly speculative at this stage and currently range between $10 and $30 per kilogram due to a number of variables, including size and location of hydrogen production facilities.
    - Additional sensitivity analysis in the Mixed scenario projects a reduction in hydrogen costs by 3% YOY beginning in 2026, assuming increases in hydrogen production and availability.
    - Hydrogen infrastructure operations and maintenance costs are assumed to be included in the cost of hydrogen.
  - Electricity
    - Electricity costs are based on Evergy’s Electric Transit Service (ETS) rate.

- Charger operations and maintenance costs are included in the fuel assessment
  - Depot charger maintenance cost estimated at $3,000/yr/charger
  - Pantograph/Inductive charger maintenance cost estimated at $7,500/yr/charger

Rate Schedule	TOU	Fixed Fees	Energy Rate [$/kWh]	Energy Surcharges [$/kWh]
Evergy Electric Transit Service	On-Peak 6:00 AM – 6:00 PM	$32.47	$0.15543	$0.051538
	Off-Peak: 6:00 PM – 6:00 AM		$0.02278	

Table 4. Evergy Electric Transit Service Rate

- General
  - Depot-Charging
    - Depot charger power: 200 kW (with 3 dispensers)
    - No depot-charging occurs during on-peak hours
    - Depot charger-to-bus ratio: 1:3 (3 single dispensers per charging unit)
  - On-Route Charging
    - Pantograph/Inductive charger power: 350 kW
    - On-route charging occurs 85% during on peak-hours and 15% during off-peak hours
    - On-route charger-to-bus ratio: 1:1

Fuel Assessment Results

Figures 16, 17, 18, and 19 show the annual fuel cost by bus and fleet composition makeup over the course of the transition period for each scenario.

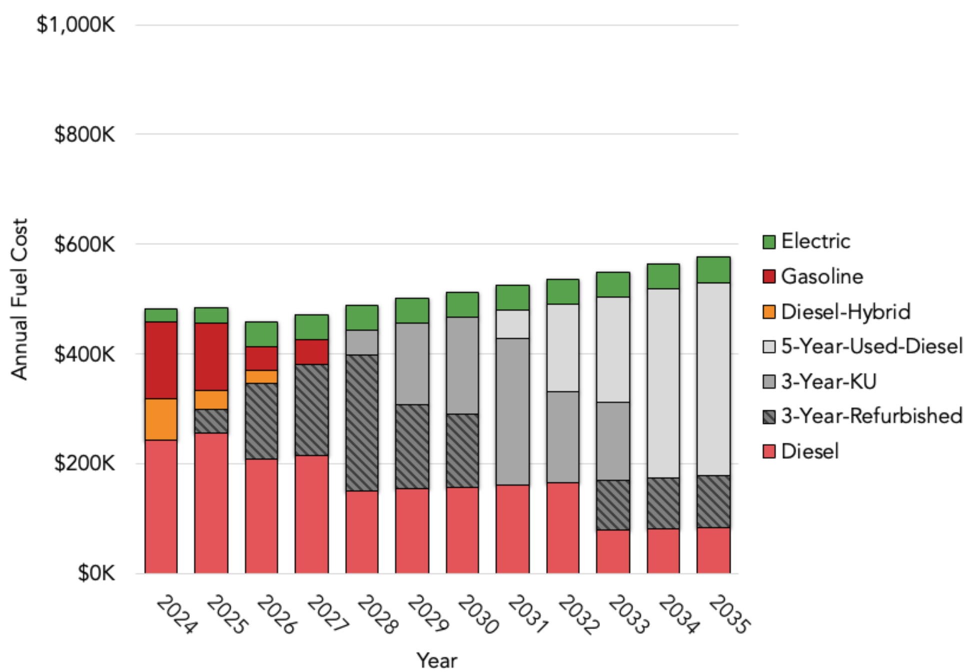

Figure 16. Fixed Route Annual Fleet Fuel Costs – Baseline Scenario

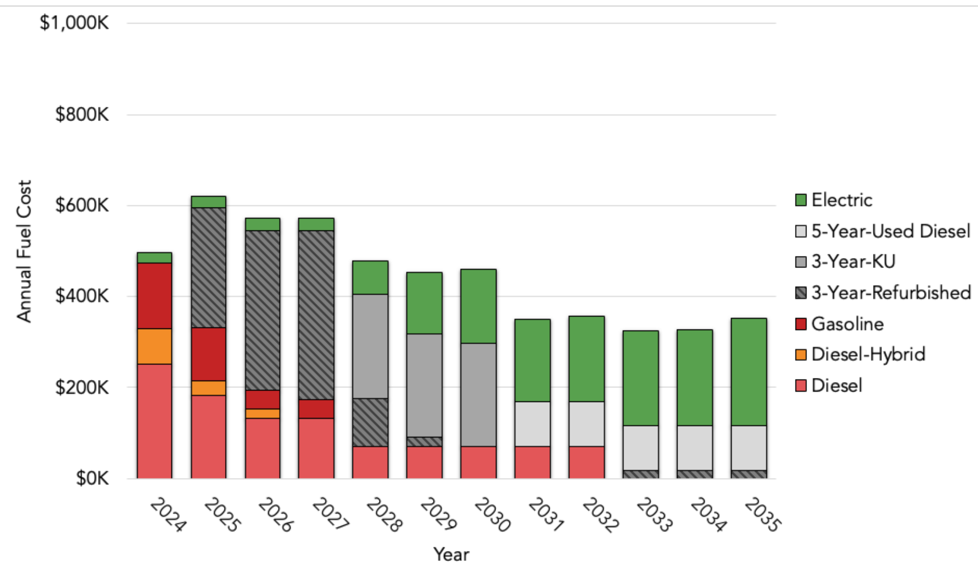

Figure 17. Fixed Route Annual Fleet Fuel Costs – Scenario 1

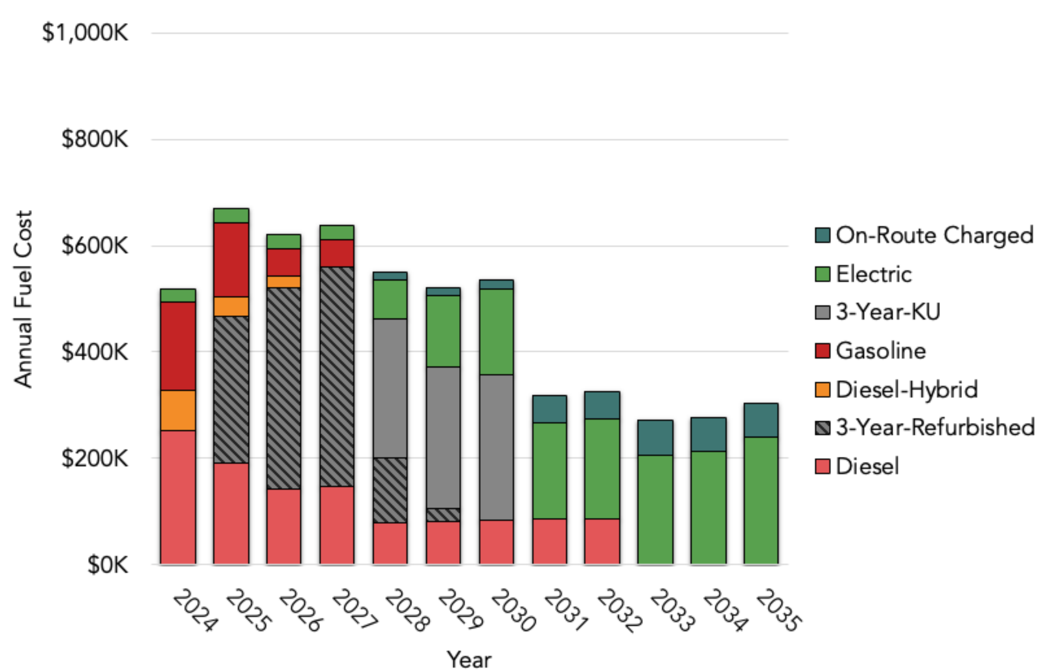

Figure 18. Fixed Route Annual Fleet Fuel Costs – Scenario 2

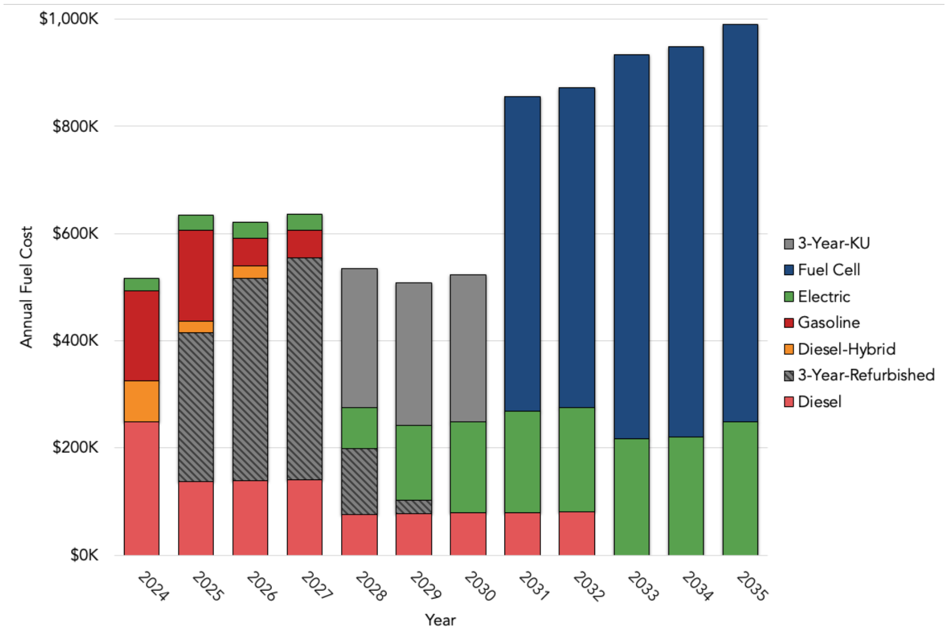

Figure 19. Fixed Route Annual Fleet Fuel Costs – Scenario 3

Hydrogen fuel prices are difficult to predict. Because of this, a hydrogen sensitivity cost analysis was included in the fuel assessment. Figure 20 shows the annual fuel costs for the Mixed Scenario, with a 3% annual decrease per kilogram of hydrogen sensitivity analysis taken into account.

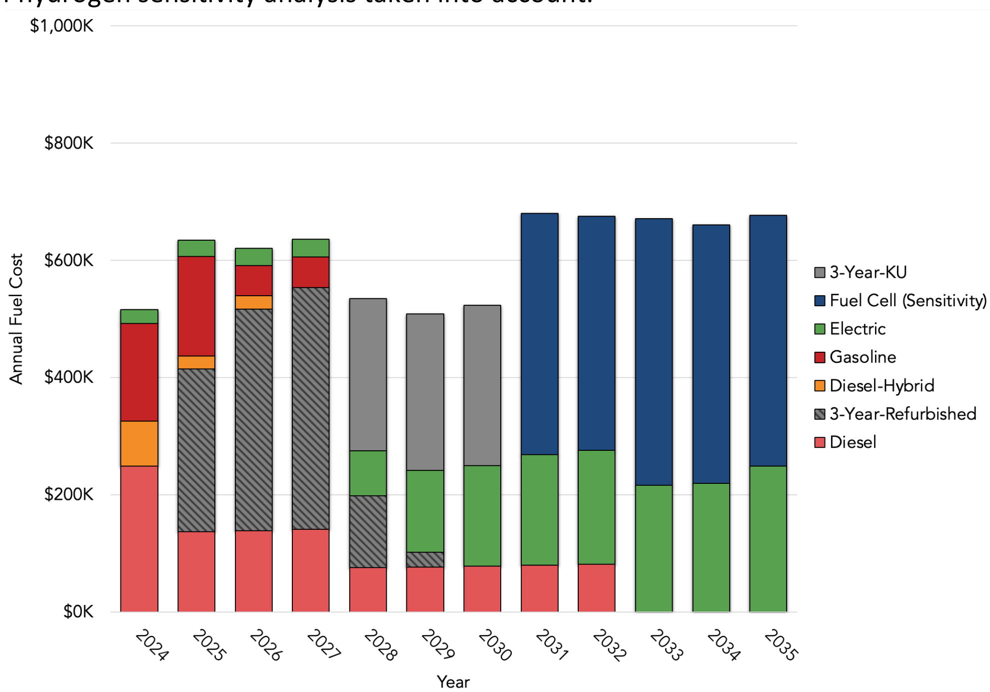

Figure 20. Fixed Route Annual Fleet Fuel Costs Hydrogen Sensitivity Analysis – Scenario 3

A comparison of cumulative fuel costs for each scenario, including the hydrogen sensitivity scenario, can be found in Figure 21 and Table 5 below.

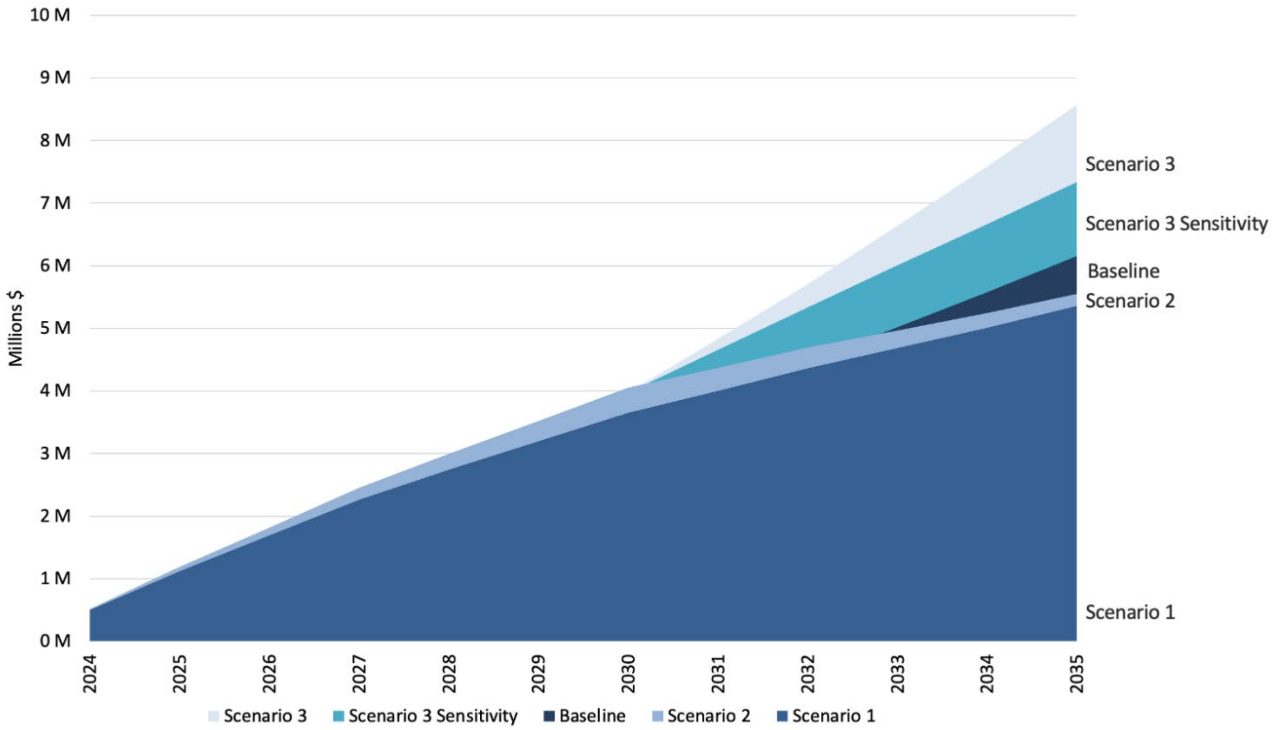

Figure 21. Fixed Route Cumulative Fuel Costs for All Scenarios – Graphic Form

Table 5. Fixed Route Cumulative Fuel Costs for All Scenarios – Tabular Form

Costs	Baseline	ZEB Scenario 1 (BEB Depot)	ZEB Scenario 2 (BEB Depot & On-Route)	ZEB Scenario 3 (BEB Depot & FCEB)	ZEB Scenario 3 Sensitivity
Cumulative ($)	$6.2M	$5.4M	$5.5M	$8.6M	$7.3M
Incremental over Baseline ($)		-$794K	-$608K	+$2.4M	+$1.2M
% ZEB Fleet by 2035	37%	90%	100%	100%	100%

Maintenance Assessment

One of the expected benefits of moving to a ZEB fleet is a reduction in maintenance costs. Conventional wisdom estimates that a transit agency could attain maintenance savings up to 30% by operating BEBs. This is due to the fact that there are fewer fluids to replace (no engine oil or transmission fluid), fewer brake changes due to regenerative braking, and far fewer moving parts than on a diesel bus. However, there has been a wide variance in the range of maintenance savings among agencies that have deployed ZEBs based on agency-specific maintenance procedures.

Maintenance Assessment Assumptions

CTE has access to historical maintenance data for Lawrence's entire fleet, which was used to determine maintenance cost per mile values for diesel, hybrid-diesel, gasoline, and electric vehicles. Because there is limited information available regarding maintenance costs for FCEBs due to the limited number of vehicles in operation in the United States, data from the Orange County Transportation Authority (OCTA), that has operated FCEBs since 2020, was used to estimate expected maintenance costs for FCEBs. These cost per mile costs are listed in Table 6.

As mentioned in the Fleet Assessment, the City does not plan to purchase any new diesel buses in the future. Instead, when a current diesel bus is up for replacement and its respective block is not feasible with a ZEB, Lawrence plans to refurbish the diesel bus that is up for replacement and use it for a few additional years. The next step after that would be to acquire a used KU diesel bus and refurbish it for Lawrence's use. The costs for these refurbishments ($50,000 each) are included in the maintenance assessment results below.

Additional assumptions include:

- Inflation is applied to the costs per mile and capital expenditure at 3% per year per the CPI Index.
- Diesel midlife overhaul assumed to be $24,300 ($20,000 engine, $4,300 transmission), based on historical bus maintenance data from Lawrence.
- Existing diesel refurbishment cost assumed to be $50,000, based on Lawrence estimate for costs.
- KU refurbishment cost assumed to be $50,000, based on Lawrence estimate for costs.
- Midlife fuel cell overhaul assumed to be $40,000, based on the average cost by OEM and fuel cell manufacturer over the life of the bus incurred at midlife.
- Cutaways are excluded from midlife overhaul costs due to 5-year service life.

Table 6. Maintenance Cost per Mile Assumptions

Fuel Type	$/mi	Source
Diesel	$0.07	Lawrence KPIs
Hybrid-Diesel	$0.11	Lawrence KPIs
Gasoline	$0.09	Lawrence KPIs
Electric	$0.10	Lawrence KPIs
Hydrogen Fuel Cell	$0.05	OCTA – 25% decrease in FCEB maintenance costs compared to diesel buses

Maintenance Assessment Results

The baseline assessment assumes no change in fleet composition for the duration of the transition period (2024-2035).

Figure 22 shows the combined labor, materials, and midlife overhaul costs for the Baseline scenario for each year of the transition.

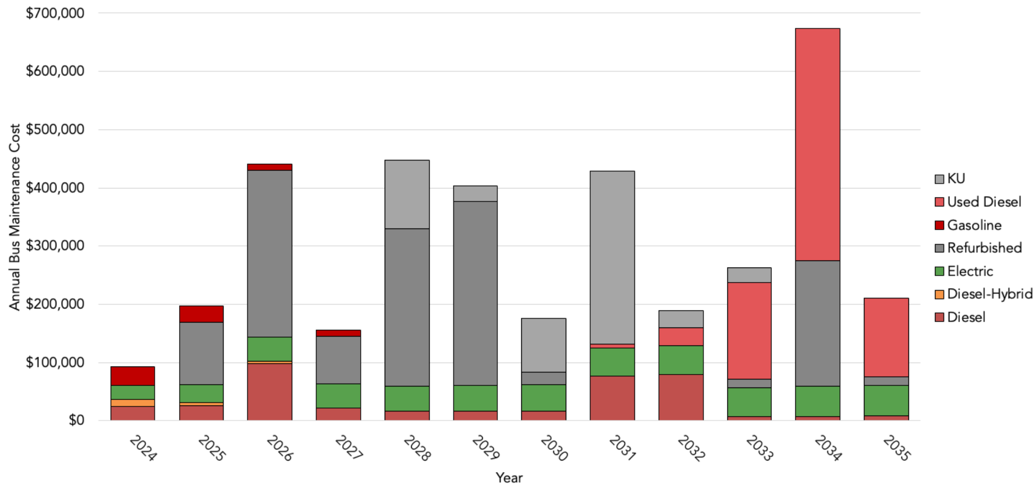

Figure 22. Fixed Route Annual Vehicle Maintenance Costs – Baseline Scenario

Figure 23, Figure 24, and Figure 25 show the annual maintenance costs for each ZEB scenario for each year of the transition.

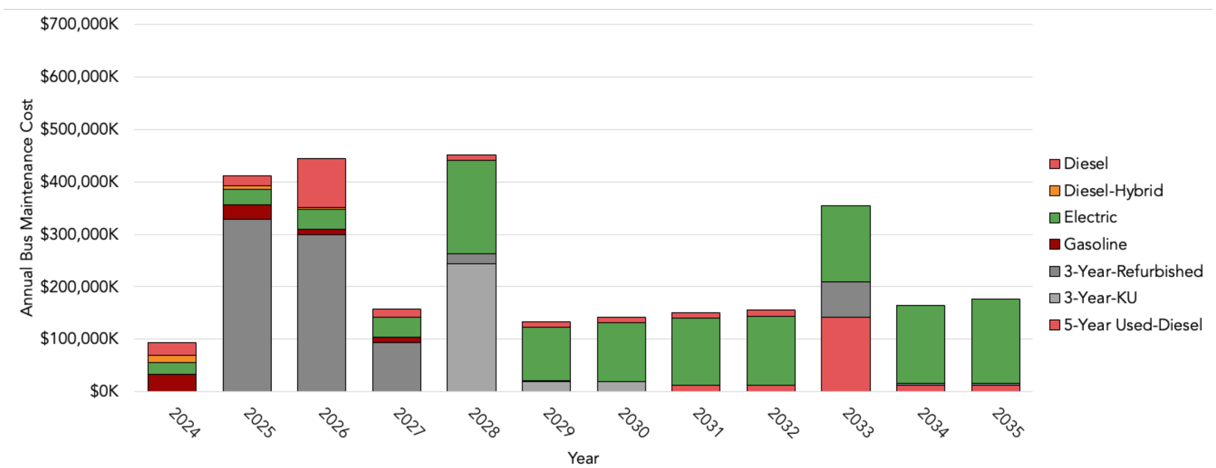

Figure 23. Fixed Route Annual Vehicle Maintenance Costs – Scenario 1

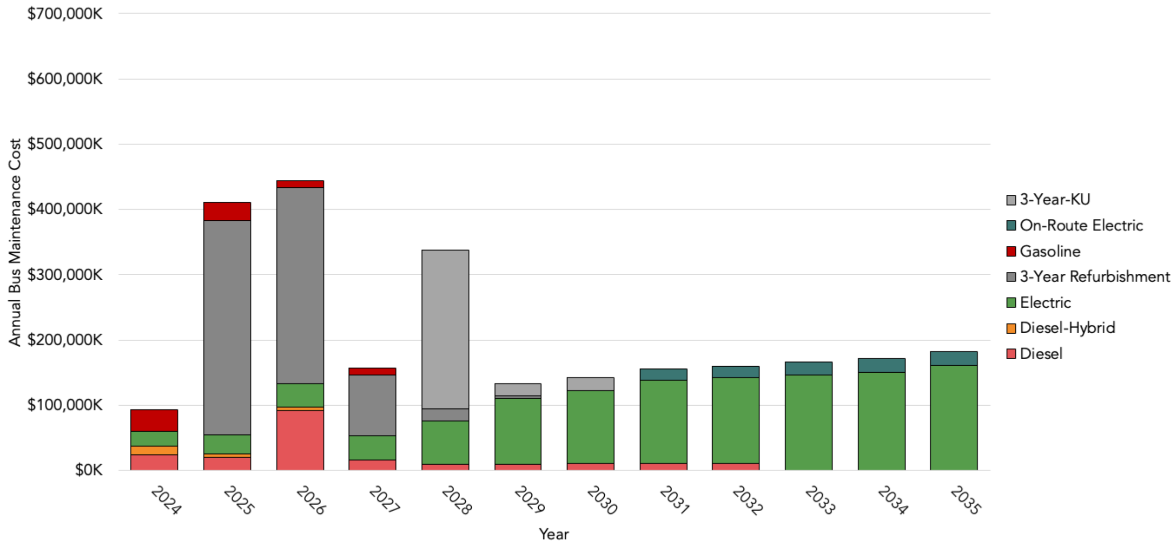

Figure 24. Fixed Route Annual Vehicle Maintenance Costs – Scenario 2

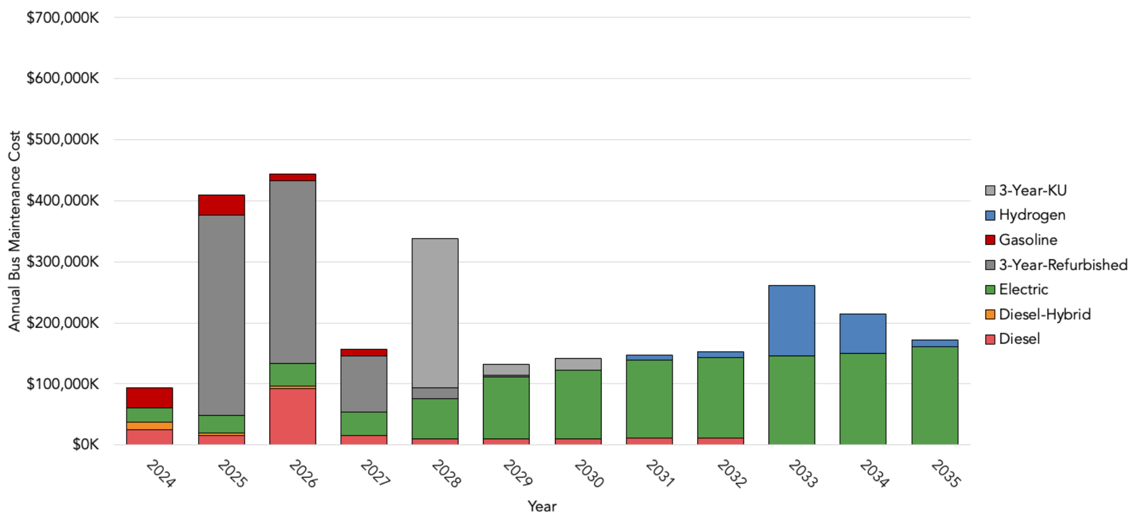

Figure 25. Fixed Route Annual Vehicle Maintenance Costs – Scenario 3

A comparison of the cumulative maintenance costs for each scenario can be found in Figure 26 and Table 7. All three ZEB scenarios experience less cumulative maintenance costs compared to the baseline scenario.

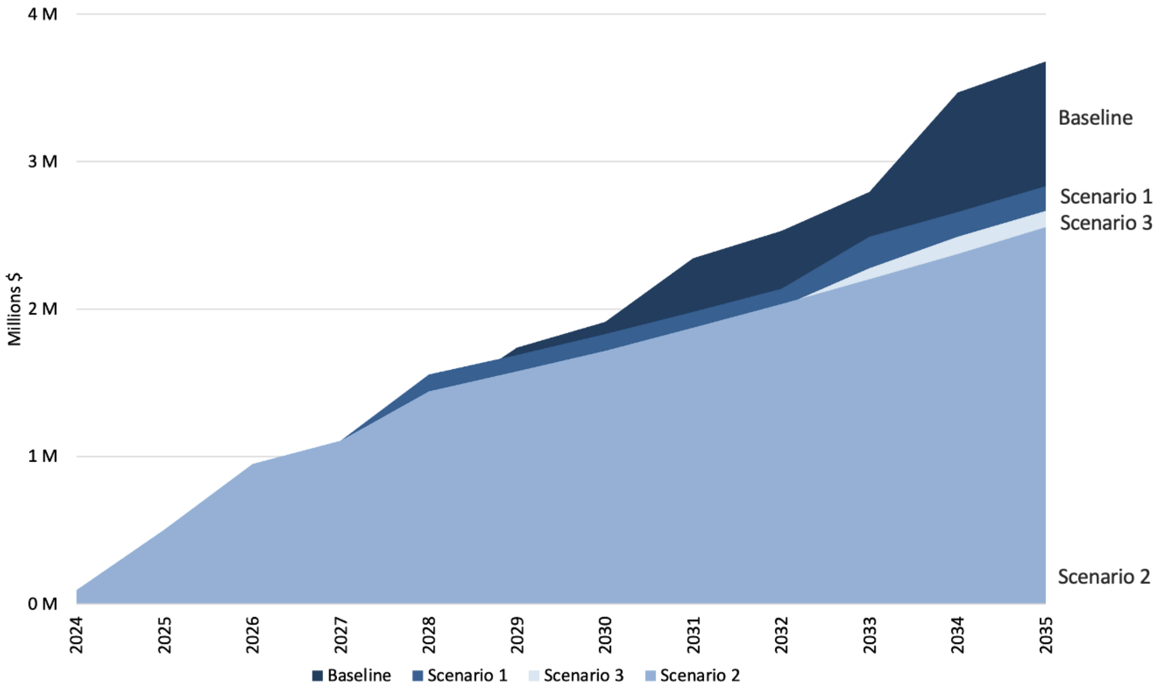

Figure 26. Fixed Route Cumulative Maintenance Cost Comparison All Scenarios – Graphic Form

Table 7. Fixed Route Cumulative Maintenance Cost Comparison All Scenarios – Tabular Form

	Baseline	ZEB Scenario 1 (BEB Depot)	ZEB Scenario 2 (BEB Depot & On-Route)	ZEB Scenario 3 (BEB Depot & FCEB)
Cumulative Maintenance Costs ($)	$3.7M	$2.8M	$2.6M	$2.7M
Incremental over Baseline ($)		-$845K	-$1.1M	-$1.0M
% ZEB Fleet by 2035	37%	90%	100%	100%

Infrastructure Assessment

The Infrastructure Assessment determines the scale of fueling infrastructure that is needed to meet the projected energy use for each scenario, i.e., charging stations for BEBs and hydrogen fueling stations for FCEBs. The requirements for fueling infrastructure are informed by the results of the Fleet and Fuel Assessments. The Infrastructure Assessment includes estimates for the costs of the associated ZEB infrastructure to support the additional ZEBs in each ZEB scenario. CTE and NV5 developed estimates for various components of infrastructure for each transition scenario analyzed. No infrastructure costs were assumed for the Baseline scenario, as the City has already invested in the fueling infrastructure necessary to support the current fleet of buses.

Infrastructure Assessment Assumptions

The City's zero emission transition does not include costs for the City's existing charging infrastructure (12 total dispensers) located at the Timberedge Road Depot; only new, additional charging and hydrogen fueling infrastructure were considered in this analysis. The new depot chargers and hydrogen fueling infrastructure is assumed to be implemented at a future facility on an adjacent property to the west of the existing Timberedge Road depot (see Appendix A for conceptual site plans). No land acquisition or new building construction costs are included in the infrastructure assessment costs. Additionally, no utility upgrade costs are included. Costs for labor and materials in the construction phase (trenching, transformers, switchboards, etc) are included, but utility side upgrades are not. Based on feedback from the City's utility, Evergy, every project requiring additional service is evaluated on an individual basis to determine whether or not the customer is responsible for any of the costs associated with adding service to a site. The City should continue engagement with Evergy throughout the transition to zero emissions and the implementation of additional infrastructure.

General Assumptions

- A 20% contingency is assumed on all equipment and construction costs.
- An escalation rate of 3% year-over-year was applied to the infrastructure costs through the transition period to reflect inflation.

The City's previous charging infrastructure project costs were used to inform the charging infrastructure costs used in this analysis.

Due to the short timeframe of the fleet transition and economies of scale in construction projects, this infrastructure analysis assumed that site work and construction (trenching, placing conduit, concrete work, stub-out, etc.) take place in the first phase. The project will allow for future installations of additional chargers and dispensers as needed to keep a 1:3 charger-to-bus ratio and a 1:1 dispenser-to-bus ratio.

Depot Charger Infrastructure Assumptions

- Future chargers stay consistent with the City's existing charging equipment – 200kW depot plug-in chargers with three dispensers each.

Table 8. Depot Charging Infrastructure Cost Assumptions

	Assumed Cost	Source/Notes
ChargePoint 200kW Charger Cabinet	$55,985 / charger	Lawrence's 2024 ChargePoint Contract; annual cost escalation of 3% assumed throughout transition
ChargePoint Single Dispenser	$23,660 / dispenser	Lawrence's 2024 ChargePoint Contract; annual cost escalation of 3% assumed throughout transition
Construction Costs (Labor + Materials)	$53,500/ dispenser	NV5 estimate based on recent projects (assuming no complicated site conditions)

Engineering Costs	7% of total project CapEx cost	NV5/CTE estimate based on project experience
Infrastructure master planning and design	$200,000 / facility	CTE estimate based on project experience; assumed in year prior to construction

On-Route Charger Infrastructure Assumptions

For analysis purposes, CTE and NV5 assumed inductive charging to estimate on-route charging infrastructure costs based on the City's interest in the technology. Inductive charging transfers power wirelessly using the same principles as wirelessly charging consumer electronics like cell phones, just at a larger scale. Systems require a ground unit with sending coils that transfer power to receiving coils mounted on the underside of a vehicle. The vehicle also requires a rectifier (costs accounted for in the fleet assessment), used to convert the received AC power to DC for the battery. Advantages include the ability to start power transfer without an operator having to manually plug a vehicle in, no overhead clearance concerns with pantographs, and no charging cables in a public area accessible to pedestrians and other vehicles. Challenges include additional hardware required on the vehicles, installation of in-ground equipment that require digging up the roadway surface, and requiring proper alignment between the vehicle and ground coils to achieve high efficiency during power transfer.

- One inductive charger was assumed per bus. The 1:1 ratio is necessary based on the City's pulse system operations, which requires that all buses are in the City's Transit Center at the same time.
- Inductive chargers are assumed to be installed at a separate facility from the depot chargers, and therefore, this scenario accounts for two "infrastructure master planning and design" costs – one for the facility for depot chargers and one for the facility with on-route chargers.

Table 9. On-Route Charging Infrastructure Cost Assumptions

	Assumed Cost	Source/Notes
Inductive Charger and Cabinet	$354,898 / charger	NV5 estimate based on costs from 2023 project utilizing Induct EV equipment; annual cost escalation of 3% to get 2031 costs (year of assumed purchase)
Construction Costs (Labor + Materials)	$932,815 / project	NV5 estimate based on recent projects (assuming no complicated site conditions); annual cost escalation of 3% for 2031 costs (year of assumed install)
Engineering Costs	7% of total project CapEx cost	NV5/CTE estimate based on project experience
Infrastructure master planning and design	$200,000 / facility	CTE estimate based on project experience, assumed in year prior to construction

Hydrogen Fueling Infrastructure Assumptions

Given the small number (3) of FCEBs projected in Scenario 3 of this transition plan, a small-scale gaseous hydrogen fueling station was assumed for the Infrastructure Assessment. Liquid hydrogen stations have too much boiloff to be economically viable for this number of FCEBs. Small scale hydrogen dispensing systems, like the FTcase, have no moving parts and are therefore expected to have high reliability and uptime with minimal capital investment. A high-pressure (450 bar or greater) tube trailer is required to be part of this fueling solution. Purchasing a high-pressure tube trailer would require the agency to maintain the trailer's certifications and to drive it to be refilled. Instead, CTE assumed a lease arrangement to minimize the agency's responsibilities. A different type of fueling solution may be needed if the City were to consider more FCEBs than defined by the transition plan.

Table 10. Hydrogen Infrastructure Cost Assumptions

	Assumed Cost	Source/Notes
FTcase portable gaseous hydrogen fueling unit from Zero Emission Industries	$179,000	CTE industry knowledge; annual cost escalation of 3% to get 2031 costs (year of assumed purchase) no fixed infrastructure needed
High pressure tube trailer lease	$23k/month	CTE industry knowledge; Assumed set monthly cost for 5-year contract

Infrastructure Assessment Results

The annual estimated infrastructure costs for each of the three transition scenarios are shown in Figure 27, Figure 28, and Figure 29 below. No infrastructure costs are estimated for the Baseline Scenario, as the Baseline is assumed to be a continuation of today's operations, and therefore infrastructure costs are not considered for this business-as-usual scenario.

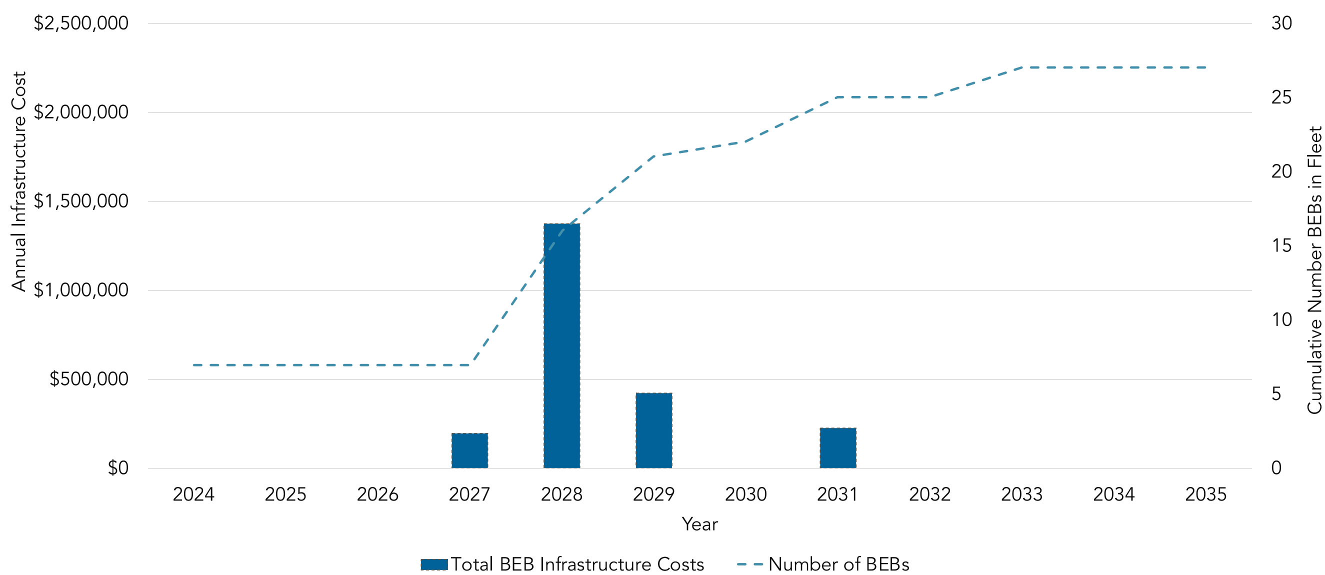

Figure 27. Fixed Route Annual Infrastructure Costs - Scenario 1

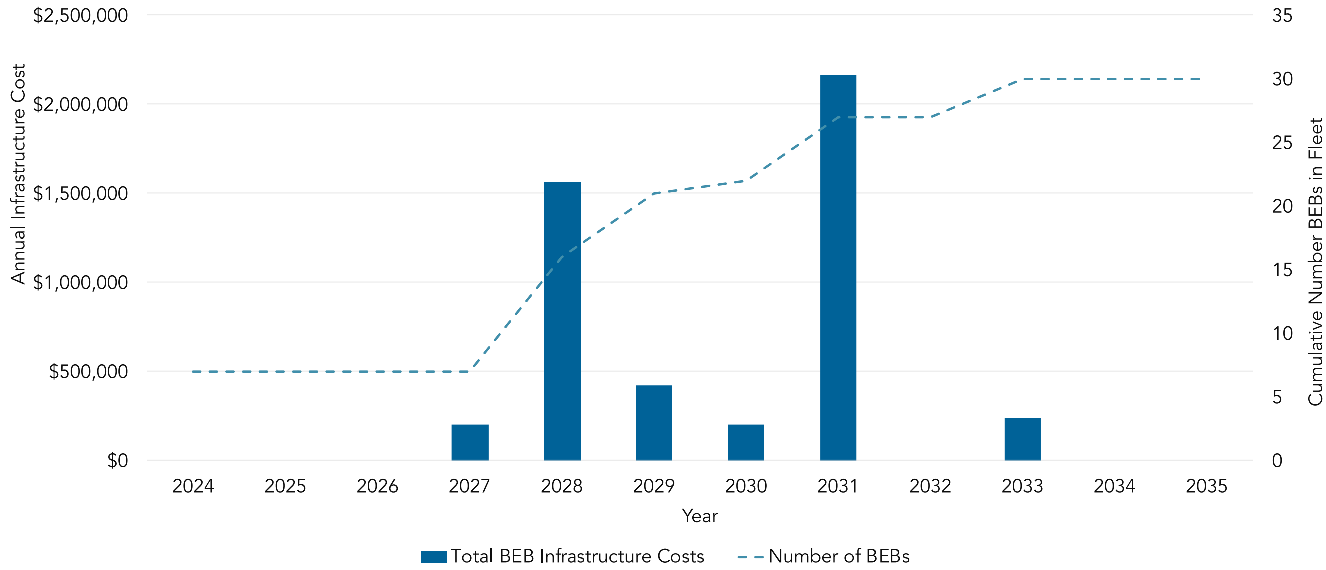

Figure 28. Fixed Route Annual Infrastructure Costs - Scenario 2

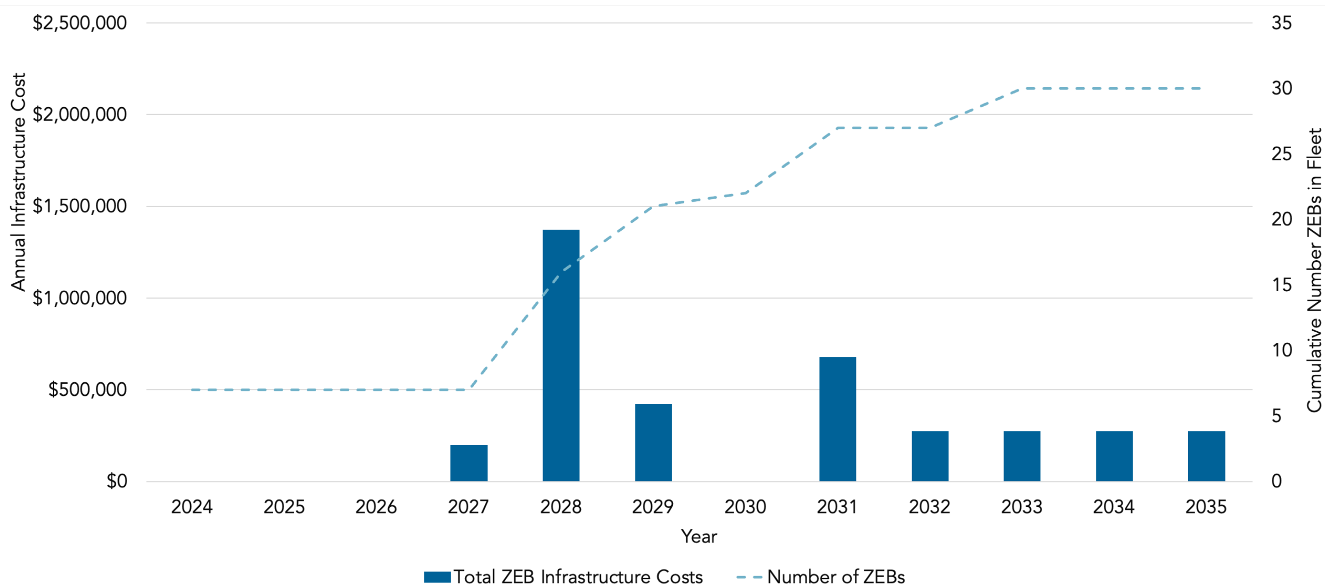

Figure 29. Fixed Route Annual Infrastructure Costs - Scenario 3

A comparison of the cumulative infrastructure costs for each scenario can be found in Figure 30 and Table 11.

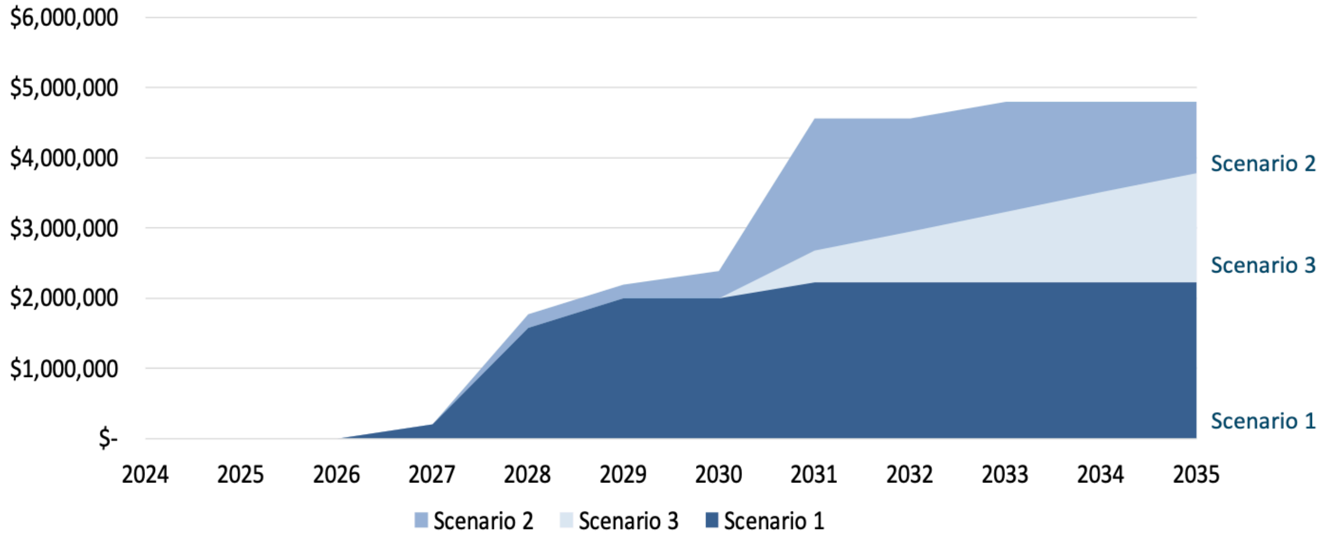

Figure 30. Fixed Route Cumulative Infrastructure Costs All Scenarios - Graphic Form

Table 11. Fixed Route Cumulative Infrastructure Costs All Scenarios - Tabular Form

	Baseline	ZEB Scenario 1 (BEB Depot)	ZEB Scenario 2 (BEB Depot & On-Route)	ZEB Scenario 3 (BEB Depot & FCEB)
Cumulative Infrastructure Costs ($)	--	$2.22M	$4.79M	$3.78M
Incremental over Baseline ($)		+$2.22M	+$4.79M	+$3.78M
% ZEB Fleet by 2035	37%	90%	100%	100%

Total Cost of Ownership Assessment

The Total Cost of Ownership (TCO) Assessment compiles the results from stacking the outcomes of the Fleet, Fuel, Infrastructure, and Maintenance Assessments to show cumulative and annual costs throughout the transition period for each scenario. Other costs may be incurred such as incremental operator and maintenance training during a fleet transition; however, these four assessment categories are the key drivers in ZEB transition decision-making.

This study assumes no cost escalation or any cost reduction due to economies of scale for ZEB technology because there is no historical basis for these assumptions. Lawrence's service level, depot locations, route alignments, block scheduling, or other operations were assumed to stay the same throughout the transition period. The analyses below provide best estimates using the information currently available and the assumptions detailed throughout this report.

TCO Assumptions

The TCO analysis does not include the costs of any resilience measures. There are also operational costs and impacts that may increase the need for personnel such as ZE project managers, operations staff, trainings, and grants managers, which are not included in this analysis. Scheduling changes are not included in this assessment.

Prices used in the analysis are a snapshot of today's market, and while they are evidence-based predictions, the hydrogen market is nascent and will likely see price reduction with increased regional production, availability, and commercialization.

TCO Results

Results of the total cost of ownership analysis are seen in Figure 31 and Table 12. The results indicate that additional capital funding will be required for each of the ZEB Scenarios when compared to the Baseline.

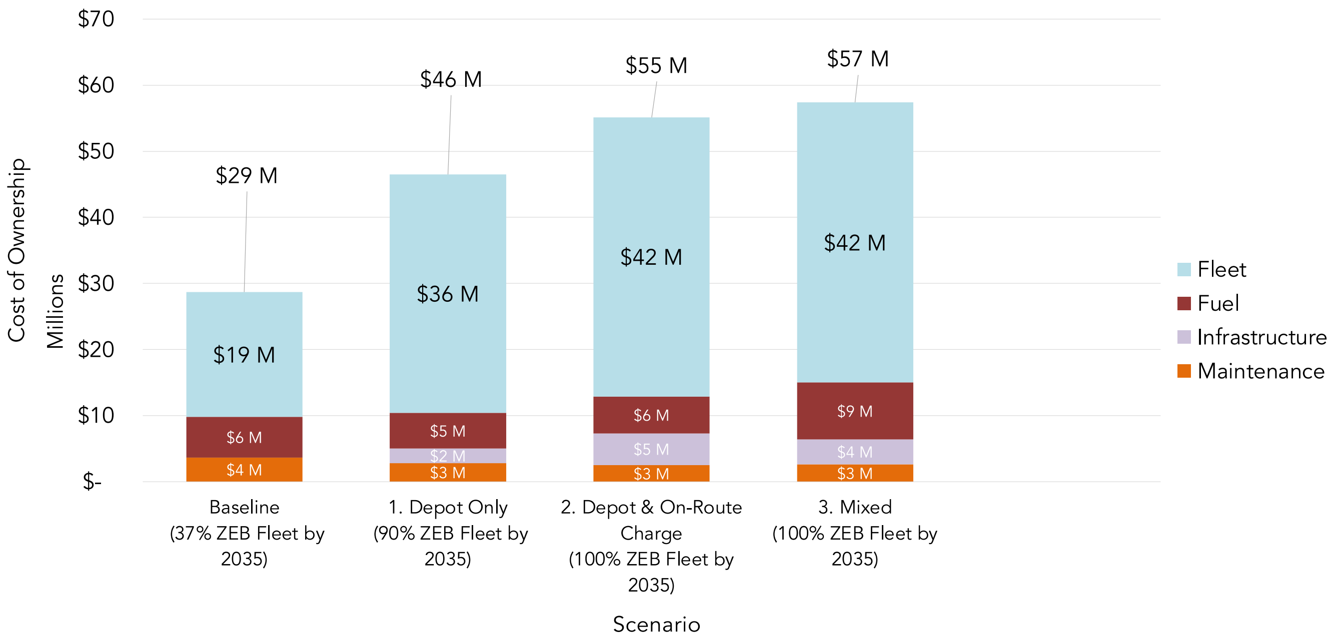

Figure 31. Fixed Cumulative TCO Costs All Scenarios (2024-2035) – Graphic Form

Table 12. Fixed Cumulative TCO Costs All Scenarios (2024-2035) – Tabular Form

	Baseline	ZEB Scenario 1 (BEB Depot)	ZEB Scenario 2 (BEB Depot & On-Route)	ZEB Scenario 3 (BEB Depot & FCEB)
Fleet	$18,842,000	$36,051,000	$42,213,000	$42,368,000
Fuel	$6,156,000	$5,362,000	$5,548,000	$8,575,000
Maintenance	$3,678,000	$2,834,000	$2,555,000	$2,665,000

Infrastructure	$-	$2,222,000	$4,791,000	$3,781,000
Total	**$28,676,000**	**$46,469,000**	**$55,107,000**	**$57,389,000**
% of Fleet that is ZEB	37%	90%	100%	100%

TCO Key Takeaways

The Baseline Scenario totals nearly $29 million over the transition period. The BEB Depot Charge Only Fleet Scenario totals over $46 million, while the BEB Depot and On-Route Fleet Scenario totals just over $55 million and the FCEB Only Fleet Scenario comes in at more than $57 million.

The largest cost difference between the ZEB scenarios and the baseline is attributed to the fleet costs. BEBs and FCEBs are significantly more costly than ICE counterparts, but in Lawrence's specific case, this difference is even more significant. This is due to the City's plan to replace ICE vehicles with refurbished vehicles instead of new ICE vehicles in the Baseline Scenario. When ICE vehicles are up for replacement, they will be refurbished and used for an additional three years ($50k assumed for refurbishment costs, which are accounted for in maintenance costs). After three years, they will be replaced with a used diesel bus from the KU fleet that will be refurbished and used for an additional three years ($50k assumed for refurbishment costs, which are accounted for in maintenance costs). After those three years, the City will purchase a used diesel vehicle to replace the refurbished KU diesel vehicle ($75k assumed for used bus purchase cost). The used diesel bus will operate for five years. Each of these three replacement options are significantly cheaper than the cost of a new BEB (~$1.2M) or FCEB (~ $1.3M) as assumed in each of the three transition scenarios, resulting in the large difference in fleet costs between the Baseline Scenario and the ZEB Scenarios.

Fuel costs for the two BEB scenarios are lower than the Baseline scenario over the course of the transition period, due to a fairly favorable electric rate for a BEB fleet. The City does not have to pay any demand charges based on the current Evergy rate, which is beneficial for a BEB fleet. The fuel costs for the Mixed Fleet Scenario are roughly $2.4M higher than the Baseline over the transition period due to the high cost of hydrogen. The hydrogen fuel cost value would only increase if the City incorporated more FCEBs than the three FCEBs that Scenario 3 assumes.

Maintenance costs for each ZEB scenario are cheaper than the Baseline scenario. One of the expected benefits of moving to a ZEB fleet is a reduction in maintenance costs due to the fact that there are fewer fluids to replace (no engine oil or transmission fluid), fewer brake changes due to regenerative braking, and far fewer moving parts than on a diesel bus.

Finally, each ZEB scenario has higher infrastructure costs since infrastructure costs are not assumed for the Baseline scenario. Scenario 2 (BEB Depot and On-Route) experiences the highest cumulative costs in this category compared to the other two ZEB scenarios. This is in part due to the high costs of adding on-route inductive charging infrastructure that is needed for midday charging, in addition to all of the charging infrastructure required for overnight charging at the depot. In the City's case, the 1:1 ratio of on-route charger to bus is needed because the pulse system requires that all buses are in the Transit Center at the same time. This leads to an increased amount of charger capital and installation costs. Additionally, Scenario 3 (Mixed Depot BEB and FCEB) has lower infrastructure costs due to the small number of FCEBs, which allows for a small-scale gaseous solution to be utilized, which has significantly lower capital costs and no installation costs, as compared to other hydrogen fueling solutions that would be needed for larger FCEB fleets. The City should revisit the FCEB infrastructure solution if more FCEBs were procured than the three assumed in Scenario 3.

Demand Response Fleet Assessment

Service Assessment

Scenarios and Assumptions

Aside from the fixed route service, the City also provides a T-Lift service and an On-Demand service. T-Lift is a door-to-door shared ride paratransit service that is available for riders who are unable to use the fixed routes due to a disability. On-Demand service is a shared ride, curb-to-curb service that operates on Sundays and night hours when fixed service does not operate. For transition planning purposes, these fleets were analyzed together as a Demand Response fleet. The project team focused on one zero-emission transition scenario for the Demand Response fleet: a depot overnight-charge-only scenario.

The Demand Response fleet consists of Ford E450 gasoline cutaways. For transition planning purposes, these fleets are assumed to be replaced with electric cutaway vehicles. Electric cutaways are an emerging market in the U.S. and have primarily been deployed by municipalities, airports, and transit agencies in California. Many electric vehicles in this class are 'repowered' meaning they are built on an OEM or factory gasoline truck chassis, such as those manufactured by Ford, Chevrolet, or Dodge. These vehicles are repowered with third-party electric drivetrains and are upfitted with specialized passenger bodies. The process of rebuilding or 'repowering' an OEM chassis with an electric drivetrain involves removing the internal combustion engine and related parts and replacing them with an electric motor and drivetrain. There has not been widespread use of these vehicles in the transit industry to date due to range limitations, and data is limited on operating performance and cost.

Due to the limited range of electric cutaway vehicles compared to the City's service needs, the Service Assessment results below show limited projected BEB feasibility of the Demand Response fleet in the 2035 timeline. Therefore, the City requested that CTE project out the feasibility to 2050 to provide a look at feasibility over a longer time period. The remainder of the transition analysis (Fleet, Fuel, Maintenance, Infrastructure Assessments) will only consider transition through 2035 for this fleet.

As was done for the fixed route service, a number of assumptions were developed based on discussions between CTE and the City during the Planning & Initiation stage of this project. Those assumptions are listed below:

- Electric cutaway battery capacities are based on the nameplate capacity (123kWh) of the Optimal electric cutaway.
- A 5% improvement in energy storage for cutaways assumed every two years.
- Projected battery capacity was based on the assumption that useable battery capacity is 80% of nameplate capacity with 10% degradation, effectively 72% of nameplate capacity, representing an approximation of average battery capacity over the expected life of the batteries. At the time of the development of this report, there are multiple BEB manufacturers that are moving towards allowing a larger percentage of the battery (greater than 80%) to be available for use; however, the 72% represents a conservative assumption of available battery capacity at the mid-life of a battery.

- Efficiencies for electric cutaways are based on CTE modeling data for Lawrence. A strenuous efficiency of 1.5 kWh/mi is assumed for the Demand Response Service Assessment.
- Electric vehicles are assumed to be depot-charged overnight to assess block feasibility.

Service Assessment Results

A screening model was used to assess the Demand Response fleet. The service assessment analysis was based on historical (March 2024) distance and duration data of the fleet. The data showed that each of the nineteen Demand Response vehicles that operated in March 2024 performed an average of 33 to 210 miles per day, with some instances of vehicles performing more than 250 miles in a day. A number of the Demand Response fleet vehicles are solely assigned to either T-Lift or On-Demand, while there are some that are assigned to both services. Lawrence will likely use battery-electric cutaways interchangeably, as each service have similar mileage requirements. Based on March 2024 mileage and quantity of vehicles in service per day, 16% of the demand-response service could be feasible with a battery-electric cutaways in 2024 with current technology, 30% could be feasible by 2035, and 54% could be feasible by 2050, as shown in Figure 32. The service assessment was conducted using March 2024 data which was a month where 19 vehicles were in service, however the Demand Response fleet has a total of 25 vehicles. The remainder of the transition assessments will use the 25-vehicle number to calculate costs based on the entire Demand Response fleet.

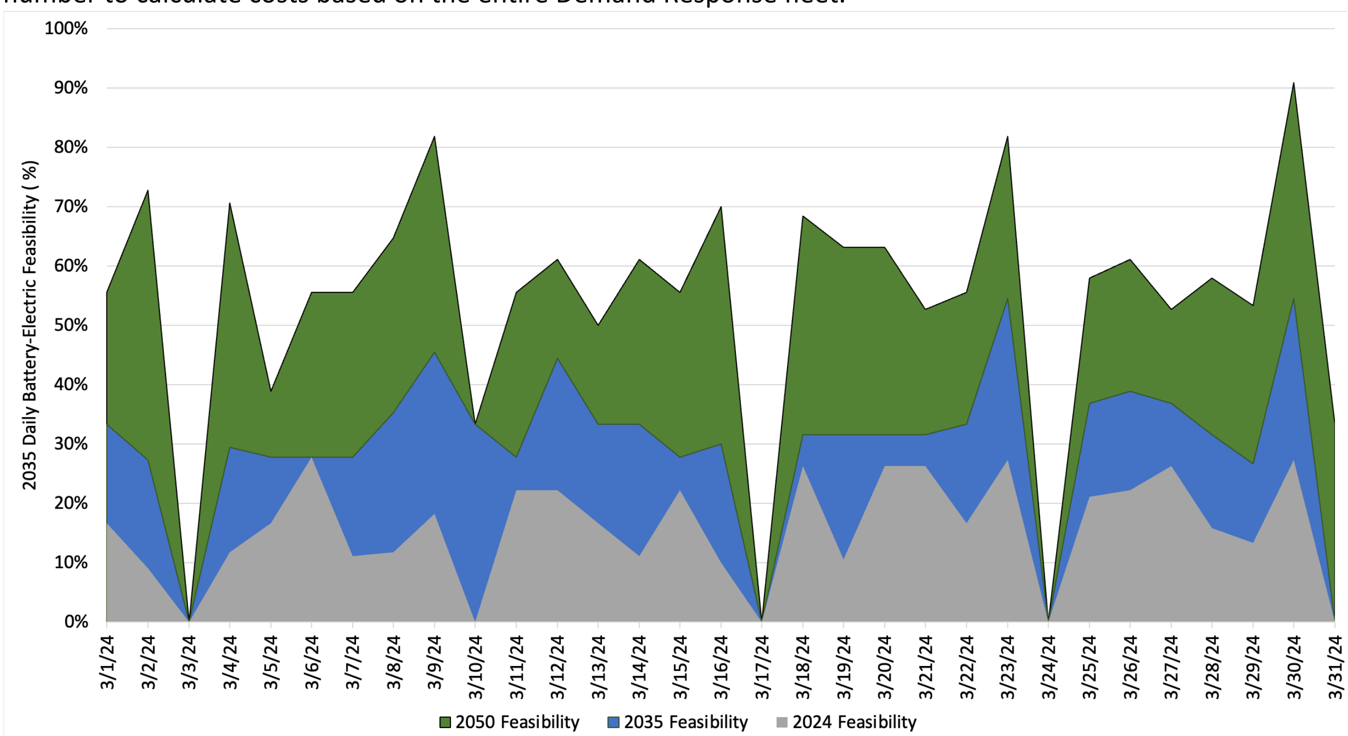

Figure 32. Demand Response Service Assessment Results 2024-2025

The Service Assessment shows the large feasibility gap that exists with transitioning Demand Response type vehicles to electric. Since on-route charging capabilities do not currently exist for cutaway-type vehicles, and the fuel cell electric cutaway market is still in the very early stages of development as compared to the battery electric market, only a BEB Depot Charge Only scenario was assumed for the Demand Response analysis.

Fleet Assessment

The goal of the Fleet Assessment is to determine the type and quantity of BEBs, as well as the schedule and cost to transition the fleet to zero-emission. Results from the Service Assessment are integrated with the City's current fleet replacement plan and purchase schedule to produce the projected bus replacement timeline for the Demand Response fleet and the associated annual and total capital costs of those replacements.

Fleet Assessment Assumptions

Key assumptions for the fleet assessment are as follows:

- The service life of demand response vehicles is assumed to be 5 years.
- The cost of an electric cutaway is assumed to be $408,675 based on Lawrence's 2024 procurement of electric Optimal cutaways.
- The cost of a gasoline cutaway cost is assumed to be $112,306 based on Lawrence's 2022 procurement of a Ford E450.
- Annual inflation rate of 4% is applied to the vehicles' costs through 2026, followed by a 2% inflation assumption for the remainder of the transition period based on historical PPI for transportation equipment and bus bodies.
- The transition plan assumes that electric vehicles will not be procured until 2028, which allows the City time to acquire funding and install necessary infrastructure.
- If the City's current gasoline vehicles exceed their useful 5-year service life and service is not feasible with an electric cutaway, they are assumed to be replaced with gasoline Ford E450s.

Fleet Assessment Results

Figure 33 depicts the annual baseline fleet composition through the transition timeline. Figure 34 shows the annual fleet costs associated with the baseline.

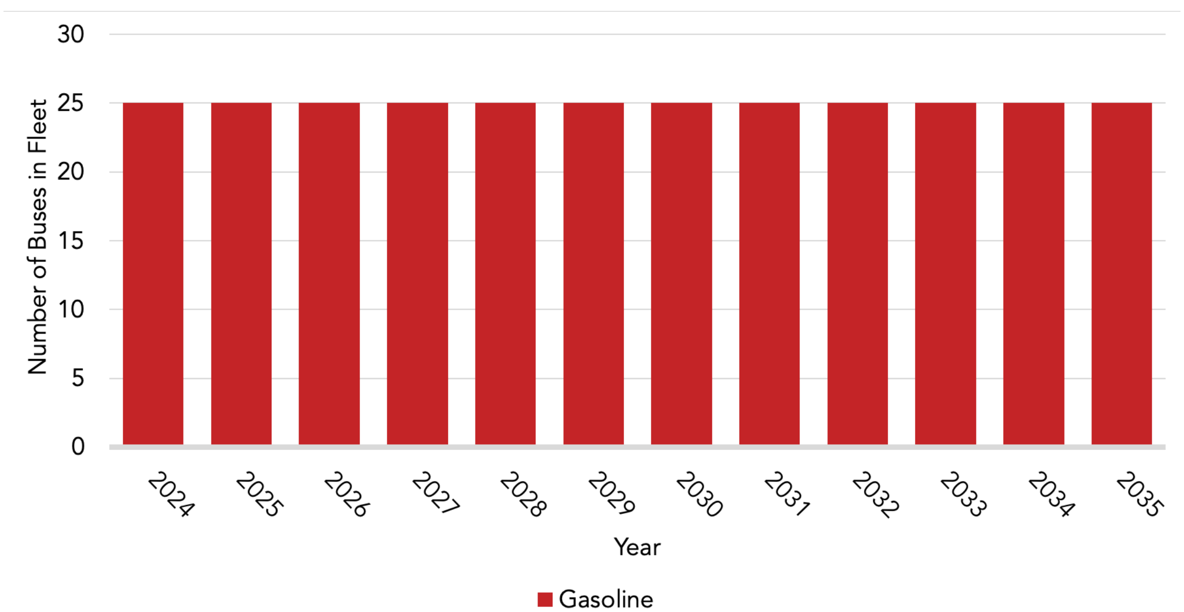

Figure 33. Demand Response Fleet Composition - Baseline

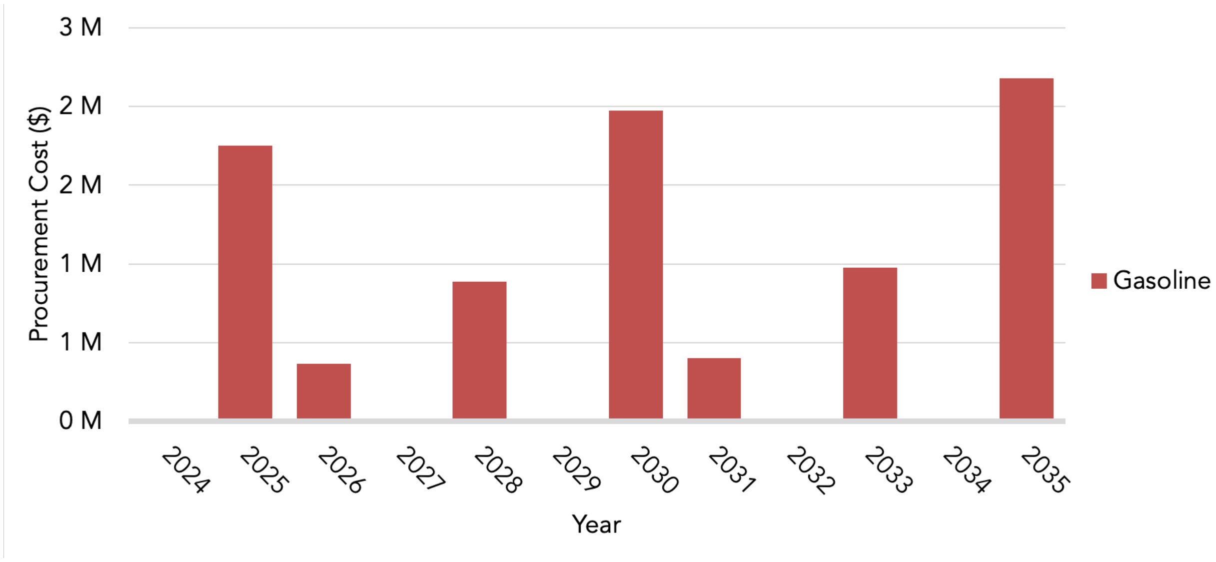

Figure 34. Demand Response Annual Fleet Costs- Baseline

Based on the feasibility analysis results in the Service Assessment, as well as the City's fleet replacement schedule, a transition timeline for the Demand Response fleet was developed. With the electric overnight depot-charge only scenario, the Demand Response fleet can reach a 36% zero emission fleet by 2035. Figure 35 shows the fleet composition for the electric scenario, while Figure 36 shows the associated annual fleet costs for the scenario.

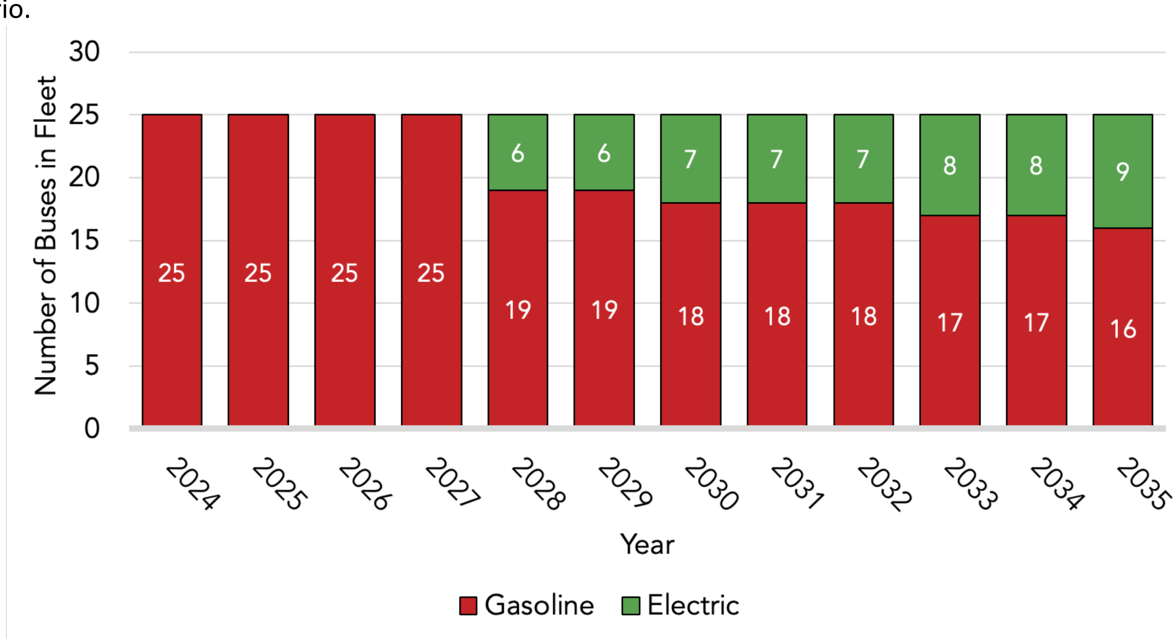

Figure 35. Demand Response Fleet Composition – Scenario 1

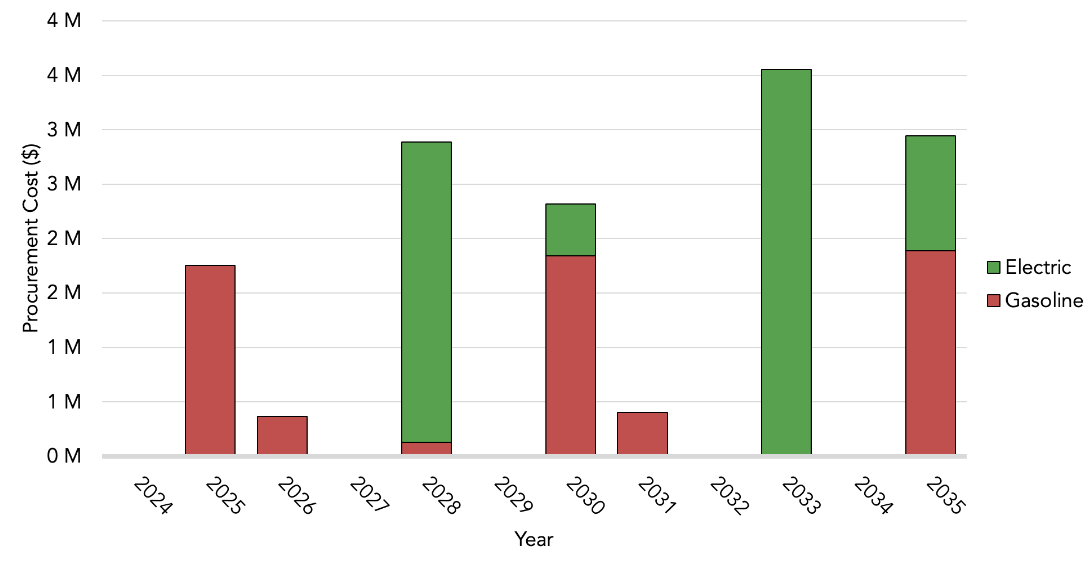

Figure 36. Demand Response Annual Fleet Costs – Scenario 1

The electric scenario is an estimated $5.7M more in fleet costs compared to the baseline scenario, as shown in Figure 37.

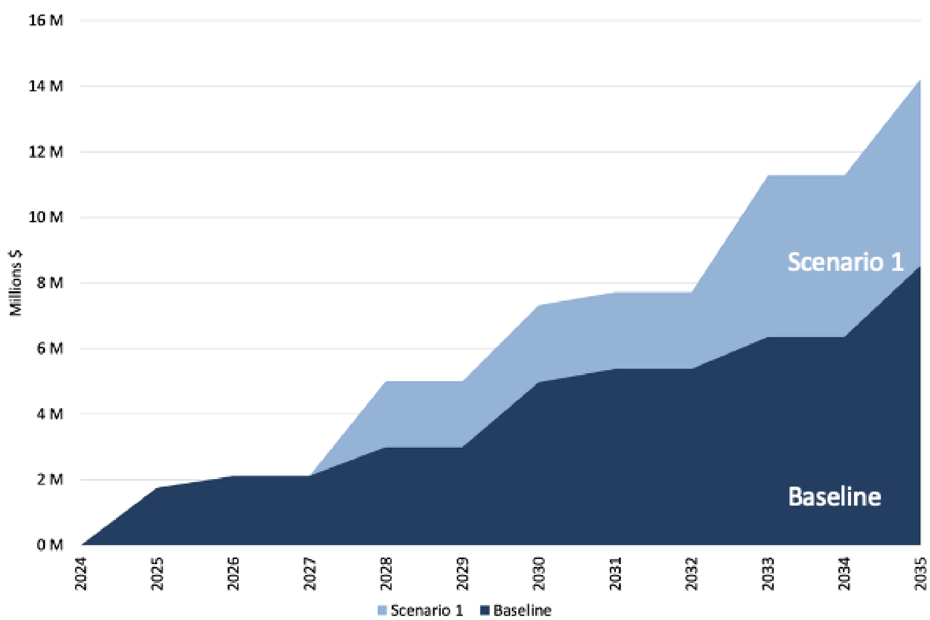

Figure 37. Demand Response Cumulative Fleet Cost Comparison

Fuel Assessment

CTE conducted a fuel assessment to determine the projected annual cost of fuel for Demand Response service during the transition period by fuel type (i.e., gas or electricity).

Fuel Assessment Assumptions

Key assumptions for both fuel consumption and fuel costs are as follows:

- Annual mileage and fuel use is constant for Demand Response service through the transition period, based on current fleet averages from 2024 annual data.
- Fuel consumption per battery electric vehicle was determined by nominal fuel efficiencies (0.9 kWh/mi) based on CTE modeling results for Lawrence.
- 80% charger efficiency assumed.
- Gasoline and electric fuel costs are escalated throughout the transition period based on EIA's 2022 Annual Energy Outlook average annual change.
- Gasoline cost is $2.72/gallon based on 2024 the City data.
- Electricity costs are based on Evergy's Electric Transit Service rate as shown in Table 13. Fixed fees associated with this rate were included in the fixed route fuel assessment and, therefore, will not be included in the Demand Response assessment to avoid double-counting.

Table 13. Evergy Electric Transit Service rate details

Rate Schedule	TOU	Fixed Fees	Energy Rate [$/kWh]	Energy Surcharges [$/kWh]
Evergy Electric Transit Service	On-Peak 6:00 AM – 6:00 PM	$32.47	$0.15543	$0.051538
	Off-Peak: 6:00 PM – 6:00 AM		$0.02278	

- Charger maintenance costs are included in the fuel assessment to reflect the total cost of operations and maintenance. Depot charger maintenance cost was assumed to be $3,000/yr/charger.
- Each Depot charger's rated power is assumed to be 200 kW, with three dispensers each.
- Charger to bus ratio assumption: 1:3 (i.e., three dispensers per charging unit)
- All depot charging will occur off-peak.

Fuel Assessment Results

Figure 38 depicts the annual baseline fuel costs throughout the transition timeline. Figure 39 shows the annual fuel costs associated with the electric scenario. Figure 40 provides a comparison of the cumulative fuel costs for each scenario. The electric scenario is an estimated $475k less than the baseline scenario.

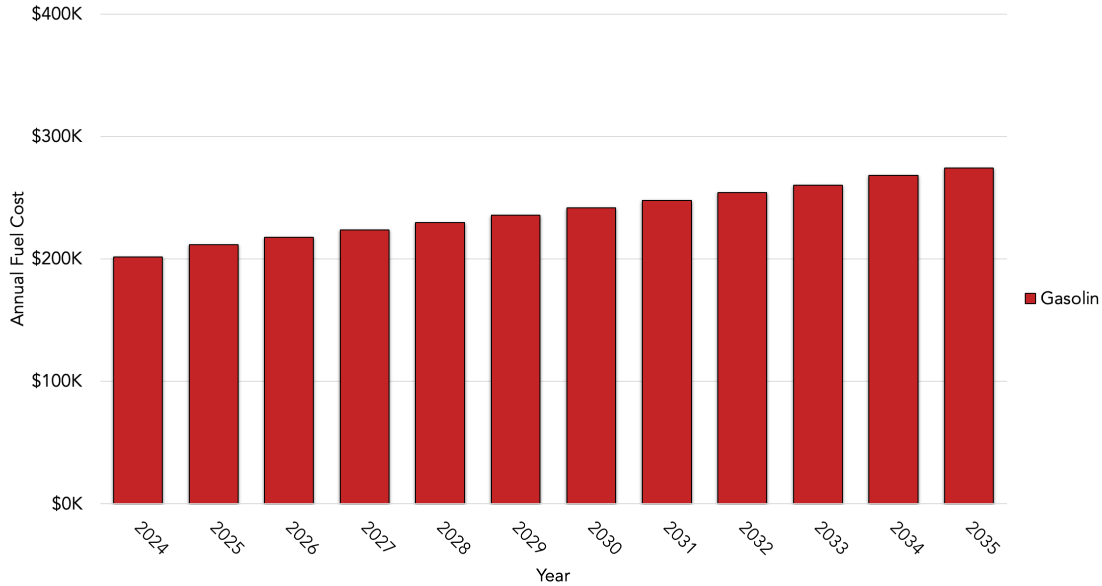

Figure 38. Demand Response Annual Fuel Costs – Baseline Scenario

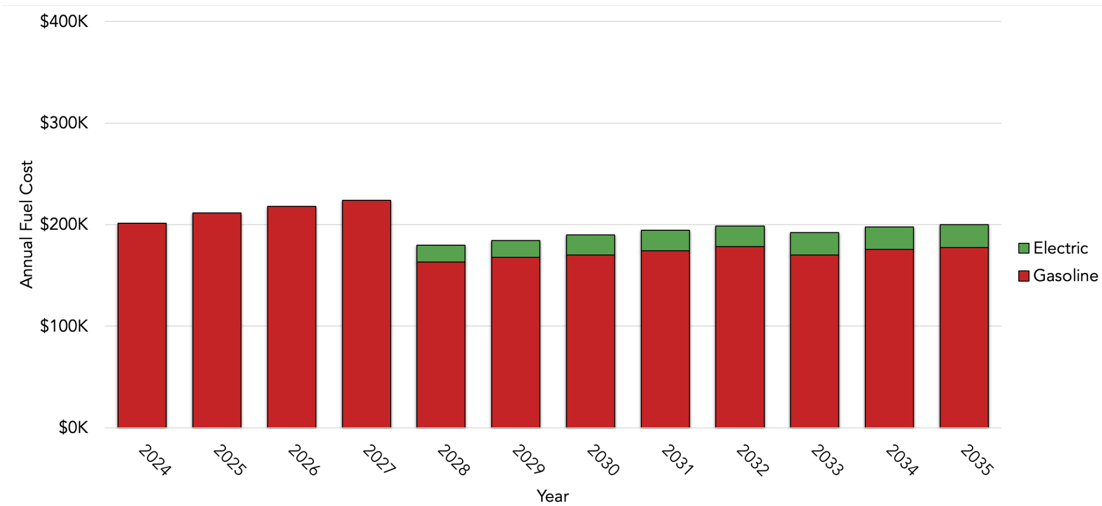

Figure 39. Demand Response Electric Scenario Annual Fuel Costs

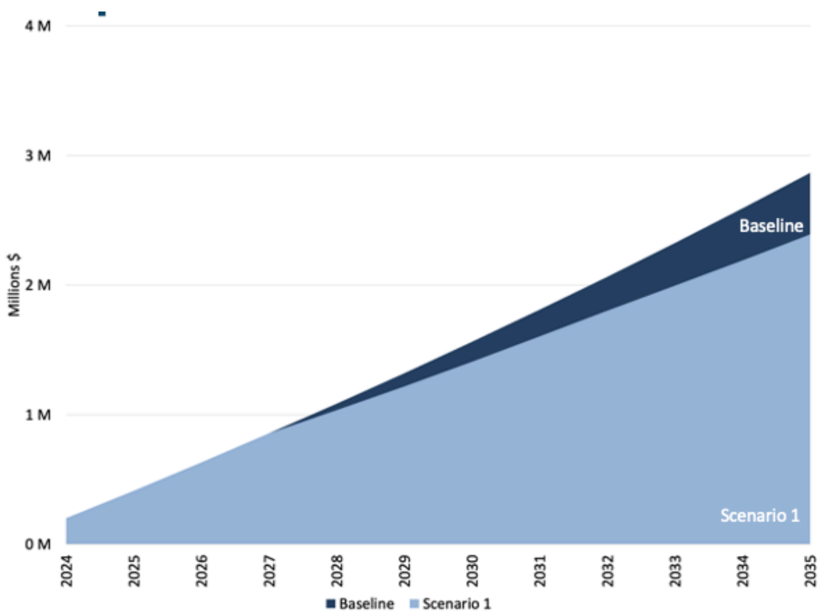

Figure 40. Demand Response Cumulative Fuel Cost Comparison

Maintenance Assessment

CTE conducted a maintenance assessment to determine the estimated annual maintenance costs for each scenario.

Maintenance Assessment Assumptions

Key assumptions for the maintenance assessment are as follows:

- Only maintenance costs for fleet vehicles are included in this assessment. Infrastructure maintenance is included in the fuel assessment.
- An inflation rate of 3% is applied through the transition period, based on historical CPI for labor.
- Maintenance cost per mile for gasoline vehicles is assumed to be $0.09/mile based on historical Lawrence fleet data.
- Maintenance cost per mile for electric vehicles is assumed to be $0.10/mile based on historical Lawrence fleet data.

Maintenance Assessment Results

Figure 41 depicts the annual baseline maintenance costs throughout the transition timeline. Figure 42 shows the annual maintenance costs associated with the electric scenario. Figure 43 provides a comparison of the cumulative maintenance costs for the electric scenario compared to the baseline. The electric scenario is an estimated $15.5k more than the baseline scenario.

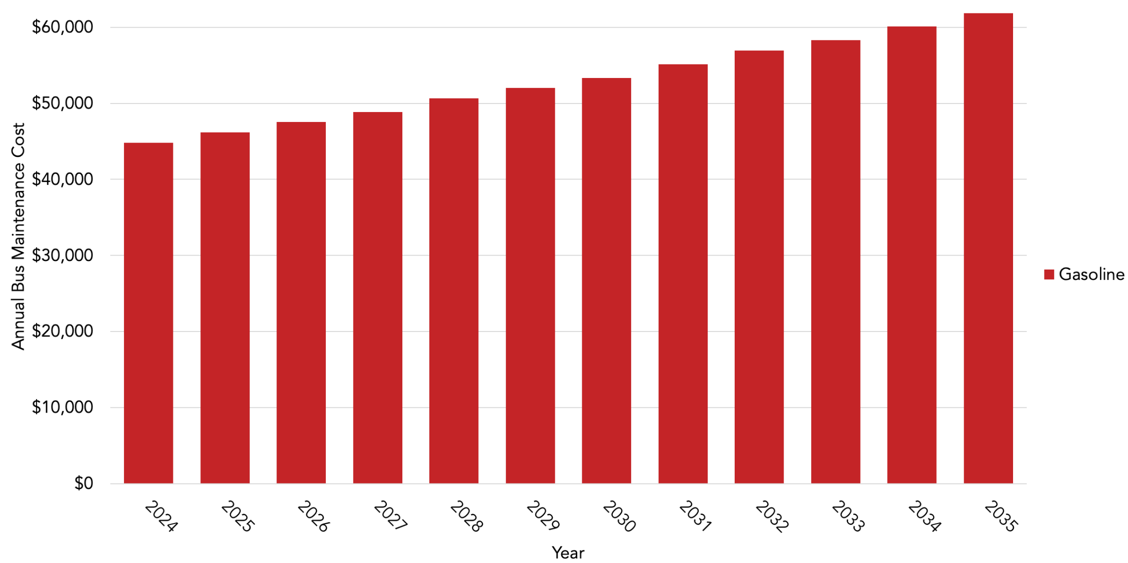

Figure 41. Demand Response Annual Maintenance Costs – Baseline Scenario

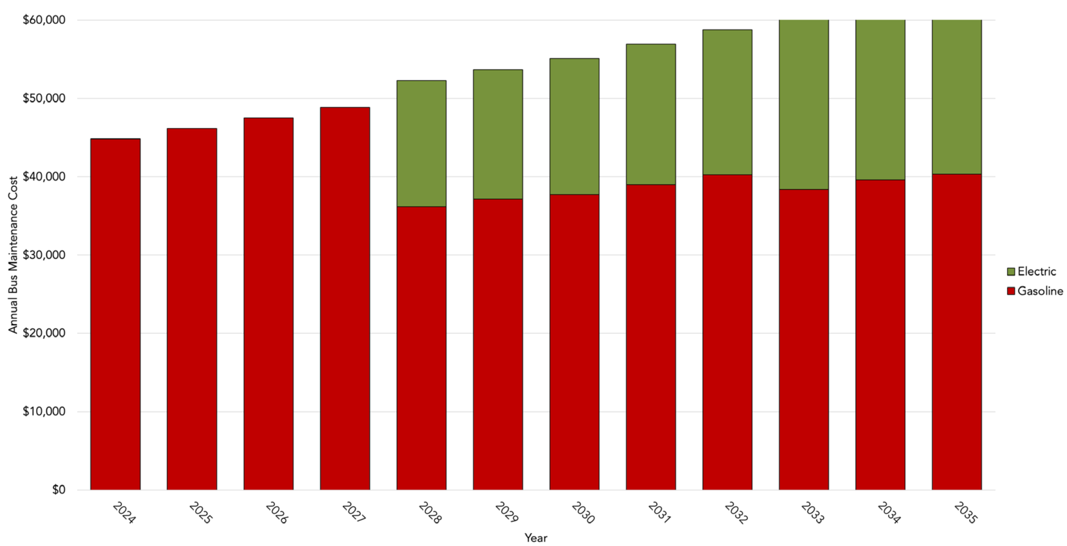

Figure 42. Demand Response Annual Maintenance Costs – Scenario 1

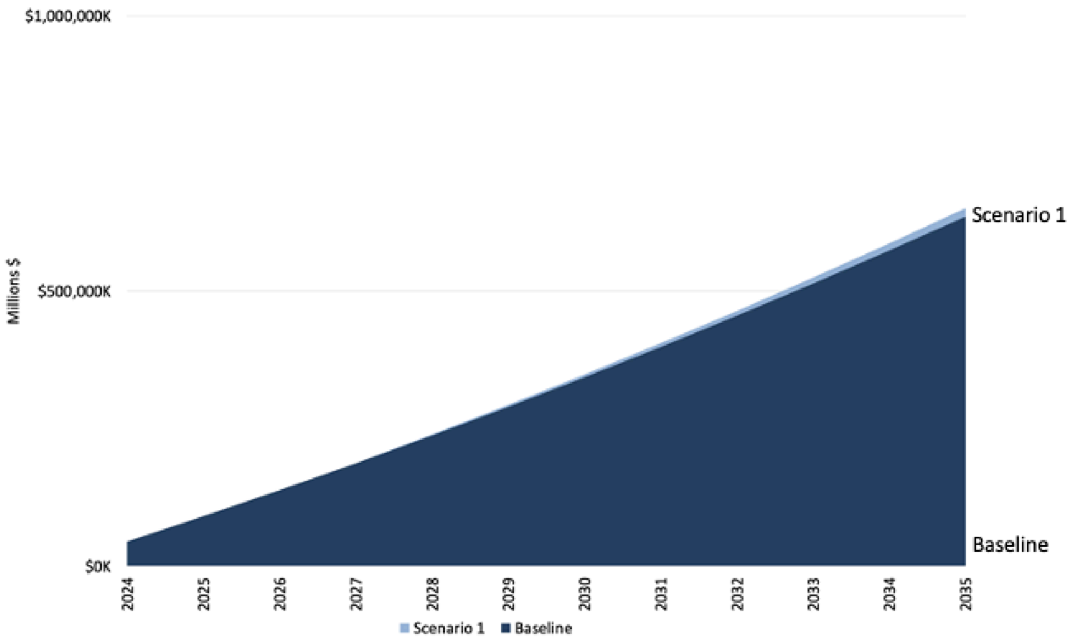

Figure 43. Demand Response Cumulative Maintenance Costs

Infrastructure Assessment

CTE conducted an Infrastructure Assessment to determine the estimated annual infrastructure costs for the Demand Response scenario.

Infrastructure Assessment Assumptions

At the request of the City, the charging equipment for the Demand Response fleet was assumed to be the same type of charging equipment that is used for the Fixed Route fleet (200kW depot plug in chargers with three dispensers each), and the charging infrastructure is assumed to be located in the same place as the Fixed Route infrastructure (see Appendix A for conceptual site plans). As with the Fixed Route analysis, no land acquisition costs are included in the infrastructure assessment costs, as well as any costs associated with construction of the new building structure on the adjacent parcel. Additionally, no utility upgrade costs are included.

General Assumptions:

- A 20% contingency is assumed on all equipment and construction costs.
- An escalation rate of 3% year-over-year was applied to the infrastructure costs through the transition period to reflect inflation.
- Master planning and engineering design costs were not included in the Demand Response analysis; the planning and engineering/design work assumed in the Fixed Route infrastructure analysis is assumed to include the necessary work for the additional Demand Response charging infrastructure.

Table 14. Demand Response Infrastructure Cost Assumptions

	Assumed Cost	Source/Notes
ChargePoint 200kW Charger Cabinet	$55,985 / charger	Lawrence's 2024 CP Contract; annual cost escalation of 3% assumed throughout transition
ChargePoint Single Dispenser	$23,660 / dispenser	Lawrence's 2024 CP Contract; annual cost escalation of 3% assumed throughout transition
Construction Costs (Labor + Materials)	$53,500/ dispenser	NV5 estimate based on recent projects (assuming no complicated site conditions)

Infrastructure Assessment Results

The annual infrastructure costs for the Demand Response fleet over the transition period can be seen in Figure 44.

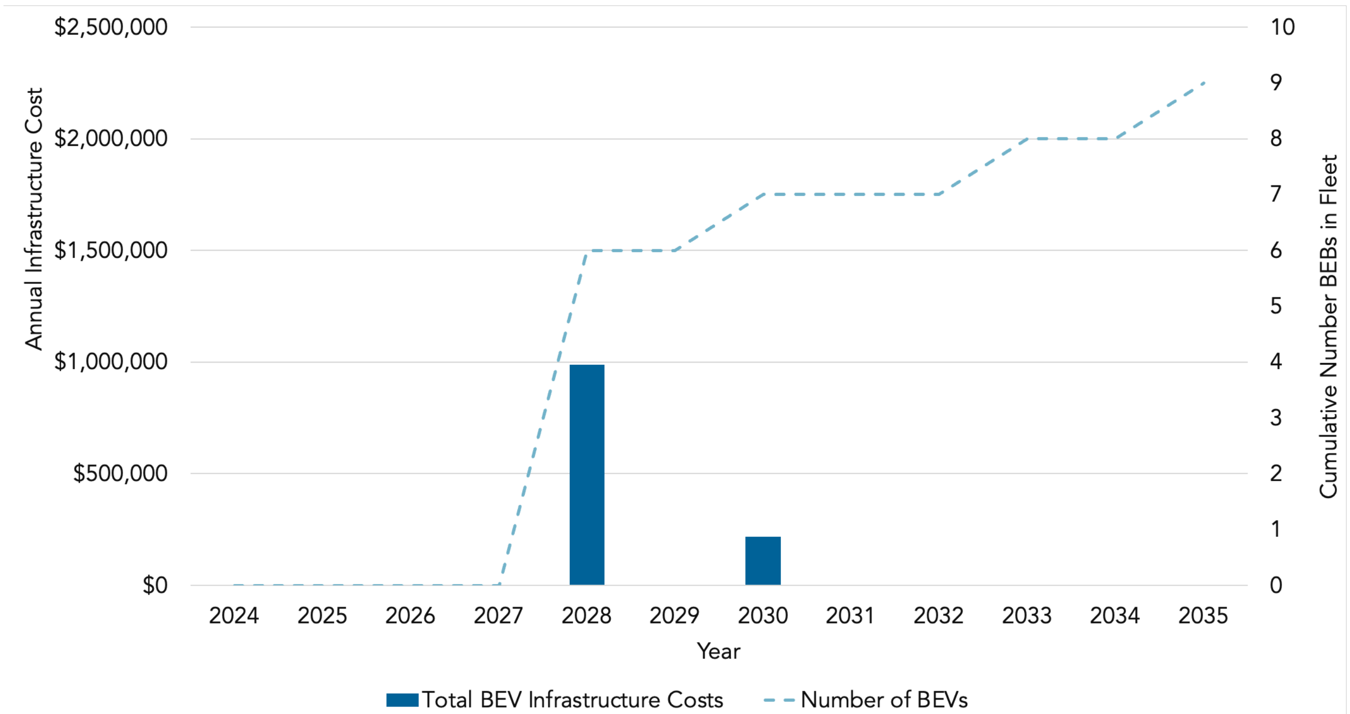

Figure 44. Demand Response Annual Infrastructure Costs - Scenario 1

TCO Assessment

The TCO Assessment compiles the results from stacking the outcomes of the Fleet, Fuel, Infrastructure, and Maintenance Assessments to show cumulative and annual costs throughout the transition period for each scenario. Other costs may be incurred, such as incremental operator and maintenance training during a fleet transition, however, these four assessment categories are the key drivers in ZEB transition decision-making.

This study assumes no cost escalation or any cost reduction due to economies of scale for ZEB technology because there is no historical basis for these assumptions. Future changes to Lawrence's service level, depot locations, route alignments, block scheduling, or other operations were kept consistent. The analyses below provide the best estimates using the information currently available and the assumptions detailed throughout this report.

TCO Assumptions

The TCO analysis does not include the costs of any resilience measures. There are also operational costs and impacts that may increase the need for personnel such as ZE project managers, operations staff, trainers, and grants managers, which are not included in this analysis. Scheduling changes are not included in this assessment. Operators can review operational modifications that may simplify their transitions to ZEV.

Prices used in the analysis are a snapshot of today's market, and while they are evidence-based predictions, the hydrogen market is nascent and will likely see price reductions with increased production and availability.

TCO Assessment Results

Results of the total cost of ownership analysis are seen in Figure 45 and Table 15. The results indicate that additional costs will be required for each of the ZEB Scenarios when compared to the Baseline.

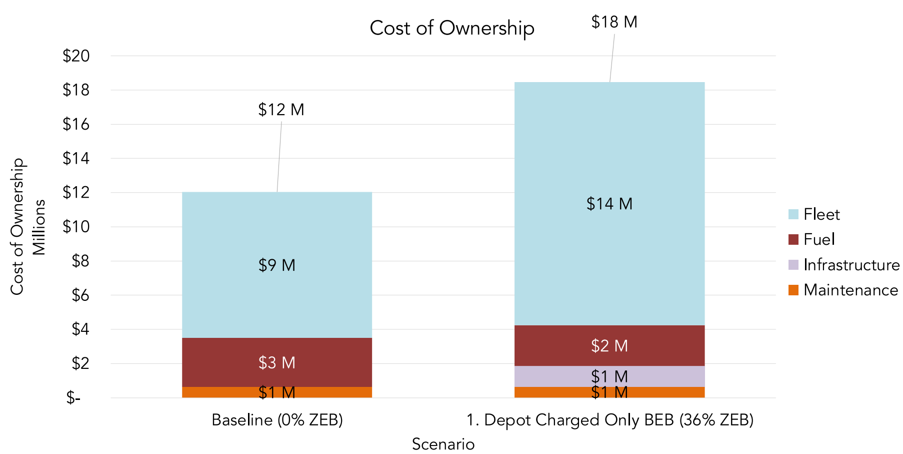

Figure 45. Demand Response TCO Costs - Graphic Form

Table 15. Demand Response TCO Costs – Tabular Form

	Baseline	ZEB Scenario 1 (BEB Depot)
Fleet	$8,530,000	$14,222,000
Fuel	$2,867,000	$2,392,000
Maintenance	$636,000	$652,000
Infrastructure	$-	$1,206,966
Total	**$12,033,000**	**$18,472,966**
% of Fleet that is ZEB	0%	36%

Microgrid Analysis

Overview

NV5 assessed the financial feasibility of solar photovoltaic (PV), battery energy storage system (BESS), and a conventional fuel generator (genset) for a microgrid at a future facility on an adjacent parcel to the west of 1260 Timberedge Rd depot. The microgrid will support Lawrence Transit's transition to BEBs to meet the 100% zero-emission vehicle (ZEV) transition goal by 2035.

This financial analysis reviews estimated future electrical consumption and performance of the conceptual solar PV, BESS, and natural gas genset microgrid under Cash Purchase and Power Purchase Agreement (PPA) financing options.

Microgrid Conceptual Layouts

For system sizing, NV5 looked at the expected energy consumption associated with the Demand Response fleets transition results (9 BEBs by 2035) combined with the expected energy consumption associated with the Fixed Route fleet's BEB Depot and On-route Charge scenario (Scenario 2) transition results (30 BEBs by 2035), because this scenario estimates the highest energy consumption across the fleet. NV5 used Scenario 2 from the Transition Plan and expected energy consumption from 2035, as shown in Table 16. By 2035, the size of the solar PV maximizes the available space on the new rooftop based on the preliminary design. The roof is expected to be a standing seam pitched roof, and the solar PV is flush mount south-facing.

Table 16. Estimated Baseline Electric Utility Costs

Year	Quantity BEBs (Fixed Route + Demand Response)	Estimated Annual Energy Consumption (kWh/yr)
2026	17	887,000
2027	18	977,000
2028	30	1,887,000
2029	30	1,887,000
2030	31	1,890,000
2031	34	2,181,000
2032	34	2,181,000
2033	38	2,455,000
2034	38	2,455,000
2035	39	2,744,000

The goals for the BESS and natural gas genset are to balance upfront cost, utility cost savings, and meet Lawrence's resiliency goals. The BEBs are expected to charge predominantly overnight. The system will charge the BESS with daytime solar PV energy and discharge the BESS overnight. The BESS is sized to optimize solar PV storage for energy arbitrage and can provide resiliency for shorter grid outages. The natural gas genset is sized at the expected peak demand and would be used to meet longer grid outages once the BESS is fully discharged. Lawrence stated resiliency goals are:

- Support 50% of bus operations for 24 hours, with modeled peak demand of 1,000 kW.
- Support 25% of bus operations for 72 hours, with modeled peak demand of 600 kW.

For BESS and genset sizing, NV5 modeled the worst-case scenario using HOMER Grid industry software. The worst-case scenario is the lowest solar generation and the highest bus demand during the outage period. The model assumes that the depot would not have advanced notice of the outage, and that there is no reserved BESS capacity for outages. The final system sizes are in Table 17.

Table 17. Microgrid System Sizes by Technology

Description	Size
Solar PV	610.2 kWp-DC
BESS	1 MW / 2 MWh
Natural Gas Genset	1 MW

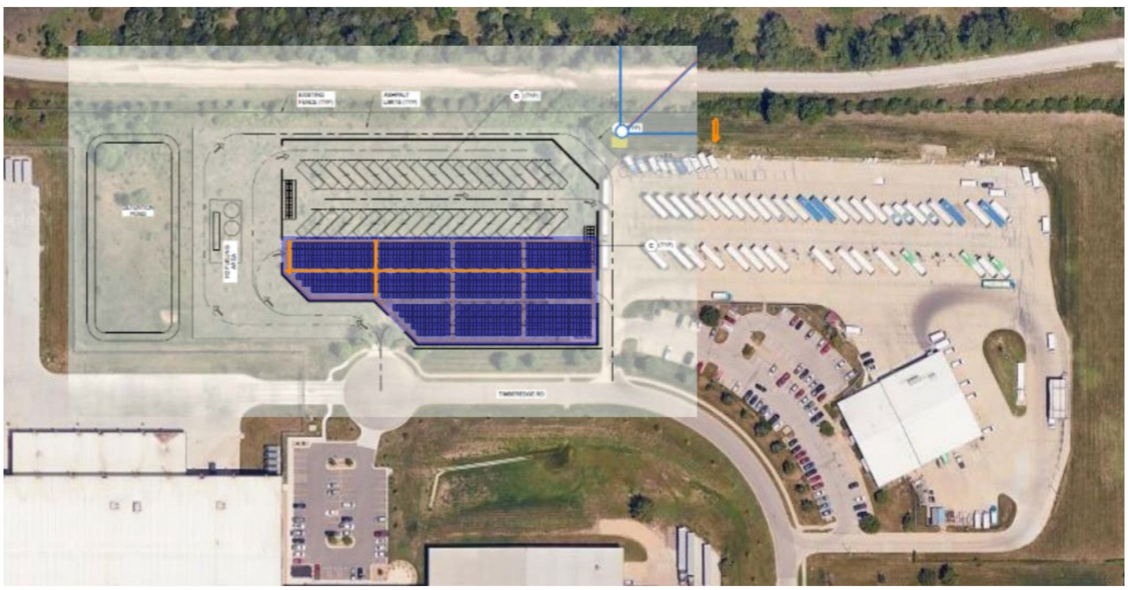

Figure 46. Site Conceptual Layout

During prolonged outages, the BESS will support a portion of the outage while the natural gas genset serves the remainder of the outage, as shown in Figure 47 for outage Scenario 1 lasting 24 hours. The duration for which the BESS can serve the BEBs without the genset depends on the BESS state-of-charge at the time of the outage, the BEB charging load, and the duration of the outage. The natural gas genset's operation is only limited by fuel supply. Lawrence expects to have the genset fuel supplied by a pipeline, rather than stored on site.

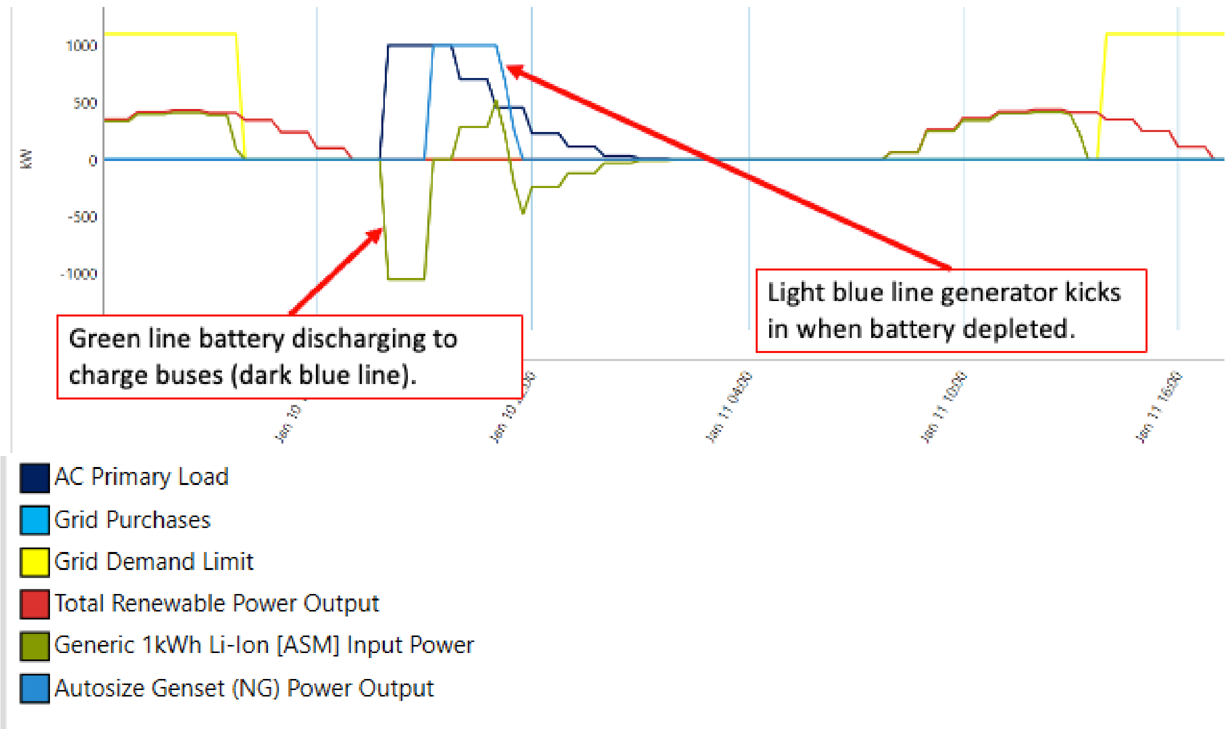

Figure 47. HOMER Grid simulation output for resiliency outage scenario 1

Financial Overview

NV5 modeled the solar PV and BESS microgrid concept under two different financing scenarios over a 25-year system lifetime: 1) Cash Purchase and 2) Power Purchase Agreement (PPA). Lifetime savings depend on the ability of the solar PV and BESS to serve the BEB and avoid grid purchases. BESS are also typically used to reduce demand charges. Currently, Evergy's ETS tariff does not have demand charges, so the solar PV and BESS only generate utility cost savings through energy arbitrage. As shown in Figure 3, the ETS tariff has a low cost of energy during the off-peak time when the BEBs will be charging. Therefore, there is limited opportunity for the BESS to generate substantial savings through energy arbitrage. Additionally, solar PV systems greater than 200 kW-AC are valued under Evergy's Parallel Generation policy, where all energy exported to the grid is valued at the monthly Avoided Cost of Generation. The BESS was sized to optimize storing solar PV generation to use on-site rather than export to the grid; however, the financial benefits are limited by the low off-peak rate. Table 18 provides key assumptions used in the financial analysis, and Figure 48 provides an overview of the expected Solar PV + BESS daily system operation with the Evergy cost of energy overlayed. The system financials would improve if the BEBs are charged during the on-peak period.

Table 18. Financial Analysis Assumptions

Assumptions	Value
Solar Tariff	Evergy Parallel Generation
Evergy Tariff	Electric Transit Service (ETS)
Investment Tax Credit (ITC), Cash Purchase[1]	25.5%
Net Present Value (NPV) Discount Rate (DR), % [2]	2.0%

Assumptions	Value
Annual Utility Cost Escalator, % [3]	-0.20%
Evergy Avoided Cost of Generation, $/kWh	$0.024
Soft Costs and Contingencies, %	4.25%

[1] Assumed 30% base ITC with 15% reduction if Lawrence KS uses tax-exempt funding.
[2] The discount rate was estimated to be 2.0% for this project.
[3] The annual utility cost escalator was estimated to be -0.20% based on U.S. Energy Information Administration Annual Energy Outlook 2021 data. Should the Utility escalate its rates at a different rate, the project savings could differ from the numbers given in this report.

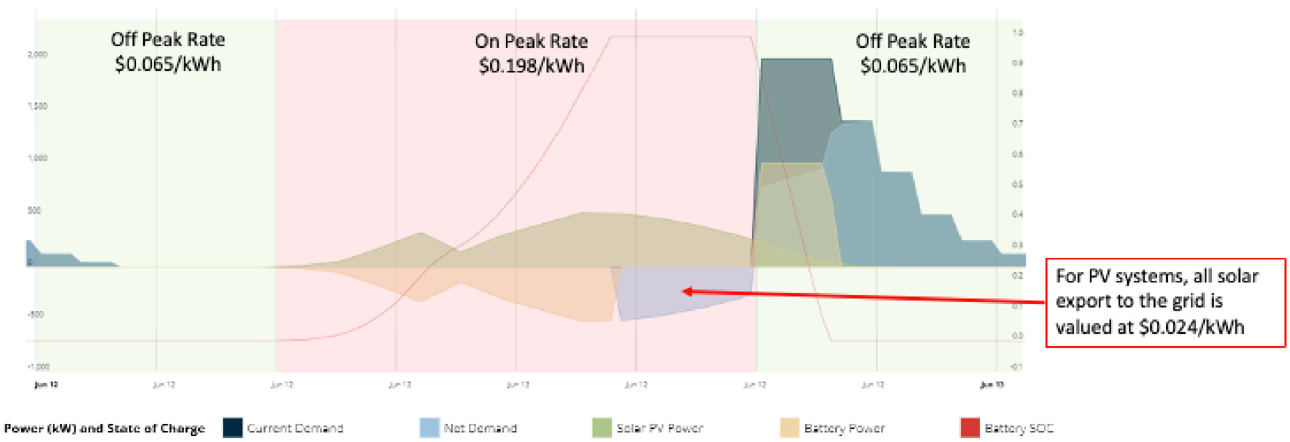

Figure 48. Example of daily solar PV and BESS operations for utility cost savings

NV5 modeled the solar PV and BESS systems over a 25-year life. The results of that analysis are shown in Table 19 for both the Cash Purchase and PPA financing options. The results are shown for both solar PV-only and the entire microgrid, including the upfront cost of the natural gas genset. NV5 did not include the costs for natural gas supply or genset maintenance.

Table 19. 25-Year Financial Analysis Overview Results

Metric		Units	Total System
Solar PV System Size		kWp-DC	610.2
BESS Size		MW / MWh	1 / 2
Genset Size		MW	1
Yr-1 Solar PV Production		kWh	816,000
Yr-1 Site Electricity Consumption Offset by Solar PV Generation		%	92%
Yr-10 Site Electricity Consumption Offset by Solar PV Generation		%	28%
Net Lifetime Savings, NPV @2.0% DR (Expected)			
Solar PV-Only	**Cash Purchase**	**$**	**$(2,257,000)**
	PPA	**$**	**$(2,966,000)**
Microgrid	**Cash Purchase**	**$**	**$(5,330,000)**

	PPA	**$**	**$(5,734,000)**

25-Year Financial Summary

Cash Purchase Overview

Table 20. 20-Year Financial Analysis Results, Cash Purchase Summary

Metric	Units	Solar PV-Only	BESS	Natural Gas Genset	Total Microgrid System
Project Capital Costs					
Base Unit Cost	$/unit	$3.85/Wp-DC	$1,000/kWh	-	-
Base Yr-0 Purchase Cost	$	$2,352,000	$2,037,000	$700,000	$5,261,000
Total Yr-0 Purchase Cost (incl. soft costs & contingencies)	$	$2,556,000	$2,214,000	$700,000	$5,470,000
ITC Incentive	$	$652,000	$565,000	-	$1,216,000
25-Yr Savings Analysis					
Net Lifetime Savings, Nominal	$	$(2,375,000)			$(5,649,000)
Net Lifetime Savings, NPV @2.0% DR	$	$(2,257,000)			$(5,330,000)
Simple Payback	Years	>25 Years			>25 Years

Based on the lifetime financial analysis, the key metrics that the model is most sensitive to include: installed system cost, annual operations & maintenance costs, annual utility (Evergy) cost escalator, system production degradation, and soft costs & contingencies.

Power Purchase Agreement (PPA) Overview

Table 21. 25-Year Financial Analysis Results, PPA Summary

Metric	Units	Solar PV-Only	BESS	Natural Gas Genset	Total Microgrid System
PPA					
PPA Base Price per kWh	$/Unit	$0.21/kWh	$13/BESS kW-month		-
Yr-1 PPA Payment	$	$171,000	$153,000		$324,000
25-Yr Savings Analysis					
Net Lifetime Savings, Nominal	$	$(3,706,000)			$(7,199,000)
Net Lifetime Savings, NPV @2.0% DR	$	$(2,966,000)			$(5,734,000)

Based on the lifetime financial analysis, the key metrics that the model is most sensitive to include: PPA price, system production degradation, and annual utility (Evergy) cost escalator.

Findings and Next Steps

1. Neither the Cash Purchase nor the PPA scenario is expected to result in positive net nominal or NPV savings over the 25-year analysis period. This is primarily due to two factors:
    a. Low cost of energy during the off-peak period when BEBs will predominantly charge.
    b. Low value for exported energy generation from Evergy's monthly Avoided Cost of Generation.
2. CapEx costs and PPA rates are based on NV5's recent procurements for commercial solar PV projects across the United States.
3. The Inflation Reduction Act (IRA) of 2022 includes a number of potentially beneficial provisions; however, the recent administration has stated intentions to modify or eliminate the current tax credits. At the time of the analysis, the provisions included:
    a. Extension of the 30% Investment Tax Credit (ITC) (included in modeling).
    b. Potential 10% ITC Domestic Content Adder (not included in this modeling).
    c. Elective (Direct) Payment option for tax-exempt entities (included in modeling).

Fundings Needs Assessment

Funding Assessment Overview

Lawrence allocates funds based on an established procurement timeline determined by the useful life of its buses. Transitioning to a zero-emission bus fleet increases overall capital funding requiremenst because of the higher incremental cost of zero-emission buses, the purchase and installation of new infrastructure, and required modifications to maintenance facilities.

Lawrence Transit Funding Needs

Over the course of the transition period, Lawrence plans to deploy additional zero-emission vehicles into its fleet. In order to move towards a successful deployment of additional zero-emission buses, the City projects it will require an additional estimated range of $19.4M - $28.2M in funding to cover the procurement of vehicles and infrastructure during the transition period for the Fixed Route fleet. The cost range includes the various transition scenarios analyzed in this transition plan.

Available Funding Resources & Resulting Funding Shortfalls

Based on the funding needs identified above and an assessment of the City's current projections, the City must identify resources to cover these additional funding needs. Traditional formula funding will provide support for the transition to a zero-emission fleet (e.g., using formula funds to cover the base price of a zero-emission bus and applying for Low-No funds for the incremental cost difference), but it is likely the City will require additional funding to offset the higher costs associated with zero-emission technology. The City is prepared to pursue funding opportunities at the federal, state, and local levels, as necessary and as available.

Federal funding sources the City is considering include:

- United States Department of Transportation (USDOT)
  - Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Grants
- Federal Transportation Administration (FTA)
  - Bus and Bus Facilities Discretionary Grant
  - Low-or No-Emission Vehicle Grant
  - Metropolitan & Statewide Planning and Non-Metropolitan Transportation Planning
  - Urbanized Area Formula Grants
  - State of Good Repair Grants
  - Flexible Funding Program – Surface Transportation Block Grant Program
- Environmental Protection Agency (EPA)

    - Environmental Justice Collaborative Program-Solving Cooperative Agreement Program
    - Climate Pollution Reduction Grants
- Volkswagen Environmental Mitigation Trust Funds

Other potential future options include:

- Revenue bonds
- Tax increases
- Public-Private Partnerships

Partnership Assessment

Establishing and maintaining a partnership with the local electric utility is critical to successfully deploying zero-emission vehicles and maintaining operations. With the addition of battery electric buses to a fleet, a transit agency may likely become a utility's largest customer. In addition to increasing energy and demand requirements, grid-side infrastructure and agency operational costs. Early coordination and discussions can avoid costly delays and misaligned operational strategies while also revealing opportunities for lower operational costs and smart investments. Fortunately, electric utilities are beginning to develop electric vehicle rates and streamlined processes for charging infrastructure interconnections that can support successful zero-emission fleet deployments.

The City has a working relationship with staff at the agency's electric utility, Evergy. Evergy has been included in conversations regarding potential infrastructure needs as the City transitions to a zero-emission fleet. The City will continue to keep Evergy involved and engaged as future decisions are made in regards to zero-emission vehicles procurements. The City recognizes Evergy as a critical partner in electrification and will continue to partner with Evergy as the agency's ZEB fleet expansion takes place.

Additionally, the City understands the importance of establishing partnerships with zero-emission vehicle OEMs and providers of fueling infrastructure. As ZEB deployments continue, the City will work to further build on existing relationships with existing partners, as well as create additional relationships with different partners, to ease the transition process.

Workforce Analysis

In order to support additional ZEB operations, the City has identified opportunities to ensure the current and future workforce is prepared to manage a larger percentage of ZEBs in its fleet. This Workforce Analysis focuses on ZEB operations and maintenance.

Workforce Analysis Overview

Developing and training the workforce required to operate and maintain ZEBs requires significant investment and planning. The City is experienced in recruiting, hiring, training, and integrating new staff to ensure that employees are qualified to provide quality services. The City contracts with Transdev for the operation and maintenance of the City's transit vehicles. The City and Transdev have an existing understanding of battery electric vehicles, because of the existing battery electric buses in Lawrence's fleet.

The City plans to further develop and maintain a qualified ZEB staff by continuing to train existing staff on zero-emission vehicles. Meaningful investment is required to upskill maintenance staff and bus operators who were originally trained in diesel vehicle maintenance and fossil fuel fueling infrastructure. Transitioning to zero-emission vehicles is a paradigm shift for all aspects of transit operations, including but not limited to scheduling, maintenance, and yard operations. The City's workforce development activities will address the identified skills and tools needed for each relevant team.

Identified Training Needs

The City is committed to ensuring new training and technologies do not displace current workers and has placed a priority on training existing staff. The identified training needs are anticipated to evolve as the zero-emission fleet expands. As such, the following training plans are intended to provide a framework.

1) *Retraining/refresher training courses*

   The City recognizes that training must be ongoing and will include refresher courses throughout its transition to ZEBs.
2) *ZEB tools*

   The following tools have been identified as top needs to procure as more of the maintenance and management falls to internal staff with an expanded ZEB fleet.
   - Diagnostic tools and computer
   - Scaffolding
   - Safety harnesses

Resources and Strategies to Meet Identified Needs

In order to incorporate the above training needs, the City envisions using following resources and strategies. To achieve these goals and ensure a successful deployment of zero-emission buses, the City will require an estimated $155,000 in funding to cover the workforce development initiatives identified. Low-No funding will ensure the workforce development plan can be implemented in parallel with deployment of vehicles and infrastructure. Please note that the resources/strategies identified below will be further evaluated following grant award to develop the most appropriate use of resources.

Table 22: Training Resources

Training Resource/Strategy	Funding
OEM Operator, Maintenance, and First Responder Training	$50,000
Safety Harnesses and Lanyards	$20,000
Diagnostic Tools & Computer	$10,000
Scaffolding	$75,000

Workforce Development Timeline

Demand for skilled and experienced workers will increase rapidly as new clean transportation policies and programs take effect and as numerous agencies begin fleet transitions. Aligning workforce development activities with the fleet transition timeline ensures that a qualified workforce is ready and available to support a successful deployment.

Workforce development is an ongoing process that must continue as fleets scale up and deploy additional zero-emission vehicles. To ensure that the workforce scales efficiently and cost-effectively, the City will employ training strategies that support additional zero-emission vehicle deployments in the future.

Conclusions and Recommendations

Zero-emission buses offer a wide range of benefits not only for the agencies deploying them but also for the communities they impact. There are significant environmental benefits associated with the transition to ZEB technology. Widespread adoption of zero-emission bus technology has the potential to greatly reduce greenhouse gas (GHG) emissions resulting from the transportation sector. Through the reduction of tailpipe emissions, ZEBs benefit the environment by delivering better air quality and health benefits to the passengers and neighboring areas which tend to be disproportionately low-income and historically disadvantaged communities. ZEBs are also significantly quieter than traditional vehicles which can help with noise reduction.

ZEB technologies are in a period of rapid development. While the technologies have been proven in many pilot deployments, they are not yet matured to the point where they can easily replace current ICE technologies on a large scale. BEBs require significant investment in facilities and infrastructure and may require changes to service and operations to manage their range constraints. On the other hand, FCEBs can provide an operational equivalent to ICE buses, but the cost of vehicles, fueling infrastructure, and fuel remain a significant barrier to mass adoption. Despite the challenges associated with ZEB technology, the City is committed to implementing environmentally-friendly policies and reducing its carbon footprint.

The Service Assessment shows the large feasibility gap that exists with transitioning Demand Response type vehicles to electric. Zero-emission cutaways are an emerging market that is still in the early stages of development and use. The fuel cell-electric market is in the earlier stages of development as compared to the battery-electric market, as there are currently only demonstration fuel cell-electric cutaways in transit service in the U.S. The battery-electric cutaway market offers more developed options, but current range abilities of these vehicles is a limiting factor. It is expected that considerable development will occur in the market in the next several years due to requirements for California transit agencies to begin transitioning cutaway vehicles as early as 2026 as a result of the Innovative Clean Transit (ICT) Rule. It will be important for the City to continue to monitor new zero-emission technologies that enter the market that could help the City meet more of its service demand for Demand Response.

Given these considerations, the recommendations for the City are as follows:

1) **Monitor local and regional developments:** In the zero-emission technology sector, developments at the local level can have the ability to catapult the industry forward. When local bus OEMs or fuel providers enter the zero-emission market, it can spark technological innovation and cost reduction. Neighboring transit agencies can also work together through group purchasing agreements and lobbying efforts to bring about reduced purchase costs or more funding opportunities.
2) **Focus on a single zero-emission technology:** The City has already procured nine battery electric vehicles that are now part of the Fixed Route fleet, with funding for an additional two already secured. Based on the results of the Service Assessment, only seven of the Fixed Route blocks are infeasible with projected depot-charge only BEB technology by 2035. Incorporating on-route charging or editing current blocks to increase BEB feasibility would be more cost effective and would avoid the introduction of an entirely new technology (hydrogen fuel cell) to the fleet, which would require new skills and understanding amongst maintenance and operational staff.
3) **Focus on fixed route transition first:** As mentioned above, there is a large feasibility gap that exists with the Demand Response fleet due to limited range abilities of electric cutaways vehicles compared to the City's service needs. There has not been widespread use of these vehicles in the

transit industry to date, due to the range limitations for the typical service needed for agencies. The fixed route zero emission transit bus market is more developed and more capable of meeting the service needs. Because of this, and the fact that the City has already started transitioning the fixed route fleet, Lawrence should consider delaying the transition of the Demand Response fleet to allow the market to mature, and instead focus on the fixed route fleet for transition in the near term.

4) **Update and revisit the ZEB Transition Plan regularly:** This transition plan is a living document that should be used alongside other decarbonization initiatives. Costs and operations can be updated and changed going forward.

The transition to ZEB technologies represents a fundamental paradigm shift in bus procurement, operation, maintenance, and infrastructure. It is only through a continual process of deployment with specific goals for advancement that the industry can achieve the goal of economically sustainable, zero-emission public transit.

Appendix A

ZEB Infrastructure Conceptual Site Plans

NV5 created conceptual site plans for the new, additional depot charging and hydrogen fueling infrastructure that was assumed for each ZEB Scenario. This infrastructure is assumed to be implemented at a future facility on an adjacent property to the west of the existing Timberedge Road depot, where the City's existing charging infrastructure (12 total dispensers) is located. The site plans include the charging infrastructure for both the Fixed Route and Demand Response fleets.

Figure A1 represents the site plan for Fixed Route Scenario 1 and Scenario 3. Figure A1 shows a total of 24 charging dispensers (fifteen (15) are assumed for Fixed Route Scenarios 1 and 3, and nine (9) are assumed for Demand Response Scenario 1). Figure A1 also shows a Hydrogen Fueling Area to the west of the charging infrastructure. This fueling area is assumed for Fixed Route Scenario 3.

Figure A2 represents the site plan for Fixed Route Scenario 2. Figure A2 shows a total of 27 charging dispensers (eighteen (18) are assumed for Fixed Route Scenario 2, and nine (9) are assumed for Demand Response Scenario 1). The on-route chargers assumed in Fixed Route Scenario 2 are not shown in the conceptual site plan, as these are chargers are assumed to be installed at a different location in Lawrence.