Zero-Emission Bus Fleet Transition Study

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Executive Summary

Mountain Line contracted with the Center for Transportation and the Environment (CTE) to develop a Zero Emission Bus (ZEB) Transition Plan to identify a zero-emission roadmap for full fleet replacement. In 2023 Mountain Line will replace two (2) hybrid diesel vehicles that have reached the end of their service life with battery-electric vehicles (BEB) through a previously awarded grant. By replacing hybrid diesel vehicles with ZEBs in accordance with the replacement schedule thereafter, Mountain Line can complete a full transition to a zero-emission fleet by 2034, supporting sustainability and climate action plans and responding to voter support for sustainable bus technologies. Board approval gave staff direction for how to proceed and assumptions to make on a variety of projects but does not commit Mountain Line to implementing the ZEB 100% moving forward. Specific decisions will be made bus by bus, project by project as funds are available and desire exists. The results of the study will inform Mountain Line Board of Directors and staff of estimated costs, infrastructure needs, impacts to local service provisions, and the benefits and constraints of several zero-emissions strategies to aid in future planning.

Zero-emission technologies considered in this study include BEBs and hydrogen fuel cell-electric buses (FCEBs). BEBs and FCEBs have similar electric drive systems that feature a traction motor powered by a battery. The primary difference between BEBs and FCEBs is the amount of battery storage and how the batteries are recharged. The energy supply in a BEB comes from electricity provided by an external source, typically the local utility's grid, which is used to recharge the batteries. The energy supply for an FCEB is completely on-board, where hydrogen is converted to electricity using a fuel cell. The electricity from the fuel cell is used to recharge the batteries to extend the range. The electric drive components and energy source for a BEB and FCEB are illustrated in **Figure ES-1.**

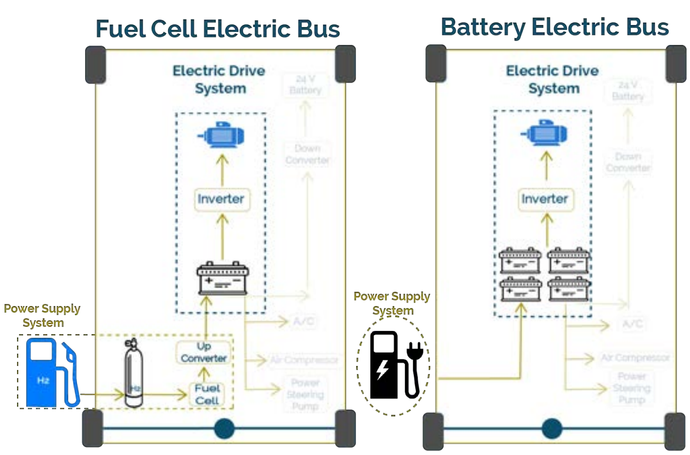

Figure ES-1 –Battery and Fuel Cell Bus Schematic

In 2008, voters approved a sales tax increase allowing Mountain Line to adopt low and zero-emissions bus technologies as their fleet expands and is replaced. Additionally, in 2018 the Flagstaff City Council adopted a Climate Action and Adaptation Plan which aims to reduce greenhouse gas emissions in Flagstaff by 30% by 2030 and by 80% by 2050. By the end of the transition period in 2034, greenhouse gas emissions will be reduced by approximately 40% to 65%, depending on the transition approach and amount of renewable energy in the electrical grid.

CTE worked closely with Mountain Line staff throughout the project to develop the approach, define the assumptions, and confirm the results. The approach for the study is based on analysis of five (5) scenarios:

1. Baseline Hybrid Diesel (current Hybrid Diesel)
2. BEB Depot-Only Charging
3. BEB On-Route and Depot Charging
4. Mixed BEB and FCEB
5. FCEB Only

The Baseline Hybrid Diesel scenario assumes that there are no changes to the current technology for bus procurements (e.g., hybrid diesel) and is used for comparison to the other ZEB transition scenarios. Mountain Line expressed that, due to space constraints at the current Mountain Line Kaspar Drive Maintenance Facility, it is likely unable to increase fleet size as a strategy for overcoming BEB range limitations. The BEB Depot-Only Charging scenario was used to help identify the required fleet size increase regardless of current space constraints. The BEB Depot-Only Charging scenario assumes that vehicles are charged only at the depot when they are not in service. In the BEB Depot-Only scenario, BEBs are deployed as one-for-one replacements for in-service buses where analysis determines that they can complete specified service blocks (e.g., meet the daily mileage requirements) and two-for-one where analysis determines that they cannot complete specified service blocks.

The BEB On-Route and Depot Charging, Mixed BEB and FCEB, and FCEB Only scenarios were developed as viable options for 100% one-for-one fleet replacement with zero-emission vehicles. In the Mixed BEB and FCEB scenario, BEBs are deployed as one-for-one replacements where analysis determines that they can complete specified service blocks, and FCEBs are deployed where analysis determines that BEBs cannot complete specified service blocks.

Improvements in technology beyond the current state are expected, but there is no indication of when the market may see BEB technology improve to the point of one-for-one replacement of internal combustion engine vehicles regardless of duty cycle, or when the cost of FCEB or hydrogen fuel will decrease to cost-competitive levels. As a result, when considering all the various scenarios, this study can be used to develop an understanding of the range of costs that may be expected for Mountain Line's ZEB transition.

The underlying basis for this assessment is CTE's ZEB Transition Planning Methodology, which is a complete set of analyses used to support agencies 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. Through the assessment methodology, CTE develops engineering estimates for vehicle efficiency and energy consumption to project the range of given vehicle technologies in Mountain Line service. Mountain Line collected sample data from nine (9) routes and used current ZEB specifications to estimate range and energy consumption on all Mountain Line fixed-service routes and blocks under varying environmental and passenger loading conditions. Once this information was established, CTE completed the following assessment to develop cost estimates for each transition scenario.

1. Fleet Assessment
2. Fuel Assessment
3. Facilities Assessment
4. Maintenance Assessment
5. Total Cost of Ownership Assessment

These assessments result in a total cost of ownership, inclusive of capital investments (buses and fueling infrastructure) and operating expenses (fuel/charging and maintenance) over the transition period (2020–2034) for each transition scenario. The table and figure below provide a side-by-side comparison of the cumulative transition costs for each scenario.

Table ES-1 – Total Cost of Ownership, by Scenario

	Baseline Hybrid Diesel	BEB Depot Only	BEB On-Route + Depot	Mixed BEB and FCEB	FCEB Only
Fleet	$ 20,800,000	$ 35,200,000	$ 26,200,000	$ 30,100,000	$ 32,300,000
Fuel	$ 8,462,000	$ 6,240,000	$ 10,396,000	$ 11,863,000	$ 14,034,000
Facilities	-----	$ 7,252,000	$ 9,090,000	$ 8,093,000	$ 5,068,000
Maintenance	$ 5,065,000	$ 7,755,000	$ 6,853,000	$ 8,178,000	$ 8,836,000
Total	**$ 34,327,000**	**$ 56,488,00**	**$ 52,539,00**	**$ 58,235,00**	**$ 60,238,000**
Incremental Cost Over Baseline Hybrid Diesel		**$ 22,121,000**	**$ 18,212,000**	**$ 23,908,000**	**$ 25,911,00**

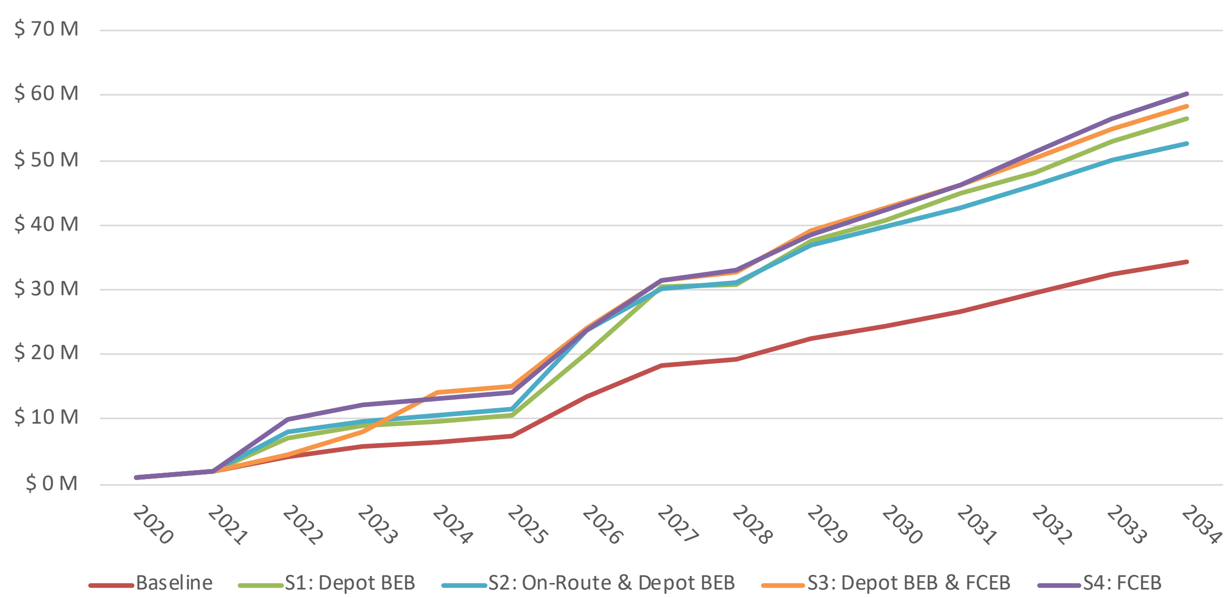

Figure ES-2 – Total Cost of Ownership, by Scenario

If Mountain Line selects an all BEB strategy, incremental ZEB transitional costs are likely to fall between $18 million for the BEB On-Route and Depot Charging scenario and $22 million for the BEB Depot-Only Charging scenario. The difference in incremental cost for these scenarios is a result of more BEBs added to the fleet for the BEB Depot-Only scenario because not all hybrid diesel vehicles in the current fleet can be replace one-for-one with BEBs.

If Mountain Line selects an FCEB Only strategy, incremental ZEB transitional costs are estimated at approximately $26 million for the full transition. All current hybrid diesel vehicles can be replaced one-for-one with FCEBs. A primary assumption for the FCEB analysis is that FCEB vehicles will be available for all vehicle types and lengths during the transition period. In addition, due to the limited deployment of FCEBs in service in the United States, fuel costs and capital costs for vehicles remain high. These costs are expected to come down in the future as more vehicles are deployed; however, there is no basis at this time to make assumptions as to how much they may be reduced. Additionally, data for FCEB maintenance costs reflect higher costs than what much of the market would expect with newer deployments because much of the data is based on older vehicles past their warranty periods and requiring expensive support from overseas companies. As such, there are more unknowns associated with the incremental costs for the FCEB Only scenario, and costs are likely to be more subject to change. Significant investments in hydrogen infrastructure will be required and will take years to develop to gain a better understanding of the long-term costs for FCEB Only deployment.

As expected, with an incremental cost of approximately $24 million, the Mixed BEB and FCEB scenario has an incremental cost that falls between an all BEB and all FCEB deployment when the current fleet size is maintained. Though the costs are cheaper for a mixed fleet deployment than the FCEB Only scenario, there are complexities with managing a mixed fleet through the transition that would require maintaining existing internal combustion engine vehicle infrastructure, installing new BEB infrastructure, and installing new FCEB fueling infrastructure. Space constraints at the depot will necessitate careful planning if this path is selected.

As a result, recommendations for Mountain Line are as follows:

1. **Be proactive with ZEB deployments:** Additional development, data collection, and analyses are needed before ZEB technology is ready for fleetwide deployment. For example, BEBs will require charge management software, hardware, and standards to manage the fleetwide transition. For FCEB deployment to be competitive with BEBs, lower fuel costs that will evolve over time with the production of hydrogen at scale will be required. Mountain Line should move forward carefully, taking advantage of various grant and incentive programs to offset the incremental cost for ZEB deployment. Incentive programs may be eliminated in future years as ZEB procurements become mandated instead of optional.
2. **Choose a ZEB transition scenario that maintains fleet size due to space constraints.** Due to limited vehicle storage space at the Kaspar Drive Maintenance Facility, the number of vehicles required to maintain current Mountain Line fixed-route service levels would exceed the facility's indoor capacity for storing and charging vehicles. The BEB Depot-Only scenario is the only scenario that requires an increase in fleet size. In addition, the Mixed Fleet scenario requires infrastructure to support both battery-electric and fuel-cell technology at the Kaspar Drive Maintenance Facility. Significant changes to facility operations would be required to support deployment of infrastructure for both technologies as there is not currently space on the facility to install a hydrogen fueling station (or on-site production).

A review of the results from the transition analysis indicates that BEB On-Route and Depot charging provides the lowest total cost of ownership over the transition period. Mountain Line already operates all service through the Downtown Connection Center (DCC), thus a central location for charging is already available. In addition, the master planning is currently underway to replace and modernize the current DCC facility beginning in 2021. CTE recommends further evaluation of the BEB On-Route and Depot Charging scenario to refine an implantation approach to begin the transition to a zero-emission future.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. ZEB technology requires significant development before it is ready to fully support fleetwide transitions. However, 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.

Introduction

Mountain Line, operated by Northern Arizona Intergovernmental Public Transportation Authority (NAIPTA), provides fixed-route bus service to Flagstaff, Arizona and seasonal bus service to Arizona Snowbowl Ski Resort.

Mountain Line contracted with the Center for Transportation and the Environment (CTE) to complete a Zero-Emission Bus (ZEB) Transition Plan in February 2020 to develop a zero-emission path forward for fleet replacement. In 2022 (or 2023), Mountain Line will replace two (2) hybrid diesel vehicles that have reached the end of their service life with battery-electric vehicles (BEB) through a previously awarded grant. By replacing hybrid diesel vehicles with ZEBs in accordance with the replacement schedule thereafter, Mountain Line can complete a full transition to a zero-emission fleet by 2034, supporting sustainability and climate action plans and responding to voter support for sustainable bus technologies. The results of the study will inform Mountain Line Board of Directors and staff of estimated costs, infrastructure needs, impacts to local service provisions, and the benefits and constraints of several zero-emissions strategies to aid in future planning.

Zero-emission technologies considered in this study include BEBs and hydrogen fuel cell-electric buses (FCEBs). BEBs and FCEBs have similar electric drive systems that feature a traction motor powered by a battery. The primary difference between BEBs and FCEBs is the amount of battery storage and how the batteries are recharged. The energy supply in a BEB comes from electricity provided by an external source, typically the local utility's grid, which is used to recharge the batteries. The energy supply for an FCEB is completely on-board, where hydrogen is converted to electricity using a fuel cell. The electricity from the fuel cell is used to recharge the batteries to extend the range. The electric drive components and energy source for a BEB and FCEB are illustrated in **Figure 1.**

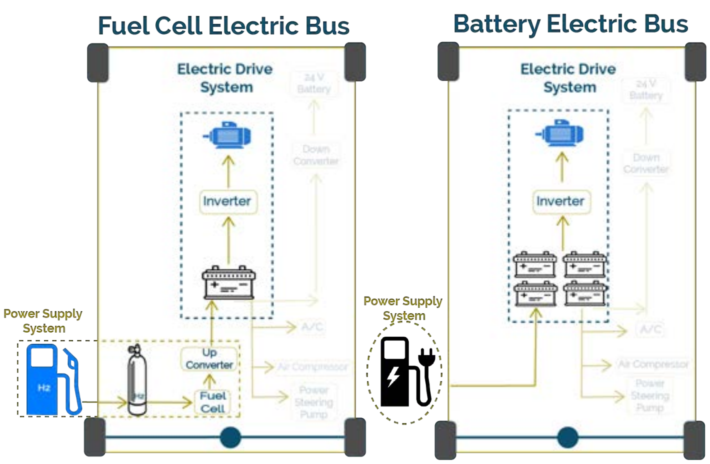

Figure 1 – Battery Fuel Cell Bus Schematic

ZEB Transition Planning

ZEB Transition Planning Methodology

This study uses CTE's ZEB Transition Planning Methodology, which is a complete set of analyses used to inform agencies 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. The work steps specific to this study are outlined below:

1. Planning and Initiation
2. Requirements & Data Collection
3. Service Assessment
4. Fleet Assessment
5. Fuel Assessment
6. Facilities Assessment
7. Maintenance Assessment
8. Total Cost of Ownership Assessment

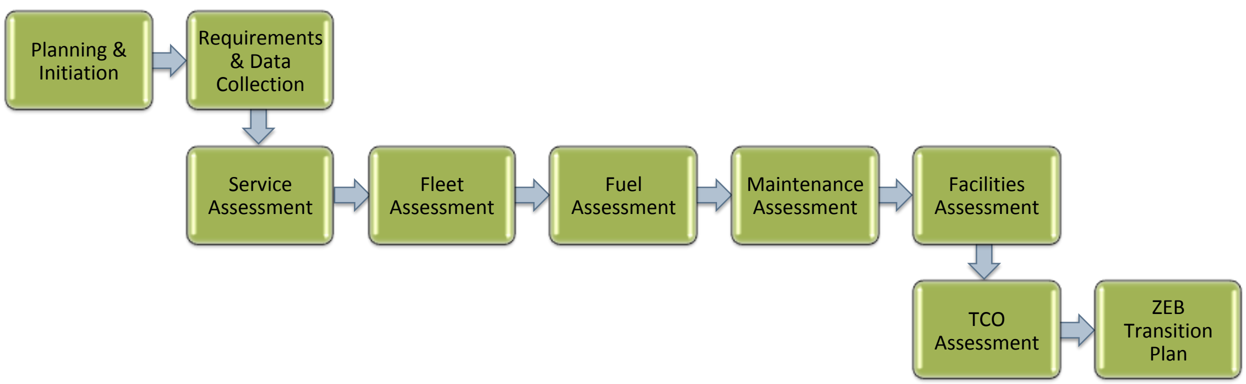

Figure 2 – CTE's ZEB Transition Study Methodology

A detailed description of the ZEB Transition Study Methodology is available in **Appendix A**.

Assessment Scenarios

The approach for this ZEB transition study is based on the creation and analysis of five (5) scenarios:

1. Baseline Hybrid Diesel
2. BEB Depot-Only Charging
3. BEB On-Route and Depot Charging
4. Mixed BEB and FCEB
5. FCEB Only

The Baseline Hybrid Diesel scenario assumes that there are no changes to the current technology for bus procurements and is used for comparison to the other ZEB transition scenarios.

Mountain Line indicated that they are likely unable to increase fleet size as a strategy to overcome BEB range limitations to achieve a 100% ZEB transition due to space constraints present at the current Kaspar Drive Maintenance Facility. The BEB Depot-Only Charging scenario was used to identify the required fleet size increase regardless of space constraints. The BEB Depot-Only Charging scenario assumes that vehicles are charged only at the depot when they are not in-service. In the BEB Depot-Only scenario, BEBs are deployed as one-for-one replacements where analysis determines that they can complete specified service blocks (e.g., meet the daily mileage requirements), and two-for-one where analysis determines that they cannot complete specified service blocks.

The BEB On-Route and Depot Charging, Mixed BEB and FCEB, and FCEB Only scenarios were developed as viable options for 100% one-for-one fleet replacement with zero-emission vehicles. In the BEB On-Route and Depot Charging and FCEB Only scenarios, respective ZEBs are deployed one-for-one according to Mountain Line's fleet replacement schedule. In these scenarios, ZEBs are able to complete all current fixed-route service blocks with the technology currently available. In the Mixed BEB and FCEB scenario, BEBs are deployed as one-for-one replacements where analysis determines that they can complete specified service blocks, and FCEBs are deployed where analysis determines that BEBs cannot complete specified service blocks.

Due to the nature of varying conditions over the period of a long-term fleet transition, it is necessary to establish a number of simplifying assumptions. These assumptions were developed based on discussions between CTE and Mountain Line and are as follows:

- Transition to a 100% ZEB fleet by 2034 following Mountain Line's fleet replacement schedule
- Current fleet composition (fiscal year 2020 fleet plan) used for the Baseline Hybrid Diesel scenario
- Currently planned fleet replacement cycles
- 15-year bus lifespan assumed for fixed-route ZEB transit buses
- Costs expressed in 2020 dollars with no escalation
- Current battery sizes for BEBs and fuel tank sizes for FCEBs are based on existing specifications for vehicles that have completed federally mandated Altoona testing
- A 5% improvement in battery capacity (for BEB) and efficiency (FCEB) every two years
- A maintenance overhaul will occur at the mid-life of each vehicle (8 years); the mid-life overhaul does not include the replacement of the batteries for BEBs
- For BEBs, instead of a mid-life battery replacement, a battery warranty of 12 years is purchased at the time of each vehicle procurement; 15 year battery warranties may be available based on negotiations with the bus OEM

Requirements Analysis

Baseline Hybrid Diesel Data Collection

It is essential to understand the key elements of Mountain Line's service to evaluate the costs associated with a full ZEB transition. Key data elements of the current Mountain Line service were provided by Mountain Line staff and include the following:

- Fleet composition
- Routes and blocks
- Mileage and fuel consumption
- Maintenance costs

Fleet

At the time of the study, the Mountain Line bus fleet totaled twenty-nine (29) fixed-route, hybrid diesel vehicles that provide service on ten (10) fixed routes. Mountain Line plans to operate the buses out of two (2) depot locations. Of the twenty-nine (29) vehicles, nineteen (19) are 35' buses that will operate out of the Kaspar Drive Maintenance Facility, four (4) are 35' buses that will operate out of the planned Northern Arizona University (NAU) facility or other separate facility, and six (6) are 60' articulated buses that will operate out of the planned NAU facility or other separate facility. Timeline for construction of the NAU facility is currently unknown, and funding has not yet been identified.

Routes and Blocks

Mountain Line operates ten (10) fixed routes. As many as fourteen (14) bus blocks are needed to operate the service on any given day. The number of daily blocks required is less during the summer and when NAU is on break.

There are currently forty-three (43) unique blocks defined. Thirty-one (31) of these blocks are operated with 35' buses and twelve (12) are operated with 60' buses. For the 35' bus blocks, seventeen (17) operate all year, five (5) operate when NAU is in session, and nine (9) during NAU breaks. For the 60' bus blocks, two (2) operate all year, six (6) during school, and four (4) during NAU breaks.

Fuel

Mountain Line's current fuel use was collected and used to estimate energy costs throughout the study period. Cost escalation is not assumed throughout the study. Mountain Line's current fixed-route fleet is comprised of all hybrid diesel buses. The annual fixed-route fleet mileage is 1,020,591 miles, of which 869,512 miles are driven annually by 35' buses and 151,079 miles are driven annually by 60' buses. The annual fixed-route fleet fuel use is 188,040 gallons of diesel, of which 156,923 gallons of diesel are consumed by 35' buses and 31,117 gallons of diesel are consumed by 60' buses.

Service Assessment

Bus efficiency and range are primarily driven by vehicle specifications; however, they can be impacted by a number of variables including the route profile (e.g., distance, dwell time, acceleration, sustained top speed over distance, average speed, traffic conditions), topography (i.e., grades), climate (i.e., temperature), driver behavior, and operational conditions such as passenger loads and auxiliary loads. As such, BEB efficiency and range can vary dramatically from one agency to another. Therefore, it is critical to determine efficiency and range estimates based on an accurate representation of the operating conditions associated with Mountain Line's system.

The first task in the Service Assessment is to develop route and bus models to run operating simulations for representative Mountain Line routes. CTE uses Autonomie, a powertrain simulation software program developed by Argonne National Labs for the heavy-duty trucking and automotive industry. CTE has modified software parameters specifically for electric buses to assess energy efficiencies, energy consumption, and range projections. Mountain Line collected GPS data from nine (9) Mountain Line routes. GPS data includes time, distance, vehicle speed, vehicle acceleration, GPS coordinates, and roadway grade that is used to develop the route model. CTE used component-level specifications and the collected route data to develop a Baseline Hybrid Diesel performance model by simulating the operation of an electric bus on each of the nine (9) routes.

The route modeling included analysis of several scenarios—varying passenger load, accessory load, and battery degradation—to estimate real-world vehicle performance, fuel efficiency, and range. The data from the routes, as well as the specifications for each of the selected bus types, was used to simulate operation of each type of bus on each respective route. The models were run with varying loads to represent "nominal" and "strenuous" loading conditions. Nominal loading conditions assume average passenger loads and moderate temperature over the course of the day, which places marginal demands on the motor and heating, ventilation, and air conditioning (HVAC) system. Strenuous loading conditions assume high or maximum passenger loading and either very low or very high temperature (based on agency's latitude) that require near maximum output of the HVAC system. This nominal/strenuous approach offers a range of operating efficiencies to use in estimating average annual energy use (nominal) or planning minimum service demands (strenuous). Modeled operating scenarios are included in **Table 1** below.

It should be noted that while GPS data was collected for nine (9) Mountain Line routes, this ZEB transition analysis evaluated all ten (10) fixed service routes. Data was not able to be collected for one seasonal route, the Mountain Express, but, for the sole purpose of ensuring enough ZEB buses are transitioned into the fleet for each scenario, Route 8 operating efficiencies were used to estimate the Mountain Express energy use. Route 8 was selected to estimate the Mountain Express energy use because it was modeled to have the highest energy use among 35' bus routes, and the Mountain Express route is predicted to have a similar high energy use due to the high speeds, grade, and elevation characterized by the route.

Table 1 – Modeled Operating Scenarios

Bus Length [ft]	Load Case	Occupants	HVAC Load [kW]	Other Loads [kW]	Total Aux Load [kW]
35	Nominal	11	4	3	**7**
35	Strenuous	32	10.5	3	**13.5**
60	Nominal	13	7.5	3	**10.5**
60	Strenuous	73	18	3	**21**

Route modeling ultimately provides an average energy use per mile (kilowatt-hour/mile [kWh/mi]) associated with each route, bus size, and load case. Using the results shown in **Table 2,** system-wide energy use and costs are estimated in the subsequent assessments. Details of each modeled route, including a map and speed, grade, and elevation profiles are included in **Appendix B**.

Table 2 – Modeling Results Summary

Bus Length [ft]	Route	Nominal Efficiency [kWh/mi]	Strenuous Efficiency [kWh/mi]
35	2	2.0	2.7
	3	1.7	2.3
	4	2.0	2.7
	5	2.0	2.7
	7	1.9	2.5
	8	2.4	3.3
	14	2.1	2.8
	66	1.8	2.4
	Mountain Express[1]	2.4	3.3
60	5x	2.8	3.9
	10	2.8	3.9

Using vehicle performance predicted from route modeling, combined with educated assumptions for battery electric and fuel cell technology, CTE analyzed the expected performance and range needed on every block in Mountain Line's fixed-route network and assessed the achievability of each block by BEBs and FCEBs over time, as range improves. This

[1] GPS route data was not collected for the Mountain Express Route. Route 8 operating efficiencies were used to estimate the Mountain Express energy use.

assessment analyzes the feasibility of maintaining Mountain Line's current level of service with BEB and FCEB vehicles. The analysis focuses on bus endurance and range limitations to determine if the ZEBs could meet the service requirements of the blocks throughout the transition period. The energy needed to complete a block is compared to the available energy for the respective bus type that is planned for the block to determine if a BEB or FCEB can successfully operate on that block. This assessment also determines a timeline for when blocks become for eligible for zero-emission vehicles as technology improves. This information is used to then inform ZEB procurements in the Fleet Assessment.

Research suggests that battery density for electric vehicles has improved by an average of 5% each year.[2] For the purposes of this study, considering the extended period of a complete fleet transition (e.g., through 2034), CTE assumes a more conservative 5% improvement every two years. If the trend continues, it is expected that buses may continue to improve their ability to carry more energy without a weight penalty or reduction in passenger capacity. Over time, BEBs are expected to approach the capability to replace all of an agency's fossil-fuel buses one-for-one. FCEBs do not have the same range constraints as BEBs. Typically, FCEBs can more readily serve an agency's current blocks on a one-to-one basis with internal combustion engine buses; however, costs of hydrogen fuel and bus capital costs can create higher barriers to entry. There is also a significant amount of research going towards fuel cell technologies. CTE assumes 5% biennial improvement in hydrogen tank size as a proxy for other component improvements such as battery capacity, motor efficiency, fuel cell efficiency, etc.

The block analysis, with the assumption of 5% improvement in battery capacity or improvement in hydrogen storage capacity every other year, is used to determine the timeline for when routes and blocks become achievable for BEBs and FCEBs, respectively, to replace hybrid diesel buses one-for-one. This information is used to then inform ZEB procurements in the Fleet Assessment. The results from the block analysis are used to estimate the number of ZEBs required to replace the hybrid diesel fleet and maintain Mountain Line's current service levels. Results from this analysis are also used to determine the specific energy requirements and develop the estimated costs to operate the ZEBs in the Fuel Assessment.

As current BEB and FCEB technology stands, 100% of Mountain Line's current fixed-route service blocks are achievable by FCEBs but not by depot-only charged BEBs. Results from the block analysis that indicate the yearly block achievability by bus length throughout the transition period for BEBs is included in **Figure 3** below.

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[2] U.S. Department of Energy; LONG-RANGE, LOW-COST ELECTRIC VEHICLES ENABLED BY ROBUST ENERGY STORAGE, MRS Energy & Sustainability, Volume 2, Wednesday, September 9, 2015; https://arpa-e.energy.gov/?q=publications/long-range-low-cost-electric-vehicles-enabled-robust-energy-storage

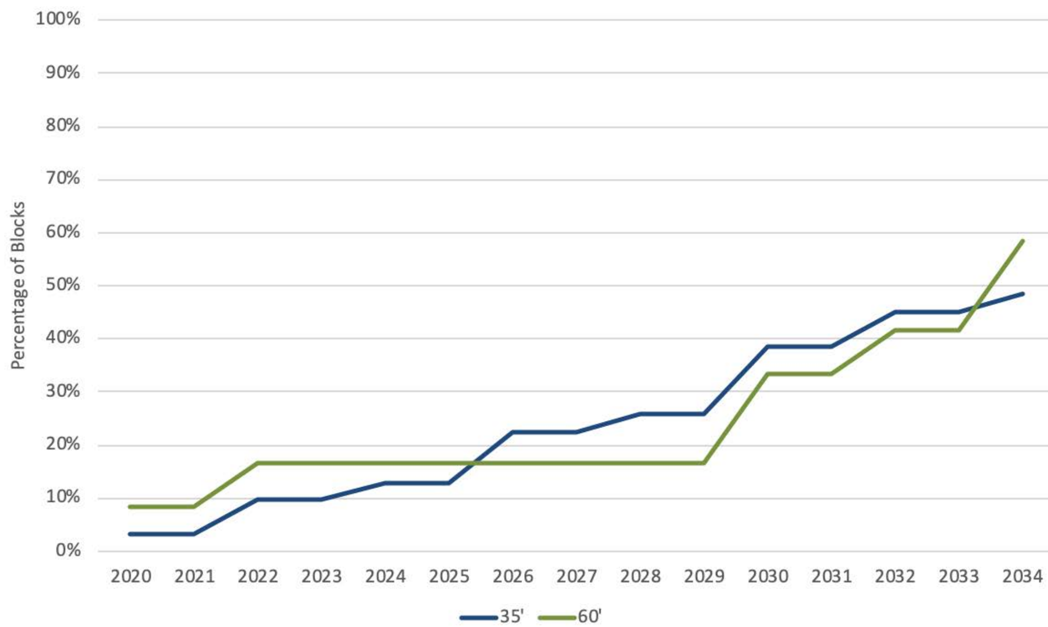


Figure 3 – BEB Block Achievability Percentage by Length

The BEB achievability in **Figure 3** shows that by 2034, it is expected that only 51% of Mountain Line's fixed-route blocks can be completed by depot-only charged BEBs. Specifically, by bus length, 48% of 35' bus blocks can be completed by BEBs and 58% of 60' bus blocks can be completed by BEBs.

While routes and block schedules are unlikely to remain the same over the course of the transition period, these projections assume the blocks will retain a similar structure to what is in place today including a similar distribution of distance, relative speeds, and elevation changes by covering similar locations within the city. This core assumption affects energy use estimates as well as block achievability in each year.

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 available service energy). Conceptually, older buses can be moved to shorter, less demanding blocks and newer buses can be assigned to longer, more demanding blocks. Mountain Line can rotate the fleet to meet the demand. This could also be said for FCEBs, although the impact of degradation is expected to be less.

Fleet Assessment

The goal of the Fleet Assessment is to determine the type and quantity of ZEBs best suited for Mountain Line's transition to a zero-emission fleet, as well as the schedule and costs associated with this transition. Results from the Service Assessment are integrated with Mountain Line's current fleet replacement plan and purchase schedule to produce two main outputs: a projected bus replacement timeline through the end of the projection period and the associated total capital costs for vehicle purchase.

While the industry is rapidly changing, there are still tradeoffs for each zero-emission technology, primarily between range, operational impact, capital costs, and operating costs. For this reason, CTE also considers a mixed fleet scenario consisting of multiple ZEB types in addition to scenarios that only consider a single technology.

Cost Assumptions

CTE developed cost assumptions for each bus length and technology type (e.g., hybrid diesel, BEB, FCEB). Key assumptions for bus costs for the Mountain Line Transition Study are as follows:

- Bus costs are based on Mountain Line procurements, industry quotes, and the State of California statewide procurement contract for BEBs and FCEBs executed in 2019
- Bus costs are inclusive of configurable options
- Bus costs are estimated where buses of a given configuration were not commercially available or where no quotes were available
- Future bus costs are based on costs in year 2020 since there is currently no basis for increases or decreases

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, a review of current data indicates that bus costs appear to have leveled out in recent years. However, vendors have added more battery storage over the same time period without increasing base costs.

FCEB prices are expected to decrease over time as vehicle orders increase; however, CTE does not currently have an adequate basis to assume reduced costs over time for the purchase of FCEBs. **Table 3** provides estimated bus costs used in the analysis.

Table 3 – Fleet Assessment Cost Assumptions for Flagstaff Area Transit Agencies

Length [ft]	Diesel Hybrid	Electric	Hydrogen
35	$ 650,000	$ 800,000	*$ 1,000,000*
60	$ 975,000	$ 1,300,000	$ 1,550,000

Note: Italic text indicates that the cost was an estimate based on similar vehicle costs

Baseline Hybrid Diesel

The Baseline Hybrid Diesel scenario is used for comparative purposes only. It assumes no changes to Mountain Line's current fleet composition throughout the life of the study. The Baseline Hybrid Diesel scenario creates context for incremental costs incurred or benefits accrued by transitioning the fleet to zero-emission.

Figure 4 provides the number of each hybrid diesel bus length that are purchased each year according to Mountain Line's fleet replacement schedule.

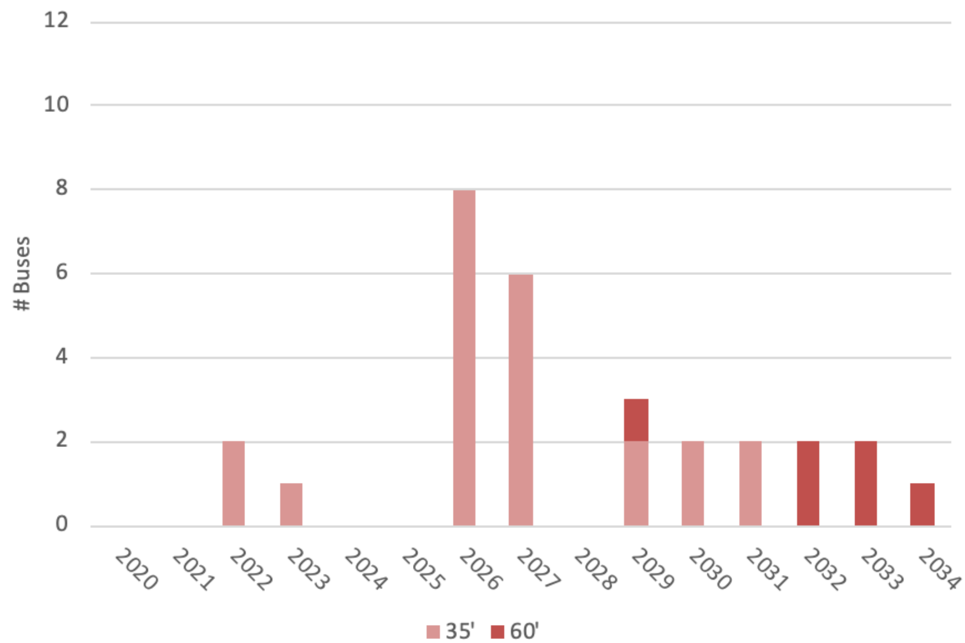


Figure 4 – Annual Vehicle Purchases, Baseline Hybrid Diesel

Figure 5 shows the annual capital costs based on the purchase schedule and bus cost assumptions for the Baseline Hybrid Diesel Scenario. Total bus purchases range from approximately $0 to $5 million each year.

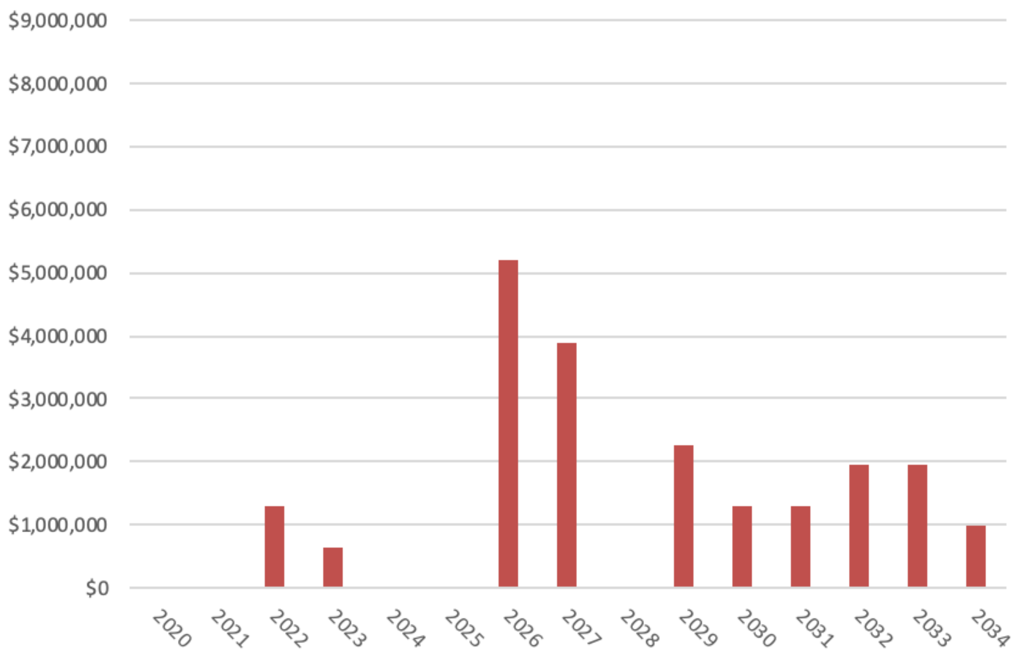


Figure 5 – Annual Capital Costs, Baseline Hybrid Diesel

BEB Depot-Only Charging

The BEB Depot-Only Charging scenario assumes that the number of BEBs transitioned into the fleet is dependent on the number of BEBs required to maintain Mountain Line's current service schedule. BEBs will replace the current hybrid diesel vehicles on a one-to-one basis following Mountain Line's vehicle replacement schedule. Additional BEBs are added over the course of the replacement schedule distributed among purchase years to account for service blocks that cannot be completed with a one-to-one replacement and to account for a spare fleet of nine (9) 35' vehicles per Mountain Line requirements. Because Mountain Line has space constraints, this scenario is used to help identify the required increase of fleet size and the degree of impact on the space constraints. **Figure 6** provides the number of BEBs purchased each year through 2034.

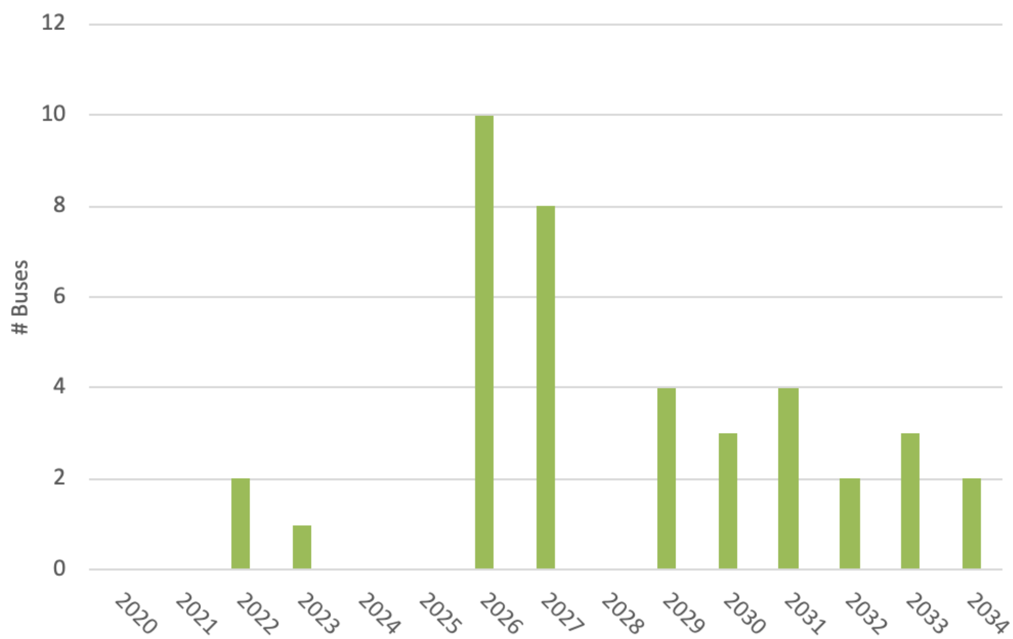


Figure 6 – Projected Vehicle Purchases, BEB Depot-Only Scenario

Figure 7 depicts the annual fleet composition through 2034. Upon completion of the full fleet transition in 2034, Mountain Line's fixed-route fleet will comprise of ten (10) more vehicles (thirty-nine (39) vehicles) than the current fleet (twenty-nine (29) vehicles).

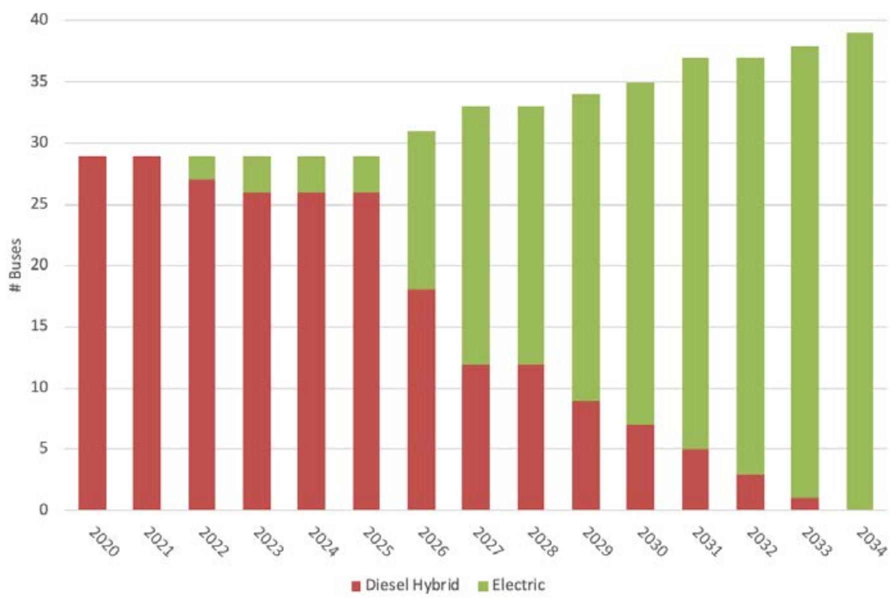


Figure 7 – Annual Fleet Composition, BEB Depot-Only Scenario

Figure 8 shows the annual bus cost for BEBs in a given year for the BEB Depot-Only Charging Scenario.

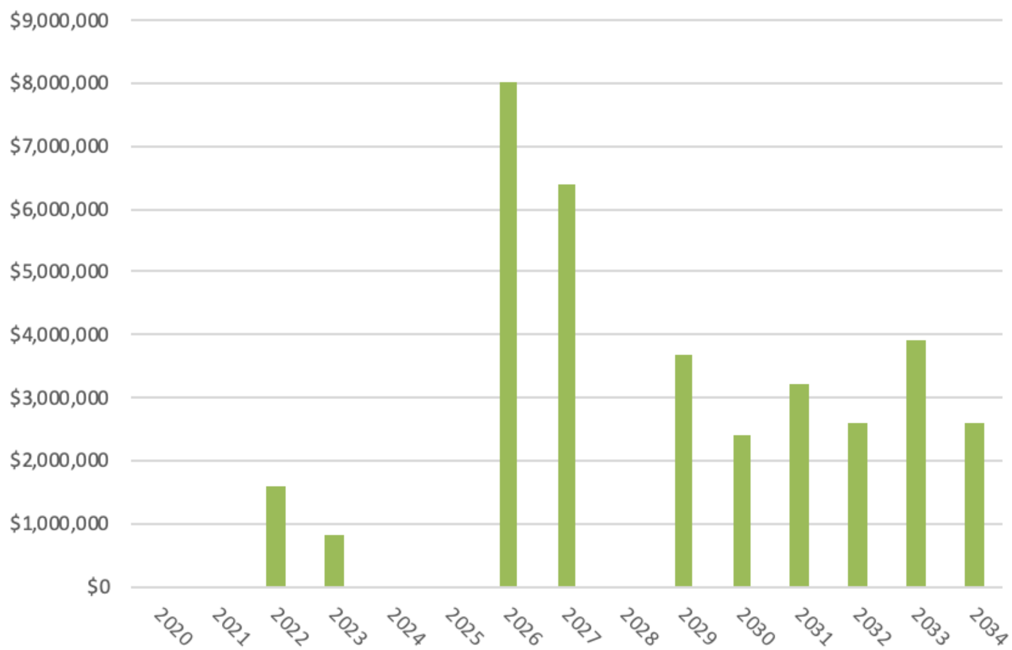


Figure 8 – Annual Capital Costs, BEB Depot-Only Scenario

BEB On-Route and Depot Charging

The BEB On-Route and Depot Charging scenario allows Mountain Line to maintain current service levels, as well as their current fleet size. On-route charging allows Mountain Line to add energy to buses while in service, providing the additional energy necessary to complete a block, without having to travel the extra distance and take the extra time to charge at a depot. Because all fixed-route service blocks have layovers at the same transit center (the Downtown Connection Center (DCC)), all BEBs will have the opportunity for on-route charging at this location. Depot charging overnight will still be necessary to replenish used energy that is not replenished from on-route charging.

Figure 9 through **Figure 11** show projected purchases, annual fleet composition, and annual total capital costs, respectively, for the BEB On-Route and Depot Charging scenario. By 2034, the addition of on-route charging allows Mountain Line to replace all current hybrid diesel vehicles one-for-one with BEBs.

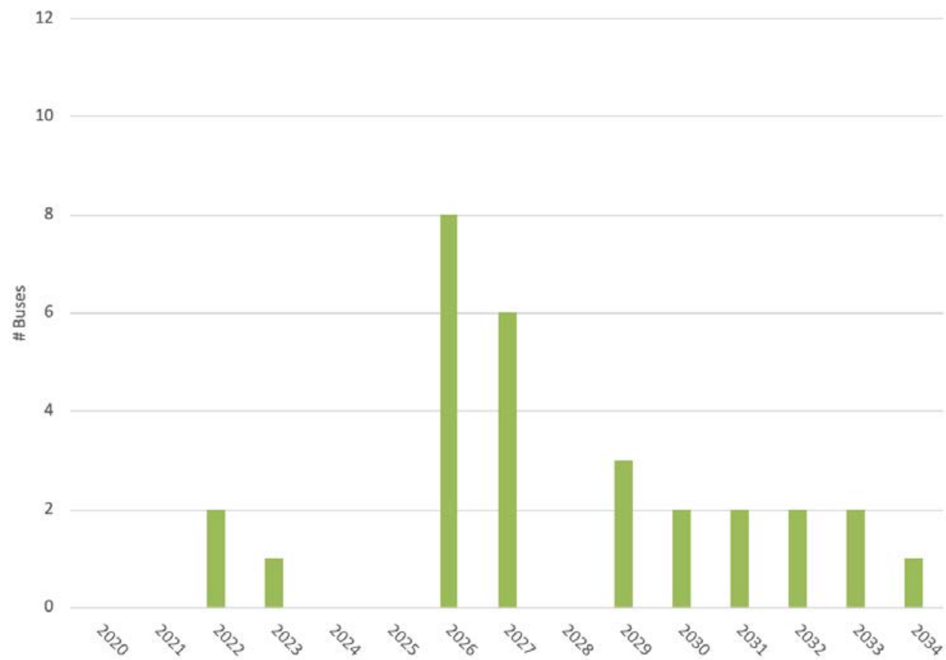


Figure 9 – Projected Vehicle Purchases, BEB On-Route and Depot Scenario

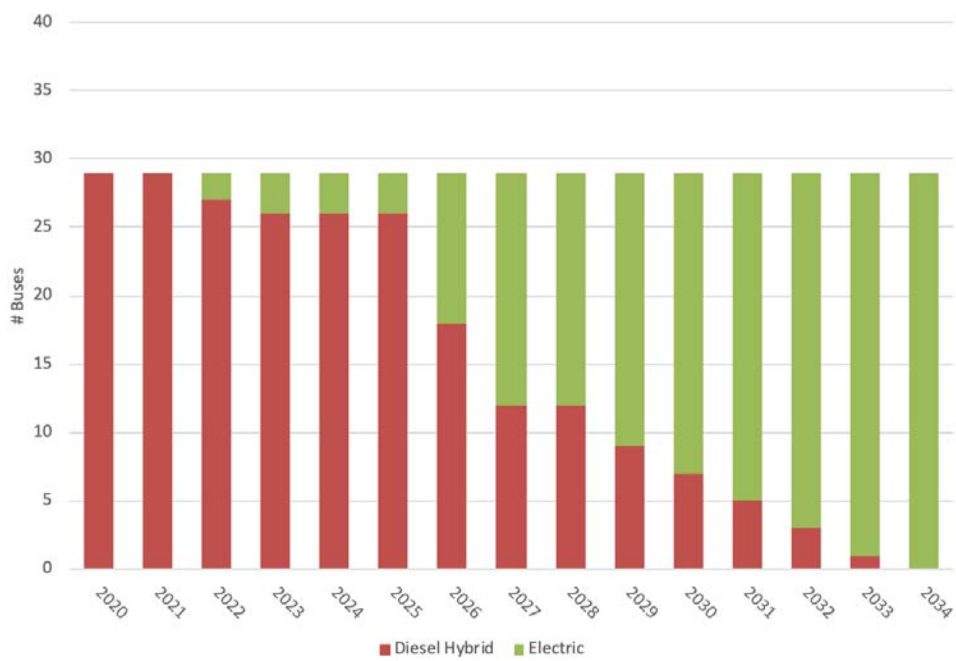


Figure 10 – Annual Fleet Composition, BEB On-Route and Depot Scenario

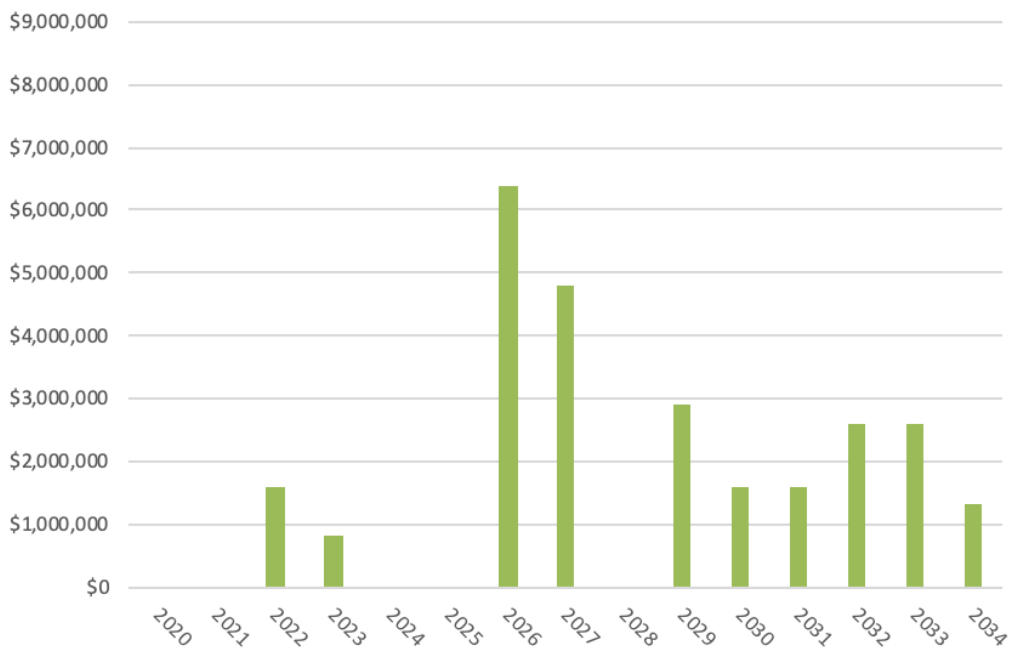


Figure 11 – Annual Capital Costs, BEB On-Route and Depot Scenario

Mixed BEB and FCEB

In the Mixed BEB and FCEB scenario, depot-charged BEBs are utilized where they can replace hybrid diesel vehicles on a one-for-one basis. Since FCEBs have a greater range, they are used on the longer blocks where BEBs are not feasible. FCEB range based on current technology is sufficient to complete all current Mountain Line fixed-route service blocks. **Figure 12** through **Figure 14** show projected purchases, annual fleet composition, and annual total capital costs for the Mixed BEB and FCEB fleet. By 2034, the Mountain Line fleet will be comprised of approximately 34% BEBs and 66% FCEBs.

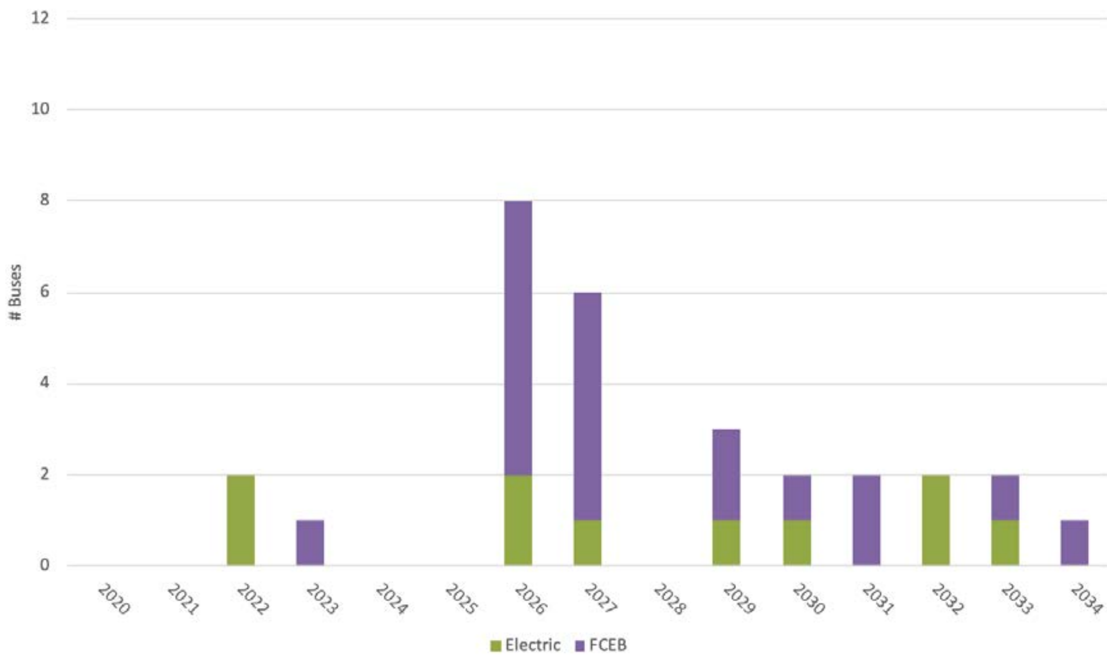


Figure 12 – Projected Vehicle Purchases, Mixed Scenario

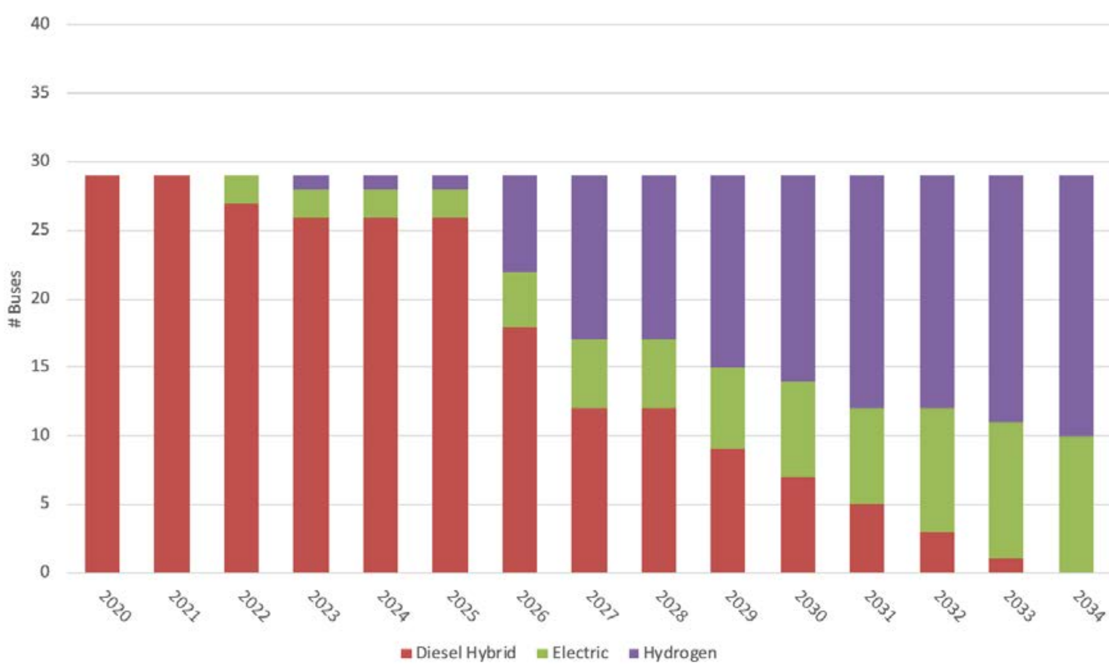


Figure 13 – Annual Fleet Composition, Mixed Scenario

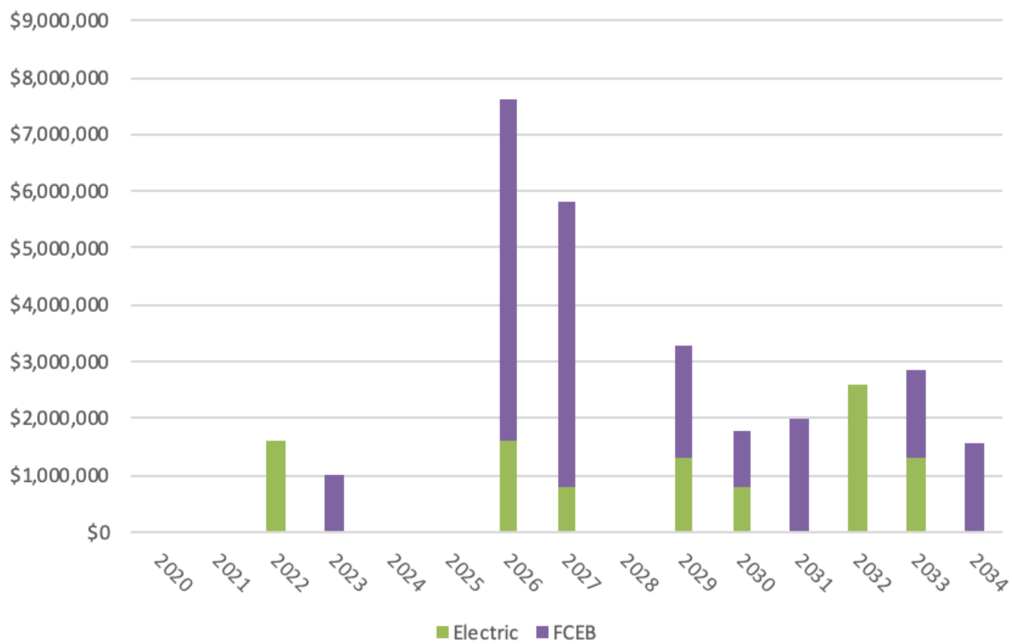


Figure 14 – Annual Capital Costs, Mixed Scenario

FCEB Only

As discussed previously, FCEBs do not have the same range constraints as BEBs. Based on the analysis completed, it is estimated that all of Mountain Line's fixed-route service blocks can be served by an FCEB on a one-for-one replacement basis. There are significant assumptions that commercially available, Altoona-tested 35' FCEBs will be available during the transition period. **Figure 15** through **Figure 17** show projected purchases, annual fleet composition and annual total capital costs for the FCEB Only scenario.

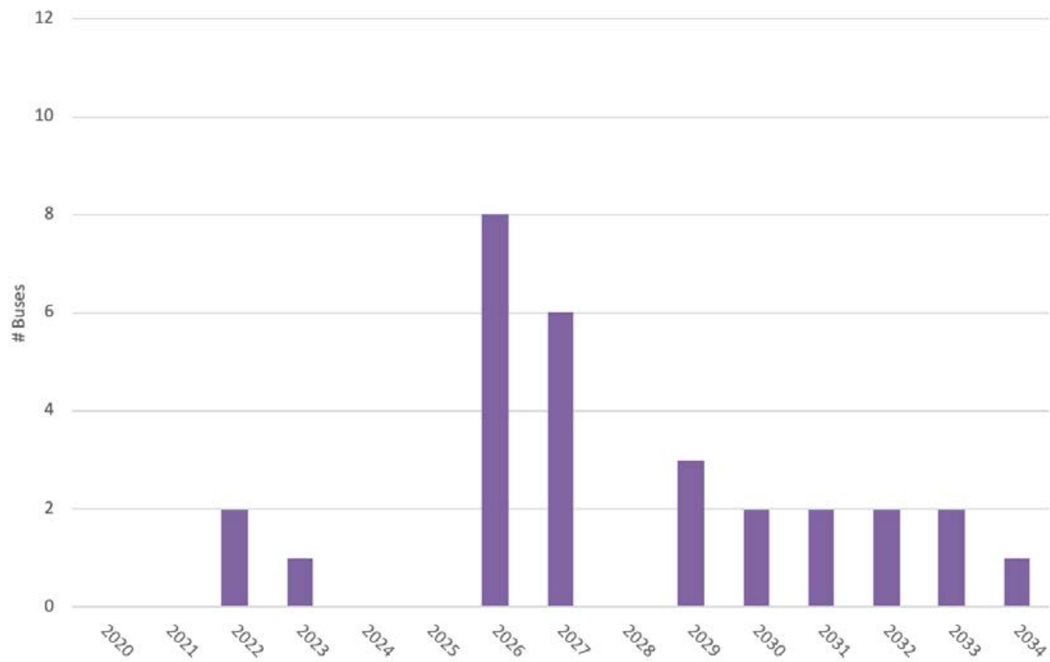


Figure 15 – Projected Vehicle Purchases, FCEB Only Scenario

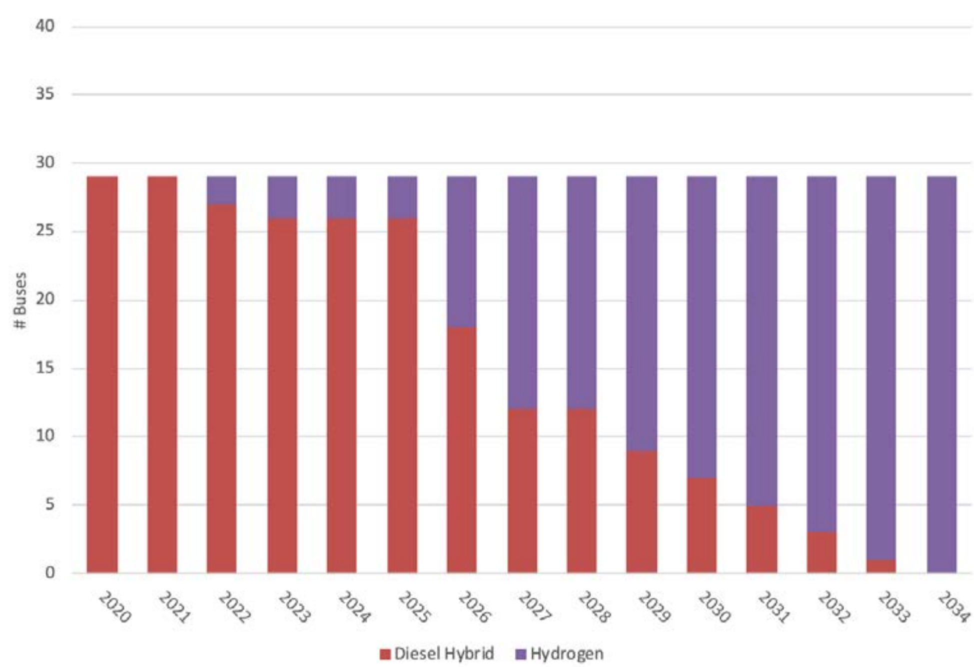


Figure 16 – Annual Fleet Composition, FCEB Only Scenario

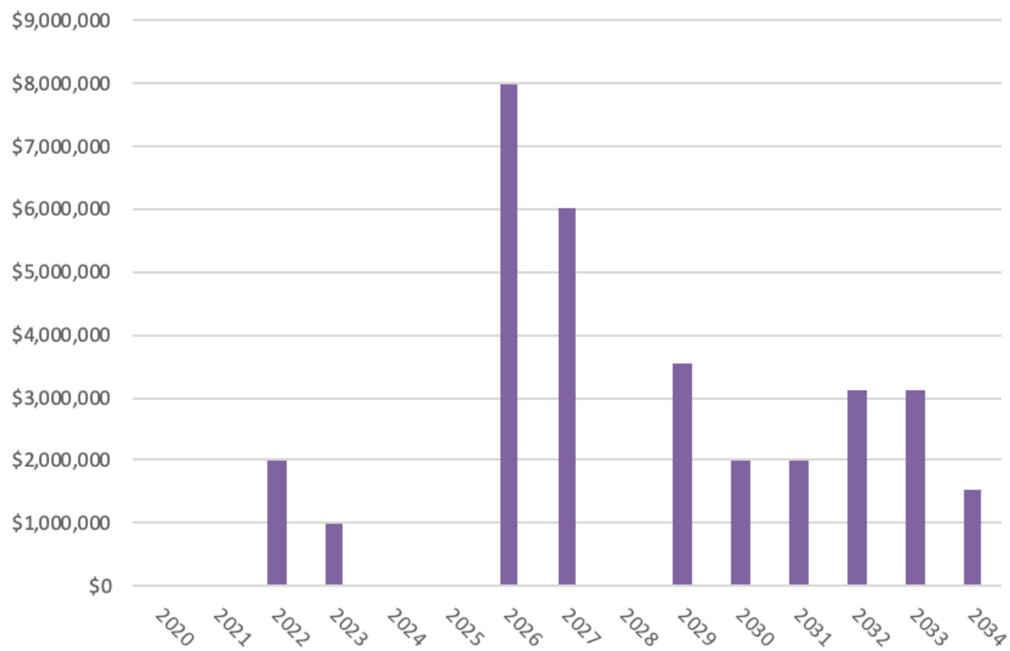


Figure 17 – Annual Capital Costs, FCEB Only Scenario

Fleet Assessment Cost Comparison

The transition schedule and fleet composition were used to develop the total capital cost for vehicle purchases through the transition period. **Figure 18** shows the cumulative fleet purchase costs for each scenario.

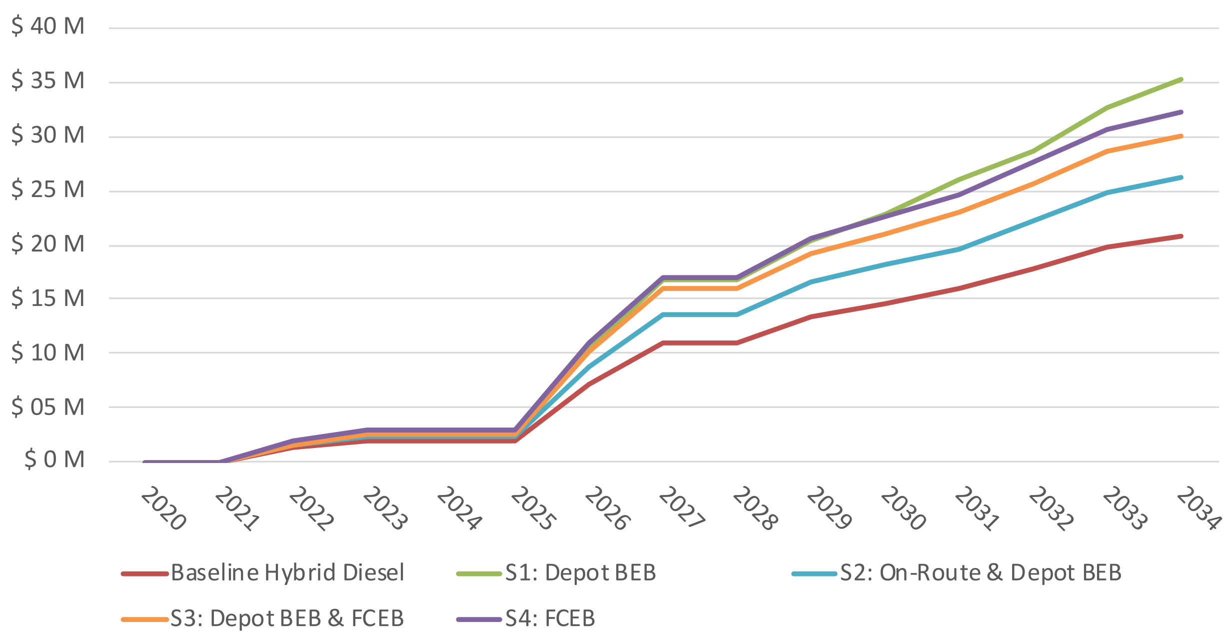


Figure 18 – Total Capital Costs, Fleet Assessment

By the end of the transition period, the cumulative vehicle costs vary substantially according to the technology selected. **Table 4** provides the combined total costs for each transition scenario, the percentage increase in cost above the Baseline Hybrid Diesel scenario, and the number of vehicles in the fleet in 2034 for the scenario.

Table 4 – Total Capital Costs, Fleet Assessment

Scenario	Cost	% Cost Increase Over Baseline Hybrid Diesel	ZEBs in 2034
Baseline Hybrid Diesel	$ 20,800,000	----	29
BEB Depot Only	$ 35,200,000	69%	39
BEB On-Route + Depot	$26,200,000	26%	29
Mixed BEB and FCEB	$ 30,100,000	45%	29
FCEB Only	$ 32,300,000	55%	29

Fuel Assessment

Using ZEB performance data from the bus modeling and route simulation, CTE analyzed the expected performance on each block in Mountain Line's service network to calculate daily energy requirements. The five (5) projection scenarios from the Fleet Assessment were used to estimate associated fuel and energy costs unique to each fleet projection throughout the study life. This assessment was used to calculate energy costs using 2020 prices. The Fuel Assessment estimated quantities and costs for Mountain Line's current hybrid diesel vehicles as well as electrical energy and hydrogen fuel quantities and costs for the future BEB and FCEBs projected in each scenario.

The terms "fuel" and "energy" are used interchangeably in this assessment, as ZEB technologies do not always require traditional liquid fuel. For clarity, in the case of BEBs, "fuel" is electricity and costs include energy, demand charges, and other utility-related costs. FCEBs are more similar to internal combustion engine vehicles as they are fueled by a gaseous or liquid hydrogen fuel. In addition to the cost of the fuel itself, however, there are additional operational costs associated with hydrogen fueling stations that must be considered. Operation and maintenance costs to maintain fueling infrastructure for both BEBs and FCEBs are built into the Fuel Assessment. Where applicable, maintenance costs of $3,500 annually per BEB charger and $100,000 annually per hydrogen fueling station are included in the Fuel Assessment. Fuel cost estimates are based on the assumptions shown in **Table 5** below.

Table 5 – Fuel Cost Assumptions applicable to Flagstaff Area Transit Agencies

Fuel	Cost	Source
Gasoline	$3.00/gal	Average cost provided by Mountain Line for evaluation
Hydrogen (trucked)	$7.80/kg	Estimate provided by Air Liquide to deliver 40% renewable hydrogen from Las Vegas, NV
Electricity	Varies	APS E-32TOU Large General Service

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 energy use and power demand increase. Rates also vary throughout the year and throughout the day, making costs highly variable. Costs not only depend on seasonal differences like temperature but also the time of day buses are charged.

Table 6 shows the current Arizona Public Service Electric (APS) rate schedule used in the Fleet Assessment to estimate electric costs for BEBs. Energy use is calculated in kWh and the maximum demand is calculated as the average kW supplied during the 15-minute period of maximum use during the billing period. The applicable rate schedule is based on secondary distribution for demand and instrument-rated meters for energy for a maximum demand between 401 kW and less than 3,000 kW per day. APS summer rates apply to the months of

May through October, and Winter rates apply to the months of November through April. On-peak hours are from 3:00 pm to 8:00 pm Monday through Friday; all other hours are considered off-peak.

Table 6 – APS E-32TOU Large General Service Rate Schedule Applicable to Flagstaff Area Transit Agencies

	Fee Type	Unit	Charge
Customer Charge	Service Fee	per day	$ 3.92
Demand Charge	On-Peak First 100 kW	per kW	$ 17.508
	On-Peak Additional kW	per kW	$ 11.795
	Off-Peak First 100 kW	per kW	$ 6.396
	Off-Peak Additional kW	per kW	$ 3.370
Energy Rates	On-Peak Summer	per kWh	$ 0.07018
	On-Peak Winter	per kWh	$ 0.05552
	Off-Peak Summer	per kWh	$ 0.05730
	Off-Peak Winter	per kWh	$ 0.04264

Charging Analysis

To accurately estimate energy use and electrical demand due to BEB charging, and their respective costs, charging was simulated at each depot for each year of the transition for applicable scenarios. For the BEB On-Route and Depot scenario, on-route charging was also simulated for estimated energy use and electrical demand at the DCC. Electrical energy and demand were estimated based on current block schedules, BEB purchase projections, and applicable APS tariff schedules to calculate an annual cost of charging. This annual cost is evaluated for each year of the study and at each depot to obtain a total BEB depot charging cost for the transition. This estimate is used as the total "fuel" cost for BEB depot charging in the subsequent assessment scenarios, and it is incremental to on-route charging costs, hydrogen fuel costs, and internal combustion engine costs.

Energy costs were calculated using the APS E-32 TOU (Time of Use) Large General Service Rate Schedule, as show in **Table 6.** Ideally, buses would all charge in the less expensive, off-peak times for the lowest overall cost. Therefore, to reduce overall energy and demand costs, charge management was modeled at the Kaspar Drive Maintenance Facility and NAU (or other separate facility) depots to optimize fuel costs. Charge management reduces electricity costs by optimizing energy use (kWh) and maximum demand (kW) to occur during cheaper time windows. Charge management as it pertains to this charging analysis limits off-service depot charging to only the off-peak timeframe for more desirable electricity costs. Additionally, a cap was placed on the number of buses charging simultaneously to minimize demand costs while still meeting pull-out requirements. The number of chargers operating simultaneously is directly proportional to demand costs. By reducing the number of chargers running at any given time, demand costs are reduced.

Baseline Hybrid Diesel

The Baseline Hybrid Diesel scenario is for comparative purposes only and assumes that there is no change in the current Mountain Line fleet configuration throughout the life of the study. The Baseline Hybrid Diesel scenario helps create context for incremental costs incurred or benefits accrued by transitioning the fleet to zero-emission.

Figure 19, below, depicts energy consumption for the hybrid diesel fleet over the transition period for the Baseline Hybrid Diesel scenario. It is assumed that the fuel economy for Mountain Line's hybrid diesel vehicles remain constant over the study life.

Figure 19 – Annual Fuel Consumption, Baseline Hybrid Diesel

Figure 20 shows the calculated annual costs for the hybrid diesel fleet over the transition period for the Baseline Hybrid Diesel scenario.

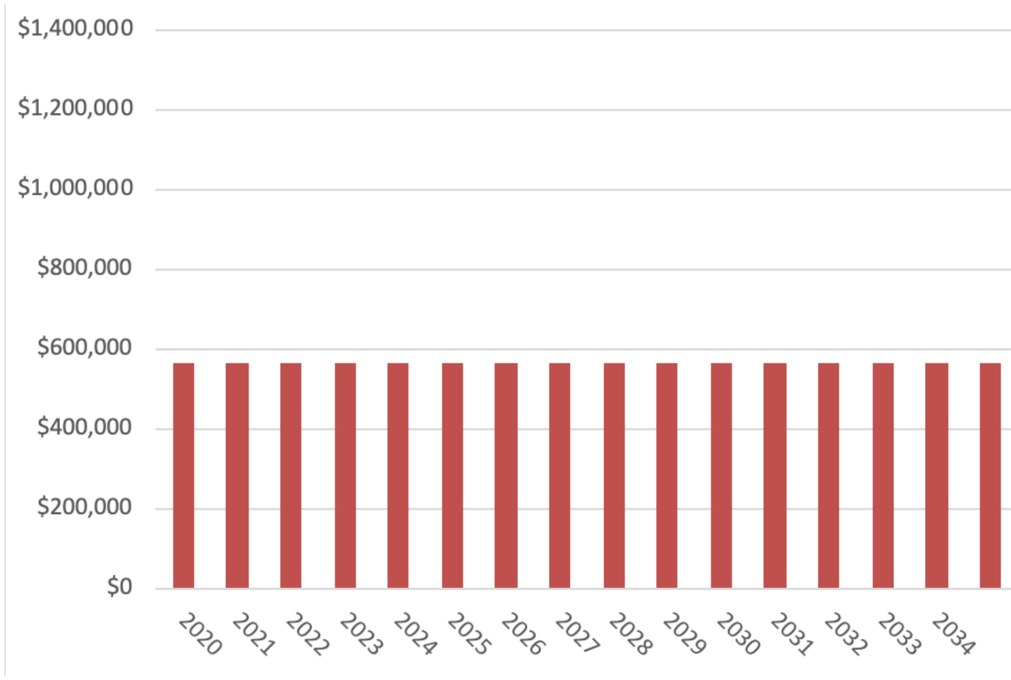


Figure 20 – Annual Fuel Costs, Baseline Hybrid Diesel

BEB Depot-Only Charging

As previously discussed, charge management was assumed for BEB scenarios to minimize fuel costs. Due to the increase in fleet size, charge management is particularly important for the BEB Depot-Only Scenario. The following figures show each weekday block's status over a single day in 2034 for the service blocks that operate during the majority of the year, which is representative of the maximum number of blocks being serviced on a given day of the year. **Figure 21** represents the Kaspar Drive Maintenance Facility which will house the majority of the 35' buses, and **Figure 22** represents the NAU facility, or other separate facility, which will house the 60' buses and seven (7) 35' buses. Blocks in orange indicate split blocks where two BEBs replaced a single hybrid diesel vehicle for achievability reasons; blue indicates the bus is in service; grey indicates setup time and delay which can be used to wash and service the buses; and green indicates charging time. Charging only occurs outside of the on-peak rate period highlighted in red (3:00 pm to 8:00 pm). It is assumed that with charge management, a maximum of eight (8) BEBs will charge simultaneously at each of the depot facilities.

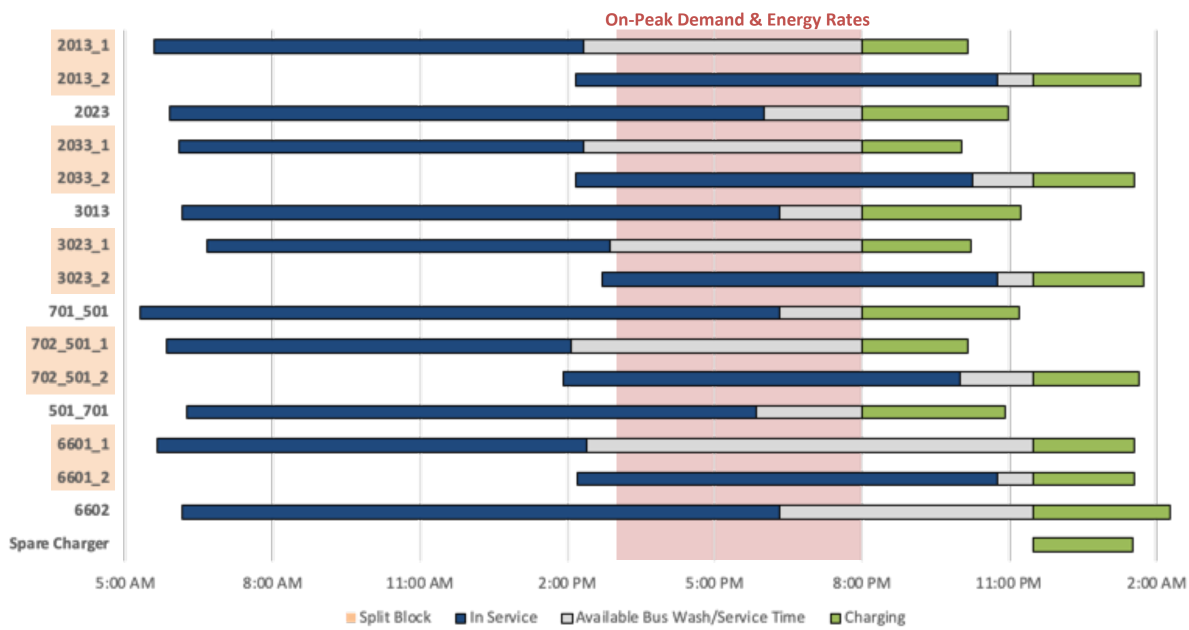


Figure 21 – Managed Charging, Kaspar Drive Maintenance Facility, Weekday, 2034

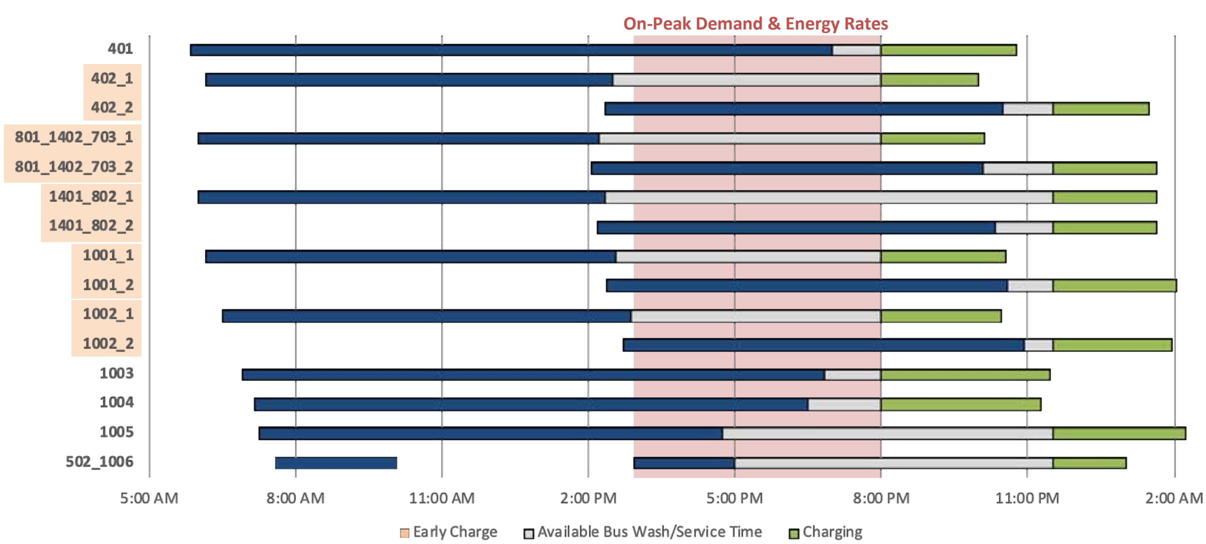


Figure 22 – Managed Charging, NAU or other separate facility, Weekday, 2034

The other main component of charge management is managing power demand and demand charges. The number of chargers operating simultaneously is directly proportional to demand costs. By reducing the number of chargers operating at any given time, demand costs are reduced. The number of chargers operating simultaneously was determined based on service pull-out needs. In this analysis, all chargers are assumed to provide 150 kW to the bus and pull approximately 167 kW from the grid due to energy losses and charger efficiency.

In **Figure 23** below, managed charging eliminates the demand during on-peak hours by delaying charging until after 8pm.

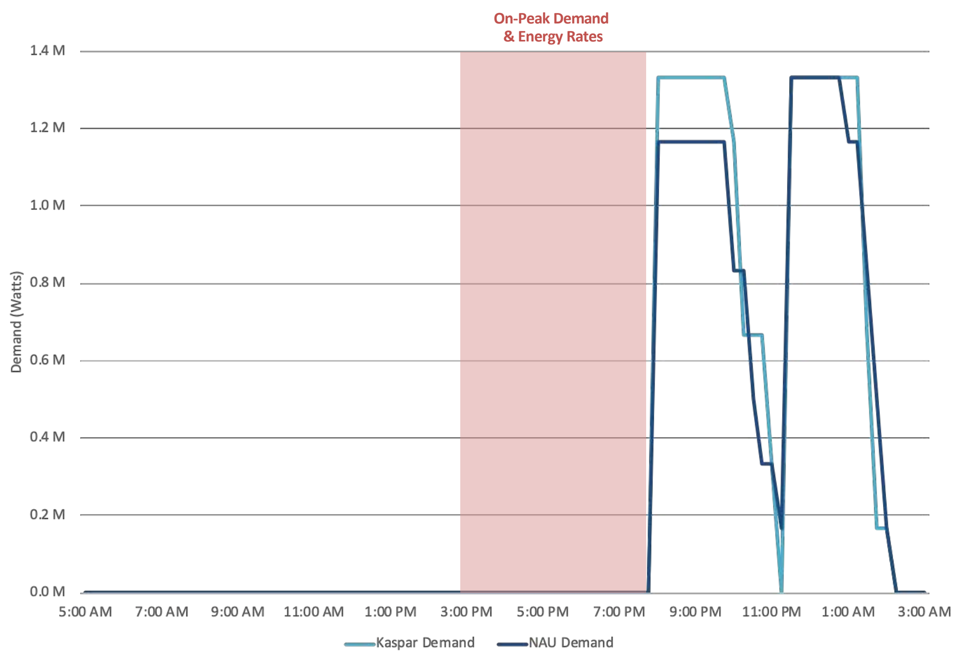


Figure 23 – Weekday Demand, 2034

Figure 24 depicts energy consumption by fuel type over the transition period for the BEB Depot-Only Charging scenario. Electricity use by BEBs, measured in kWh, is converted to diesel gallon equivalents (DGE) for this analysis. Total energy use in 2034 is less than half of that in 2020 due to the improved efficiency of BEBs over hybrid diesel vehicles.

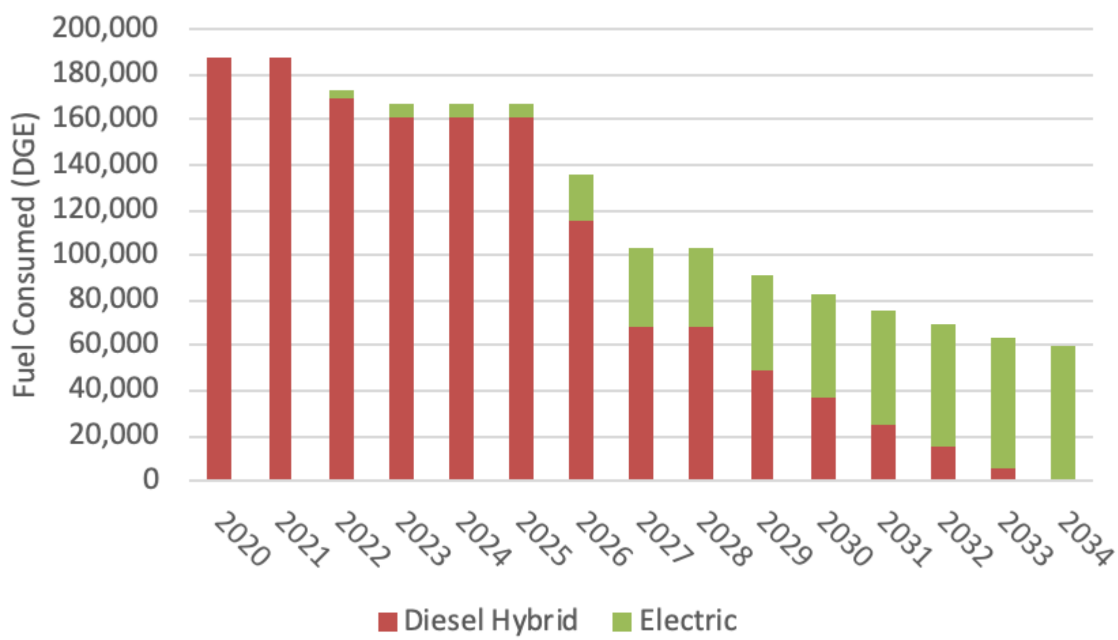


Figure 24 – Annual Fuel Consumption, BEB Depot-Only Scenario

Figure 25 shows the annual costs for each fuel type based on the quantities shown in **Figure 24**. Total estimated fuel costs in 2034 are approximately $300,000.

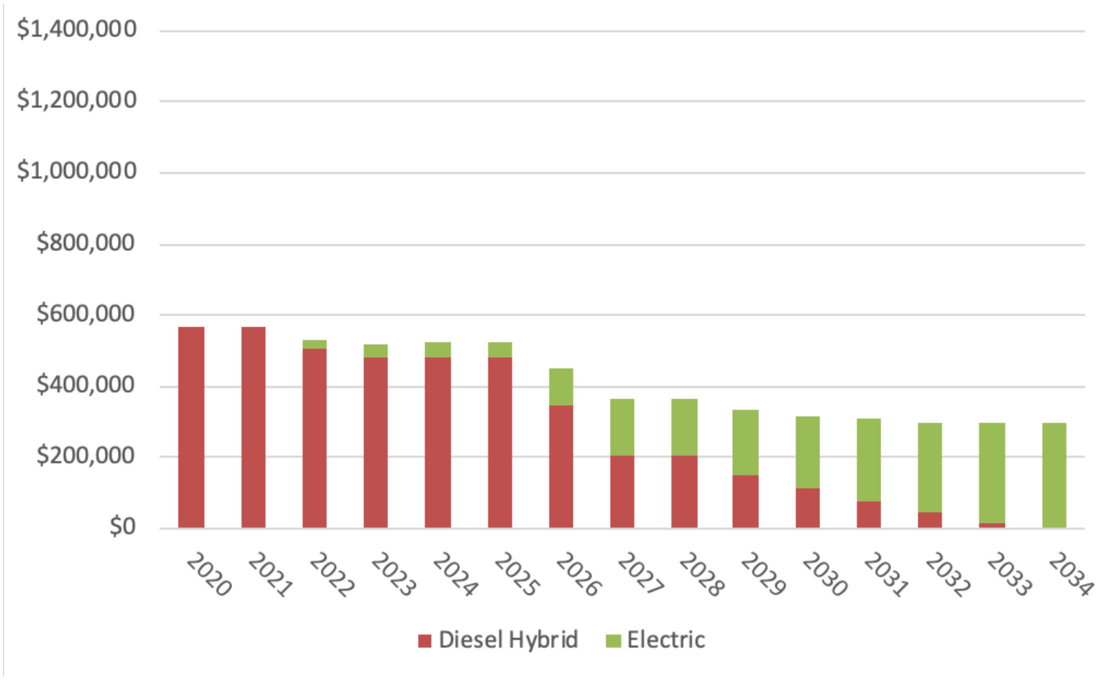


Figure 25 – Annual Fuel Costs, BEB Depot-Only Scenario

BEB On-Route and Depot Charging

In contrast to the BEB Depot-Only scenario, on-route charging allows Mountain Line the capability to do one-to-one BEB replacements for their current hybrid diesel fleet and maintain current service levels. On-route charging allows an agency to add energy to buses while in service, providing the additional energy necessary to complete a block without having to travel the extra distance and take the extra time to charge at a depot. All on-route charging will occur at the DCC, a transit facility that all fixed-route service blocks spend layover time at. Based on Mountain Line's service schedule, the charging analysis estimates that a maximum of eight buses will be charging simultaneously at the DCC.

Figure 26 depicts energy consumption for each fuel type over the transition period assuming combination of depot and on-route charged BEBs. Electricity use by BEBs, measured in kWh, is converted to DGE for this analysis. Total energy use in 2034 is less than half of that in 2020 due to the improved efficiency of BEBs over fossil-fuel vehicles.

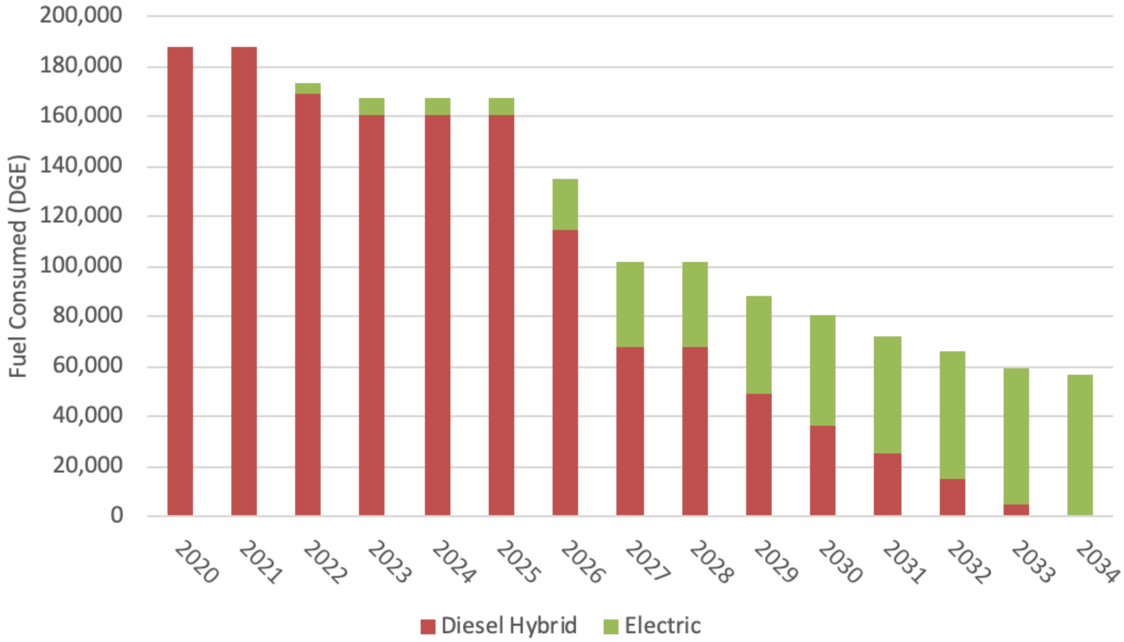


Figure 26 – Annual Fuel Consumption, BEB On-Route and Depot Scenario

Figure 27 shows the annual costs for each fuel type based on the quantities shown in **Figure 26**. Total estimated fuel costs in 2034 are approximately $700,000. The costs are driven by the need to charge during on-peak times throughout the day.

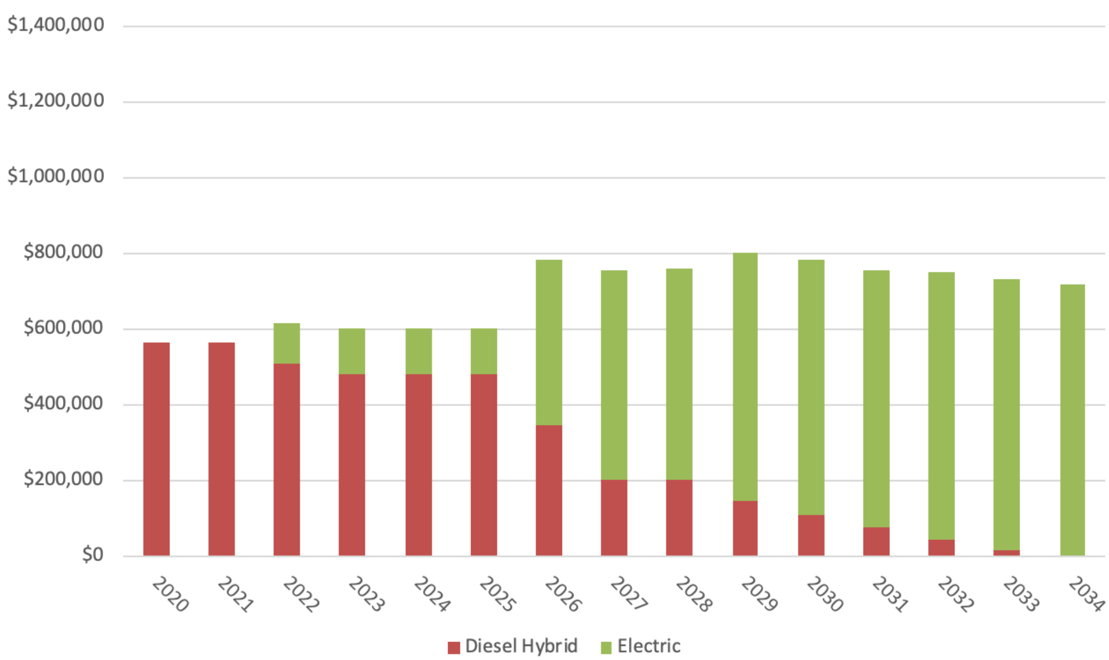


Figure 27 – Annual Fuel Costs, BEB On-Route and Depot Scenario

Mixed BEB and FCEB

In the Mixed BEB and FCEB scenario, BEBs are utilized where they can replace hybrid diesel vehicles on a one-for-one basis. Since FCEBs have a greater range, they are used on the longer blocks where BEBs are not feasible. By the end of the transition period, an FCEB replaces the original Mountain Line hybrid diesel vehicle in any instance where block coverage was insufficient.

Figure 28 depicts energy consumption for each fuel type over the transition period for the Mixed BEB and FCEB scenario. Electricity use by BEBs and hydrogen use for FCEBs is converted to DGE for this analysis. Equivalent fleet energy use is reduced from 2020 to 2034 by approximately 41%.

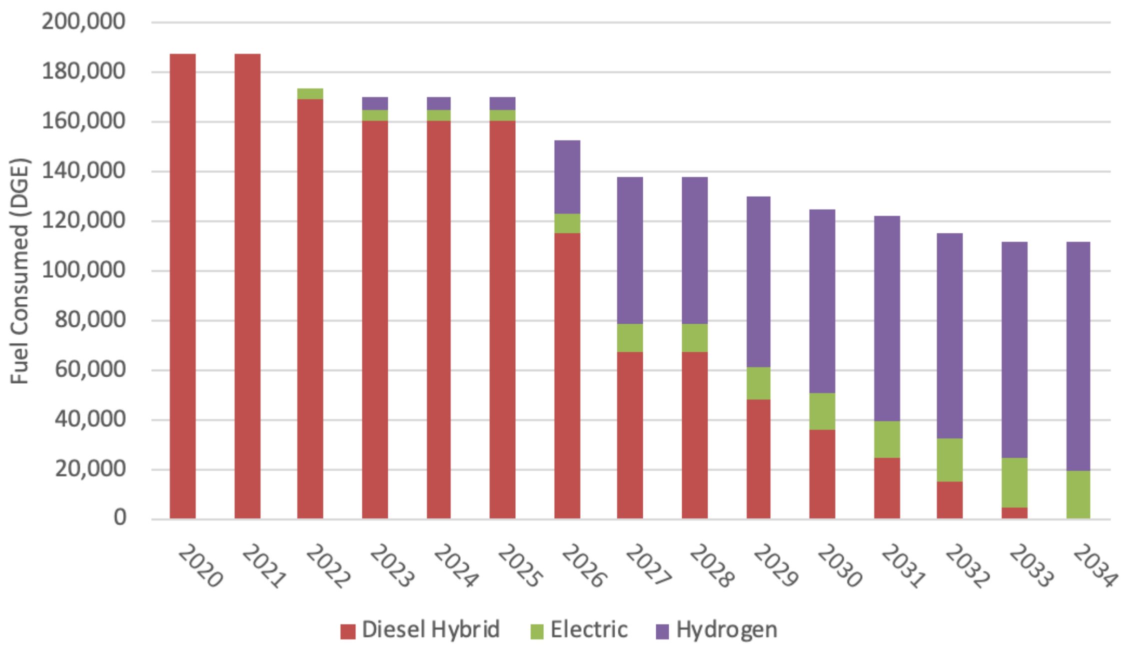


Figure 28 – Annual Fuel Consumption, Mixed Scenario

Figure 29 shows the estimated annual costs for each fuel type based on the quantities found in **Figure 28**. Total estimated fuel costs in 2034 are approximately $1 million, a majority of which are from hydrogen use for FCEBs.

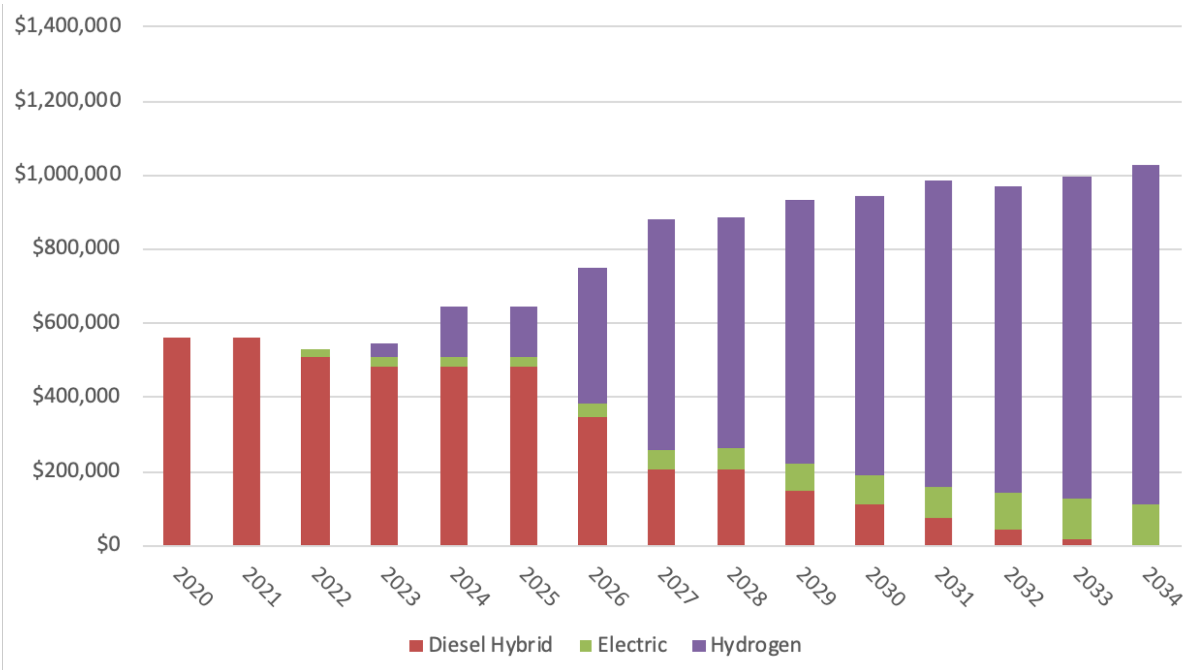


Figure 29 – Annual Fuel Costs, Mixed Scenario

FCEB Only

FCEBs are able to complete all of Mountain Line's current fixed service blocks. **Figure 30** depicts fuel consumption for each fuel type over the transition period for the FCEB Only scenario. Total energy use in 2034 is reduced by approximately 25% from 2020.

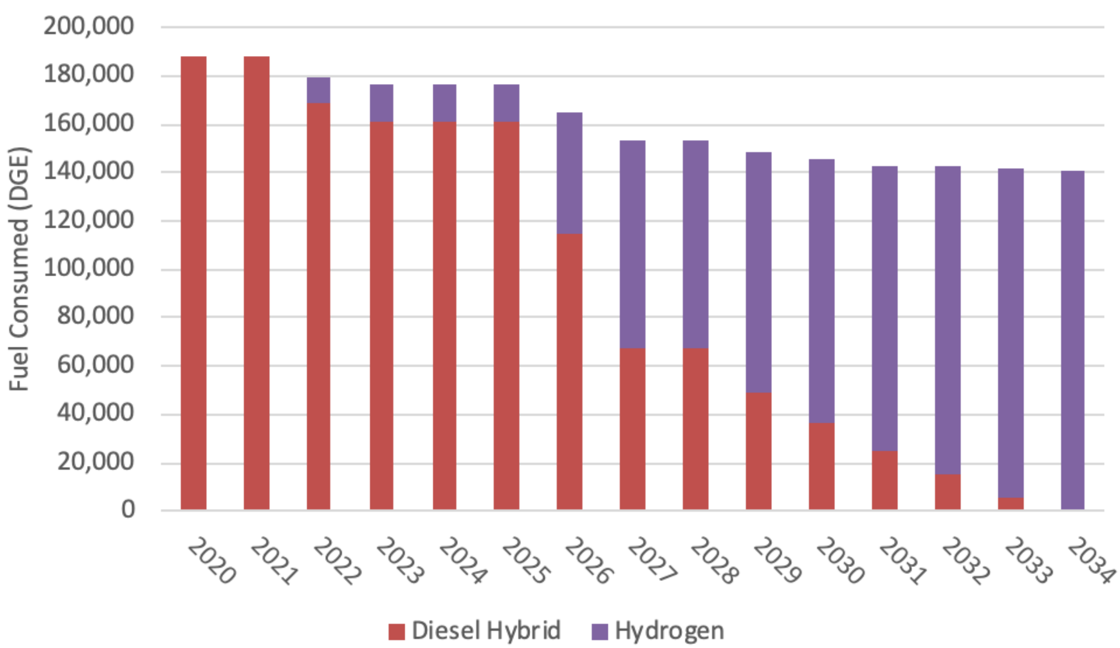


Figure 30 – Annual Fuel Consumption, FCEB Only Scenario

Figure 31 shows estimated annual costs for each fuel type based on the quantities shown in **Figure 30**. Total estimated fuel costs in 2034 are approximately $1.4 million, the bulk of which is from hydrogen.

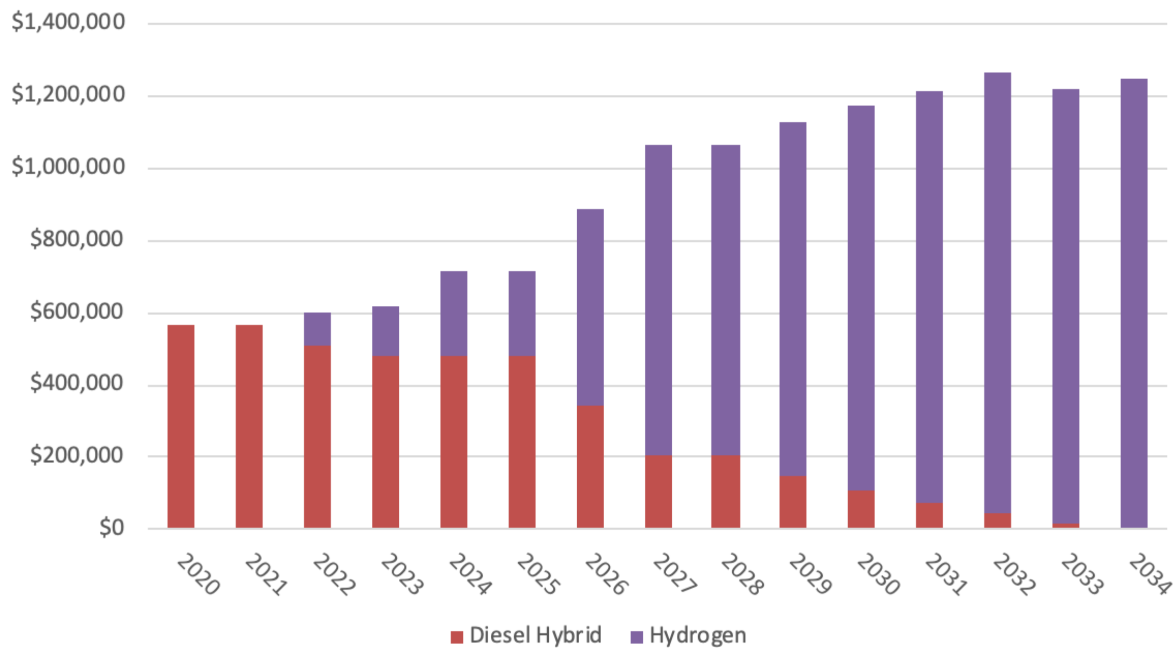


Figure 31 – Annual Fuel Costs, FCEB Only Scenario

Fuel Assessment Cost Comparison

The Fuel Assessment includes all electrical and fuel costs over the transition for each scenario. **Figure 32** shows the cumulative fuel costs for each scenario. **Table 7** shows the combined total costs for each scenario, the incremental cost over the Baseline Hybrid Diesel and the number of vehicles in the fleet in 2034.

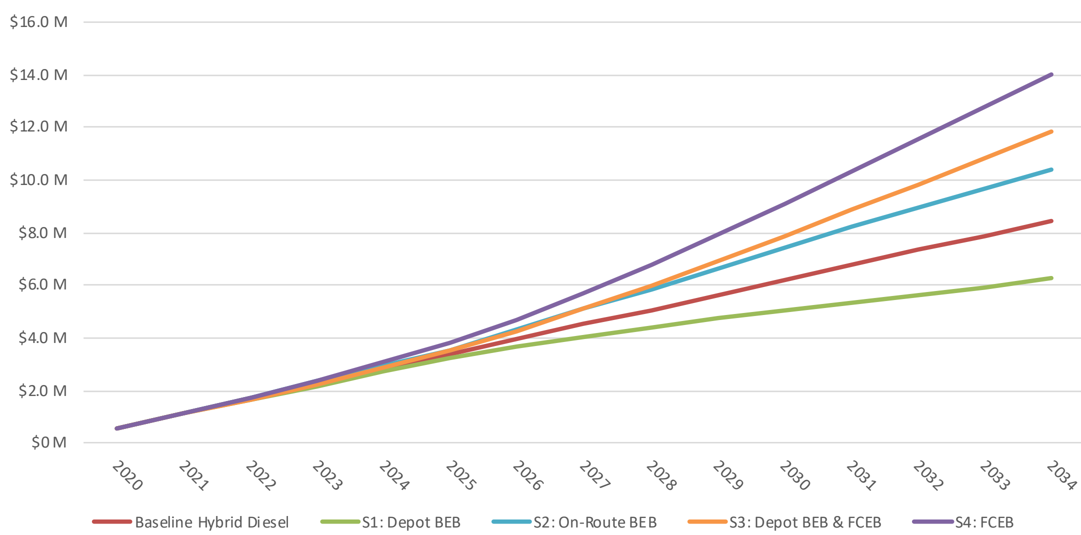


Figure 32 – Total Costs, Fuel Assessment

Table 7 – Total Costs, Fuel Assessment

Scenario	Cost	% Cost Increase Over Baseline Hybrid Diesel	ZEBs in 2034
Baseline Hybrid Diesel	$ 8,462,000	----	29
BEB Depot Only	$ 6,240,000	(26%)	39
BEB On-Route + Depot	$ 10,396,000	23%	29
Mixed BEB and FCEB	$ 11,863,000	40%	29
FCEB Only	$ 14,034,000	66%	29

Facilities Assessment

Once bus and fueling requirements are understood for the ZEB transition, the requirements for supporting infrastructure can be determined including the charging equipment for BEBs and/or hydrogen fueling equipment for FCEBs. The Facilities Assessment determines the scale of charging and/or hydrogen infrastructure necessary to meet the demands of the projected fleet and energy use estimated in the Fleet and Fuel Assessments, as well as all associated costs with installation of this infrastructure.

BEB Charging Infrastructure

With pilot BEB deployments, charging requirements are met relatively easily with a handful of plug-in pedestal chargers and minimal infrastructure investment. An example of a plug-in pedestal charger is included in **Figure 33**. Scaling to a fleetwide BEB deployment requires a substantially different approach to charging and infrastructure upgrades. Plug-in charging is typically no longer practical as charger dispensers installed in the parking area create a hazard.

Figure 33 - Plug-In Pedestal Charger Example

Instead, the preferred approach is to use overhead pantograph or reel dispensers attached to gantries or to the existing overhead roof structure for facilities that are covered like Mountain Line's Kaspar Drive Maintenance Facility and the future NAU facility or other separate facility. Examples of an overhead pantograph installed on a gantry and attached to overhead roof structure are included in **Figure 34** and **Figure 35**, respectively.

Figure 34 - Pantograph Attached to Gantry

In addition to the installation of the charging stations, improvements to existing electrical infrastructure including switchgear, service connections, etc. are required to support deployment of BEBs. Design work will be required to support BEB deployment including development of detailed electrical and construction drawings required for permitting once specific charging equipment has been selected. Examples of electrical infrastructure necessary to support charging as well as charging equipment are included in **Appendix C**.

Figure 35 - Pantograph Attached to Roof Structure

BEB Depot-Only Charging

Charging infrastructure to support thirty-nine (39) depot-charged BEBs in 2034 is required, as calculated in the Fleet Assessment. Charging infrastructure is required at two (2) depot facilities. Twenty-four (24) 35’ BEBs are estimated operate out of the Kaspar Drive Maintenance Facility, and eight (8) 60’ BEBs and seven (7) 35’ BEBs are expected to operate out of the NAU or other separate facility.

Key Assumptions:

- Pedestal charging is not practical for a full-fleet transition due to facility obstructions. In addition, the Kaspar Drive Maintenance Facility is equipped with radiant floor heat creating significant installation challenges.
- Overhead pantograph or reel dispensers attached roof structure will be used.
- One (1) plug-in reel or pantograph per bus
- Two (2) buses per 150 kW charger
- Charge management software to manage charging
- Maximize off-peak, overnight charging
- Minimize concurrent charging (demand) with two charge windows, i.e., no more than half the buses charge at any given time.
- Charging technology remains at current levels throughout transition period.
- Estimates based on total number of BEBs required to meet service requirements.
- Costs to be incurred in the year infrastructure is deployed and available for service.

Kaspar Drive Maintenance Facility

The Kaspar Drive Maintenance Facility is expected to store all 35’ vehicles. For the BEB Depot-Only scenario, twenty-four (24) 35’ BEBs are expected to operate out of the Kaspar Drive Maintenance Facility. The Kaspar Drive Maintenance Facility will be equipped with twelve (12) 150 kW depot chargers with two (2) dispensers each. It is assumed that a maximum of twelve (12) vehicles could be charged simultaneously at the Kaspar Drive Maintenance Facility; however, it is likely that demand can be managed such that a maximum of eight (8) chargers are actually necessary to operate at one time to meet pull-out requirements as previously discussed in the charging analysis. The additional chargers will allow all vehicles parked at the facility to be plugged in at the same time. A total of twenty-four (24) dispensers, one per BEB, will be installed such that movement of vehicles is not required. The chargers and electrical equipment will be installed outside of the facility and dropdown reels or pantograph dispensers will be attached to the roof inside the facility as depicted in **Figure 36**.

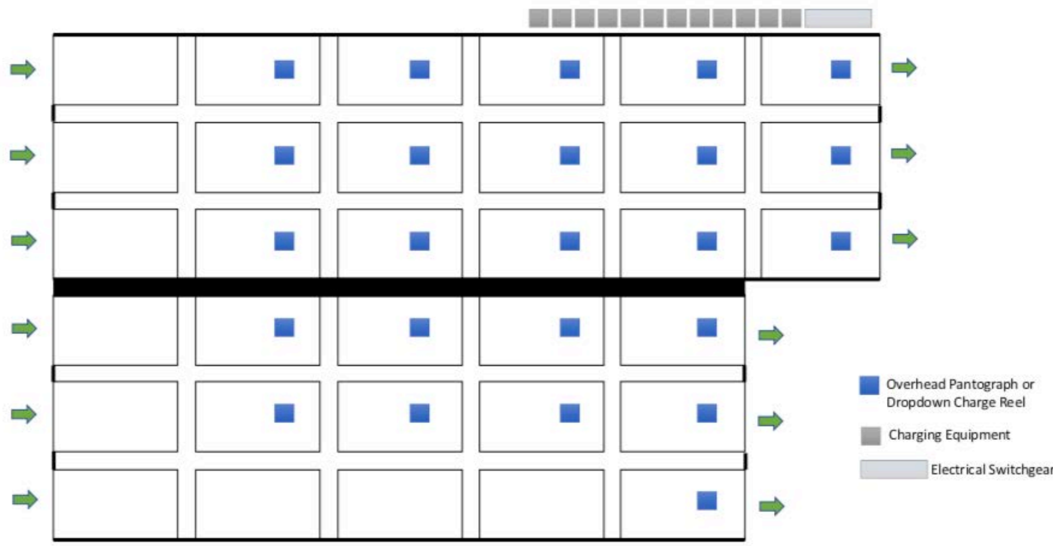


Figure 36 - BEB Charging Storage Facility Conceptual Layout

Electrical cabling would run from the chargers, outside of the building, through the overhead structure of the building to the pantograph or drop-down dispenser location. An engineering evaluation is needed to determine if the facility roof structure is able to hold the load of the dispensers or if additional support is required. Based on the size of the chargers, a minimum of approximately 1.8 megawatts (MW) of power is required to supply the chargers at the Kaspar Drive Maintenance Facility at full build out; however, electrical design by a licensed professional and in accordance with current National Electrical Code (NEC) will be required to support charger installation.

NAU or other separate Facility

The NAU facility, which is still to be funded and constructed and could be another separate facility, is expected to store eight (8) 60' articulated vehicles and seven (7) 35' BEBs. The NAU or other separate facility will be equipped with eight (8) 150 kW depot chargers with two (2) dispensers each. As previously discussed in the Fuel Assessment, it is assumed that a maximum of eight (8) vehicles will be charged simultaneously. Sixteen (16) dispensers with charge management software adequately support the charging of eight (8) vehicles in the facility across two (2) charge windows during off-peak hours. A conceptual layout for the NAU or other separate facility has not been developed at this time. Based on the size of the chargers, a minimum of approximately 1.2 MW of power is required to supply the chargers at full build out at NAU or other separate facility; however, electrical design by a licensed professional and in accordance with current NEC will be required to support charger installation.

BEB Depot-Only Charging Infrastructure Cost Summary

Table 8 summarizes total costs for charging infrastructure by facility for the BEB Depot-Only Charging scenario. The estimated total infrastructure costs for the BEB Depot-Only Charging scenario are approximately $7 million. This value includes the following at both facilities: engineering and planning, installation of the required number of chargers and dispensers, upgrade of the electrical system with the required switchgear and power electronics equipment, and added 20% contingency on all costs. A rough order of magnitude (ROM) estimate for the BEB Depot-Only Charging Infrastructure scenario is included in **Appendix D**. Costs do not include backup generation or upgrade costs for any required APS service expansion or redundant power feed to the facilities. APS is currently evaluating costs associated with redundant power to the Kaspar Drive Maintenance Facility. Additionally, costs for the construction of the NAU or other separate facility, other than the costs associated with the charging equipment design and installation, are not incorporated in this analysis.

Table 8 – Total Infrastructure Costs, BEB Depot-Only Scenario

Facility	Cost
Kaspar	$ 5,174,000
NAU	$ 2,075,000
Total	**$ 7,249,000**

BEB On-Route and Depot Charging

Charging infrastructure to support on-route charging at the DCC will be required in addition to charging infrastructure for depot charging required at both the Kaspar Drive Maintained Facility and NAU (or other separate) facilities. However, the BEB On-Route and Depot Charging scenario assumes that majority of the energy used will be replenished with on-route charging; therefore, depot charging infrastructure is not required to the extent described in the previous section. Charging infrastructure in all will support twenty-nine (29) BEBs. Nineteen (19) 35' BEBs are estimated to operate out of the Kaspar Drive Maintenance Facility, while six (6) 60' BEBs and four (4) 35' BEBs are estimated to operate out of the NAU or other separate facility. All vehicles will utilize on-route charging at the DCC.

On-route chargers do not require any additional support structure, such as gantries to be built, as shown previously in **Figure 34**, and do not require any structural project planning, as with depot chargers. An example of an on-route charger is included in **Figure 37.** Required infrastructure projects for on-route chargers include planning, power upgrade, and charger purchase and installation. Power upgrade costs are not included in the Facilities Assessment. It is assumed that the utility, APS, will provide transformers at no cost to Mountain Line based on payback calculations. APS is currently evaluating the load estimates and determining if they will provide transformers at no cost to Mountain Line.

Figure 37 - On-Route Overhead Charger with Pantograph

Key Assumptions:

- Eight (8) 450 kW overhead chargers at DCC at full-build out
- Two (2) 450 kW overhead chargers at Kaspar Drive Maintenance Facility
- Two (2) 450 kW overhead charger at NAU or other separate facility
- The number of chargers is based on requirements for operating peak service (14 blocks on a weekday).
- Charging technology remains at current levels throughout transition period.
- Costs to be incurred in the year infrastructure is deployed and available for service.
- New electrical switchgear and power electronics required at each facility.

Downtown Connection Center (DCC)

All vehicles operating out of both depots have layovers at the DCC and will utilize on-route charging at this transit connection center. Based on Mountain Line's service schedule, once fully transitioned in 2034, a maximum of eight (8) BEBs will require on-route charging simultaneously at the DCC. It is assumed that eight (8) 450 kW on-route chargers will be installed at the DCC to ensure that all required vehicles are charged. A preliminary sketch of the DCC bus parking layout is provided in **Figure 38**. Based on the size of the chargers, a minimum of approximately 3.6 MW of power is required to supply the chargers at full build out at the DCC; however, electrical design by a licensed professional in accordance with NEC is required to support charger installation.

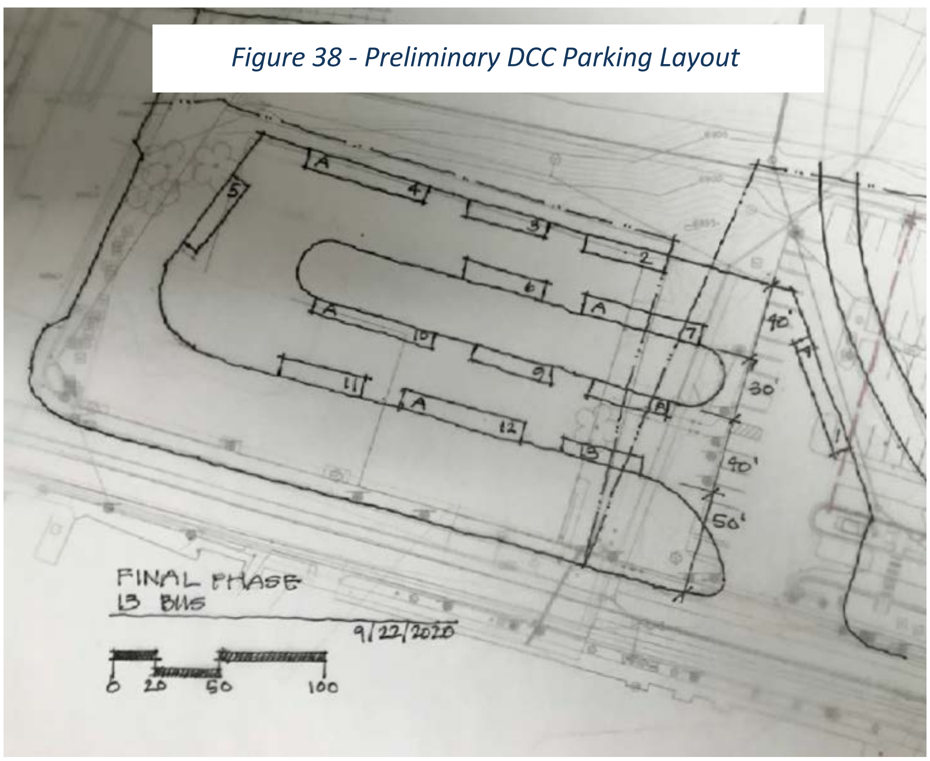


Figure 38 - Preliminary DCC Parking Layout

Kaspar Drive Maintenance Facility

The Kaspar Drive Maintenance Facility is expected to store all 35' vehicles. For the BEB On-Route and Depot scenario, nineteen (19) 35' BEBs are expected to operate out of the Kaspar Drive Maintenance Facility. The Kaspar Drive Maintenance Facility will be equipped with two (2) 450 kW overhead chargers as shown in **Figure 39.**

Figure 39 - Kaspar Drive Maintenance Facility Preliminary Charging Layout

As previously discussed, the majority of charging needs will be supplied by the on-route chargers at the DCC. Therefore, the two (2) overhead chargers at the Kaspar Drive Maintenance Facility will be used to top off 35' BEBs following the end of a service block, as needed to maintain sufficient energy levels for the next service block. Operations at the depot are expected to remain relatively unchanged from current operations, with buses being charged at the overhead chargers upon return rather than fueled at the existing diesel fueling island, and then washed, cleaned, and serviced before parking in the storage building. An estimated 15 minutes of charging per vehicle is required at the depot at the end of the service day to top off the vehicles depending on operating conditions. A review of the current block structure indicated that two (2) overhead chargers is sufficient to meet the charging needs at Kaspar Drive Maintenance Facility. This analysis assumes that at most one vehicle will be required to queue to wait for charging upon return during peak return (6:15-6:30 PM and 10:45-11:00 PM). Based on the size of the chargers, a minimum of approximately 1 MW of power is required to supply the chargers at full build out at Kaspar Drive Maintenance Facility; however, electrical design by a licensed professional and in accordance with current NEC will be required to support charger installation.

NAU or other separate Facility

The NAU or other separate facility is expected to store six (6) 60' articulated BEBs and four (4) 35' BEBs. The NAU or other separate facility will be equipped with two (2) 450 kW overhead chargers. Because the majority of charging needs will be supplied by the on-route chargers at the DCC, the overhead chargers at the NAU or other separate facility will be used to top off BEBs following the end of a service block, as needed to maintain sufficient energy levels for the next service block. The top of charge at the end of the service day is expected to average approximately 15 minutes per bus based on analysis of the current block structure. Two (2) overhead chargers are sufficient to meet the charging needs at NAU or other separate facility based on the current block structure. Based on the size of the chargers, a minimum of approximately 1 MW of power is required to supply the chargers at full build out at the NAU (or other separate facility); however, electrical design by a licensed professional and in accordance with current NEC will be required to support charger installation. A conceptual site plan for the NAU or other separate facility has not been developed at this time.

BEB On-Route and Depot Charging Infrastructure Summary

Table 9 summarizes total costs for charging infrastructure by facility for the BEB On-Route and Depot Charging scenario. The estimated total infrastructure costs for the BEB On-Route and Depot Charging scenario are almost $10 million; this value includes the following at all charging locations: all structural projects, all power upgrade projects, all charger and dispenser installations, all planning projects, design engineering costs and added 20% contingency on all costs. A rough-order-magnitude (ROM) estimate for the BEB On-Route and Depot Charging scenario infrastructure is included in **Appendix D**. Costs do not include backup generation or upgrade costs for any required APS service expansion or redundant power feed to the facilities. APS is currently evaluating costs associated with redundant power to the Kaspar Drive Maintenance Facility and the DCC based on estimated electrical loads provided. Details of resiliency recommendations will be included in the Implementation Plan as part of the second phase of this analysis that is currently in development. Additionally, costs for the construction of the NAU or other separate facility were not incorporated in this analysis.

Table 9 – Total Infrastructure Costs, BEB On-Route and Depot Charging Scenario

Facility	Cost
Kaspar Drive Maintenance Facility	$ 1,629,000
NAU or other separate facility	$ 1,629,000
DCC	$ 6,481,000
Total	**$ 9,739,000**

Hydrogen Fuel Cell Infrastructure Scenarios

A primary advantage of FCEBs is that fueling operations with hydrogen are similar to diesel fueling operations. As with electric, rather than building out the infrastructure all at once, projects are sized and scheduled to meet the near-term fueling requirements. Hydrogen fuel can be produced either through steam methane reformation (SMR), using natural gas and energy as the primary inputs, or through electrolysis, using water and energy as primary inputs. In addition, hydrogen can be produced either on-site or off-site. Off-site SMR with fuel delivery to the site and on-site SMR were considered as viable means of generating hydrogen for fuel at the Kaspar Drive Maintenance Facility. On-site electrolysis was not considered a viable alternative due to the large volume of water and high energy demand at the facility to produce hydrogen.

Conceptual locations and the associated footprint of hydrogen fueling equipment at the Kaspar Drive Maintenance Facility is shown in **Figure 40.**

Figure 40 - Hydrogen Generation, Storage, and Fueling Equipment Location

- **Replace existing storage building with hydrogen generation and storage equipment**
- **~ 20' x 40' footprint for on-site hydrogen generation equipment (steam methane reformation)**
- **~ 40' x 60' minimum footprint for hydrogen storage equipment**

Install two (2) hydrogen dispensers on existing fueling island

Off-Site SMR and Delivery

Off-site SMR assumes trucking of liquid hydrogen to the depot, on-site storage at the depot, and installation of fuel handing and dispensing equipment. Infrastructure costs were based on similar projects either completed to date or scoped and are applicable to all Flagstaff area transit agencies. The FCEB infrastructure assumes that the fueling system would be installed at the Kaspar Drive Maintenance Facility. Costs to relocate other facility operations to accommodate hydrogen fueling at the Kaspar Drive Maintenance Facility are not included in this estimate.

To define the timeline and costs to build-out hydrogen fueling infrastructure, the scope of work includes four key project types: (1) planning, (2) structural, (3) maintenance bay upgrades, and (4) fueling.

CTE based ROM cost estimates for FCEB infrastructure on costs developed from previous projects as well from costs determined using the Heavy-Duty Refueling Simulation Analysis Model (HDRSAM) developed by Argonne National Laboratory. Estimates for total costs associated with hydrogen fueling infrastructure are included in **Table 10**.

Table 10 – Cost Assumptions for Hydrogen Fueling Infrastructure

Project	Cost Estimate	Source
Infrastructure Planning	$150,000 per depot	Engineer's estimate
30-Bus Incremental Mechanical Equipment and Installation Package	Includes design, permitting, and installation for two (2) dispensers; all mechanical process equipment; electrical utilities and switchgear. Excludes storage tanks. Estimated at ~$3,386,000	HDRSAM Model; Other project costs
Incremental Addition of 15,000 Liquid Hydrogen Tank	$290,000 per tank for installation	Engineer's estimate, vendor quotes
Maintenance Upgrades	Electrical, Lighting, Ventilation, and Gas Detection - $125,000 per service bay upgrade - $40/square foot for storage areas	Engineer's estimate

Planning Projects

The build-out of hydrogen infrastructure will require planning. It is assumed that each planning project will cost $150,000 and will be incurred only once per depot.

30-Bus Incremental Mechanical and Installation Package Projects

30-Bus Incremental Mechanical and Installation Package projects include all of the work necessary to design and install the hydrogen fueling equipment to serve up to 30-buses. This includes design, permitting, and installation of two-dispensers, vaporizers, chillers, and fuel pumps, as well as electrical system upgrades, and all site required site work. The estimated cost to provide complete the design and installation is approximately $3,386,000, and is based on results from HDRSAM as well as from costs developed for other similar installation.

Storage Capacity Projects

Storage capacity projects include the incremental addition of one or more 15,000-gallon liquid hydrogen storage tanks. Tanks are sized at 15,000 gallons to accommodate one truckload of liquid hydrogen, or approximately 3,000 kg. A review of the block analysis indicates that between approximately 414 kg and 566 kg of hydrogen are expected to be used each day to operate the service, depending on operational conditions. As a result, a single tank of hydrogen fuel is expected to be able to fuel the fleet for between 5 and 7 days. A standalone, single-tank project costs approximately $290,000.

Maintenance Bay Upgrade Projects

Maintenance bays and storage buildings require hydrogen detection and exhaust equipment to ensure safety. CTE assumes a cost of $125,000 per maintenance bay to retrofit facilities for hydrogen buses at each depot and $40 per square foot for storage areas.

On-Site SMR

On-site SMR was evaluated to understand the capital costs associated with self-generation of hydrogen on-site. Assumptions for on-site SMR are that a modular system would be utilized to generate hydrogen that could deliver sufficient capacity to fuel up to 30 vehicles per day. On-Site SMR requires installation of a modular SMR unit, electrical system upgrades, upgrade of the water system to supply cooling water to the unit, and installation of a high-pressure natural gas line that can deliver gas at up to 170 pounds per square inch (psi). UniSource Energy indicated that natural gas is available near the facility in the required capacity to support on-site SMR. There are significant space considerations for deployment of a modular on-site SMR system that would require major site renovations and reconfiguration, as detailed in Figure 40, above. As detailed in the figure, the existing storage building would have to be demolished and replaced with hydrogen fueling infrastructure. Further analysis would be required to determine if the location of the equipment would meet local, state, and federal code requirements due to the proximity to adjacent properties and buildings.

Mixed BEB and FCEB Infrastructure Summary

In the Mixed BEB and FCEB scenario, charging infrastructure is required to service a total of ten (10) BEBs in addition to hydrogen fueling infrastructure required to service nineteen (19) FCEBs from both depots.

BEB charging infrastructure necessary to support the Mixed BEB and FCEB scenario mimics the costs provided in the BEB Depot-Only Charging scenario. In addition to BEB charging, hydrogen fueling is required to support the Mixed BEB and FCEB scenario. The FCEB fueling costs are developed as discussed in the FCEB Only scenario where the scope of work is broken into four (4) key project types: (1) planning, (2) structural, (3) maintenance bay upgrades, and (4) fueling. Infrastructure is built out over time as necessary to support FCEB deployment. Hydrogen fueling infrastructure estimates were based on delivery of hydrogen to the facility.

Table 11 provides the total infrastructure costs for the Mixed BEB and FCEB scenario for the transition. This total buildout of required BEB and FCEB infrastructure is expected to require approximately $8.2 million. Note that all of the hydrogen fueling operations are located at the Kaspar Drive Maintenance Facility.

Table 11 – Total Infrastructure Costs, Mixed BEB and FCEB Scenario

Division	Cost
Kaspar Drive Maintenance Facility	$ 6,619,000
NAU or other separate facility	$ 1,474,000
Total	**$ 8,093,000**

FCEB Only Infrastructure Summary

FCEBs can complete all current fixed-route service blocks; therefore, they will replace all hybrid diesel vehicles on a one-to-one basis following the replacement schedule. The following estimates calculate necessary hydrogen infrastructure costs to support a fleet of twenty-nine (29) FCEBs in 2034 across both depots. The Kaspar Drive Maintenance Facility will store twenty-three (23) 35’ FCEBs, and the NAU or other separate facility will store six (6) 60’ FCEBs but all fueling will occur at the Kaspar Drive Maintenance Facility.

Table 12 provides the total infrastructure costs for the FCEB Only scenario for the transition. The costs were based upon delivery of hydrogen to the facility rather than on-site production. The total buildout of required FCEB infrastructure will require approximately $5 million for the FCEB Only scenario. On-site SMR infrastructure is estimated to cost approximately $8.8 million.

Table 12 – Total Infrastructure Costs, FCEB Only Scenario

Division	Cost
Kaspar Drive Maintenance Facility	$ 5,068,000
NAU or other separate facility	$ ---
Total	**$ 5,068,000**

Facilities Assessment Cost Comparison

The Facilities Assessment includes all infrastructure-related costs over the transition for each scenario. **Figure 41** shows the cumulative infrastructure costs for each scenario.

Table 13 shows the combined total costs and number of vehicles in 2034. Note that the percent increase over Baseline Hybrid Diesel is not provided in the table because no additional infrastructure is required for the Baseline Hybrid Diesel scenario fleet, and therefore the infrastructure costs incurred in the Baseline Hybrid Diesel scenario are zero.

Figure 41 – Total Costs, Facilities Assessment

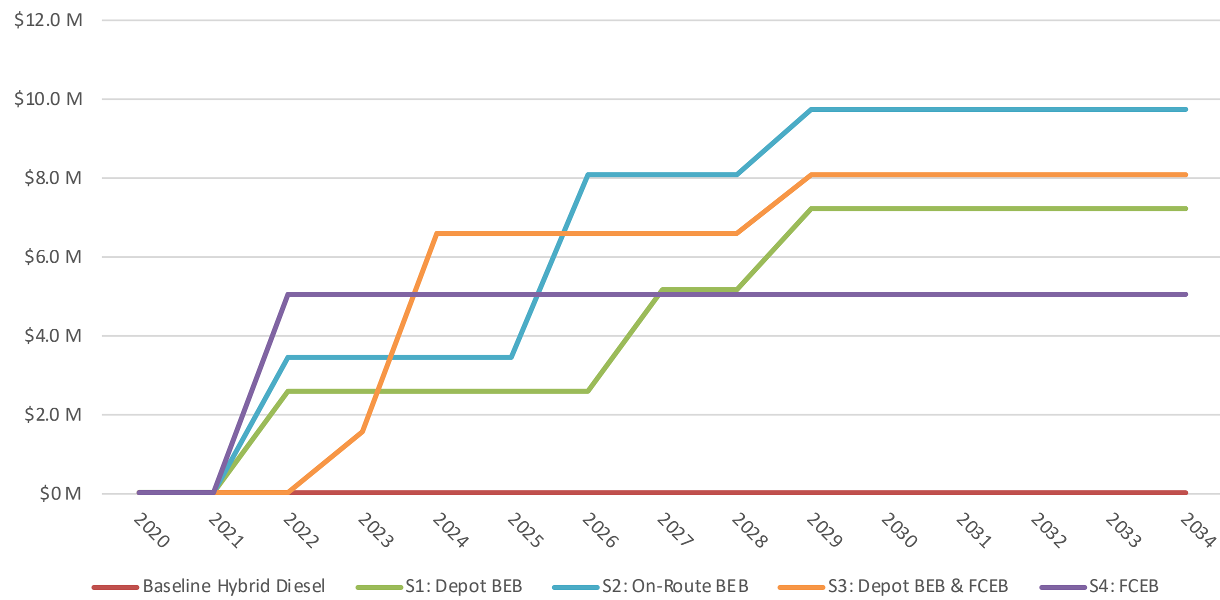
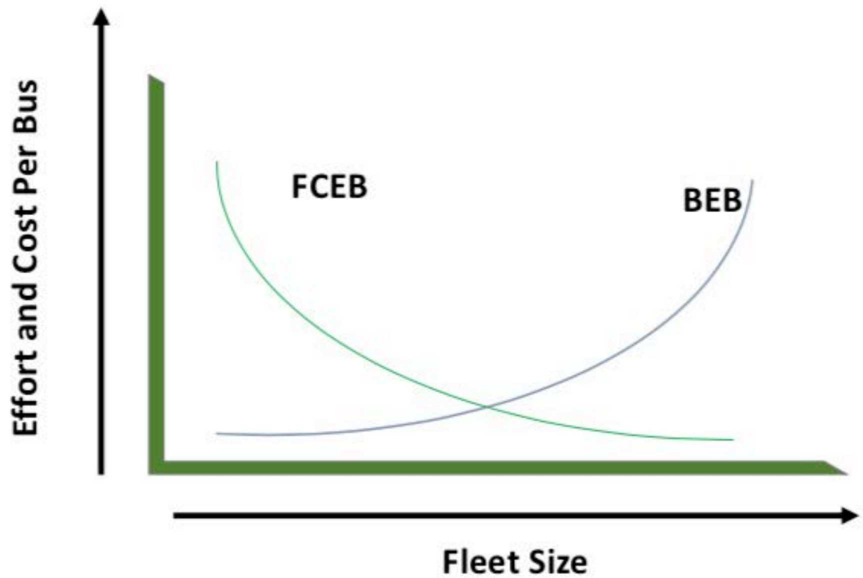


Table 13 – Total Costs, Facilities Assessment

Scenario	Cost	% Cost Increase Over Baseline Hybrid Diesel	ZEBs in 2034
Baseline Hybrid Diesel	----	----	29
BEB Depot Only	$ 7,252,000	NA	39
BEB On-Route + Depot	$9,739,000	NA	29
Mixed BEB and FCEB	$8,093,000	NA	29
FCEB Only	$5,068,000	NA	29

As can be seen from **Table 13**, costs for hydrogen fueling infrastructure to support FCEB operations is less expensive than deploying large scale electrical infrastructure to support BEB operations for Mountain Line at full-scale deployment. This is typical of FCEB and BEB deployments, where infrastructure costs are typically lower for small scale BEB deployments than FCEB deployments; however, as the fleet size increases, FCEB infrastructure becomes more cost competitive as it can be scaled to larger numbers of vehicles more easily. **Figure 42** depicts the relationship between fleet size and infrastructure costs for BEB and FCEB deployments.

Figure 42 - Infrastructure and Scalability



Maintenance Assessment

One of the anticipated benefits for a transit agency in moving to a BEB or FCEB fleet is maintenance costs. Conventional wisdom indicates that a transit agency may attain savings in maintenance cost for a ZEB compared to a conventional fuel vehicle. These savings are 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 an internal combustion engine bus. However, the savings in traditional maintenance costs may be offset by the cost of battery or fuel-cell replacements over the life of the vehicles.

There is limited data available on early deployments and many early deployments are from new manufacturers where production quality issues manifest as maintenance issues. Internal combustion engine vehicle labor and maintenance costs for hybrid diesel vehicles are provided by Mountain Line. BEB maintenance costs come from New Flyer projected maintenance requirements and costs, and BEB labor is based on current labor costs provide by Mountain Line. There is limited information available regarding maintenance costs for FCEBs due to the limited number of vehicles in operation in the United States. Much of the information comes from Alameda-Contra Costa Transit District (AC Transit), which has the largest FCEB fleet in the country. Unfortunately, these buses are older models that require a significant amount of maintenance. In addition, the buses are out of warranty, and support from their European manufacturer is expensive. In addition to labor and materials, the cost impact of battery warranties and mid-life overhauls for major components for each type of bus are also estimated. **Table 14** shows the assumed costs of scheduled and unscheduled labor and maintenance used in this analysis. The estimated cost of $40 per labor hour used in the analysis.

Table 14 – Labor and Materials Cost Assumptions for Flagstaff Area Transit Agencies

Type	Estimate	Source
Diesel Hybrid	$0.28/mi	Mountain Line actual costs
BEB	$0.24/mi	New Flyer maintenance projections & Mountain Line labor costs
FCEB	$0.66/mi	AC Transit maintenance costs & Mountain Line labor costs

Also included in the Maintenance Assessment costs is the estimated cost to extend battery warranties for up to 12-years for BEBs and FCEBs. This cost is incurred upon the purchase of each vehicle. Battery warranties are expected to cost approximately $75,000 per BEB and $25,000 per FCEB and typically cover degradation of the battery to 80% of the nameplate capacity, whereas replacement of a battery at mid-life of a vehicle (7.5 years for Mountain Line) is expected to cost approximately $500 per kWh of battery capacity, or approximately $225,000. Because Mountain Line is projected to utilize on-route charging to operate its service, the reduction in capacity to 80% is off-set by the ability to charge on-route during each pass through the DCC, and it is not necessary to return the battery to its original nameplate capacity in order to complete the daily service. As a result, the purchase of a battery warranty is a more economical solution to ensure that the battery remains at greater than 80% of its nameplate capacity. Other assumptions used in this analysis are given in **Table 15.** These costs are estimates provided by vehicle OEMs.

Table 15 – Battery Warranty Cost Assumptions

Type	Estimate	Source
BEB	$75k per bus	Bus OEM
FCEB	$25k per bus	Fuel Cell OEM

In addition to labor, maintenance, and battery warranties, the cost impact of mid-life overhauls of major components for each type of bus is estimated. Assumptions used in this analysis are given in **Table 16.** These costs are from Mountain Line for hybrid diesel buses and for BEB and FCEB, mid-life overhaul cost estimates are provided by vehicle OEMs.

Table 16 – Mid-Life Overhaul Cost Assumptions

Type	Overhaul Scope	Estimate	Source
Diesel Hybrid	Engine/Transmission Overhaul	$30k per bus	Mountain Line
BEB	Miscellaneous Major Component Replacement	$25k per bus	Bus OEM
FCEB	Fuel Cell Overhaul	$40k per bus	Fuel Cell OEM

Baseline Hybrid Diesel

The Baseline Hybrid Diesel assumes no changes to Mountain Line’s current fleet configuration throughout the life of the study. **Figure 43** shows the combined labor, materials and mid-life overhaul costs for the Baseline Hybrid Diesel scenario fleet projection for each year of the study, in 2020 dollars. Annual fleet maintenance costs average approximately $340,000 per year.

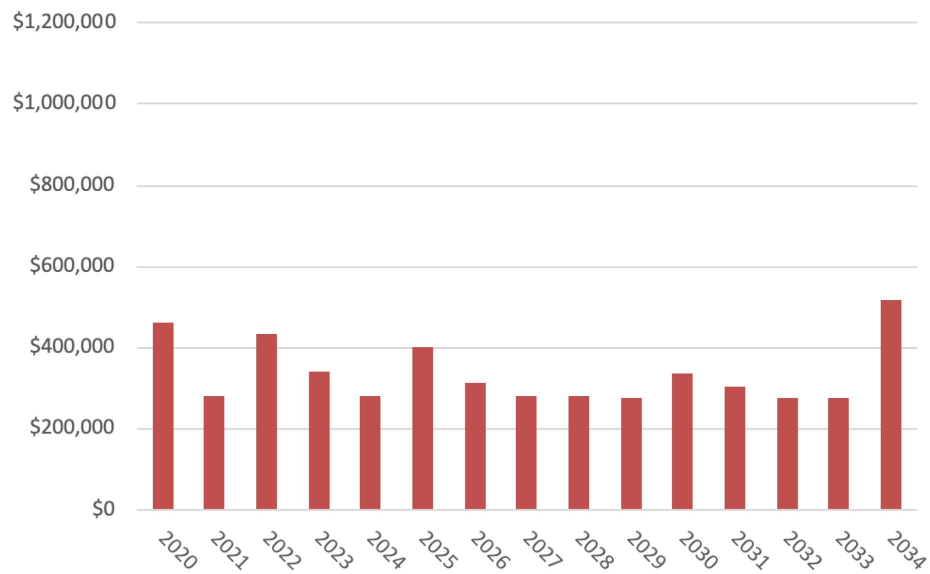


Figure 43 – Annual Fleet Maintenance Costs, Baseline Hybrid Diesel

BEB Depot-Only Charging

Figure 44 shows the combined labor, materials, and mid-life overhaul costs for the BEB Depot-Only Charging scenario for each year of the transition, in 2020 dollars. The spike in 2026 is associated with the cost of ten (10) extended battery warranties for the ten (10) BEBs purchased that year, as battery warranty costs are incurred at the time of purchase but are included in the maintenance assessment costs.

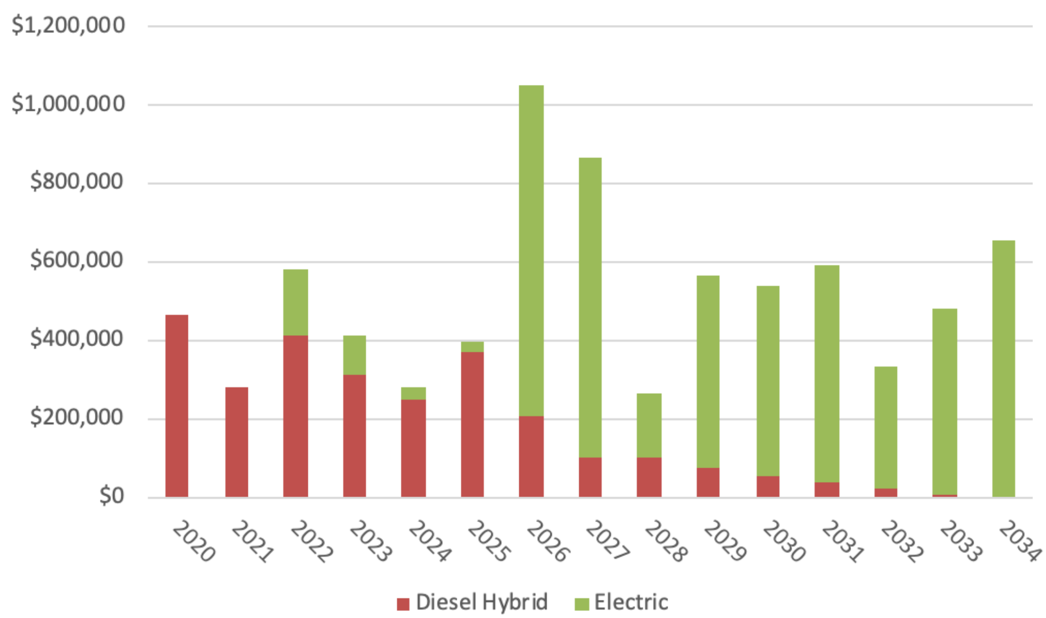


Figure 44 – Annual Fleet Maintenance Costs, BEB Depot-Only Scenario

BEB On-Route and Depot Charging

Figure 45 shows the combined labor, materials, and mid-life overhaul costs for the BEB On-Route and Depot Charging scenario for each year of the transition, in 2020 dollars.

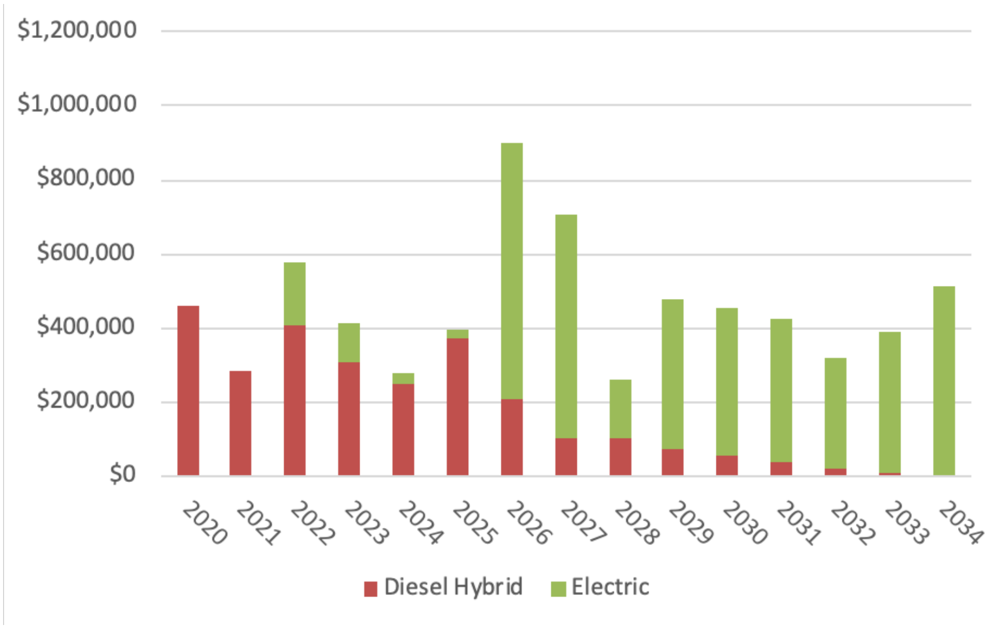


Figure 45 – Annual Fleet Maintenance Costs, BEB On-Route and Depot Scenario

Mixed BEB and FCEB

Figure 46 shows the combined labor, materials, and mid-life overhaul costs for the Mixed BEB and FCEB scenario for each year of the transition, in 2020 dollars.

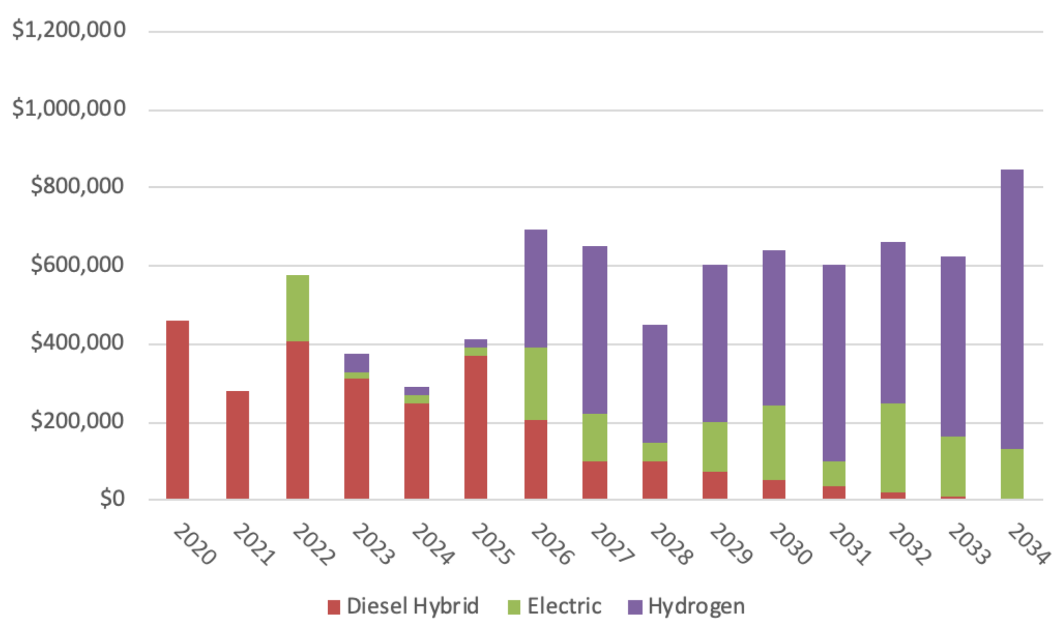


Figure 46 – Annual Fleet Maintenance Costs, Mixed Scenario

FCEB Only

Figure 47 shows the combined labor, materials, and mid-life overhaul costs for FCEB Only scenario for each year of the transition, in 2020 dollars.

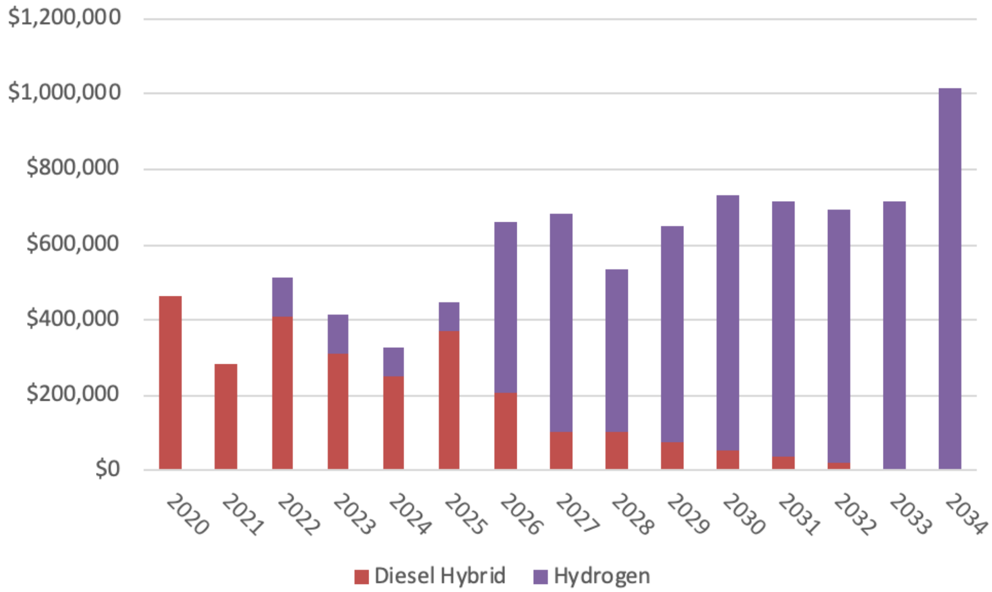


Figure 47 – Annual Maintenance Costs, FCEB Only Scenario

Maintenance Assessment Cost Comparison

The Maintenance Assessment includes all labor, materials, and overhaul costs over the transition for each scenario. **Figure 48** shows the cumulative maintenance costs for each scenario. **Table 17** shows the combined total costs and the incremental cost over the Baseline Hybrid Diesel.

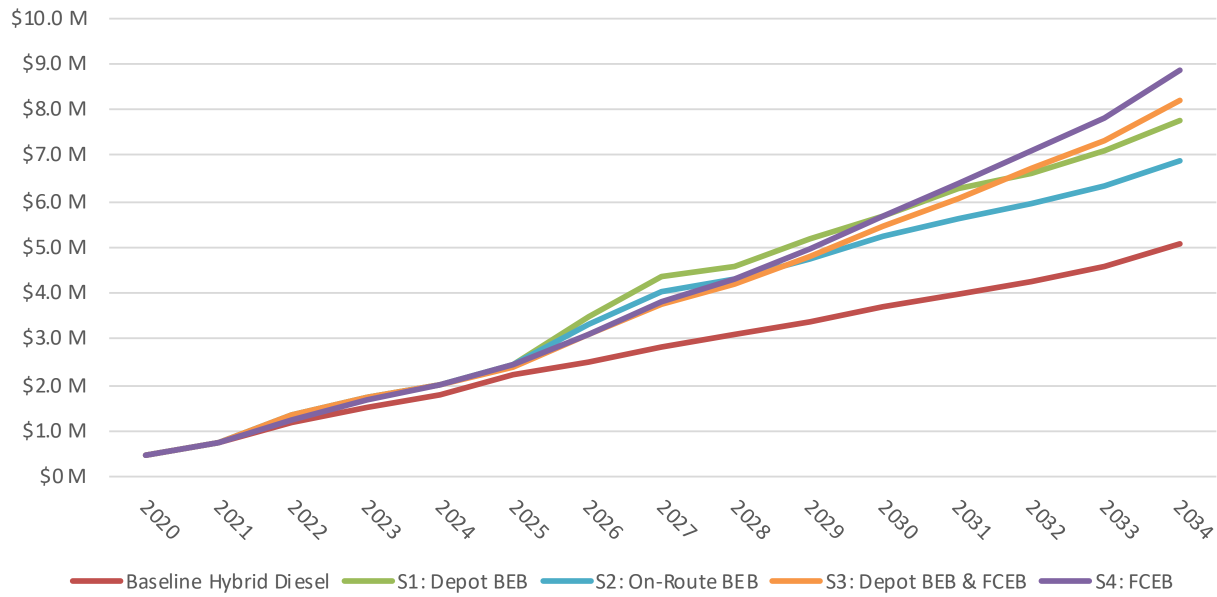


Figure 48 – Total Costs, Maintenance Assessments

Table 17 – Total Costs, Maintenance Assessments

Scenario	Cost	% Cost Increase Over Baseline Hybrid Diesel	ZEBs in 2034
Baseline Hybrid Diesel	$ 5,065,000	----	29
BEB Depot Only	$7,755,000	53%	39
BEB On-Route + Depot	$6,853,000	35%	29
Mixed BEB and FCEB	$8,178,000	61%	29
FCEB Only	$8,836,000	74%	29

Estimated maintenance costs actually increase over Baseline Hybrid Diesel for all scenarios due to the low maintenance costs associated with the Mountain Line fleet as well as the warranty and mid-life replacement costs associated with ZEBs.

Emissions Assessment

A primary benefit of transitioning an entire fleet from hybrid diesel vehicles to zero-emission is the reduction of greenhouse gas (GHG) emissions. GHG emissions consist primarily of carbon dioxide (CO_2) but also include small amounts of methane (CH_4) and Nitrous Oxide (N_2O), emitted during fuel combustion[3]. In the transportation sector the vast majority of GHG emissions is from CO_2. For completeness, total GHG emissions are also calculated but the primary focus is on reduction of CO_2.

In addition to GHGs, additional emissions called "criteria pollutants" are generated when burning traditional transportation fuels. These include substances that are commonly thought of as smog and are known to damage human health. Some examples are carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOC) and particulate material under 10 microns and 2.5 microns in diameter (PM10 and PM2.5).

The primary sources of data to support this analysis are listed below:

- Argonne National Laboratory – *Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool*
- EPA Motor Vehicle Emissions Simulator (MOVES)
- Mountain Line – data on existing fleet mileage and fuel economy

Carbon Emissions

There are three categories of emissions generally referred to in the context of zero emission vehicle transportation: well-to-wheel emissions (WTW), tailpipe emissions and upstream emissions.

WTW emissions include all emissions generated by the vehicle during operation *and* emissions generated by the powerplant or refinery to produce the electricity or fuel used by the vehicle. WTW emissions are present for the generation of nearly all different fuels, be it diesel, gasoline, CNG or electricity, as these fuels require a combination of petroleum, natural gas and coal for their production (except in the case of electricity produced by 100% renewable energy).

Tailpipe emissions include all emissions generated by the vehicle during operation. We assume fossil fuel vehicles produce emissions on a per mile or per gallon basis according to AFLEET which uses the EPA's MOVES model. BEBs and FCEBs do not produce any tailpipe emissions.

Upstream emissions are generated by the fuel refinery or powerplant during extraction, processing and transportation of the fuel. In this analysis, upstream emissions are calculated by the difference between WTW and tailpipe emissions.

Emissions from electricity production uses inputs from APS as part of user defined entries into the AFLEET set of assumptions. The APS energy mix is as follows: renewables (20.6%), natural gas (25.5%), coal (22.7%), and nuclear (31.7%). In addition, hydrogen generation for the hydrogen that would be delivered to the facility is assumed to be from 40% renewable

[3] EPA, Sources of Greenhouse Gas Emissions; https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions#transportation

resources based on discussions with a major provider to the region. The emissions from delivery of the hydrogen to the facility is included in the emissions estimate.

Emissions analyses were performed for the transition scenarios discussed in this document and detailed below:

1. Baseline Hybrid Diesel (for comparison)
2. BEB Depot Only
3. BEB On-Route + Depot
4. Mixed BEB and FCEB (assumes off-site SMR and hydrogen delivery)
5. FCEB Only (assumes off-site SMR and hydrogen delivery

Figure 49 compares the total estimated well-to-wheel greenhouse gas emissions for each scenario. The Baseline Hybrid Diesel scenario generates 40,000 tons of GHGs over the life of the transition period (2020-2034). This scenario assumes "business as usual" and does not attempt to replace any fossil fuel vehicles with ZEBs. The BEB Depot + On-Route Charging scenario results in the lowest cumulative GHG emissions of approximately 26,000 tons during the transition period. The BEB Depot + On-Route Charging scenario results in an approximate 34% savings over Baseline Hybrid Diesel, following by the BEB Depot Only scenario at 33%, Mixed FCEB and BEB scenario at 28% and FCEB Only scenario at 25%.

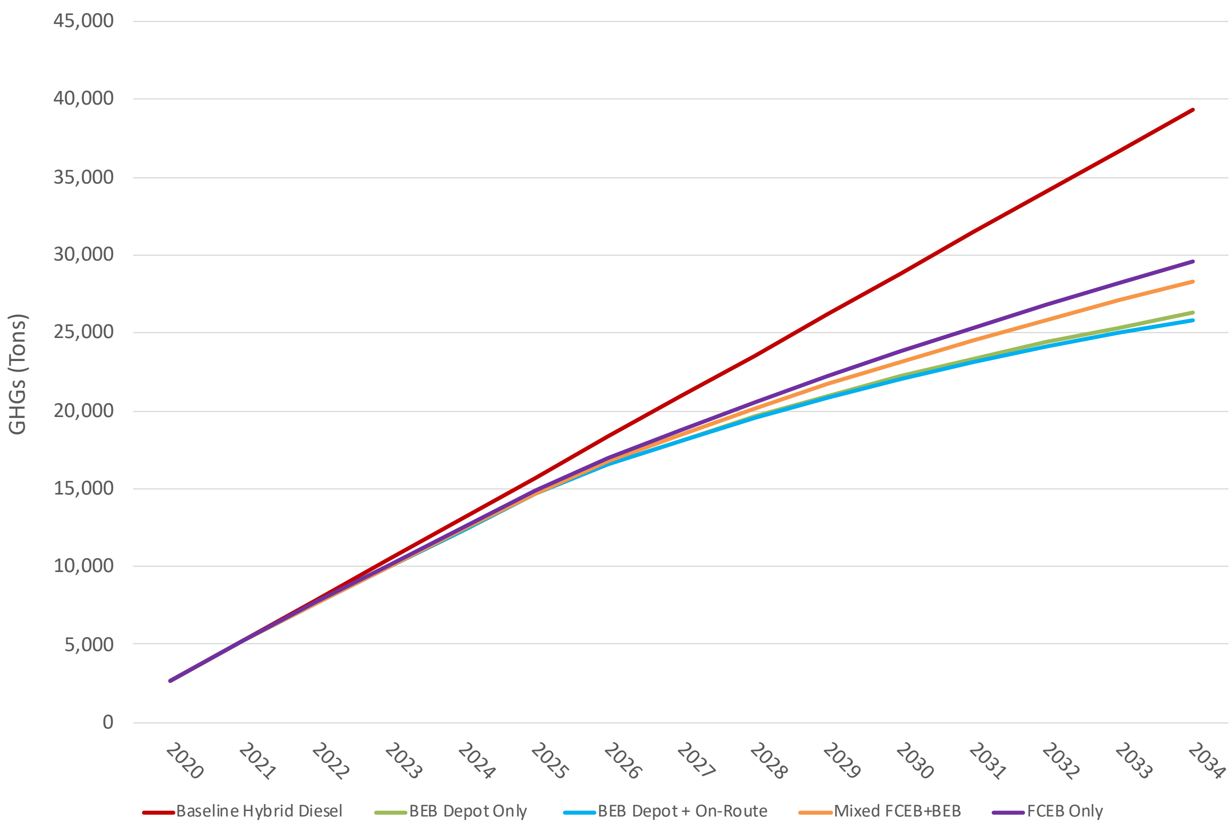


Figure 49 – Cumulative WTW GHGs, 2020-2034

Estimated annual WTW GHG emissions when the fleet is fully converted to ZEBs, the percent reduction from the Baseline Hybrid Diesel scenario, and the equivalent number of passenger vehicles removed from the road annually based on the USEPA Greenhouse Gas Equivalencies Calculator is included in **Table 18.** Note that WTW GHG emissions may be reduced further depending on integration of more renewables in electrical power generation and/or hydrogen production.

Table 18 –WTW GHG Emissions, Annual, 2034 and Beyond

Scenario	GHG (tons)	% Reduction from Baseline Hybrid Diesel	Equivalent Passenger Vehicles Eliminated Annually
Baseline Hybrid Diesel	2,620	----	----
BEB Depot Only	899	66%	273
BEB On-Route + Depot	840	68%	282
Mixed BEB and FCEB	1233	53%	220
FCEB Only	1440	45%	187

Criteria Pollutants

As discussed previously, criteria pollutants are compounds that are considered hazardous to human health. These include, but is not limited to, CO, VOCs, NOx, and PM10 and PM2.5. Fossil fuel vehicles produce these pollutants during combustion and as such, these emissions are emitted along roadways and near population centers, unlike upstream pollutants, which occur at the power plant or refinery. **Table 19** compares the projected total tailpipe criteria pollutants in each scenario; these estimates are cumulative over the transition period. Since ZEBs do not produce any tailpipe emissions, the reductions are a direct result of replacing of hybrid diesel vehicles with zero-emission. **Table 20** compares the emissions savings as a percentage over the Baseline Hybrid Diesel.

Table 19 –Tailpipe Criteria Pollutants, Cumulative, 2020-2034

Scenario	CO (lbs)	VOC (lbs)	NOx (lbs)	PM2.5 (lbs)	PM10 (lbs)
Baseline Hybrid Diesel	7,792	1,352	36,397	596	664
BEB Depot Only	4,164	718	20,665	330	364
BEB On-Route + Depot	4,164	718	20,665	330	364
Mixed BEB and FCEB	4,049	701	19,458	310	344
FCEB Only	3,890	668	17,090	292	326

Table 20 – Criteria Pollutant Savings Over Baseline Hybrid Diesel, Cumulative, 2020-2034

Scenario	CO (lbs)	VOC (lbs)	NOx (lbs)	PM2.5 (lbs)	PM10 (lbs)
BEB Depot Only	47%	47%	43%	45%	45%
BEB On-Route + Depot	47%	47%	43%	45%	45%
Mixed BEB and FCEB	47%	48%	47%	48%	48%
FCEB Only	50%	51%	53%	51%	51%

Total Cost of Ownership Assessment

The Total Cost of Ownership Assessment compiles and organizes the results from the Fleet, Fuel, Facilities, and Maintenance Assessments to show total and annual costs throughout the transition. It includes selected capital and operating costs of each transition scenario over the transition timeline. There may be other costs incurred (i.e., incremental operator and maintenance training, see chapter/page in phase 2 report); however, these four assessment categories are the key drivers in ZEB transition decision-making. Redundancy, external battery storage, battery recycling, and potential costs associated with depot and transit center construction are not included in this analysis but are important considerations that will also be factors during the transition and will be addressed in the more detailed Phase 2 analysis.

No cost escalation is assumed nor does CTE assume any cost reduction due to economies of scale for ZEB technology because there is no historical basis for this assumption. Future changes to Mountain Line's service level, depot locations, route alignments, block scheduling, etc., are unforeseen. The sections below provide best estimates using the information currently available and the assumptions explained throughout this study.

Costs by Scenario

The following sections show total costs per scenario, broken down by assessment type.

Baseline Hybrid Diesel

The Baseline Hybrid Diesel scenario is used for comparative purposes only. It assumes no changes to the agency's current fleet configuration throughout the life of the study, i.e., no ZEB-related purchases. **Table 21** shows the fleet, fuel, facilities and maintenance costs for the Baseline Hybrid Diesel scenario in 2020 dollars. Mountain Line's total operating and capital costs are an estimated $34.3 million from 2020 to 2034. There are no facilities costs for this scenario. As Mountain Line is assumed to not add any additional buses other than those that are already included in the Baseline Hybrid Diesel scenario, no additional facilities are required.

Table 21 – Total Costs, Baseline Hybrid Diesel [millions $]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	Total
Fleet	-	-	1.3	0.7	-	-	5.2	3.9	-	2.3	1.3	1.3	2.0	2.0	1.0	20.8
Fuel	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	8.5
Facilities	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Maintenance	0.5	0.3	0.4	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.5	5.1
Total	**1.0**	**0.8**	**2.3**	**1.6**	**0.8**	**1.0**	**6.1**	**4.7**	**0.8**	**3.1**	**2.2**	**2.2**	**2.8**	**2.8**	**2.1**	**34.3**

BEB Depot-Only Charging

Table 22 shows the combined fleet, fuel, facilities, and maintenance costs for the BEB Depot-Only Charging scenario in 2020 dollars. The total estimated combined cost is approximately $56.4 million over the length of the transition, from 2020 to 2034. This scenario estimates a total of thirty-nine (39) BEBs in service by 2034.

Table 22 – Total Costs, BEB Depot-Only Scenario [millions $]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	Total
Fleet	-	-	1.6	0.8	-	-	8.0	6.4	-	3.7	2.4	3.2	2.6	3.9	2.6	35.2
Fuel	0.6	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	6.2
Facilities	-	-	2.6	-	-	-	-	2.6	-	2.1	-	-	-	-	-	7.3
Maintenance	0.5	0.3	0.6	0.4	0.3	0.4	1.1	0.9	0.3	0.6	0.5	0.6	0.3	0.5	0.7	7.8
Total	**1.0**	**0.8**	**5.3**	**1.7**	**0.8**	**0.9**	**9.5**	**10.2**	**0.6**	**6.7**	**3.3**	**4.1**	**3.2**	**4.7**	**3.6**	**56.4**

BEB On-Route and Depot Charging

Table 23 shows the combined fleet, fuel, facilities, and maintenance costs for the BEB On-Route and Depot Charging scenario in 2020 dollars. The total estimated combined cost is approximately $53.2 million over the length of the transition, from 2020 to 2034. This scenario estimates a total of twenty-nine (29) BEBs in service by 2034.

Table 23 – Total Costs, BEB On-Route and Depot Scenario [millions $]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	Total
Fleet	-	-	1.6	0.8	-	-	6.4	4.8	-	2.9	1.6	1.6	2.6	2.6	1.3	26.2
Fuel	0.6	0.6	0.6	0.6	0.6	0.6	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	10.4
Facilities	-	-	3.5	-	-	-	4.6	-	-	1.6	-	-	-	-	-	9.7
Maintenance	0.5	0.3	0.6	0.4	0.3	0.4	0.9	0.7	0.3	0.5	0.5	0.4	0.3	0.4	0.5	6.9
Total	**1.0**	**0.8**	**6.3**	**1.8**	**0.9**	**1.0**	**12.7**	**6.3**	**1.0**	**5.8**	**2.8**	**2.8**	**3.7**	**3.7**	**2.5**	**53.2**

Mixed BEB and FCEB

Table 24 shows the combined fleet, fuel, facilities, and maintenance costs related to the Mixed BEB and FCEB scenario in 2020 dollars. The total estimated combined cost is approximately $58.2 million over the length of the transition, from 2020 to 2034. This scenario estimates a total of ten (10) BEBs and nineteen (19) FCEBs [twenty-nine (29) total ZEBs] in service by 2034.

Table 24 – Total Costs, Mixed Scenario [millions $]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	Total
Fleet	-	-	1.6	1.0	-	-	7.6	5.8	-	3.3	1.8	2.0	2.6	2.9	1.6	30.1
Fuel	0.6	0.6	0.5	0.5	0.6	0.6	0.7	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	11.9
Facilities	-	-	-	1.6	5.1	-	-	-	-	1.5	-	-	-	-	-	8.1
Maintenance	0.5	0.3	0.6	0.4	0.3	0.4	0.7	0.6	0.4	0.6	0.6	0.6	0.7	0.6	0.8	8.2
Total	**1.0**	**0.8**	**2.7**	**3.5**	**6.0**	**1.1**	**9.0**	**7.3**	**1.3**	**6.3**	**3.4**	**3.6**	**4.2**	**4.5**	**3.4**	**58.2**

FCEB Only

Table 25 shows the combined fleet, fuel, facilities, and maintenance costs related to the FCEB Only scenario in 2020 dollars. The total estimated combined cost is approximately $60.2 million over the length of the transition, from 2020 to 2034. This scenario estimates a total of twenty-nine (29) FCEBs in service by 2034.

Table 25 – Total Costs, FCEB Only Scenario [millions $]

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	Total
Fleet	-	-	2.0	1.0	-	-	8.0	6.0	-	3.6	2.0	2.0	3.1	3.1	1.6	32.3
Fuel	0.6	0.6	0.6	0.6	0.7	0.7	0.9	1.1	1.1	1.1	1.2	1.2	1.3	1.2	1.2	14.0
Facilities	-	-	5.1	-	-	-	-	-	-	-	-	-	-	-	-	5.1
Maintenance	0.5	0.3	0.5	0.4	0.3	0.4	0.7	0.7	0.5	0.6	0.7	0.7	0.7	0.7	1.0	8.8
Total	**1.0**	**0.8**	**8.2**	**2.0**	**1.0**	**1.2**	**9.5**	**7.7**	**1.6**	**5.3**	**3.9**	**3.9**	**5.1**	**5.0**	**3.8**	**60.2**

Total Estimated Costs

Table 26 provides the detailed cost totals, total cost increase over Baseline Hybrid Diesel, and the number of ZEBs in the fleet in 2034.

Table 26 – Total Estimated Transition Costs

	Baseline Hybrid Diesel	BEB Depot-Only	BEB On-Route + Depot	Mixed BEB and FCEB	FCEB Only
Fleet	$20,800,000	$35,200,000	$26,200,000	$30,100,000	$32,300,000
Fuel	$8,462,000	$6,240,000	$10,396,000	$11,863,000	$14,034,000
Facilities	–	$7,252,000	$9,739,000	$8,093,000	$5,068,000
Maintenance	$5,065,000	$7,755,000	$6,853,000	$8,178,000	$8,836,000
Total	**$34,327,000**	**$56,448,000**	**$53,188,000**	**$58,235,000**	**$60,238,000**
Incremental Cost Over Baseline Hybrid Diesel		$22,121,000	$18,861,000	$23,908,000	$25,911,000
ZEBs in 2034	**29**	**39**	**29**	**29**	**29**

Conclusions and Recommendations

ZEB technologies are in a period of rapid development and change. While the technology is proven in many pilot deployments, it is not yet matured to the point where it can easily replace current fossil-fuel technologies on a large scale. BEBs will require significant investment in facilities and infrastructure and may require changes to service and operations to manage their inherent constraints. On the other hand, FCEBs are believed to provide an operational equivalent to CNG or diesel; however, the incremental cost of buses, fueling infrastructure, and fuel places this technology at a serious disadvantage.

In 2008, voters approved a sales tax increase allowing Mountain Line to adopt low and zero-emissions bus technologies as their fleet expands and is replaced. Additionally, in 2018 the Flagstaff City Council adopted a Climate Action and Adaptation Plan which aims to reduce greenhouse gas emissions in Flagstaff by 30% by 2030 and by 80% by 2050. By the end of the transition period in 2034, greenhouse gas emissions will be reduced by approximately 40% to 65%, depending on the transition approach and amount of renewable energy in the electrical grid.

If Mountain Line selects an all BEB strategy, incremental ZEB transitional costs are likely to fall between approximately $19 million for the BEB On-Route and Depot Charging scenario and $22 million for the BEB Depot-Only Charging scenario. The difference in cost for these scenarios is the result of more BEBs added to the fleet for the BEB Depot-Only scenario because not all hybrid diesel vehicles in the current fleet can be replace one-for-one with BEBs.

If Mountain Line selects an FCEB Only strategy, incremental ZEB transitional costs are estimated at approximately $26 million for the full transition. All current hybrid diesel vehicles can be replaced one-for-one with FCEBs. A primary assumption for the FCEB analysis is that FCEB vehicles will be available for all vehicle types and lengths during the transition period. In addition, due to the limited deployment of FCEBs in service in the United States, fuel costs and capital costs for vehicles remain high. These costs are expected to come down in the future as more vehicles are deployed; however, there is no basis at this time to make assumptions as to how much they may be reduced. Additionally, data for FCEB maintenance costs reflect higher costs than what much of the market would expect with newer deployments because much of the data is based on older vehicles past their warranty periods and requiring expensive support from overseas companies. As such, there are more unknowns associated with the incremental costs for the FCEB Only scenario, and costs are likely to be more subject to change. It is expected that the cost of the FCEB Only scenario will come down if a larger number of vehicles and infrastructure is deployed, but to what extent is unknown. Significant investments in hydrogen infrastructure will be required and will take years to develop to gain a better understanding of the long-term costs for FCEB Only deployment.

As expected, with an incremental cost of approximately $24 million, the Mixed BEB and FCEB scenario has an incremental cost that falls between an all BEB and all FCEB deployment when the current fleet size is maintained. Though the costs are cheaper for a mixed fleet deployment than FCEB Only, there are complexities with managing a mixed fleet through the transition: requiring maintenance of existing internal combustion engine vehicle infrastructure, installing new BEB infrastructure, and installing new FCEB fueling infrastructure. Space constraints at the depot will require careful planning if this path is selected.

As a result, recommendations for Mountain Line are as follows:

1. **Be proactive with ZEB deployments:** Additional development, data collection, and analyses are needed before ZEB technology is ready for fleetwide deployment. For example, BEBs will require charge management software, hardware, and standards to manage the fleetwide transition. For FCEB deployment to be competitive with BEBs, lower fuel costs that will evolve over time with the production of hydrogen at scale will be required. Mountain Line should move forward carefully, taking advantage of various grant and incentive programs to offset the incremental cost for ZEB deployment. Incentive programs may be eliminated in future years as ZEB procurements become mandated instead of optional.
2. **Choose a ZEB transition scenario that maintains fleet size due to space constraints.** Due to limited vehicle storage space at the Kaspar Drive Maintenance Facility, the number of vehicles required to maintain current Mountain Line fixed-route service levels would exceed the facility's indoor capacity for storing and charging vehicles. The BEB Depot-Only scenario is the only scenario that requires an increase in fleet size. In addition, the Mixed Fleet scenario requires infrastructure to support both battery-electric and fuel-cell technology at the Kaspar Drive Maintenance Facility. Significant changes to facility operations would be required to support deployment of infrastructure for both technologies as there is not currently space on the facility to install a hydrogen fueling station (or on-site production).

A review of the results from the transition analysis indicates that BEB On-Route and Depot charging provides the lowest total cost of ownership over the transition period. Mountain Line already operates all of the service blocks through the DCC, thus a central location for charging is already available. In addition, the master planning is currently underway to replace and modernize the current DCC facility beginning in 2021. CTE recommends further evaluation of the BEB On-Route and Depot Charging scenario to refine an implementation approach to begin the transition to a zero-emission future.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. ZEB technology requires significant development before it is ready to fully support fleetwide transitions. However, 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 Transition Planning Methodology Description

ZEB Transition Planning Methodology

This study uses CTE's ZEB Transition Planning Methodology, which is a complete set of analyses used to inform agencies 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. The work steps specific to this study are outlined below:

1. Planning and Initiation
2. Requirements & Data Collection
3. Service Assessment
4. Fleet Assessment
5. Fuel Assessment
6. Facilities Assessment
7. Maintenance Assessment
8. Total Cost of Ownership Assessment

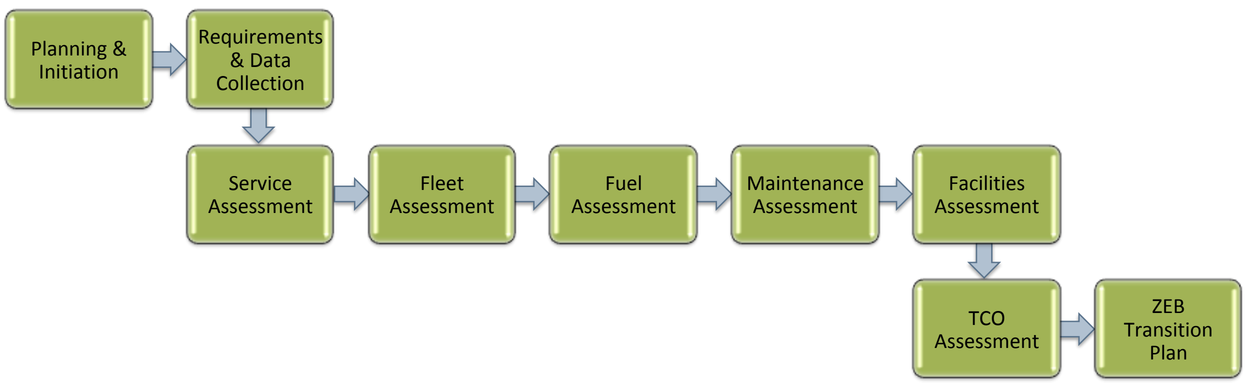


Figure A1 – CTE's ZEB Transition Study Methodology

The **Planning and Initiation** phase builds the administrative framework for the transition study. During this phase, the project team drafted the scope, approach, tasks, assignments, and timeline for the project. CTE worked with Mountain Line staff to plan the overall project scope and all deliverables throughout the full life of the study. CTE conducted an "Assumptions Workshop" to start the **Requirements & Data Collection** phase. The assumptions collected during this phase provide key parameters used in each of the Assessment phases that follow. CTE collected fleet, operational, maintenance, and facilities information to define the Baseline Hybrid Diesel scenario. CTE also collected route and block (individual bus) mileage and duty cycle information, or the ratio of the time the vehicles are in service compared to out of service, as the basis for the Service Assessment.

During the **Service Assessment**, CTE worked with Mountain Line staff to assess how Mountain Line fleet vehicles are used and to identify service requirements. CTE leveraged several different tools and methods—including route modeling and simulation software, and empirically-derived screening models based on real-world operational data—to calculate expected energy efficiency, range, endurance, and energy consumption and identify any limitations to the application of electric vehicle technologies. Modeling results were used to estimate if a vehicle could complete a block on a single charge or fill, also known as block achievability, of every fixed service block in Mountain Line's network using BEBs and FCEBs. The results from the Service Assessment were used to guide ZEB procurements in the Fleet Assessment and to determine energy requirements (depot charging, on-route charging, and/or hydrogen) in the Fuel Assessment.

The **Fleet Assessment** developed a projected timeline for replacement of current buses with ZEBs that is consistent with the agency's fiscal year 2020 fleet replacement plan. Multiple projection scenarios were created utilizing different combinations of ZEB technologies. This assessment also included a projection of fleet capital cost over the transition lifetime, and it can be optimized with regard to any mandates or regulations, or to meet agency goals, such as minimizing cost or maximizing service levels.

The **Fuel Assessment** merged the results of the Service Assessment and Fleet Assessment to determine annual fuel requirements and associated costs. In the Fuel Assessment, energy costs were calculated through the full life of the transition for each scenario, including the Mountain Line's current hybrid diesel vehicles. To more accurately estimate BEB charging costs, CTE performed a focused charging analysis to simulate daily system-wide charging use. The Fuel Assessment provided total energy cost over the transition lifetime as well as projected changes in energy costs as hybrid diesel vehicles were phased out and ZEBs phase in.

The **Facilities Assessment** determined the necessary infrastructure to support the projected zero-emission fleet based on results from the Fleet Assessment and Fuel Assessment. The Facilities Assessment was calculated for each scenario used in the Fleet and Fuel Assessments. The results provide the hydrogen and battery electric infrastructure necessary to support a full-scale transition and the associated costs.

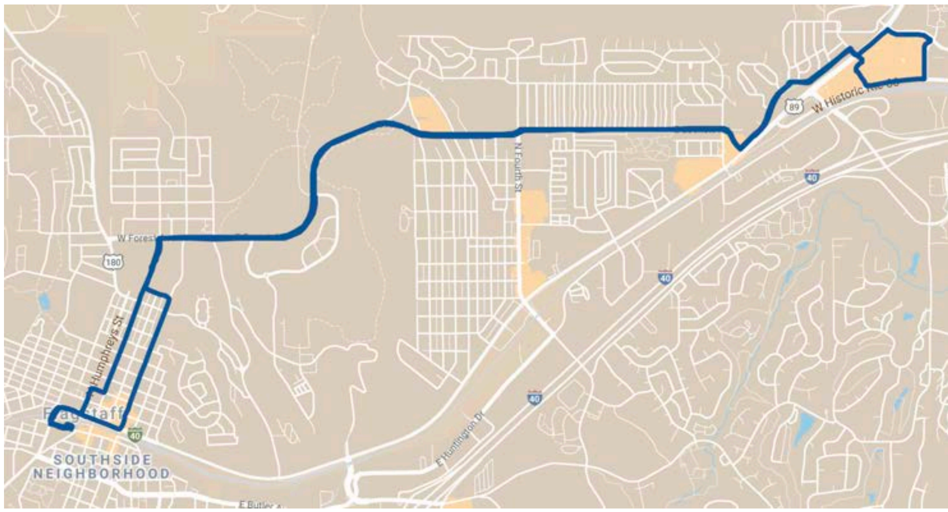
The **Maintenance Assessment** calculated all projected fleet maintenance costs over the life of the project. This projection includes costs related to existing hybrid diesel vehicles remaining in the fleet, as well as new BEBs and FCEBs, calculated for each scenario.

The **Total Cost of Ownership Assessment** compiled results from the previous assessment stages and provides a comprehensive view of all associated costs, organized by scenario, over the transition lifetime.

APPENDIX B

Route Profiles

Route 2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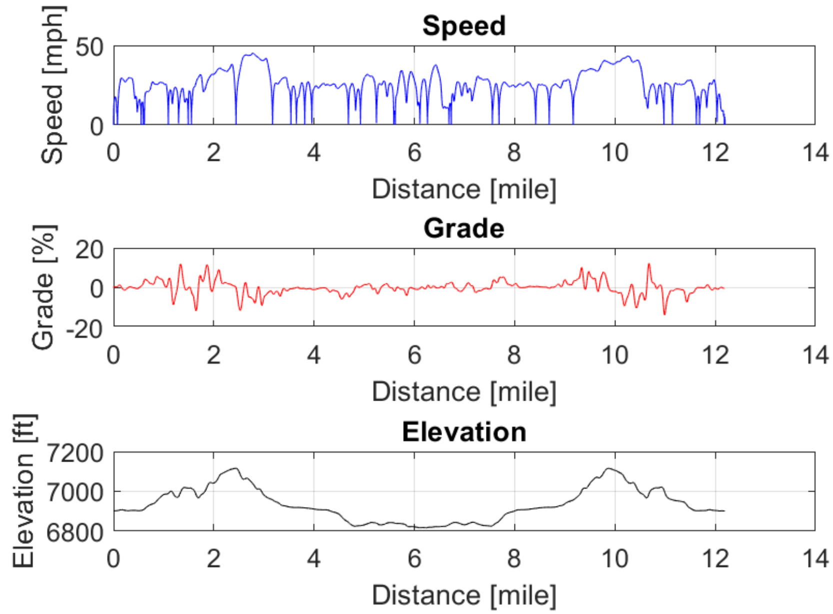
Humphreys St
W Forest
E Huntington Dr
SOUTHSIDE
NEIGHBORHOOD
E Butler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Grade [%]
Distance [mile]
Elevation
Elevation [ft]
Distance [mile]

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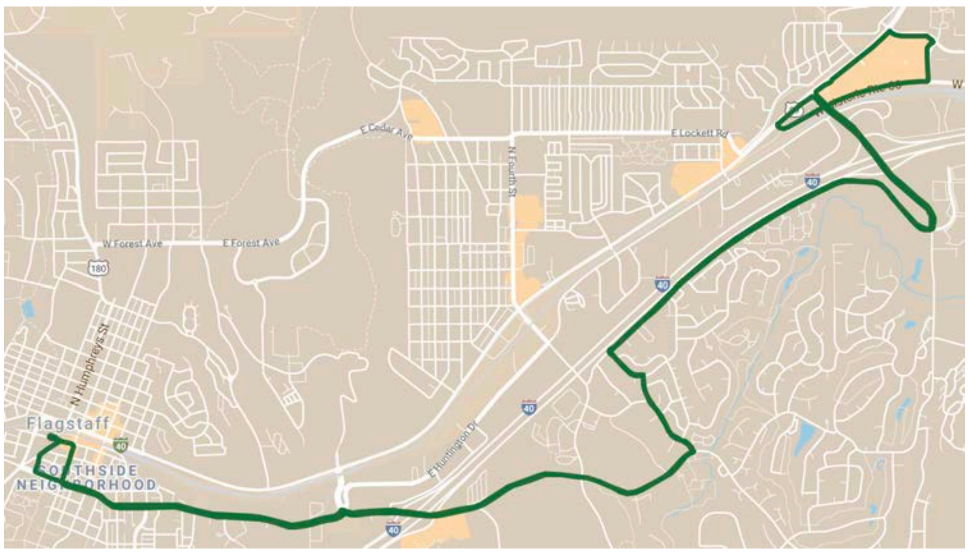

Flagstaff
SOUTHSIDE NEIGHBORHOOD
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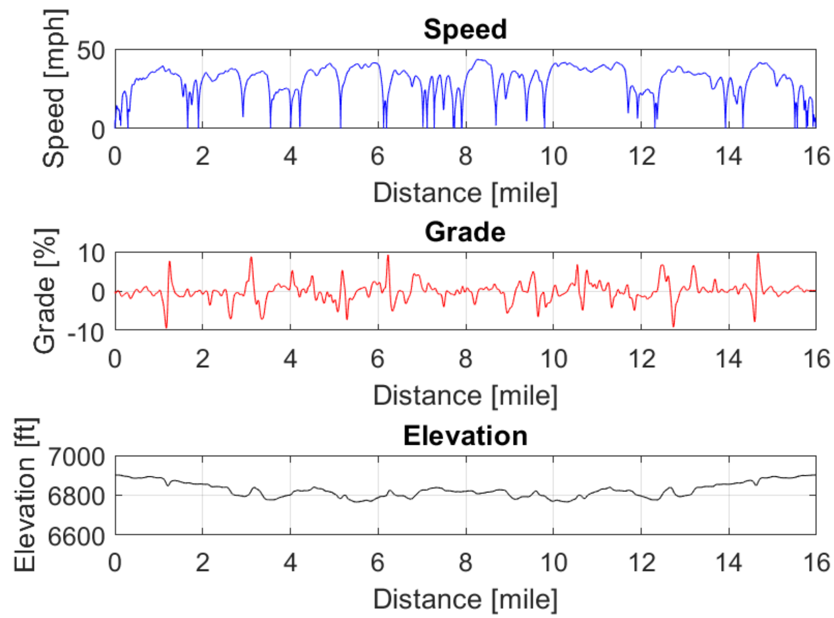
E Forest Ave
E Cedar Ave
E Lockett Rd
N Fourth St
N Humphreys St
E Huntington Dr



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Distance [mile]
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Grade [%]
Distance [mile]
Elevation
Elevation [ft]
Distance [mile]

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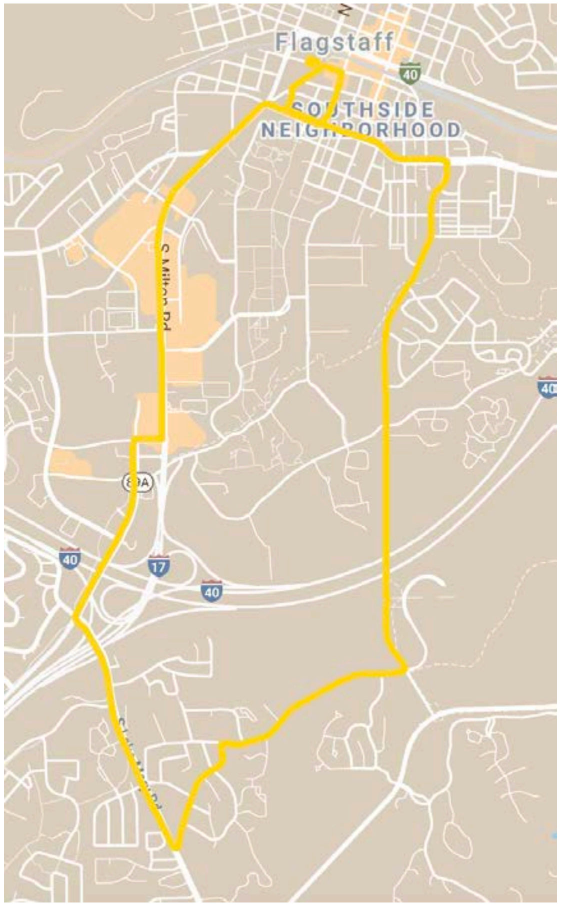
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SOUTHSIDE
NEIGHBORHOOD
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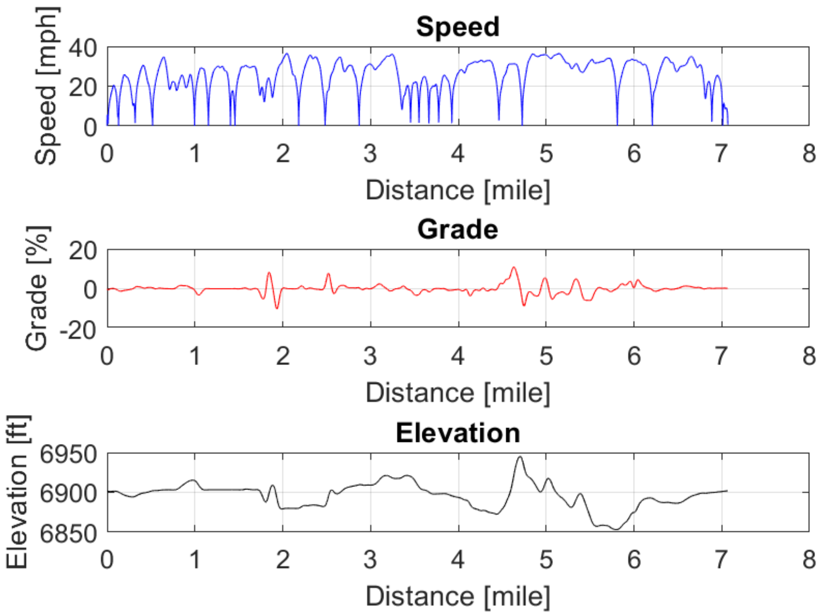
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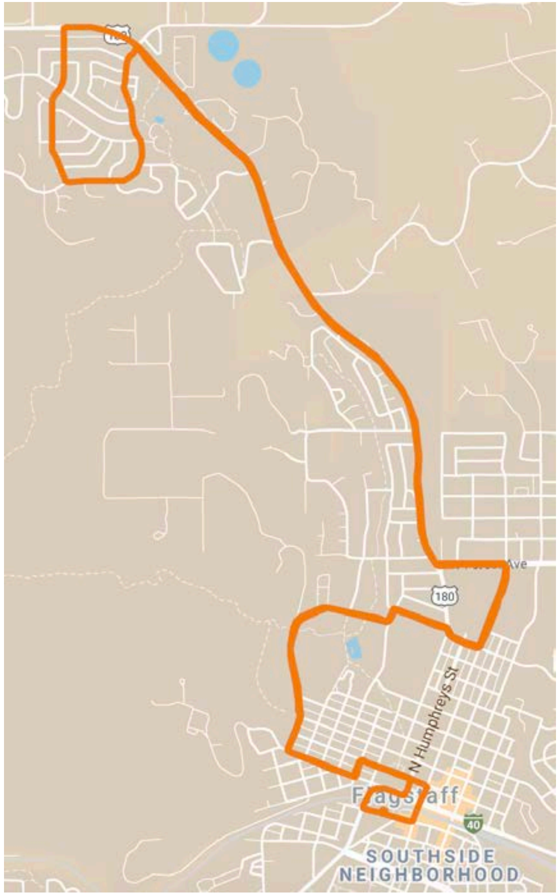

N Humphreys St
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Flagstaff
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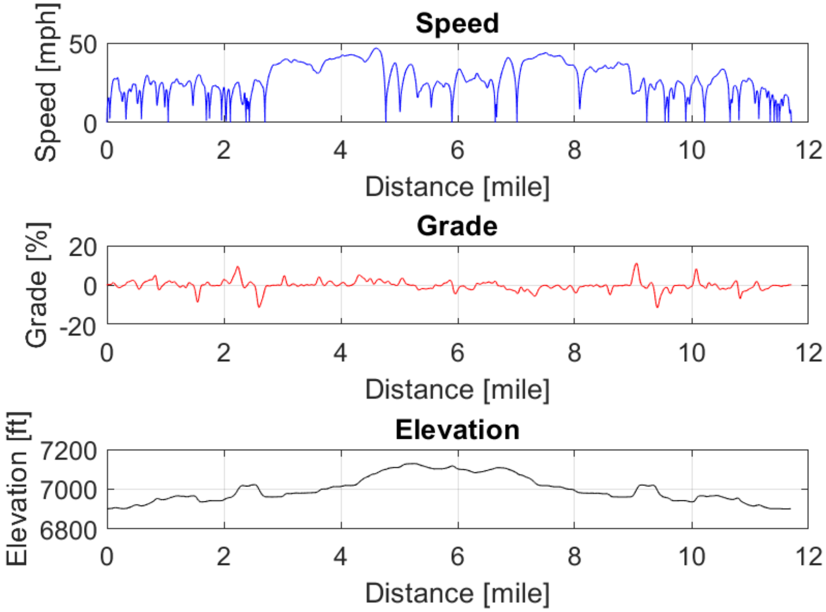
SOUTHSIDE
NEIGHBORHOOD



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6
8
10
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Elevation [ft]
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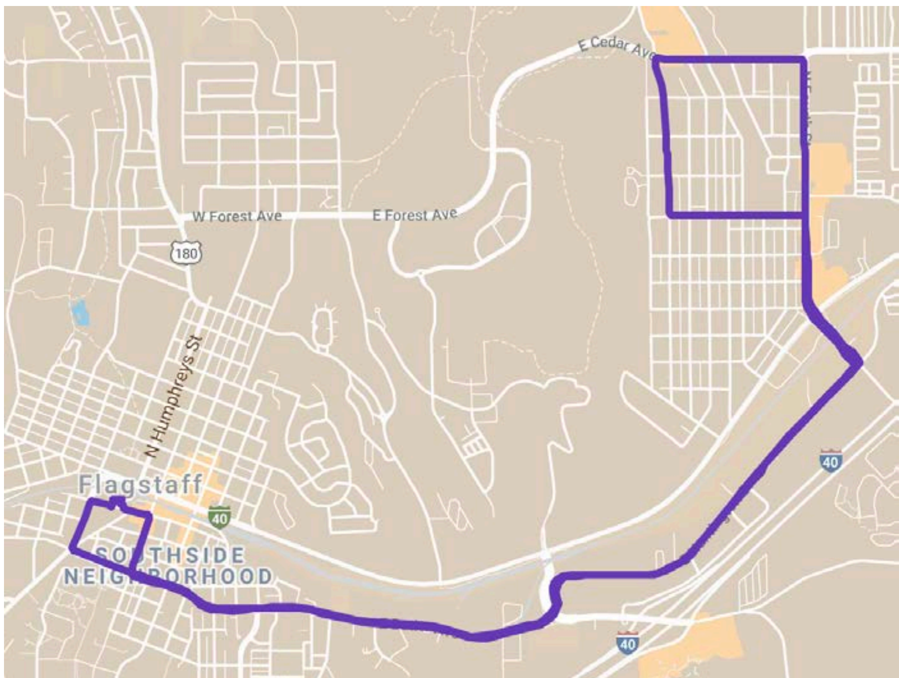
6
8
10
12
Distance [mile]

Route 7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N Humphreys St
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SOUTHSIDE
NEIGHBORHOOD
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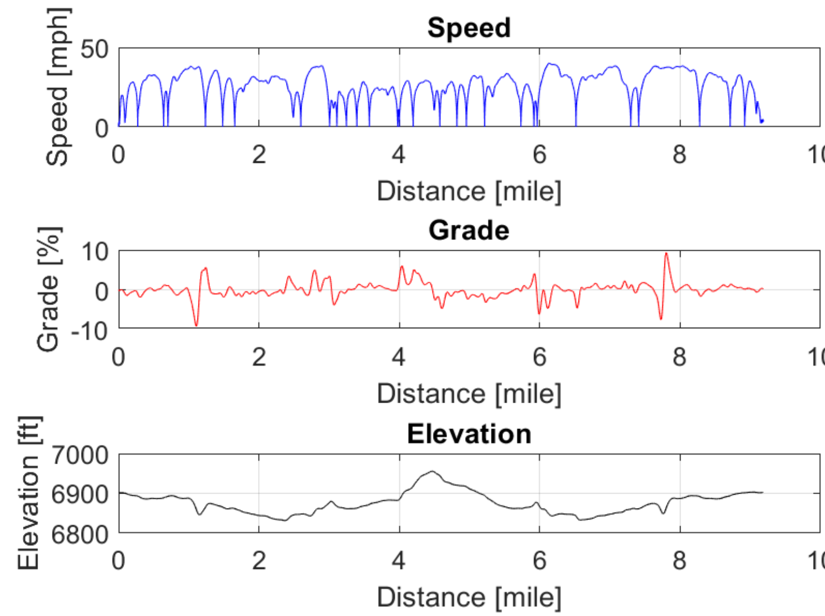
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4
6
8
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Distance [mile]
Elevation
Elevation [ft]
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6900
6800
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2
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6
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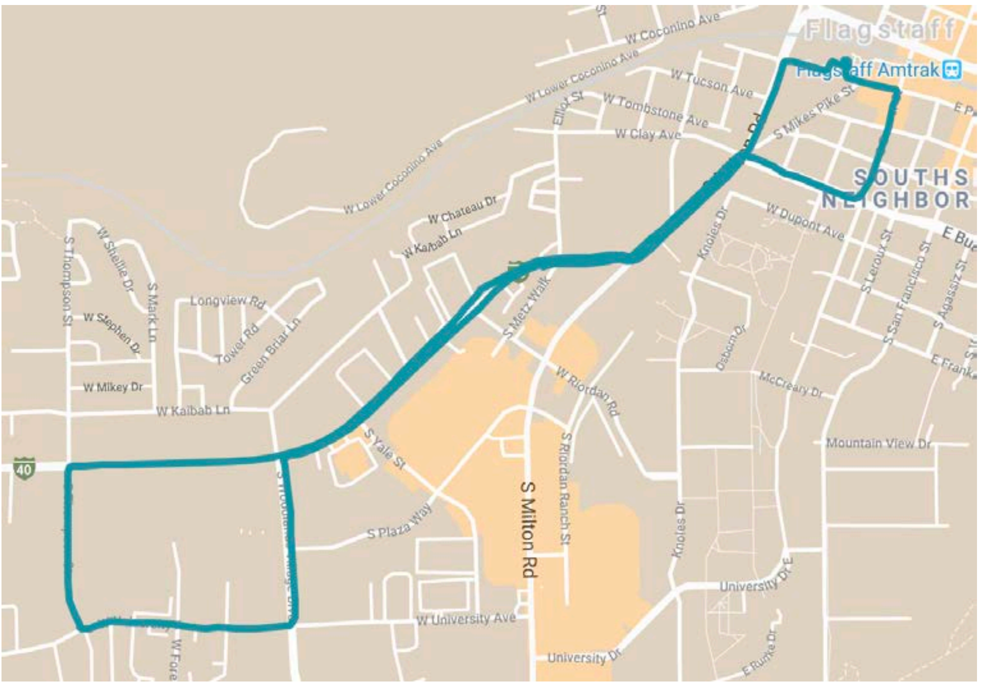
Distance [mile]

Route 8


Flagstaff
Flagstaff Amtrak
SOUTHSIDE NEIGHBOR
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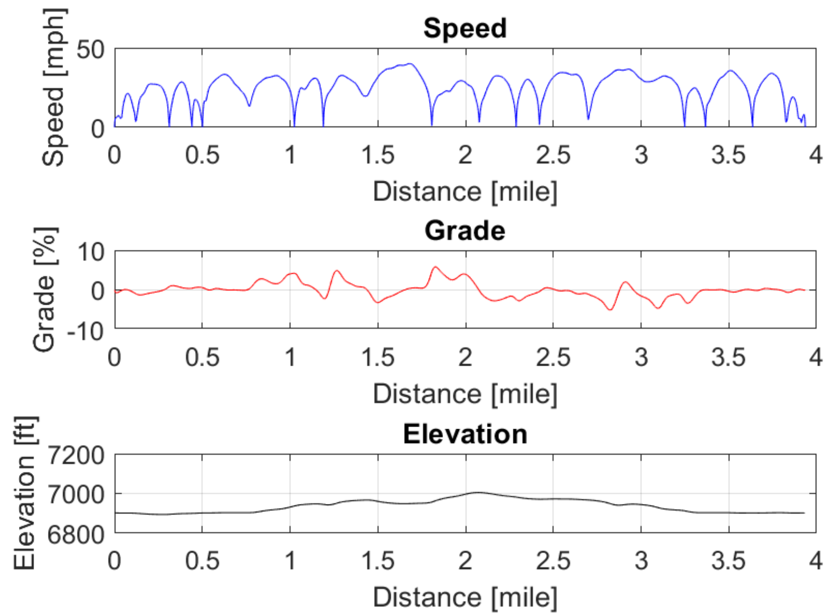
W Lower Coconino Ave
W Tucson Ave
W Tombstone Ave
W Clay Ave
S Mikes Pike St
W Dupont Ave
W Chateau Dr
W Kaibab Ln
Longview Rd
W Kaibab Ln
S Yale St
S Plaza Way
S Milton Rd
W University Ave
University Dr
Mountain View Dr
McCreary Dr
W Riordan Rd
S Riordan Ranch St
Knoles Dr
S Thompson St
S Mark Ln
W Mikey Dr
Tower Rd
Green Briar Ln
40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Grade [%]
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0
-10
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Elevation
Elevation [ft]
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7000
6800
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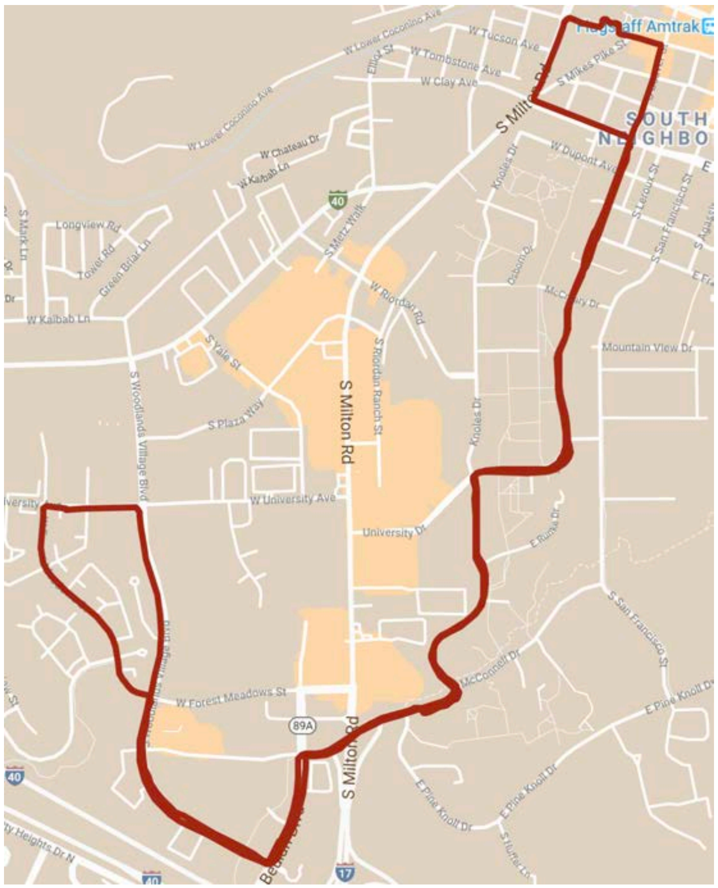
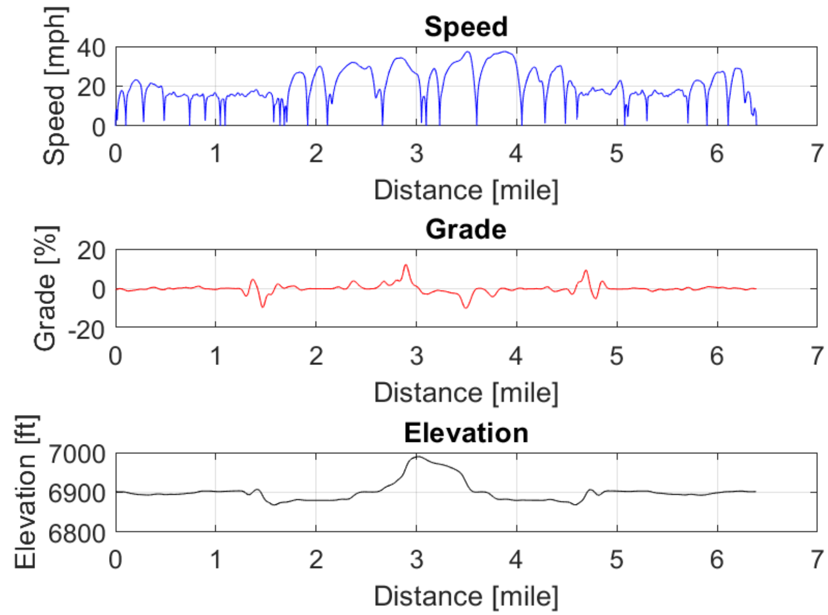
Distance [mile]

Route 10


S Milton Rd
W University Ave
University Dr
S Woodlands Village Blvd
W Forest Meadows St
89A
S Riordan Ranch St
Mountain View Dr
SOUTH
NEIGHBO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Grade
Grade [%]
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-20
0 1 2 3 4 5 6 7
Distance [mile]
Elevation
Elevation [ft]
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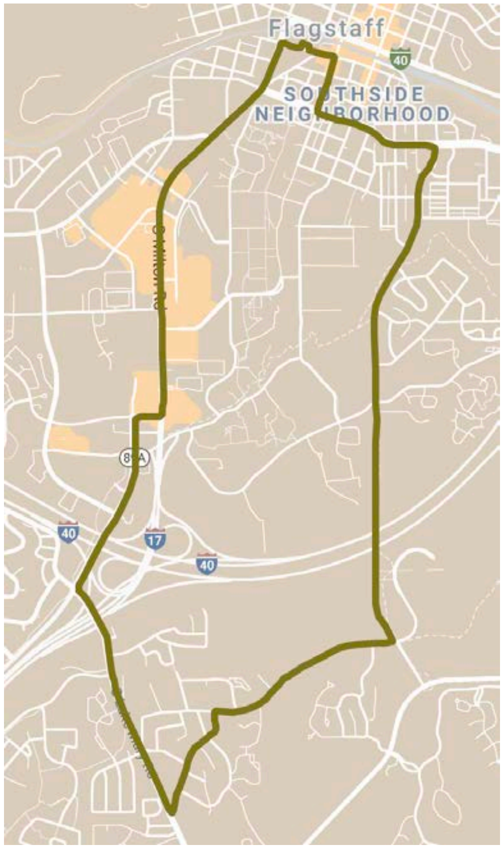
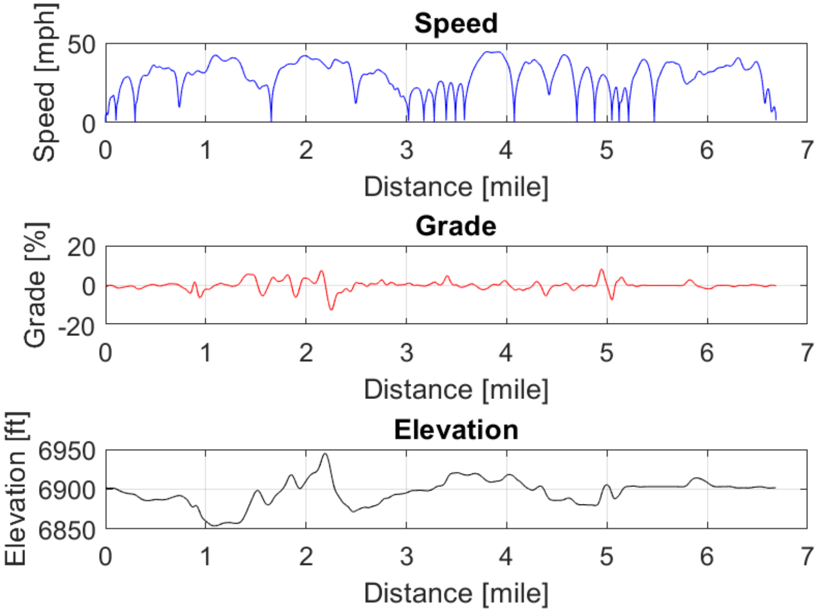
6900
6800
0 1 2 3 4 5 6 7
Distance [mile]

Route 14


Flagstaff
SOUTHSIDE
NEIGHBORHOOD
40
17
40
40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Speed [mph]
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0
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Distance [mile]
Grade
Grade [%]
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0
-20
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Distance [mile]
Elevation
Elevation [ft]
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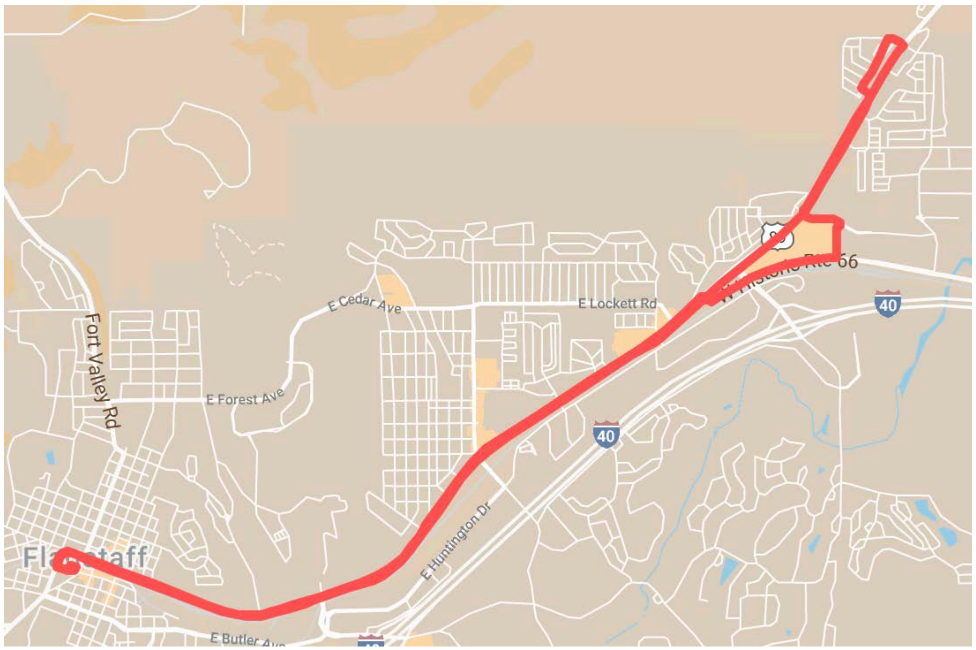
6900
6850
0 1 2 3 4 5 6 7
Distance [mile]

Route 66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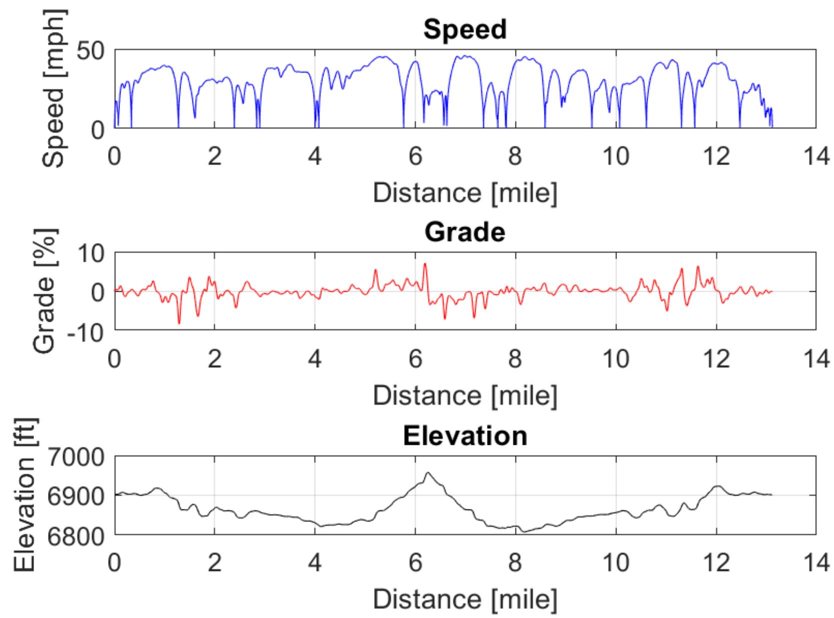
E Lockett Rd
Fort Valley Rd
E Forest Ave
Flagstaff
E Huntington Dr
E Butler Ave
W Historic Rte 66
40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Distance [mile]
Grade
Grade [%]
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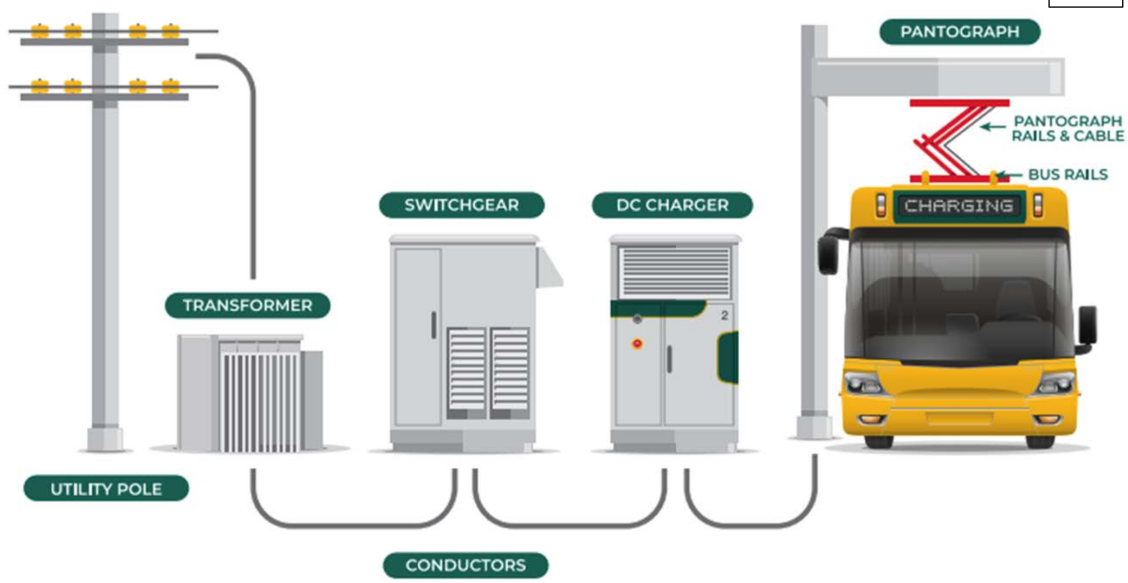
0
-10
Distance [mile]
Elevation
Elevation [ft]
7000
6900
6800
Distance [mile]
0 2 4 6 8 10 12 14

APPENDIX C

Typical Electrical Equipment and BEB Charging Infrastructure

Charging infrastructure and layout can vary substantially across different operators due a number of factors, including: charging technology chosen, size of electric vehicle fleet, real estate available, policies regarding redundancy and back-up generation, operational flow considerations, and locations of charging (depot only versus locations on route, etc.), budget and future expansion plans, among other considerations. The pictures and graphics below are for educational purposes only, as an aid in familiarizing stakeholders with the types of hardware that might be included in a charging infrastructure similar to what Mountain Line is considering in their future plans. Figure A provides a schematic of the typical infrastructure used to support heavy duty electric vehicle charging.

A



Transformers

A transformer is a passive electrical device that transfers electrical energy from one electrical circuit to another, or to multiple circuits. Photo B shows a typical transformer as well as the marker where underground conduit will approach and connect with the unit. Photo C shows a transformer (left) next to a pad where switchgear and charger cabinets will be installed.


B


C

Switchgear

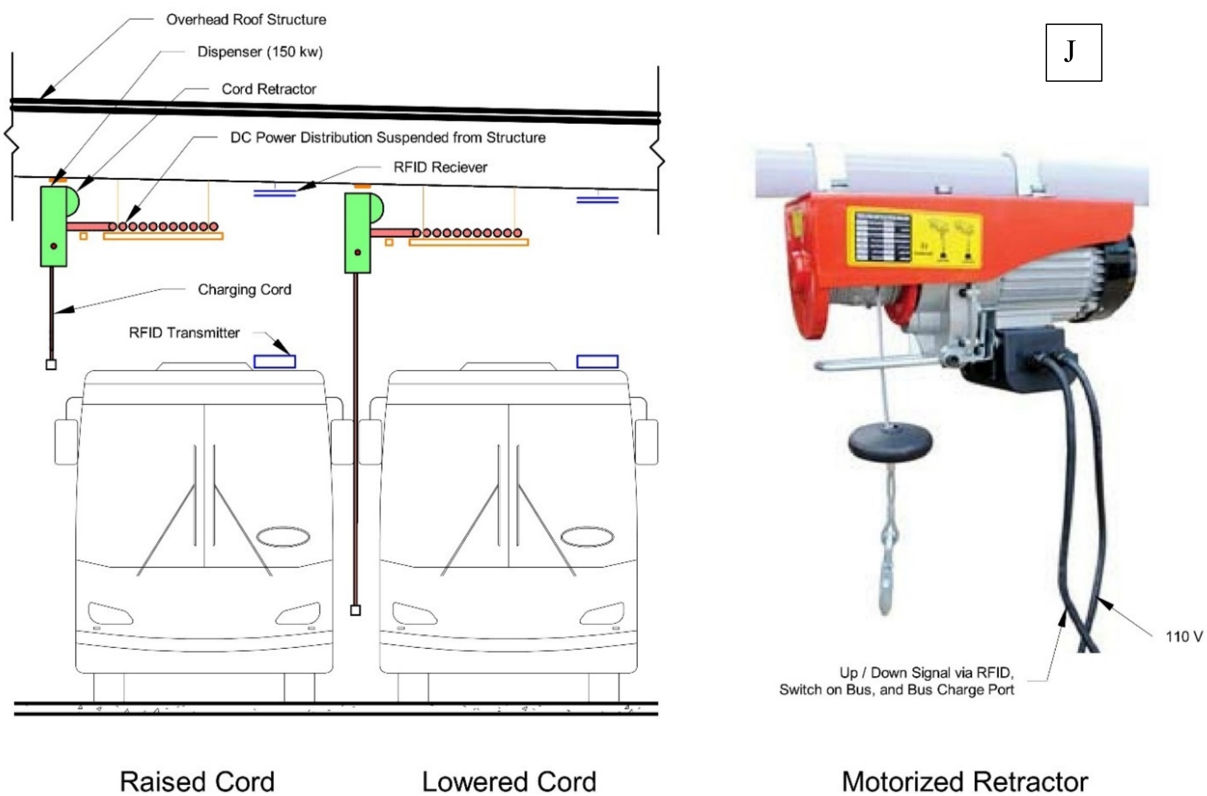
Electrical switchgear is composed of electrical disconnect switches, fuses or circuit breakers use to control, protect, and isolate electrical equipment. Photo's D and E are typical switchgear structures. Switchgear Photo D shows switchgear (gray enclosures on right) installed in front of charger cabinets- transformer from Photo B is on the left side of this picture.

Charger Cabinets

Charger cabinets house the charger power and control systems. Photo F shows a single charger cabinet, while photo G is a series of them.

Charge Dispensers (Overhead, Conductive)

Charge dispensers are how the buses are connected to the charging system. Photos H and I provide examples of pantograph-down charge head configurations. Figure J is a depiction of an electric drop-down charge reel from an overhead structure.



Gantries

Photos K and L are typical gantry structures. Charger style is pantograph-up.

K


L

Charge Dispensers (Depot, Plug-In)

Photo M is of a series of dispensers installed at a depot outside lot. Photos N is an integrated charger and dispenser. Photo O is a dispenser with an adjacent cabinet.


M

N

O

Other Components (Power Switch, Backup Generation)

Photo P is a transfer switch that allows the operator to switch from grid power to backup power. Photo Q is of a backup generator (raised structure on left. Item on bottom right is a transformer. Photo R shows overhead electrical feeders.

APPENDIX D

Rough Order of Magnitude Cost Estimates for ZEB Scenarios

Depot Only Charging Rough Order of Magnitude Cost Estimate

Kaspar Drive

Description	Qty	UOM	Qty	UOM	Unit Cost	UOM	Ext	Notes
Utility Transformer								
Concrete Pad								Provided by utility
Run from Concrete Pad to 4000A Service Switch								
Gravel Trench and backfill	1	EA	300	LF	$ 6.00	LF	$1,800.00	
3000A Feeder (Copper)	1	EA	300	LF	$ 520.00	LF	$156,000.00	
Distribution Switchboard								
3000A Distribution Switchboard	1	EA	1	EA	$ 84,000.00	EA	$84,000.00	
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
150 kW Charging Cabinets	12	EA	1	EA	$ 130,000.00	EA	$1,560,000.00	
Dispenser	24	EA	1	EA	$ 10,000.00		$240,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	12	EA	50	LF	$ 90.00	LF	$54,000.00	
Primary Run from Cabinets to Dispensers (Roof Mounted)								
300A feeder in Conduit 1 (copper)	24	EA	250	LF	$ 70.00	LF	$420,000.00	
Cabling in Conduit 2	24	EA	250	LF	$ 35.00	LF	$210,000.00	
Structural Support Frame for Charging Cabinets	12	EA	1	EA	$ 1,500.00	EA	$18,000.00	
Structural Support for overhead dispensers and electrical equipment	1	EA	1	EA	$ 300,000.00		$300,000.00	
Pipe Bollards								
Ovrhead 150 kW dispenser Unit	Included in price of chargers							
Motorized Reel	24	EA	1	EA	$ 3,880.00	EA	$93,120.00	
Feeder for motorized reel	24	EA	250	LF	$ 30.00	LF	$180,000.00	
RFID swithcing for motorized reel	24	EA	1	EA	$ 550.00	EA	$13,200.00	
Subtotal							$3,330,120.00	
Project Management and Design Services	10.00%	$333,012.00						
Contingency	20.00%	$666,024.00						
Construction								
General Conditions	5.00%	$166,506.00						
General Requirements	7.00%	$233,108.40						
Performance & Payment Bonds	1.50%	$49,951.80						
General Liability Insurance	1.35%	$44,956.62						
Permit Fees	0.50%	$16,650.60						
Overhead & Profit	10.00%	$333,012.00						
Design and Construction Management Fees		$1,843,221.42						
Total - Kaspar Drive		**$5,173,341.42**						
30%		**$6,725,343.85**						
-20%		**$4,138,673.14**						

NAU or Other Facility

Description	Qty	UOM	Qty	UOM	Unit Cost	UOM	Ext	Notes
Utility Transformer								
Concrete Pad								Provided by utility
Run from Concrete Pad to 1600A Service Switch								
Gravel Trench and backfill	1	EA	250	LF	$ 6.00	LF	$1,500.00	
1600A Feeder (Copper)	1	EA	250	LF	$ 520.00	LF	$130,000.00	
Distribution Switchboard								
1600A Distribution Switchboard	1	EA	1	EA	$ 35,000.00	EA	$35,000.00	
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
150 kW Charging Cabinets	5	EA	1	EA	$ 130,000.00	EA	$650,000.00	
Dispenser	10	EA	1	EA	$ 10,000.00		$100,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	5	EA	50	LF	$ 90.00	LF	$22,500.00	
Primary Run from Cabinets to Dispensers (Roof Mounted)								
300A feeder in Conduit 1 (copper)	10	EA	250	LF	$ 70.00	LF	$175,000.00	
Cabling in Conduit 2	10	EA	250	LF	$ 35.00	LF	$87,500.00	
Structural Support Frame for Charging Cabinets	10	EA	1	EA	$ 1,500.00	EA	$15,000.00	
Pipe Bollards								
Ovrhead 150 kW dispenser Unit	Included in price of chargers							
Motorized Reel	10	EA	1	EA	$ 3,880.00	EA	$38,800.00	
Feeder for motorized reel	10	EA	250	LF	$ 30.00	LF	$75,000.00	
RFID swithcing for motorized reel	10	EA	1	EA	$ 550.00	EA	$5,500.00	
Subtotal							$1,335,800.00	
Project Management and Design Services	10.00%	$ 133,580						
Contingency	20.00%	$ 267,160						
Construction		$ -						
General Conditions	5.00%	$ 66,790						
General Requirements	7.00%	$ 93,506						
Performance & Payment Bonds	1.50%	$ 20,037						
General Liability Insurance	1.35%	$ 18,033						
Permit Fees	0.50%	$ 6,679						
Overhead & Profit	10.00%	$ 133,580						
Design and Construction Management Fees		$ 739,365						
Total - NAU		**$ 2,075,165**						
30%		**$ 2,697,715**						
-20%		**$ 1,660,132**						

DEPOT ONLY CHARGING TOTAL		**$ 7,249,000**
30%		**$ 9,424,000**
-20%		**$ 5,799,000**

Depot + On-Route Charging Rough Order Magnitude Cost Estimate

Downtown Connection Center

Description	Qty	UOM	Qty	UOM	Unit Cost	UOM	Ext	Notes
Utility Transformer								
Concrete Pad								Provided by utility
Run from Concrete Pad to 4000A Service Switch								
Gravel Trench and backfill	1	EA	300	LF	$ 6.00	LF	$1,800.00	
Feeder (Copper)	1	EA	300	LF	$ 520.00	LF	$156,000.00	
Distribution Switchboard								
3000A Distribution Switchboard	2	EA	1	EA	$ 64,000.00	EA	$128,000.00	Assume installed in room at facility
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
450 kW Charging Cabinets	8	EA	1	EA	$ 400,000.00	EA	$3,200,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	24	EA	250	LF	$ 90.00	LF	$540,000.00	3 feeders per 450 kW charger
Primary Run from Cabinets to pole/pantograph								
300A feeder in Conduit 1 (copper)	8	EA	150	LF	$ 70.00	LF	$84,000.00	
Cabling in Conduit 2	8	EA	150	LF	$ 35.00	LF	$42,000.00	
Concrete Pad for Charging Cabinets	8	EA	50	SF	$ 15.00	SF	$6,000.00	
Pantograph and Pole	Included in price of chargers							
Concrete foundation for pole	8	EA	1	EA	$ 750.00	EA	$6,000.00	
Bollards	16	EA	1	EA	$ 500.00	EA	$8,000.00	
Subtotal							$4,171,800.00	
Project Management and Design Services	10.00%	$417,180.00						
Contingency	20.00%	$834,360.00						
Construction								
General Conditions	5.00%	$208,590.00						
General Requirements	7.00%	$292,026.00						
Performance & Payment Bonds	1.50%	$62,577.00						
General Liability Insurance	1.35%	$56,319.30						
Permit Fees	0.50%	$20,859.00						
Overhead & Profit	10.00%	$417,180.00						
Design and Construction Management Fees		$2,309,091.30						
Total - DCC		**$6,480,891.30**						
30%		**$8,425,158.69**						
-20%		**$5,184,713.04**						

Kaspar Drive

Description	Qty	UOM	Qty	UOM	Unit Cost	UOM	Ext	Notes
Utility Transformer								**Provided by utility**
Concrete Pad								Provided by utility
Run from Concrete Pad to 1600A Service Switch								
Gravel Trench and backfill	1	EA	250	LF	$ 6.00	LF	$1,500.00	
Feeder (Copper)	1	EA	250	LF	$ 520.00	LF	$130,000.00	
Distribution Switchboard								
1600A Distribution Switchboard	1	EA	1	EA	$ 32,000.00	EA	$32,000.00	Assume installed in room at facility
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
450 kW Charging Cabinets	2	EA	1	EA	$ 400,000.00	EA	$800,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	6	EA	100	LF	$ 90.00	LF	$54,000.00	3 feeders per 450 kW charger
Primary Run from Cabinets to pole/pantograph								
300A feeder in Conduit 1 (copper)	1	EA	250	LF	$ 70.00	LF	$17,500.00	
Cabling in Conduit 2	1	EA	250	LF	$ 35.00	LF	$8,750.00	
Concrete Pad for Charging Cabinets	2	EA	50	SF	$ 15.00	SF	$1,500.00	
Pantograph and Pole	Included in price of chargers							
Concrete foundation for pole	2	EA	1	EA	$ 750.00	EA	$1,500.00	
Bollards	4	EA	1	EA	$ 500.00	EA	$2,000.00	
Subtotal							$1,048,750.00	
Project Management and Design Services	10.00%	$104,875.00						
Contingency	20.00%	$209,750.00						
Construction								
General Conditions	5.00%	$52,437.50						
General Requirements	7.00%	$73,412.50						
Performance & Payment Bonds	1.50%	$15,731.25						
General Liability Insurance	1.35%	$14,158.13						
Permit Fees	0.50%	$5,243.75						
Overhead & Profit	10.00%	$104,875.00						
Design and Construction Management Fees		$580,483.13						
Total - Kaspar Drive		**$1,629,233.13**						
30%		**$2,118,003.06**						
-20%		**$1,303,386.50**						

NAU Facility

Description	Qty	UOM	Qty	UOM	Unit Cost	UOM	Ext	Notes
Utility Transformer								**Provided by utility**
Concrete Pad								Provided by utility
Run from Concrete Pad to 1200A Service Switch								
Gravel Trench and backfill	1	EA	250	LF	$ 6.00	LF	$1,500.00	
Feeder (Copper)	1	EA	250	LF	$ 520.00	LF	$130,000.00	
Distribution Switchboard								
1600A Distribution Switchboard	1	EA	1	EA	$ 32,000.00	EA	$32,000.00	Assume installed in room at facility
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
450 kW Charging Cabinets	2	EA	1	EA	$ 400,000.00	EA	$800,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	6	EA	100	LF	$ 90.00	LF	$54,000.00	3 feeders per 450 kW charger
Primary Run from Cabinets to pole/pantograph								
300A feeder in Conduit 1 (copper)	1	EA	250	LF	$ 70.00	LF	$17,500.00	
Cabling in Conduit 2	1	EA	250	LF	$ 35.00	LF	$8,750.00	
Concrete Pad for Charging Cabinets	2	EA	50	SF	$ 15.00	SF	$1,500.00	
Pantograph and Pole	Included in price of chargers							
Concrete foundation for pole	2	EA	1	EA	$ 750.00	EA	$1,500.00	
Bollards	4	EA	1	EA	$ 500.00	EA	$2,000.00	
Subtotal							$1,048,750.00	
Project Management and Design Services	10.00%	$104,875.00						
Contingency	20.00%	$209,750.00						
Construction								
General Conditions	5.00%	$52,437.50						
General Requirements	7.00%	$73,412.50						
Performance & Payment Bonds	1.50%	$15,731.25						
General Liability Insurance	1.35%	$14,158.13						
Permit Fees	0.50%	$5,243.75						
Overhead & Profit	10.00%	$104,875.00						
Design and Construction Management Fees		$580,483.13						
Total - NAU Facility		**$1,629,233.13**						
30%		**$2,118,003.06**						
-20%		**$1,303,386.50**						

TOTAL	**$9,739,000.00**
30%	**$12,661,000.00**
-20%	**$7,791,000.00**

FCEB Rough Order Magnitude Cost Estimate

Liquid Hydrogen Delivery		$3,385,702	Heavy Duty Refueling Simulation Analysis Model (HDRAM) developed by Argonne National Lab
On-site reformation		$8,798,075	Heavy Duty Refueling Simulation Analysis Model (HDRAM) developed by Argonne National Lab
Service Bay Upgrades		$125,000	per service bay
No. of service bays		3	
Storage facility H2 upgrades		$40	per square foot
Storage facility size		32,670	square feet
Total	**$**	**5,068,000**	
30%	**$**	**6,588,000**	
-20%	**$**	**4,054,000**	

Mixed Fleet (BEB + FCEB) Rough Order Magnitude Cost Estimate

Kaspar Drive

Description	**Qty**	**UOM**	**Qty**	**UOM**	**Unit Cost**	**UOM**	**Ext**	**Notes**
Utility Transformer								
Concrete Pad								Provided by utility
Run from Concrete Pad to 4000A Service Switch								
Gravel Trench and backfill	1	EA	300	LF	$ 6.00	LF	$1,800.00	
1600A Feeder (Copper)	1	EA	300	LF	$ 520.00	LF	$156,000.00	
Distribution Switchboard								
1600A Distribution Switchboard	1	EA	1	EA	$ 36,000.00	EA	$36,000.00	
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
150 kW Charging Cabinets	3	EA	1	EA	$ 130,000.00	EA	$390,000.00	
Dispenser	6	EA	1	EA	$ 100,000.00	EA	$600,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	3	EA	50	LF	$ 90.00	LF	$13,500.00	
Primary Run from Cabinets to Dispensers (Roof Mounted)								
300A feeder in Conduit 1 (copper)	6	EA	250	LF	$ 70.00	LF	$105,000.00	
Cabling in Conduit 2	6	EA	250	LF	$ 35.00	LF	$52,500.00	
Structural Support Frame for Charging Cabinets	6	EA	1	EA	$ 1,500.00	EA	$9,000.00	
Structural Support for overhead dispensers and electrical equipment	1	EA	1	EA	$ 75,000.00		$75,000.00	
Pipe Bollards								
Ovrhead 150 kW dispenser Unit	Included in price of chargers							
Motorized Reel	6	EA	1	EA	$ 3,880.00	EA	$23,280.00	
Feeder for motorized reel	6	EA	250	LF	$ 30.00	LF	$45,000.00	
RFID swithcing for motorized reel	6	EA	1	EA	$ 550.00	EA	$3,300.00	
Subtotal							$1,510,380.00	
Project Management and Design Services	10.00%	$7,500.00						
Contingency	20.00%	$15,000.00						
Construction								
General Conditions	5.00%	$3,750.00						
General Requirements	7.00%	$5,250.00						
Performance & Payment Bonds	1.50%	$1,125.00						
General Liability Insurance	1.35%	$1,012.50						
Permit Fees	0.50%	$375.00						
Overhead & Profit	10.00%	$7,500.00						
Design and Construction Management Fees		$41,512.50						
Total - Kaspar Drive		**$1,551,892.50**						
30%		**$2,017,460.25**						
-20%		**$1,241,514.00**						

NAU

Description	**Qty**	**UOM**	**Qty**	**UOM**	**Unit Cost**	**UOM**	**Ext**	**Notes**
Utility Transformer								
Concrete Pad								Provided by utility
Run from Concrete Pad to 1600A Service Switch								
Gravel Trench and backfill	1	EA	250	LF	$ 6.00	LF	$1,500.00	
1200A Feeder (Copper)	1	EA	250	LF	$ 520.00	LF	$130,000.00	
Distribution Switchboard								
1600A Distribution Switchboard	1	EA	1	EA	$ 36,000.00	EA	$36,000.00	
Run from Distribution Panel to Charger Cabinets								
Feeder (cost provided below with charger cabinets)								
Charging Cabinets								
150 kW Charging Cabinets	3	EA	1	EA	$ 150,000.00	EA	$450,000.00	
Dispenser	6	EA	1	EA	$ 100,000.00	EA	$600,000.00	
300 A feeder to each cabinet (copper) from Distribution Panel	3	EA	50	LF	$ 90.00	LF	$13,500.00	
Primary Run from Cabinets to Dispensers (Roof Mounted)								
300A feeder in Conduit 1 (copper)	6	EA	250	LF	$ 70.00	LF	$105,000.00	
Cabling in Conduit 2	6	EA	250	LF	$ 35.00	LF	$52,500.00	
Structural Support Frame for Charging Cabinets	6	EA	1	EA	$ 1,500.00	EA	$9,000.00	
Pipe Bollards								
Ovrhead 150 kW dispenser Unit	Included in price of chargers							
Motorized Reel	6	EA	1	EA	$ 3,880.00	EA	$23,280.00	
Feeder for motorized reel	6	EA	250	LF	$ 30.00	LF	$45,000.00	
RFID swithcing for motorized reel	6	EA	1	EA	$ 550.00	EA	$3,300.00	
Subtotal							$1,469,080.00	
Project Management and Design Services	10.00%	$ 900						
Contingency	20.00%	$ 1,800						
Construction		$ -						
General Conditions	5.00%	$ 450						
General Requirements	7.00%	$ 630						
Performance & Payment Bonds	1.50%	$ 135						
General Liability Insurance	1.35%	$ 122						
Permit Fees	0.50%	$ 45						
Overhead & Profit	10.00%	$ 900						
Design and Construction Management Fees		$ 4,982						
Total - NAU		**$ 1,474,062**						
30%		**$ 1,916,280**						
-20%		**$ 1,179,249**						

DEPOT ONLY CHARGING TOTAL		**$ 3,026,000**
30%		**$ 3,934,000**
-20%		**$ 2,421,000**
Liquid Hydrogen Delivery	**$3,385,702**	
On-site reformation	**$8,798,075**	

Based on Modeling Results from Heavy-Duty Refeuling Simulation Analysis Model (HDRAM) developed by Argonne National Lab
Costs may be evaluated by Fiedler and Associates in next phase of project

TOTAL		**$ 6,411,702**