TRANSFORT

Zero Emission Bus Transition Screening Assessment

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HATCH LTK
Positive Change for the Next Century

fiedlergroup

Table of Contents

Tables

Figures

Appendices

1 Introduction

Transfort is a municipal department of the City of Fort Collins (City), located in Northern Colorado within Larimer County. Transfort's prime service area covers approximately 54 square miles and mainly operates within the city limits of Fort Collins. However, Transfort also operates a regional route, FLEX, that extends from Fort Collins south through the communities of Loveland, Longmont, Berthoud and Boulder. Transfort contracts for all *Americans With Disabilities Act (*ADA) complementary paratransit service and some supplemental fixed-route service.

Transfort began converting the fleet to compressed natural gas (CNG) in 2008 and all but three revenue vehicles are currently fueled by CNG. The remaining three buses are diesel which Transfort plans to replace with battery electric buses (BEBs) in the next year. The City has adopted aggressive climate action goals and aims to become carbon neutral by 2050. To align with these goals, Transfort has begun exploring fleet electrification and has secured funding for its first eleven (11) BEBs.

At this time, Transfort has one maintenance and operational facility (TMF) located at 6750 Portner Road in Fort Collins, this facility contains a CNG fueling station. Transfort is concurrently planning for the potential addition of a second maintenance facility located in the northern area of Fort Collins.

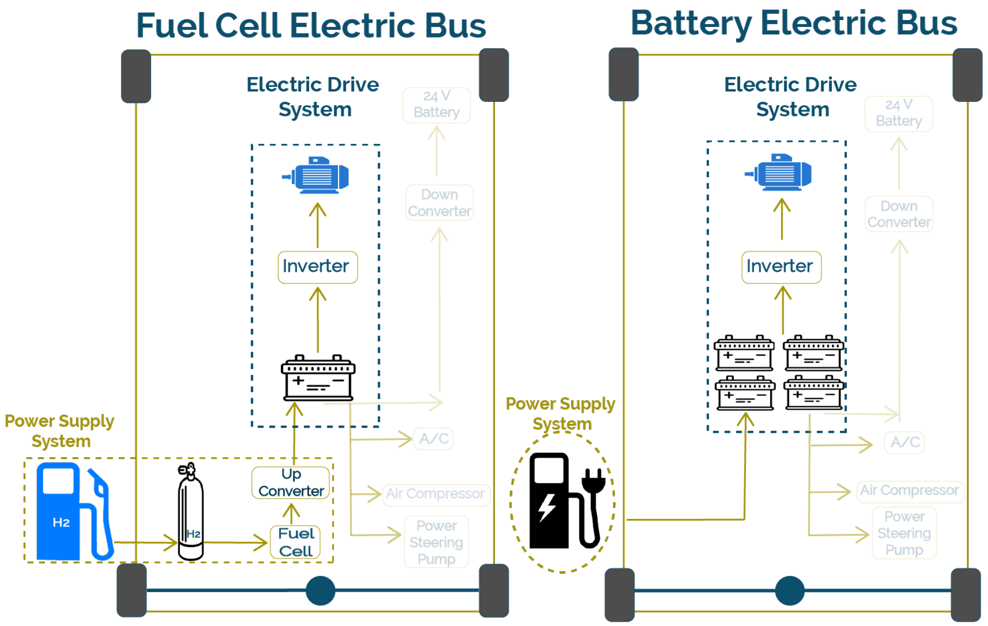
The objectives of the Zero Emission Bus Transition Study are to:

1. Determine the most cost-effective capital approach to a 100 percent (%) ZEB fleet by 2040
2. Determine capital improvements requirements required to achieve a 100% ZEB fleet
3. Provide financing and purchasing strategy that allows Transfort to sustainably meet internal ZEB deadlines
4. Develop a comprehensive understanding – both positives and negatives – of how compliance with the City of Fort Collins *Climate Action Plan* objective (100% zero emission by 2050) will impact Transfort in the future, and how federal legislation may impact the plan

The analysis is being conducted in two phases. Phase I is a screening level technology analysis to assess Transfort's service related to the technology options and provide 'order of magnitude' costs for multiple ZEB transition scenarios. Phase II is a detailed analysis of the scenario selected by Transfort following completion of the Phase I screening level assessment. This report details the results from the Phase I analysis.

Zero-emission technologies considered in this study include both 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, however, 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 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. Illustrated below is the electric drive components and energy source for a BEB and FCEB.

Figure 1 - Schematic of ZEB Technologies



There are considerations and limitations associated with each technology. One of the primary limitations of BEBs is overall energy storage capacity. Although BEBs are four times more efficient than diesel vehicles, the total amount of energy that can be stored on board without adding excessive weight is still considerably less than CNG. That means that using current technology, the overall BEB range on one charge is less than the range of a CNG vehicle on one tank of fuel. Range limitations can be mitigated by the use of the appropriate charging technologies and strategies, and this is a very important element in the planning for any BEB deployment, especially when considering a full fleet transition.

Furthermore, battery and charging technologies are changing at a rapid pace. The trends toward higher battery energy densities and increasingly sophisticated software-based charge management methodologies are expected to improve the range of BEBs to levels more comparable with traditional CNG vehicles over time. New charging vendors continue to enter the marketplace, offering various charger configurations and charge rates that help agencies customize a charging strategy and reduce operational risk associated with BEB deployments. Regardless of which battery technology or chemistry is utilized, all high voltage vehicle batteries in the market today degrade over time. Therefore, the impact on performance over time and associated battery warranties should be reviewed to optimize operations and further reduce risk.

Finally, lifecycle costs of electricity and overall infrastructure represent significant investments. Charging an entire fleet of buses can require a substantial real estate footprint and associated upfront cost to purchase and install the required equipment, not to mention the appropriate training and ongoing operational requirements.

There are similar considerations in FCEB deployment in that the infrastructure footprint can be substantial and since battery technology is also utilized there are similar concerns with degradation and end-of-life performance. Current FCEBs do have a range that is longer than BEBs and more similar to traditional CNG buses, so theoretically there will be less operational risk due to fueling strategies when incorporating FCEBs into a fleet. However, both the upfront cost of FCEB vehicles and the cost of fuel are higher than with their BEB counterparts (hydrogen vs. electricity). Finally, there are still a limited number of demonstrations of FCEBs to learn from partly because BEB charging technology is easier to scale and deploy to small fleets (which has been a large part of BEB deployment activity to date).

The *Zero Emission Bus Transition Screening Assessment* is arranged in the following sections:

- Section 1 – Introduction
- Section 2 – Transition Planning Methodology
- Section 3 – Transition Scenarios and Assumptions
- Section 4 – Baseline Data
- Section 5 – Service Assessment
- Section 6 – Fleet Assessment
- Section 7 – Fuel Assessment
- Section 8 – Maintenance Assessment
- Section 8 – Facilities Assessment
- Section 9 – Maintenance Assessment
- Section 10 – Total Cost of Ownership
- Section 11 – Emission Analysis
- Section 12 – Conclusions and Path Forward

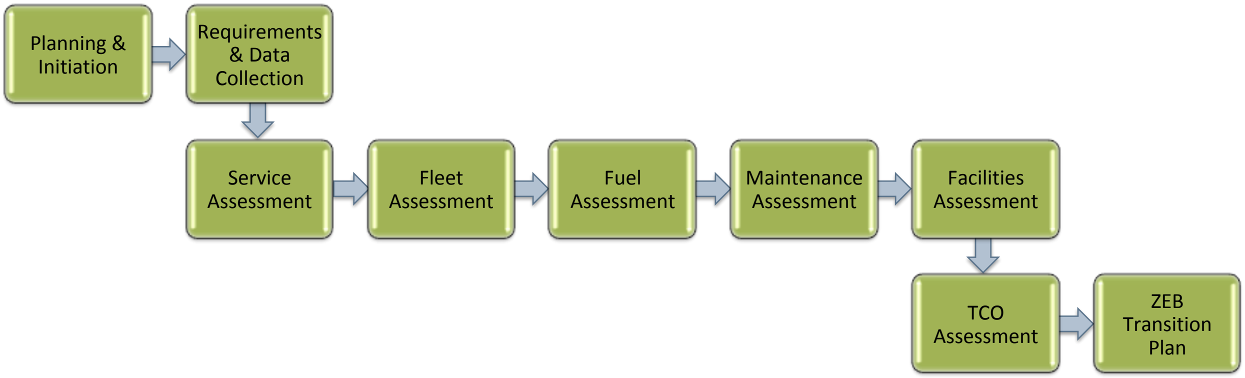
This study reflects the state of technology at the time that it was prepared whereas the transition to a full zero-emission bus fleet is expected to take over 20 years to complete. CTE recommends that the study be reviewed and updated periodically to reflect the latest state of technology development, costs, regulatory environment, service requirements, and supply chain to ensure that the Transfort continues to meet their mission in the most effective and efficient way possible.

2 Transition Planning Methodology

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

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

Figure 2 - 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 Transfort staff to plan the overall project scope and all deliverables throughout the full life of the study.

The **Service Assessment** phase initiated the data collection and technical analysis of the study. CTE met with Transfort to define assumptions and requirements used throughout the study and to collect operational data (**Requirements & Data Collection**). CTE used a screening analysis to estimate energy needs on each of Transfort's routes and ultimately the achievability of every block in Transfort's service network using BEBs and FCEBs. The results from the Service Assessment were used to guide ZEB procurements in the Fleet Assessment and determine energy needs for the Fuel Assessment.

The **Fleet Assessment** analyzed the capabilities of the current ZEB technologies to meet Transfort's service requirements. The analysis projected the timeline for replacement of CNG vehicles with BEBs and FCEBs consistent with Transfort's fleet replacement schedule.

The **Fuel Assessment** analyzed annual fueling requirements and developed cost estimates based on current and proposed electrical rate structures provided by the City of Fort Collins Utilities, the local electrical utility, as well as estimates for hydrogen fuel costs. These costs were compared to the expected costs to refuel CNG vehicles based on current and projected fuel costs.

The **Maintenance Assessment** analyzed labor and materials costs for maintenance over the transition period as well as major component replacements for each technology type.

The **Facilities Assessment** defined the requirements for charging and hydrogen fueling infrastructure including costs, operational impact, and utility service requirements.

The **Total Cost of Ownership Assessment** summarizes the costs of annual bus procurements, operation and maintenance costs, and infrastructure and facility upgrades over the transition period.

3 Transition Scenarios and Assumptions

Transition Scenarios

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

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

The Baseline scenario assumes that there are no changes to the current technology for bus procurements (compressed natural gas [CNG]) and is used for comparison to the other ZEB transition scenarios. The BEB Depot-Only Charging and FCEB Only scenarios are used as the ‘bookends’ to help identify potential constraints or risks in scaling to fleetwide adoption of ZEBs that may not be readily apparent from pilot-bus deployments. At the current state of technology, neither BEBs nor FCEBs have sufficient range to allow for a “one-for-one” replacement of all internal combustion engine buses. Improvements are expected to be made over time; however, there are significant challenges to overcome, and the timeline to achieve the goal is uncertain.

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 only deployed in-service where analysis determines that they can complete specified service blocks (e.g. meet the daily mileage requirements). CTE also determined the estimated number of additional vehicles that would be required to run the service if fleet expansion was considered.

Tranfort has limited availability to accommodate fleet expansion today due to space constraints at the current TMF, though fleet expansion is planned in the future to accommodate service expansion. As such, Transfort is planning for future construction of another TMF but the location and the timeline are currently in development. The BEB Depot and On-Route Charging scenario was developed to mitigate the need for additional bus purchases and consider another alternative to meet a 100% ZEB fleet. In this scenario, BEBs are charged at the depots when not in-service and on-route where necessary to complete service requirements. The FCEB scenario assumes that FCEBs are utilized where based on analysis they meet daily service requirements. Finally, the Mixed BEB and FCEB scenario utilizes both BEB and FCEBs. The underlying assumption is that neither technology is suitable for 100% of the fleet replacement due to inherent constraints; however, using a mixed fleet of BEBs and FCEBs can achieve, or nearly achieve, a 100% zero-emission fleet.

Due to the inherent 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 Transfort, and are as follows:

- Transition to a 100% ZEB fleet by 2040
- Increase in fleet size from 53 to 82 during the study period as detailed in the *Fort Collins Transit Master Plan* (April 2019*)*.
- Current fleet composition (Fiscal Year 2021) used for the baseline scenario

- Currently planned fleet replacement cycles
- 15-year bus lifespan assumed for future heavy duty transit buses
- Costs expressed in 2021 dollars with no escalation

Other operational assumptions associated with the current fleet replacement schedule and vehicle technology include the following:

- In the BEB transition, current 30-foot buses will be replaced with 35-foot buses and 40-foot buses (split evenly)
- In the FCEB transition, there are no commercially available 35-foot FCEBs available; however, it was assumed that these vehicles would be available in the market by the time of replacement
- Current battery sizes for BEBs and fuel tank sizes for FCEBs are based on existing specification for vehicles that have completed Altoona Testing
- A 5% improvement in battery (for BEB) and fuel tank (for FCEB) capacity every two years
- Transfort will purchase a battery warranty or fuel cell warranty that will cover the battery/fuel cell for the life of the vehicle to 80% of the nameplate capacity, when available

In addition to the uncertainty of technology improvements, there are other risks to consider. Although current BEB range limitations may be remedied over time as a result of advancements in battery energy density and more efficient components, battery degradation may re-introduce range limitations as a risk to an all-BEB fleet over time. In emergency scenarios that require use of BEBs, agencies may face challenges supporting long-range evacuations and providing temporary shelters in support of fire and police operations. Furthermore, fleetwide energy service requirements and power redundancy and resilience may be difficult to achieve at any given depot in an all-BEB scenario. Higher capital equipment costs and availability of hydrogen may constrain FCEB solutions.

4 Baseline Data

It is essential to understand the key elements of Transfort's service to evaluate the rough order magnitude (ROM) costs associated with a full-ZEB transition. Key data elements of the existing Transfort service were provided by Transfort staff and include the following:

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

Fleet

At the time of this study, Transfort's bus fleet consisted of 53 CNG heavy-duty vehicles of various lengths that provide service for 22 fixed-routes. There are 2 routes that are contracted out (FHS and GOLD) that operate utilizing cutaway vehicles and are not included in this analysis.

The following table provides a breakdown of the existing fleet vehicles by length and fuel type. The remaining three (3) diesel vehicles are expected to be retired and replaced with BEBs by the end of 2022 using existing funding.

Table 1 - Current Bus Quantity by Length and Fuel Type

Vehicle Length	CNG	Diesel
30’	7	3
35’	13	0
40’	22	0
60’	8	0
TOTAL	***50***	***3***

All service operates out of the TMF, located at 6570 Portner Road in Fort Collins. Tranfort also has three separate transit centers for transit connections: the Downtown Transit Center; South Transit Center; and the Colorado State University (CSU) Transit Center. Transfort's goal is to maintain buses for a minimum of 15 years before retirement.

Routes and Blocks

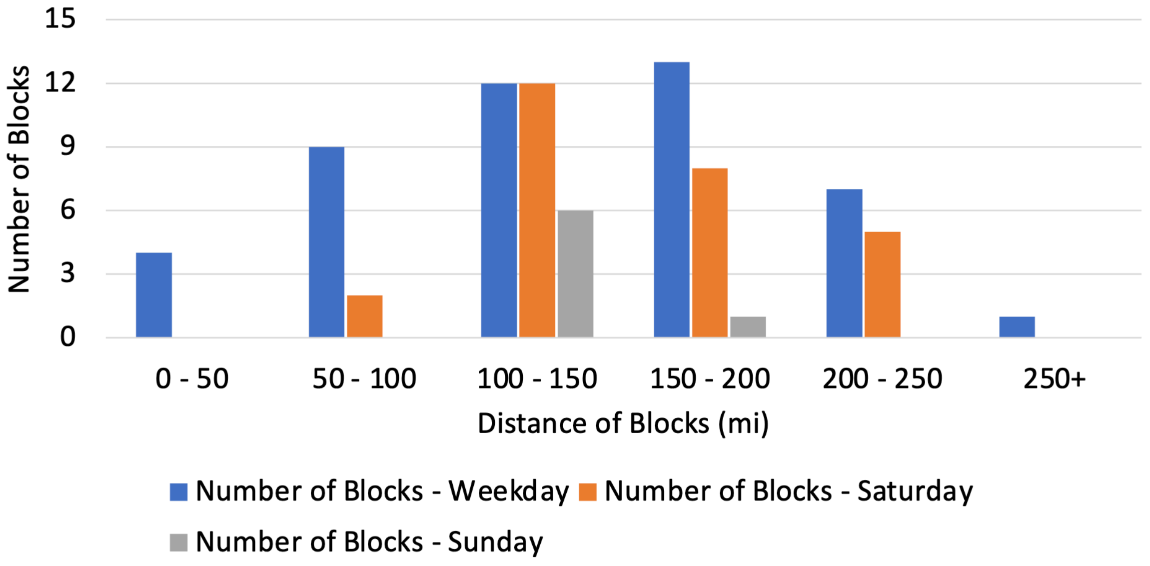
Transfort's fixed-route service currently consists of 22 routes run on 80 blocks as detailed in **Table 2.**

Table 2 - Number of Blocks by Bus Length and Weekday

Vehicle Length	Weekdays	Saturday	Sunday
30’	7	4	1
35’	11	6	2
40’	22	11	2
60’	6	6	2
TOTAL	***46***	***27***	***7***

The mileage distribution for the blocks, which is critical for understanding feasibility of operating ZEBs, is depicted in **Figure 3.**

Figure 3 - Mileage Distribution of Current Blocks



Fuel

CTE prepared an assessment of Transfort’s Weekday, Saturday, and Sunday block schedules. Tranfort’s peak pullout take place during the weekdays, with a total of 46 total blocks in operation. Information regarding the total mileage of the blocks is included in **Table 3**.

Table 3 - Daily Block Mileage

Schedule Type	Total Blocks	Total Mileage
Weekday	46	6,362
Saturday	27	4,160
Sunday	7	897

Assigned block mileage does not account for holidays beyond designated out of service periods or inclement weather rerouting. Assigned block mileage based on the blocking information provided to CTE tracks closely with the historical average annual mileage, with a reasonable level of error given possible service changes. Historical fuel economy, in miles per gallon-diesel gallon equivalent (mpgde) for CNG, can be found below. Note that the average is for all of the vehicles of the same length in the fleet and may be influenced by the age of the vehicles.

Table 4 – Average Fuel Economy by Bus Length and Fuel Type

Vehicle Length	CNG (mpgde)
30’	3.8
35’	3.5
40’	3.9
60’	2.4

The average fuel cost per mile for operating CNG vehicles was calculated for each vehicle size based on 2020 mileage and fuel costs and is included in **Table 5**.

Table 5 - Average Fuel Cost per Mile by Bus Length

Vehicle Length	Mileage (mi)	Fuel Consumption (dge)	Cost ($)	Cost per Mile ($/mi)
30’	181,505	47,541	$107,569	$0.59
35’	374,307	106,255	$240,014	$0.64
40’	623,147	159,254	$359,615	$0.58
60’	216,927	88,824	$200,601	$0.92
Total	**1,395,886**	**401,874**	**$907,799**	**$0.65**

Maintenance

Historical maintenance costs are used to project future maintenance costs for CNG vehicles. All diesel vehicles are planned to transition to CNG or battery-electric by late 2022 so diesel was not considered in the maintenance cost analysis.

Table 6 - Average Maintenance Cost per Mile

Fuel Type	Total Maintenance Costs	Total Vehicle Mileage	Maintenance Cost per Mile
CNG	$8,315,876	16,339,946	$0.51

It should be noted that the average maintenance costs per mile are affected by the age of the vehicle or fleet, as older fleets typically experience higher maintenance costs per mile. The average midlife overhaul cost for the current vehicles was determined to be $27,531, although transmission and engines overhauls were only completed on vehicles as needed.

5 Service Assessment

Bus efficiency and range are primarily driven by vehicle specifications; however, it can be impacted by a number of variables including the route profile (i.e., distance, dwell time, acceleration, sustained top speed over distance, average speed, traffic conditions, etc.), 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 that are based on an accurate representation of the operating conditions associated with Transfort's system to complete the assessment.

The first step in the Service Assessment is typically to develop route and bus models to run operating simulations for representative routes; however, Transfort requested that a screening analysis be conducted rather than detailed route modeling to identify which scenario should be selected for future detailed analysis. The Screening Model is based on data from comparable BEB deployments managed and monitored by CTE. The analysis assumes generic BEB models for 35', 40', and 60' model, with assumptions for onboard energy capacity for current and future scenarios included in **Table 7**. The model also assumes the batteries degrade to 80% of their original capacity over the estimated service life of the batteries. The generic bus models were developed by CTE to reflect the current (2021) state of practice.

Table 7 - Generic Battery Electric Bus Characteristics (Current)

Variable	Description	New Battery Scenario (35', 40', and 60' Buses)	End of Life Battery Scenario (35', 40', and 60' Buses)
Total Battery Energy (kWh)	The total energy contained in the battery.	420 500 550	336 400 440
Useable Energy (kWh)	The total energy that can be withdrawn from the battery before needing to stop.	336 400 440	269 320 352
Service Energy (kWh)	Maximum energy that should be used in revenue service; "Usable Energy" minus "Reserve Energy."	315 379 412	247 299 324
Reserve Energy (kWh)	Energy required to travel approximately 10 miles to the depot from an on-route location; a "safety net" to ensure the bus can return to the depot if a bus experiences an issue on-route, causing it to use more energy than expected.	21.4 21.4 28	
Nominal Motive Energy Consumption (kWh/mi)	Energy required to move the vehicle under nominal conditions.	1.27 1.27 1.60	
Strenuous Motive Energy Consumption (kWh/mi)	Energy required to move the vehicle under strenuous conditions.	2.14 2.14 2.8	
Nominal Auxiliary Power (kW)	The amount of power needed to operate auxiliary systems under nominal conditions.	6.5 6.5 10	
Strenuous Auxiliary Power (Electric Cabin Heating) (kW)	The amount of power needed to operate auxiliary systems under strenuous conditions using the electric cabin heater.	27 27 36	
Strenuous Auxiliary Power (Diesel Cabin Heating) (kW)	The amount of power needed to operate auxiliary systems under strenuous conditions using a supplementary diesel cabin heater.	6.5 6.5 16	

Research suggests that battery density for electric vehicles has improved by an average of 5% each year.[1] For the purposes of this study, considering the extended period of a complete fleet transition (e.g. through 2040 being the goal for Transfort), CTE assumes a more conservative

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[1] 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

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 CNG buses one-for-one. For FCEBs, improvements in hydrogen compression and storage technologies are expected to occur over the course of the transition period. As a result, CTE assumed a 5% improvement in efficiency for FCEBs every other year. Future expected bus characteristics used in the analysis are included in **Table 8.**

Table 8 - Generic Battery Electric Bus Characteristics (Future)

Variable	New Battery Scenario (35’, 40’, and 60’ Buses)			End of Life Battery Scenario (35’, 40’, and 60’ Buses)		
	2025	2030	2040	2025	2030	2040
Total Battery Energy (kWh)	463	536	684	370	429	547
	551	638	814	441	511	652
	606	702	896	485	562	717
Useable Energy (kWh)	370	429	547	296	343	438
	441	511	652	353	408	521
	485	562	717	388	449	573
Service Energy (kWh)	349	407	526	275	322	416
	420	489	630	331	387	500
	457	534	689	360	421	545
Reserve Energy (kWh)	21.4 21.4 28					
Nominal Motive Energy Consumption (kWh/mi)	1.27 1.27 1.60					
Strenuous Motive Energy Consumption (kWh/mi)	2.14 2.14 2.8					
Nominal Auxiliary Power (kW)	6.5 6.5 10					
Strenuous Auxiliary Power (Electric Cabin Heating) (kW)	27 27 36					
Strenuous Auxiliary Power (Diesel Cabin Heating) (kW)	6.5 6.5 16					

CTE evaluated all 30’, 40’, and 60’ bus service blocks (i.e., the scheduled pieces of work to which each bus is dispatched), and categorizes their feasibility with regard to the **service energy**[2] storage capacity available on a standard ZEB for each vehicle size. The scenarios were evaluated 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 conditions (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 requires 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). In addition, the use of auxiliary heating (diesel) was evaluated in the strenuous loading condition.

Standard ZEBs used for the screening model were based on currently available bus technology and average battery capacity. In the evaluation of current blocks served by 30’ buses, CTE assumed ZEBs serving those blocks would be transitioned to 35’ or 40’ BEBs based on discussions with Transfort. CTE assigned bus lengths to blocks based on the block’s distance and duration, with 35’ vehicles assigned to the bottom half and 40’ vehicles assigned to the upper half of these blocks. The analysis focused on bus endurance and range limitations to determine if the ZEBs could meet the service requirements of the blocks today and in the future scenario (2040). 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. Feasibility analysis was completed to determine if each block was:

- **Feasible:** Blocks that are feasible regardless of the foreseeable route conditions.
- **Unfeasible:** Blocks that are not anticipated to be feasible under foreseeable route conditions.
- **Maybe Feasible:** Blocks that may be feasible under nominal conditions but not under strenuous conditions.

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 CNG buses one to one. This information is used to then inform ZEB procurements in the Fleet Assessment. The results from the block analysis are used to determine when/if a full transition to BEBs or FCEBs may be feasible. 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.

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[2] It is important to note that ‘service energy’ reflects the amount of energy available for daily use, which is significantly less than stated or ‘nameplate’ capacity of the bus (e.g., 450 kWh). This is because bus battery systems are not designed to access all of the nameplate energy storage capacity for several reasons including; (1) utilizing high and low ends of the battery pack can rapidly accelerate degradation and (2) the voltage available when the battery is nearing empty is insufficient to power all bus systems. Additionally, CTE advises agencies to reserve a portion of the battery capacity for use as a reserve, which is not considered part of the service energy. Ultimately, the service energy of a BEB is limited to the amount of the battery that can be used (typically 80% of the nameplate capacity) minus the reserve energy (typically 10-30 kWh to provide confidence the buses can return to the depot in the event of unforeseen energy consumption (e.g., a detour or being stuck in traffic).

Depot-Only BEB Charging

The results of the feasibility assessment for the Depot-Only Charged Battery Electric Bus Current scenario are shown on **Figure 4, Figure 5,** and **Figure 6**.

Figure 4 - BEB Block Feasibility on Weekdays (Current)

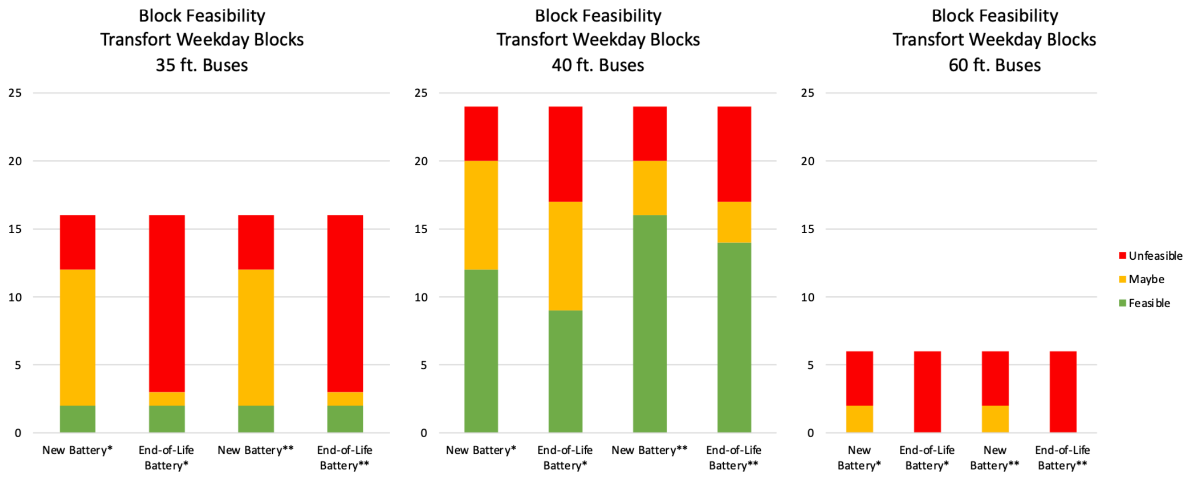
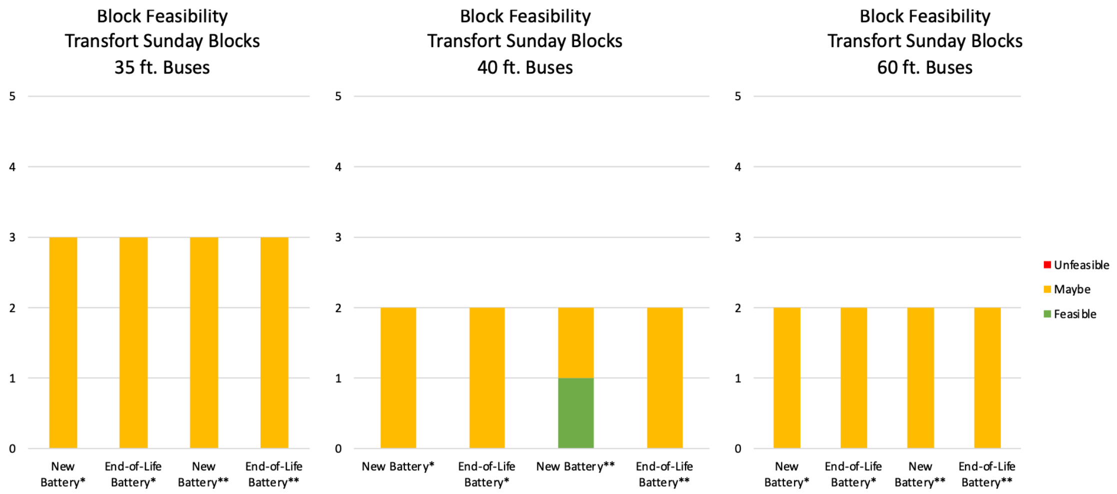


Figure 5 - BEB Block Feasibility on Saturdays (Current)

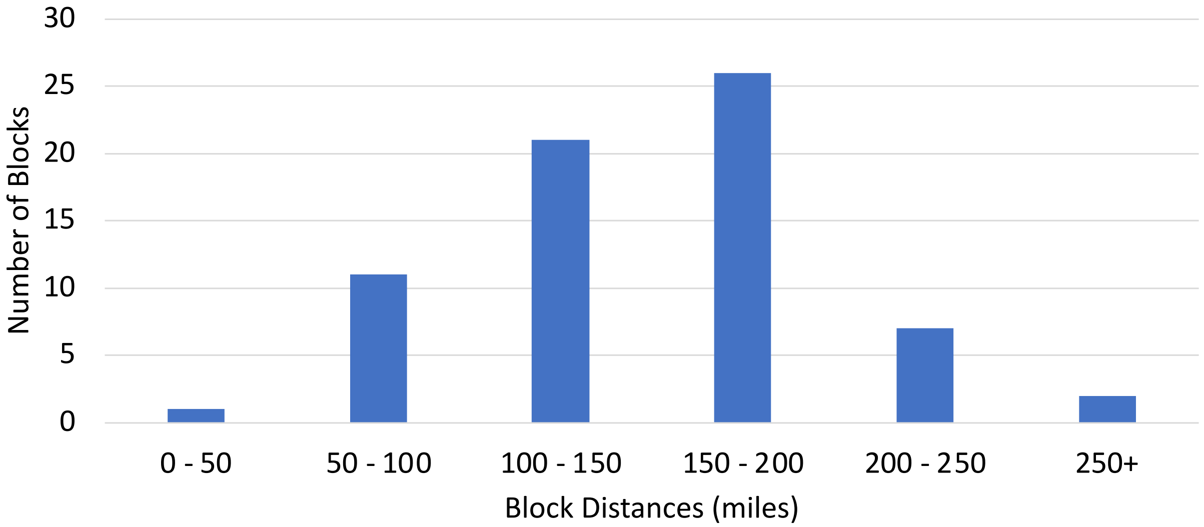
Figure 6 - BEB Block Feasibility on Sundays (Current)



As detailed in the figures, the block evaluation indicates that approximately 39% of Transfort's blocks are achievable based on current BEB technical specifications in 2021 (assuming the use of auxiliary diesel heating). Fleet expansion to accommodate operating more than a single BEB on an individual block allows for 100% of Transfort's blocks to be electrified in the future. The number of additional vehicles will be discussed in the Fleet Assessment section of this report.

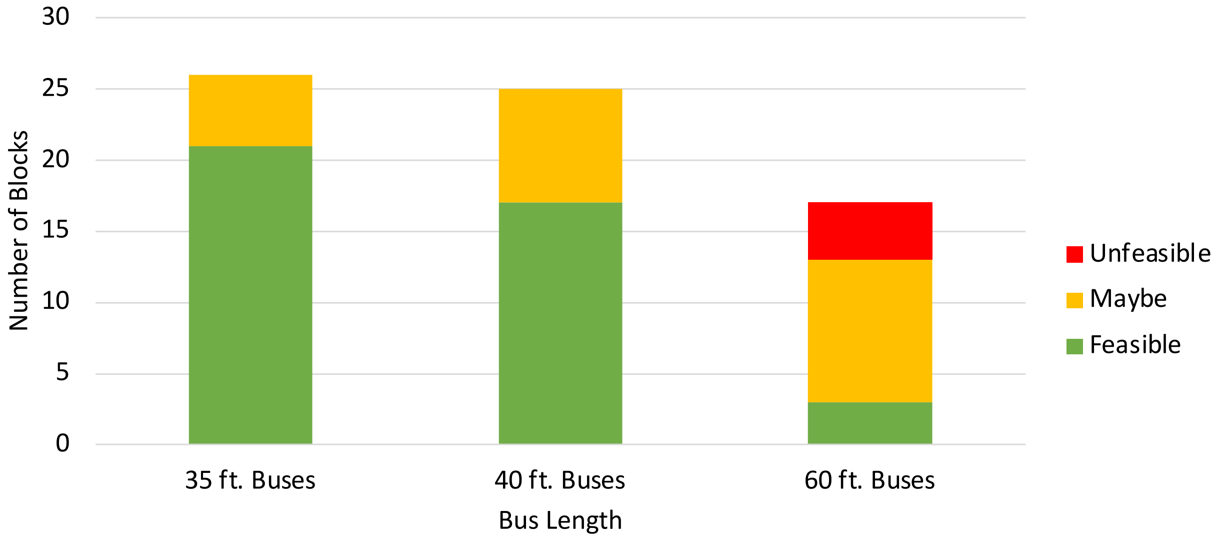
CTE utilized data from the *Fort Collins Transit Master Plan* to develop estimated blocks based on service expansion needs and current block length distribution to develop a block schedule for the future scenario analysis. A total of 68 blocks were assumed for the future analysis. The projected future block distribution by length is included in **Figure 7.**

Figure 7 - Mileage Distribution of Projected Future Blocks



Results from the analysis indicates that approximately 60% of Transfort's blocks appear achievable in the future scenario. BEB block feasibility for the future weekday case is depicted in **Figure 8**. As discussed previously, fleet expansion with more than one BEB operating on a single block would allow for 100% of Transfort's blocks to be electrified; however, cost and space considerations must be considered.

Figure 8 - BEB Block Feasibility on Weekdays (Future)



While routes and block schedules are unlikely to remain the same over the course of the transition period, this projection assumes the blocks will retain a similar structure to what is in place today. Despite changes over time, this analysis assumes blocks will maintain a similar distribution of distance, relative speeds, and elevation changes by covering similar locations within the city and using similar roads to get to these destinations. This core assumption affects energy use estimates as well as block achievability in each year.

Depot-Only BEB + On-Route Charging

Augmenting depot charging with on-route charging can be used to increase the portion of the fleet that is feasible to replace with electric vehicles. On-route chargers (either overhead conductive or in-ground inductive) are typically installed at major stops or transit centers where layovers may occur. These chargers usually serve multiple buses, and are often utilized with buses with smaller battery packs and shorter range, but faster charging capabilities. Buses will charge at these stations anywhere from 5 to 20 minutes at a higher power than traditional plug-in charging at the depot. Utilization of this method can allow for 24-hour continuous bus operation if there is sufficient charging time available throughout the day. In practice, there are two operational modes for on-route charging: Charge Sustaining and Charge Depleting. Charge Sustaining operations rely on longer periodic charging events to fully replenish the batteries throughout the day, while Charge Depleting operations gradually drain the battery throughout the service day, but devote less time to charging or are operating on more challenging routes. Operators must then fully recharge at the depot or at the beginning or end of the day when operating in a Charge Depleting mode to ensure they are ready for the next revenue operations. A generic charging profile depicting the effect of Charge Sustaining vs. Charge Depleting modes for on-route charging are depicted in **Figure 9.**

Figure 9 - On-Route Charging Methods

Disadvantages of on-route charging include higher infrastructure costs and higher impacts from peak demand charges. Land rights must be obtained at charging sites, and overhead systems may interfere with road clearances or may require a dedicated pull-off. This type of fixed infrastructure is costly to relocate, which may constrain future route changes for buses.

CTE assessed the feasibility of on-route charging for 21 weekday blocks. Blocks that were either feasible in the BEB Depot-Only Charging scenario or did not have layovers at one of the three transit centers (Downtown, South, and CSU) were excluded from the analysis. Details of the blocks evaluated for on-route charging are included in the following table.

Table 9 - Blocks Evaluated for On-Route Charging

South		CSU		Downtown	
Block	**Route(s)**	**Block**	**Route(s)**	**Block**	**Route(s)**
1	MAX-5	12	6	9	14-18-5
3	MAX-6	13	2	10	5-14-18
4	MAX-3	22	7	11	9-10
5	MAX-2	25	702	15	8
7	1602	27	32	19	18-5-14
14	16-11-12			20	81
18	11-12-16				
21	MAX-4				
28	19				
36	MAX-1				

Vehicle energy consumption per trip between layovers was estimated utilizing the vehicle modeling methodology used for the depot charging scenario. Available on-board energy assumptions were also held constant from the depot charging scenario.

CTE assessed a range of available charging power based on both current charger models and battery power acceptance levels for different models of BEBs. Charger power ranged from 262.5 to 330 kW delivered to the vehicle. Future modeling scenarios for on-route charging could incorporate more vehicle-specific and charger-specific data, along with more granular block data to assess the operational feasibility of on-route charging.

The analysis indicated that all blocks that were evaluated appear feasible for on-route charging. All buses were able to maintain charge sustaining mode in the nominal scenario while Bus Rapid Transit blocks would operate in a charge depleting mode in the strenuous case within the charging power ranges evaluated. Energy requirements calculated for each block are included in *Appendix A*. Based on the analysis, a total of approximately 85% of Transfort's current blocks appear feasible when utilizing a combination of overnight depot charging and on-route charging at the three transit centers.

The future analysis assumed that the same blocks would be used for on-route charging. Additional blocks could be added assuming sufficient charging capacity at the identified transit centers. Approximately 92% of the future blocks developed for analysis appear feasible when utilizing a combination of overnight depot charging and on-route charging at the existing three transit centers without expanding the on-route charging network.

Additional analysis would be required to verify these assumptions based on specific buses and chargers from different OEMs and a detailed model of the route requirements. A sensitivity analysis would also provide additional insight into the impacts of potential risks, which include deadhead time, skipped charging sessions, charger outages, range loss in slippery conditions, and manufacturer-specific charging rates and battery capacities. Potential strategies to recharge buses after completion of service include charging at the end of a block before deadheading, fast-charging upon pull-in at the depot, plug-in charging overnight at the depot, or charging after morning deadheading to the transit center.

Fuel Cell Only

As part of the screening analysis, CTE evaluated the portion of Transfort's fleet that could be replaced today and in the future with FCEBs. The assumptions used in the analysis are included in **Table 10.**

Table 10 - Assumptions for FCEB Feasibility Analysis

Variable	Description	35' and 40' Buses	60' Buses
Total Fuel Storage	The total amount of hydrogen fuel that can be carried onboard.	37.5 kg	67.5 kg
Useable Fuel Storage	The total amount of usable hydrogen fuel.	35.25 kg	63.5 kg
Nominal Motive Energy Consumption	Energy required to move the vehicle under nominal conditions.	6.91 mi/kg	4.75 mi/kg
Strenuous Auxiliary Power	The amount of power needed to operate auxiliary systems under strenuous conditions.	7 kW	16 kW

Please note that 35-foot FCEBs are not currently commercially available; however, CTE expects that these vehicles will be available during the transition period. A review of the data indicates that an estimated 85% of the current blocks are achievable using FCEBs. By the end of the transition period in 2040, an estimated 93% of the blocks are achievable. It should be noted that FCEB operations are similar to CNG in that the vehicles can be refilled (or partially refilled) quickly during the service day to extend the range as long as hydrogen fueling capacity is available.

Depot Charged BEB + Fuel Cell

The Depot Charged BEB + Fuel Cell scenario, also called the Mixed Fleet scenario, utilizes both BEB and FCEBs. For the analysis, blocks that are achievable from a single overnight depot charge are operated with BEBs while longer blocks that would require more than a single depot charge are operated with FCEBs. Challenges to consider when implementing a Mixed Fleet approach are that there may be multiple vehicle types and associated fueling requirements on a single TMF (CNG, electrical charging, and hydrogen fueling). Results from the analysis indicate that approximately 85% of the current blocks are achievable by using a mixed fleet while approximately 93% are estimated to be achievable in the future in 2040.

Table 11 and **Table 12** and provide summaries of the block achievability for each scenario based on current and estimated future operations, respectively.

Table 11 - Block Feasibility Summary (Current)

Scenario	Total Weekday Blocks	Achievable Blocks in all Conditions	% Achievable Blocks
1A – BEB Depot Charging Only – No Fleet Expansion	46	18	39%
1B – BEB Depot Charging Only – Fleet Expansion	46	46	100%
2 – BEB Depot + On-Route Charging	46	39	85%
3 – Mixed Fleet (BEB Depot Charging + FCEB)	46	39	85%
4 – FCEB Only	46	39	85%

Table 12 - Block Feasibility Summary (Future)

Scenario	Total Blocks	Achievable Blocks in all Conditions	% Achievable Blocks
1A – BEB Depot Charging Only – No Fleet Expansion	68	41	60%
1B – BEB Depot Charging Only – Fleet Expansion	68	68	100%
2 – BEB Depot + On-Route Charging	68	62	92%
3 – Mixed Fleet (BEB Depot Charging + FCEB)	68	63	93%
4 – FCEB Only	68	63	93%

6 Fleet Assessment

The goal of the Fleet Assessment is to determine the type and quantity of ZEBs, as well as the schedule and cost to transition a transit fleet to zero emission. Results from the Service Assessment are integrated with Transfort's current fleet replacement plan and purchase schedule to produce the projected bus replacement timeline and the associated total capital cost.

Cost Assumptions

CTE and Transfort created cost assumptions for this analysis for each bus length and technology type (e.g. BEB, FCEB). Key assumptions for the bus cost estimate are as follows:

- Bus costs are based on both Transfort procurements and prices available on the California State Vehicle Procurement Contract as any agency can purchase off of this contract
- BEB and FCEB costs include $75,000 estimated battery/fuel cell warranty costs and $50,000 configurable items
- Future bus costs are based on year 2021 costs because 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, costs appear to have leveled out in recent years. However, it should be also noted that 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 reduce the costs over time for the purchase of FCEBs.

Table 13 provides cost estimates for new vehicle purchases used in the analysis. All bus purchase prices are inclusive of tax and configurable options and are based on actual purchase prices, known quotes, or state contracted rates.

Table 13 - Bus Cost Assumptions

Length	CNG	BEB	FCEB
35’	$604,676	$994,225	$1,065,000
40’	$620,000	$995,000	$1,065,000
60’	$867,299	$1,459,000	$1,514,000

ZEB Fleet Transition Schedule and Composition

Given the block analysis and Transfort's fleet replacement schedule and currently planned procurements, a baseline and future fleet composition were developed as provided in the following table.

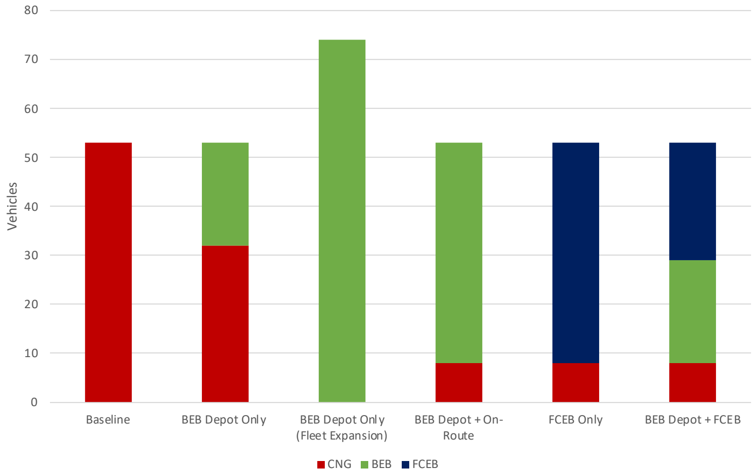
Table 14 - Current and Future Fleet Composition by Length

Bus Size	Current	Future
30’	10	0
35’	13	31
40’	22	31
60’	8	20
Total	***53***	***82***

The Baseline scenario represents like replacement of CNG vehicles with CNG vehicles. It is understood that Transfort will be replacing two (2) vehicles with BEBs in late 2021 and has identified funding to replace up to a total of eleven (11) CNG vehicles with BEBs; however, for the purposes of comparison, CNG was held constant as the Baseline fleet. Despite recent increases in energy storage, BEBs are still subject to range limitations and cannot be placed into service on every block on a one to one replacement basis for CNG.

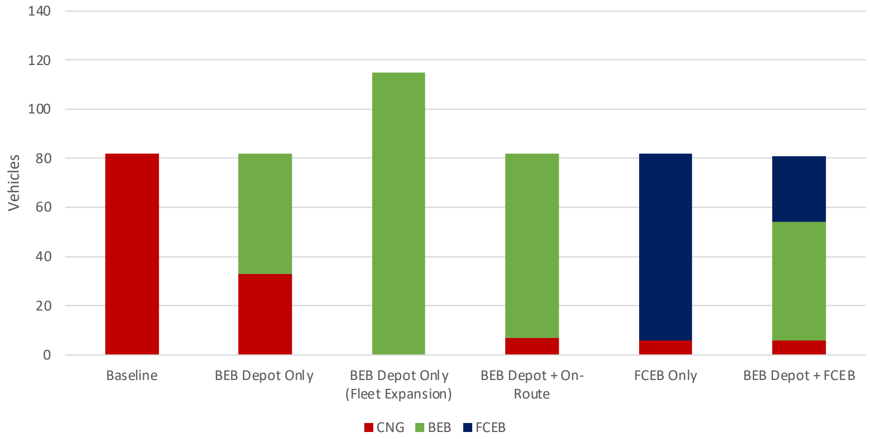
As discussed in the Service Assessment section, BEBs can currently be operated on approximately 39% of Transfort’s blocks by 32 vehicles. By increasing the fleet size from 53 vehicles to 73 vehicles, Transfort can complete all of the current blocks with BEBs. Alternately, by incorporating on-route charging, Transfort can complete approximately 85% of the current blocks using 45 BEBs. Although FCEBs provide a range closer to current CNG vehicles, there are still range considerations that must be overcome. FCEBs can currently operate approximately 85% of Transfort’s blocks on one fueling using 45 vehicles. Finally, a mixed fleet scenario utilizing FCEBs (34) and depot-charged BEBs (21) can operate approximately 85% of Transfort’s current blocks today. Blocks that cannot be operated with one charger or hydrogen fueling were assumed to remain operated with CNG vehicles; however, because the time to fuel FCEBs is similar to CNG, it is possible that FCEB could be used in place of CNG with multiple fueling required. The following figure depicts the fleet mix for each scenario based on the current block assignments.

Figure 10 - Fleet Composition by Scenario (Current)



Results for the future fleet composition based on the block scheduled to accommodate service expansion in the future developed by CTE is included in **Figure 11**. Please note that in order to accommodate reach a 100% ZEB fleet using depot-charged BEBs, the fleet size would need to increase from 82 vehicles to an estimated 115 vehicles. Even with the battery and fuel cell improvements estimated to improve range by 2040, it is unlikely that BEBs and FCEBs will have the range to completely replace CNG vehicles on a one to one basis in all cases. However, as discussed previously, FCEB refueling is similar to CNG and thus the range on a single fueling is not as critical as with BEB charging.

Figure 11 - Fleet Composition by Scenario (Future)



BEB Fleet Transition Costs

The fleet composition for each scenario currently and in the future were used to develop estimated costs to replace the entire fleet. The cost represents the total investment to replace each vehicle in the fleet with a ZEB alternative or with a CNG vehicle if the vehicle cannot meet service requirements. While it is expected that changes in costs over time are likely to occur, given the rapid change in the industry at this time, CTE has no reliable basis upon which to incorporate price changes in these projections and, as a result, costs are provided in 2021 dollars. Estimated capital costs for bus replacement are included in
Table 15 and **Table 16.**

Table 15 - ZEB Capital Costs (Current)

Scenario	# of Vehicles	# of ZEBs	% ZEB	Estimated Fleet Replacement Cost (2021 $)	Incremental Cost to Replace Vehicles over Baseline (2021 $)	% Cost over Baseline
BEB Depot Charging Only	53	21	39%	$44,200,000	$9,960,000	29%
BEB Depot Charging Only – Fleet Expansion	74	74	100%	$80,700,000	$46,460,000	136%
BEB Depot + On-Route Charging	53	45	85%	$54,600,000	$20,360,000	59%
FCEB Only	53	45	85%	$56,700,000	$22,460,000	66%
BEB Depot Charging + FCEB	53	45	85%	$55,900,000	$21,660,000	63%

Table 16 - ZEB Capital Costs (Future)

Scenario	# of Vehicles	# of ZEBs	% ZEB	Estimated Fleet Replacement Cost (2021 $)	Incremental Cost to Replace Vehicles over Baseline (2021 $)	% Cost over Baseline
BEB Depot Charging Only	82	49	60%	$76,800,000	$18,700,000	32%
BEB Depot Charging Only – Fleet Expansion	115	115	100%	$133,800,000	$75,700,000	130%
BEB Depot + On-Route Charging	82	75	92%	$88,500,000	$30,400,000	52%
FCEB Only	82	76	93%	$89,900,000	$31,800,000	55%
BEB Depot Charging + FCEB	53	45	93%	$86,600,000	$28,500,000	49%

7 Fuel Assessment

Using ZEB performance data from the screening analysis, CTE analyzed the expected performance on each block in Transfort's service network to calculate daily energy requirements. The projection scenarios from the Fleet Assessment are used to estimate associated annual fuel and energy costs unique to each fleet projection. The Fuel Assessment estimates quantities and costs for Transfort's current and future CNG 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 analysis, 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 and other utility charges. FCEBs are more similar to CNG 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 the hydrogen fueling station that must be considered. Operation and maintenance costs to maintain fueling infrastructure are built into the Fuel Assessment. Fuel cost estimates are based on the assumptions in **Table 17.**

Table 17 - Fuel Assessment Assumptions

Fuel	Cost	Source
Diesel fuel	$1.92/gallon	Average cost provided by Transfort
Hydrogen (trucked)	$9.00/kilogram (kg)	Estimated cost provided by Linde was $8-$10/kg; only includes cost of the fuel
Electricity	Varies	City of Fort Collins Utilities E-300 (Large Commercial) and E-400 (Industrial)

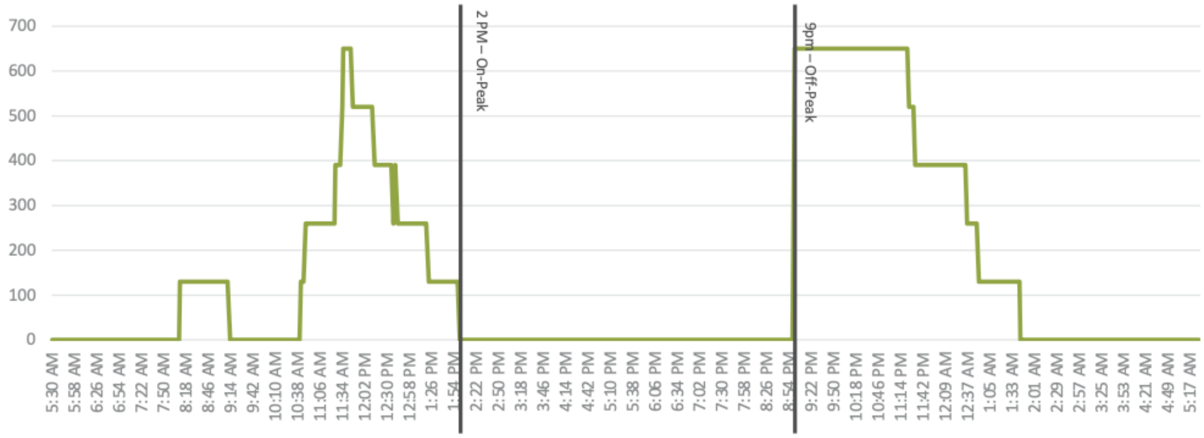
Managed Demand Charging Schedule - BEB

Typically, electrical costs are comparably complex compared with other fuels. This is because pricing is generally driven by three factors: the amount of energy (as with conventional fuels), demand charges—which depend on how fast that energy is pulled from the grid (i.e. charging speed and number of buses charging at the same time)—and other additional fees. Demand charges are typically the major cost contributor for BEB operations and very sensitive to charging behavior. Transfort's utility rate structure includes all of these typical components. Two rate schedules were utilized during this analysis, depending on the total kW demand required: the E-300 plan (Large Commercial) and the E-400 Plan (Industrial, higher demand).

The rate schedule also includes additional fees for "coincident peak demand" which is demand from charging that coincides with peak demand periods of the immediate region, as defined by the utility. If demand occurs during this time period, a significant unit cost rate is applied per kW of demand (higher than and in addition to the normal demand fees). The project team agreed that best practice is to avoid the coincident periods during the day wherever possible. Therefore, for depot charging, charging schedule was managed to avoid this time period. In the case of on-route charging this was unavoidable, as buses will be charging at multiple times during the middle of the day.

Figure 12 provides the estimated peak demand curve for the BEB Depot-Only Charging scenario servicing the current blocks.

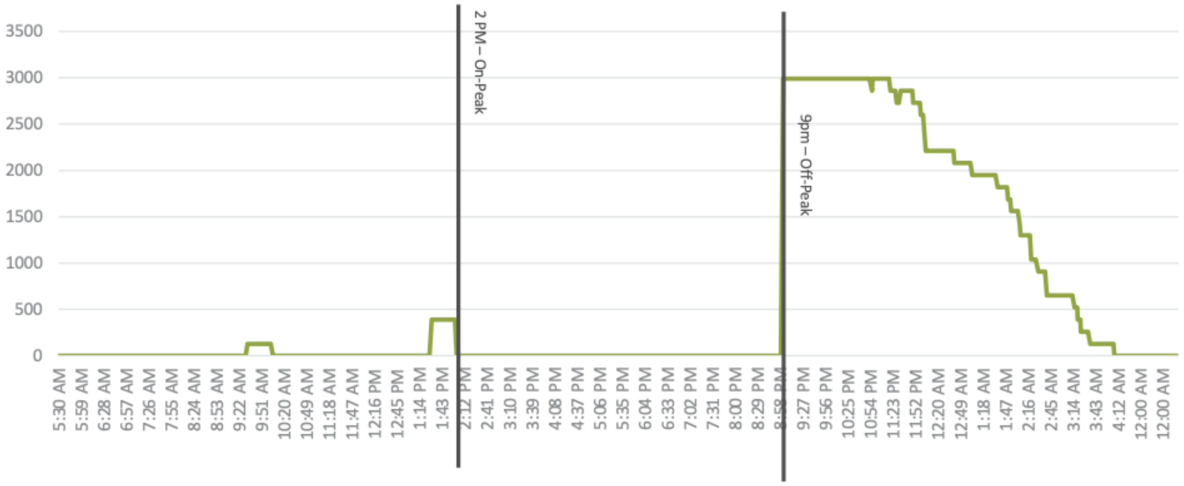
Figure 12 - Managed Demand for BEB Depot-Only Charging (Current)



Review of the results indicates that a total of 18 achievable blocks (39% of the current blocks) can be serviced utilizing 5 chargers equipped with three dispensers each. A total off-peak demand of 650 kW and daily energy use of approximately 3,500 kilowatt-hours (kWh) during the weekdays and approximately 2,400 kWh and 320 kWh on Saturday and Sunday, respectively, are expected. Charging was managed such that it does not occur during the 2 PM to 9 PM window when coincident peak demand is expected to occur.

Figure 13 provides the estimated peak demand curve for the BEB Depot-Only Charging scenario servicing the projected future blocks developed for the analysis.

Figure 13 - Managed Demand for BEB Depot-Only Charging (Future)



Review of the results indicates that a total of 41 achievable blocks (60% of the expected blocks) can be serviced utilizing 23 chargers (5 chargers equipped with 3 dispensers each and 18 chargers equipped with 2 dispensers each). A total off-peak demand of approximately 3,000 kW and daily energy use of approximately 15,250 kWh during the weekdays and approximately 11,000 kWh and 1,500 kWh on Saturday and Sunday, respectively, are expected. Charging was managed such that it does not occur during the 2 PM to 9 PM window when coincident peak demand is expected to occur.

CTE also developed estimated demand and energy needs for the BEB Depot-Only + On-Route Charging scenario. Results from the demand analysis are included in **Table 18.**

Table 18 - Demand Analysis for On-Route Charging

	Equipment Summary			Max Demand (kW)
Transit Center	# Additional Blocks	# Buses	# Chargers (450 kW)	Weekday (Peak/Off-Peak)
CSU	5	5	1	367
Downtown	6	6	2	734
South	10	10	2	734

As discussed previously, a total of 21 blocks were identified as being feasible for on-route charging, increasing the total block feasibility to approximately 85% of current blocks and 92% of future blocks. A maximum estimated demand of approximately 367 kW is required assuming one on-route charger at the CSU Transit Center and 734 kW is estimated for the Downtown and South Transit Centers assuming two on-route chargers at each location. Daily energy use of approximately 6,700 kWh during the weekdays and approximately 4,800 kWh and 630 kWh on Saturday and Sunday, respectively, are expected to operate the vehicles on the 21 blocks. Charging occurs each time a bus passes through the above-referenced transit center. As a result, there is no reasonable way to avoid charging during peak demand periods.

Fuel Costs

Inputs from the fleet transition schedule/composition, fuel cost assumptions for CNG and hydrogen, and energy rate plans available from the City of Fort Collins Utilities were used to calculate the average fuel cost per mile per scenario for both current and future operations. It should be noted that the cost included in the analysis for hydrogen fuel of $9/kg assumes that liquid hydrogen is transported from Texas and does not reflect the use of low-carbon hydrogen. The team also considered potential on-site hydrogen production via electrolysis or reformation of renewable natural gas. The capital costs associated with these options are discussed in the facility infrastructure portion of the analysis.

Following discussions with Transfort, it was determined that BEBs would be equipped with auxiliary diesel heaters to improve comfort and range in cold weather. As a result, CTE estimated 10 gallons of diesel use per day per achievable block for auxiliary heating, assuming it would be used 90 days per year. The cost for diesel fuel is incorporated into the cost analysis for the energy costs associated with BEB operations. Fuel costs assumptions were previously provided in **Table 17**. The average fuel cost per mile for each scenario based on current blocks and the future estimated blocks are provided in **Table 19** and **Table 20**.

Table 19 - Average Fuel Cost Per Mile per Scenario (Current)

Scenario	% ZEB	Annual ZEB Mileage	Fuel Cost/Mile for ZEB Operations ($/mi)
BEB Depot Only	39%	399,884	0.45
BEB Depot + On-Route	85%	1,487,202	0.69
Mixed Fleet	85%	1,487,202	1.23
FCEB Only	85%	1487,202	1.40

Table 20 - Fuel Cost per Mile by Scenario (Future)

Scenario	% ZEB	Annual ZEB Mileage	Fuel Cost/Mile for ZEB Operations($/mi)
BEB Depot Only	60%	1,626,903	0.38
BEB Depot + On-Route	92%	2,946,479	0.54
Mixed Fleet	93%	2,989,502	0.99
FCEB Only	93%	2,989,502	1.40

Results from analysis of current Transfort operations indicates that the average CNG cost per mile in 2020 was $0.65/mile, including the cost of station maintenance, fuel, tires, and major services. By comparison, BEB Depot-Only Charging appears to be more cost effective on a cost per mile basis for fuel than using CNG to operate the vehicles, assuming no changes to the utility rate structure. BEB Depot-Only + On-Route Charging costs are comparable on a per mile basis to CNG, even when having to charge during peak demand periods. FCEB fueling has the highest cost per mile; however, it also has the most potential for reduction over time as hydrogen production expands as it is more accepted as a transportation fuel.

8 Maintenance Assessment

One of the expected benefits of moving to a ZEB fleet is a reduction in maintenance costs. Conventional wisdom estimates that a transit agency may attain 30% to 50% in maintenance cost savings for BEBs. This is due to the fact that there are fewer fluids to replace (no engine oil or transmission fluid), fewer brake changes due to regenerative braking, and far fewer moving parts than on a CNG bus. The savings in traditional maintenance costs may be offset by the cost of battery or fuel-cell replacements over the life of the vehicle; however, for this analysis, it was assumed that Transfort would purchase either extended battery or fuel cell replacement warranties at a cost of $75,000 per vehicle. As a result, mid-life replacements were not considered in the maintenance costs but were included in the capital cost of the vehicles at purchase.

BEB maintenance costs were derived from analysis of four different studies performed by the U.S. Department of Energy National Renewable Energy Laboratory (U.S. DOE NREL). There is limited information available regarding maintenance costs for FCEBs due to the limited number of vehicles in operation in the United States. Data from FCEB deployments at AC Transit and Orange County Transportation Association (OCTA) were used to estimate the average cost per mile for FCEB maintenance. In addition to labor and materials, the cost impact of mid-life overhauls for major components for each type of bus is also estimated; however, these costs were not used in the maintenance analysis as previously discussed. Maintenance cost assumptions are included in **Table 21** and **Table 22.**

Table 21 - Maintenance Cost Assumptions

Type	Estimate	Source
CNG	$0.54/mile, including tires and major services	Transfort actual costs
BEB	$0.40/mile	U.S. DOE NREL[1,2,3,4]
FCEB	$0.59/mile	AC Transit and OCTA actual costs

[1] *Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses,* Leslie Eudy and Matthew Jeffers, US DOE NREL, February 2018

[2] *Long Beach Transit Battery Electric Bus Progress Report; Data Period Focus: Jan 2019 through Jun 2019,* Leslie Eudy and Matthew Jeffers, US DOE NREL, January 2020

[3] *Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses,* Leslie Eudy and Matthew Jeffers, US DOE NREL, 2018

[4] *Foothill Transit Agency Battery Electric Bus Progress Report – Data Period Focus Jul 2019 through Dec 2019,* Leslie Eudy and Matthew Jeffers, US DOE NREL, March 2020

Table 22 - Mid-Life Overhaul Cost Assumptions

Type	Overhaul Scope	Estimate	Source
CNG	Engine & transmission overhaul	$30k per bus	Transfort data
BEB	Battery replacement	$500 per kWh	Bus Manufacturer
FCEB	Battery replacement Fuel cell overhaul	$500 per kWh $40k per bus	Bus Manufacturer Fuel Cell Manufacturer

The average maintenance cost per mile for ZEBs in each scenario for current and future service are included in **Table 23** and **Table 24.**

Table 23 - Average Maintenance Cost Per Mile by Scenario (Current)

Scenario	% ZEB	Annual ZEB Mileage	Maintenance Cost/Mile for ZEB Operations ($/mi)
BEB Depot Only	39%	399,884	0.40
BEB Depot + On-Route	85%	1,487,202	0.40
Mixed Fleet	85%	1,487,202	0.55
FCEB Only	85%	1,487,202	0.59

Table 24 - Average Maintenance Cost Per Mile by Scenario (Future)

Scenario	% ZEB	Annual ZEB Mileage	Maintenance Cost/Mile for ZEB Operations($/mi)
BEB Depot Only	60%	1,626,903	0.40
BEB Depot + On-Route	92%	2,946,479	0.40
Mixed Fleet	93%	2,989,502	0.49
FCEB Only	93%	2,989,502	0.59

Results from the analysis indicate that BEBs are expected to be more cost effective to maintain on a per mile basis at an estimated cost of $0.40/mile compared to $0.54/mile for the current CNG fleet (based on 2020 data). FCEBs are slightly more expensive to maintain than the CNG fleet and a mixed fleet is comparable to the cost of maintaining the CNG vehicles. Mixed fleet maintenance costs are a weighted average cost per mile based on the expected mileage operated by the BEBs and FCEBs in the fleet.

9 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. Scaling to a fleetwide BEB deployment requires a substantially different approach to charging and infrastructure upgrades. Plug-in charging is often not practical as charger dispensers installed in the parking area can create a hazard. 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. For the current storage and maintenance facility, a combination of charging hardware is proposed.

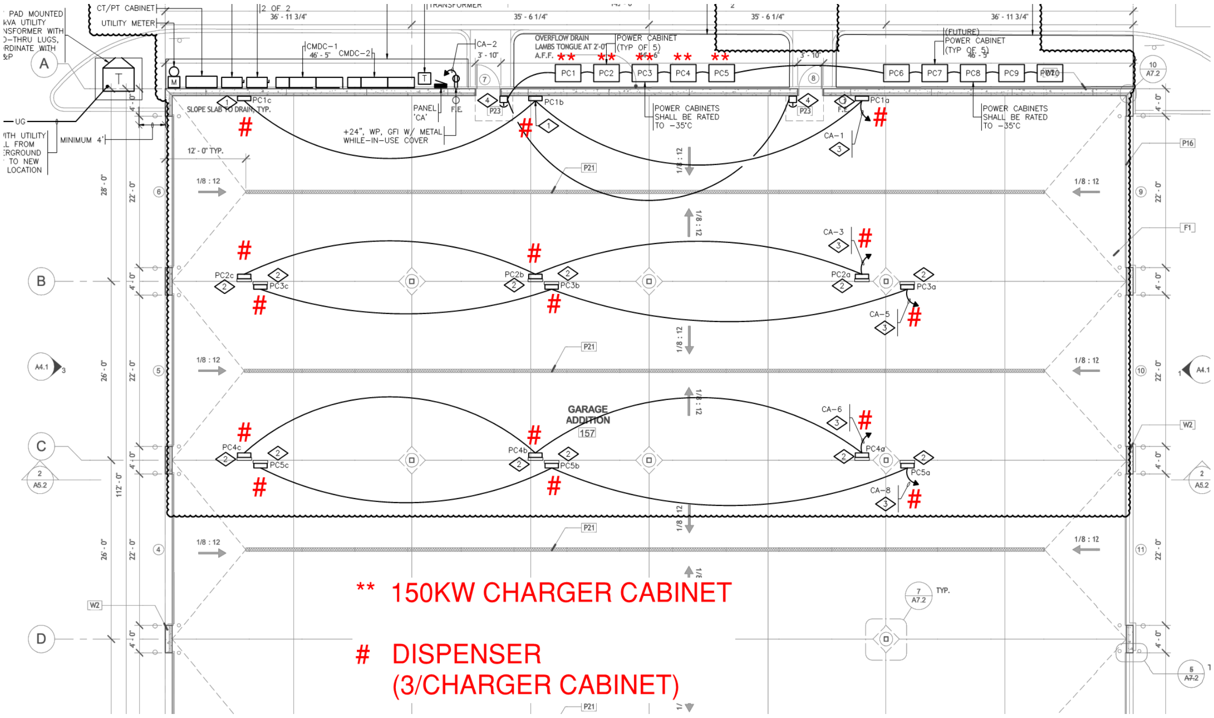
In addition to the installation of the charging stations, improvements to existing electrical infrastructure including switchgear, service connections, etc. are required to support deployment of BEBs. Design work will be required to support BEB deployment including development of detailed electrical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

Current Service

The City of Fort Collins Utilities (a department of the City of Fort Collins) provides primary electric service to the TMF and has an operational high voltage transmission and medium voltage distribution substation directly across the street. According to Fort Collins Utilities, there are several spare medium voltage circuit breaker feeders available to serve the TMF in the future.

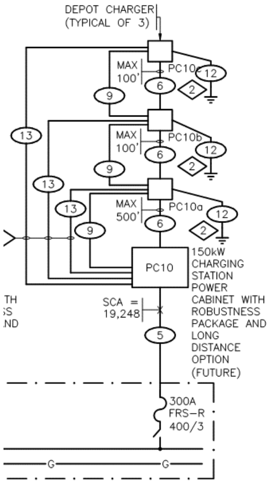
Transfort has developed a design to accommodate up to ten (10) 150-kW ABB depot chargers with plans to install the first six (6) with three (3) dispensers each at the existing storage and maintenance garage as part of their current Electric Bus Service Upgrade Project to support pilot deployment of BEBs. The first two (2) BEBs are scheduled for delivery in mid-December 2021. Design work for this installation has been prepared by *[au]workshop Architects+Urbanists* working in conjunction with the City of Fort Collins Utilities. The first two chargers are expected to be installed in November 2021. A schematic of the planned installation is included in **Figure 14**.

Figure 14 - Phase I BEB Deployment Charging Infrastructure



As part of this ZEB transition analysis, Hatch LTK reviewed the existing and expected demand associated with the installation of the first five (5) chargers. Each 150 kW direct current charging cabinet is fed by a separate fused disconnect and a typical feeding schematic is shown in **Figure 15.**

Figure 15 - Typical Charger Feed Schematic



Per the NEC *ARTICLE 625 Electric Vehicle Power Transfer System*, the power transfer equipment shall have sufficient rating to supply the load served. Electric vehicle charging loads shall be continuous loads and shall have a rating of not less than 125% of the maximum load of the equipment. According to the ABB HVC-150 charger specifications, the input power rating for the chargers is 174 kilovolt-amperes (kVA) at a maximum depot charging current of 200 amps. NEC code allows decreasing the maximum equipment load for a charging station if an automatic load management system is used. The maximum load will then be determined based on the maximum load permitted by the automatic load management system. Based on the load requirements, and including the subpanel requirements, a total maximum load of 878 kVA (834 kW at a 95% power factor) for the 480-volt, 3-phase service is required to supply the chargers. This calculation does not include the additional 25% ampacity rating required for being in continuous load but that can be managed by the automatic load management system. Fort Collins Utilities has planned to install a 750 kVA transformer, smaller than is required based on these load calculations; however, the utility has indicated that they derate transformers based on the expected operational profile and will upgrade the sizing based on performance needs, as necessary. Ultimately the utility is responsible for supply, installation, and maintenance of the transformer.

The estimated cost to complete the installation of the first five(5) chargers and associated fifteen (15) dispensers is detailed in **Table 25**. Charger costs were based on contracted rates from Winn Marion while the electrical service and charger installation costs were based on a previous estimated prepared for Transfort by Cumming. Capacity fees are based on the size of the service required. Capacity fees and the service feed installation are charged by the utility to install the service.

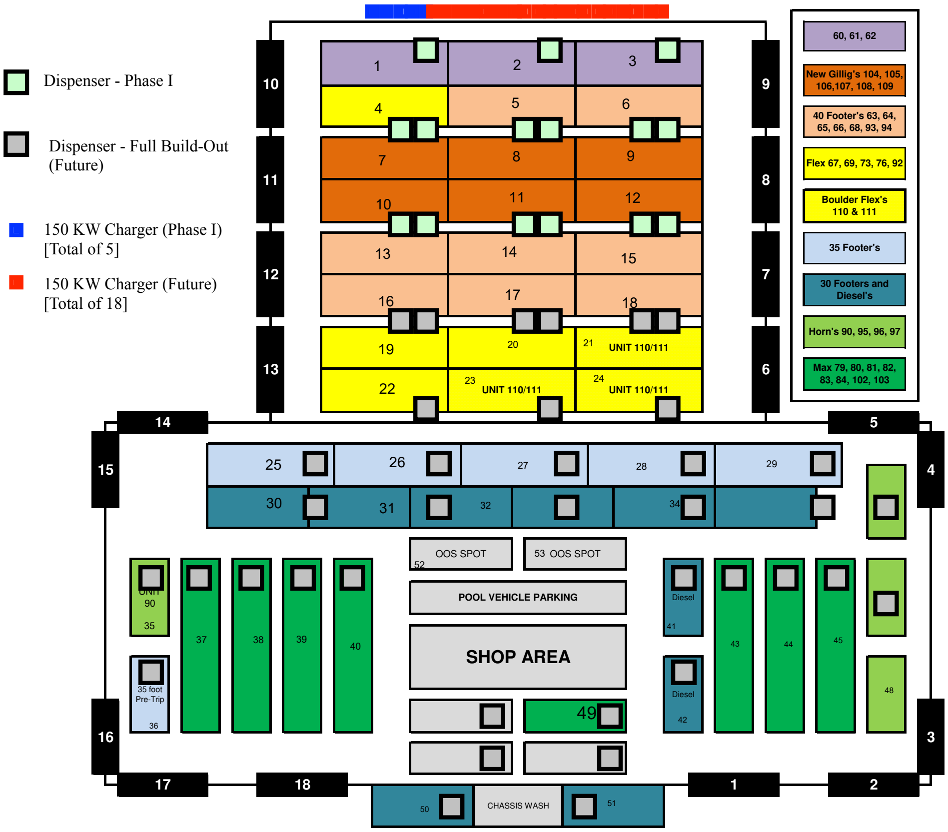
Table 25 - Estimated Phase I Charger Infrastructure Costs

Item	Cost ($)	Source
Charger Purchase	750,000	Winn Marion
Electrical and Charger Install	412,000	Weifeld Group Contracting
Capacity Fees*	277,000	Fort Collins Utilities
Service Feed Installation	50,000	Fort Collins Utilities
TOTAL	***1,489,000***	

Future Service

The BEB block feasibility analysis indicates that Transfort can support approximately 60% of the future blocks with BEBs. A total of 49 BEBs were estimated to complete this service. The current TMF accommodates a total of 53 vehicles. As such, a conceptual approach was developed to fully electrify the existing facility to support BEB deployment. A conceptual layout for full electrification of the current TMF is included as **Figure 16**. Based on the charging analysis, a minimum of 23 chargers are required to adequately charge the vehicles and limit the need to move vehicles.

Figure 16 - Full Electrification of Current Bus Storage Facility



Five (5) of the chargers will be equipped three (3) dispensers each and the remainder with two (2) dispensers each. All of the dispensers installed in the north storage area (parking stalls 1 through 24) will be pedestal mounted either on the wall or adjacent to an existing structural pillar that does not impede traffic flow. Due to limited space in the remainder of the building, the dispensers located in the south section of the building (parking stalls 25 through 51 and the service bays) will be installed overhead with a drop down reel or an overhead pantograph. Examples of the drop down reel and overhead pantograph style dispenser are included in **Figure 17.** The charger cabinets will be installed on the north side of the building (outside) adjacent to the charger cabinets planned for Phase I. Due to space limitations along the north exterior wall the cabinets may be installed on a mezzanine catwalk structure or a portion. Alternately, a section of the existing driving lane may be used as a charger compound area.

Figure 17 - Cable Reel (left) and Overhead Pantograph (right)

The total maximum load estimated to supply the 23 chargers in the future is 4,002 kVA (3,802 kW). This calculation does not include the additional 25% ampacity rating required for being in continuous load but that can be managed by the automatic load management system.

Estimated ROM costs to complete the full-scale installation (assuming the first 5 chargers have been installed) is detailed in **Table 26**. Charger costs were based on contracted rates from Winn Marion while the electrical service and charger installation costs were based on estimates prepared by Hatch LTK. Estimated design fees of approximately 6% of the capital costs are included in the estimate. Capacity fees are based on the size of the service required. Capacity fees and the service feed installation are charged by the utility to install the service. A cost range of -20% to +30% was applied to the estimate due to the conceptual nature at this time.

Table 26 - Full Scale Depot Charger Infrastructure Costs

Item	Units (EA)	Unit Cost ($)	Total Cost ($)	Source
Charger Purchase: Includes charger, pedestal or cable reel, 2 dispenser boxes, long distance package, installation support and commissioning	18	150,000	2,700,000	Winn Marion
Electrical and Charger Install: Includes 2 x 2000A switchgear; 3-phase feeders and breakers; DC charging power conduits; low voltage conduit; communication wiring	1	1,253,800	1,253,800	Hatch LTK
Indirect Costs (General Contractor): General Conditions; Mobilization/Demobilization; Overhead; Profit; Insurance & Bonding; Permits	1	663,200	663,200	Hatch LTK (34% of Construction Costs)
Design Fees	1	168,000	168,000	Engineer's Estimate (10% of Construction Costs))
Capacity Fees for installation of 13 additional 150 kW chargers	1	365,000	365,000	Fort Collins Utilities
Service Feed Installation	1	50,000	50,000	Fort Collins Utilities
TOTAL			***$4,962,800***	
-20% to +30%			***$3,970,200 - $6,451,600***	

On-Route Charging

As detailed in the Service Assessment, a total of 21 blocks were identified as being feasible for on-route charging (not including blocks that could be feasibly charged at the depot overnight). Load analysis was completed to understand the sizing requirements for the service at each of the transit centers identified to support on-route charging. Analysis was previously completed to identify the maximum demand that would be required by the buses to calculate estimated demand chargers; however, the load summary is driven by the specified size of the charging equipment and is a requirement of the electrical design. The load summary is included in

Table 27.

Table 27 - Load Summary for On-Route Charging

Transit Center	# Additional Blocks	# Buses	# Chargers (450 kW)	Load Summary (kW)
CSU	5	5	1	450
Downtown	6	6	2	900
South	10	10	2	900

In order to support on-route charging, it is expected that each facility will need to be supplied with 480-volt, 3-phase electrical service. A 500 KVA transformer is recommended for supply at the CSU transit center, while 1,000 KVA transformers are recommended for supply at the Downtown and South transit centers.

Conceptual schematics for the on-route charging infrastructure at the CSU, Downtown, and South transit centers are provided in *Appendix B.* ROM costs to complete on-route charging equipment installation at the CSU Transit Center are provided in **Table 28** and ROM costs for the Downtown Transit Center and South Transit Center are provided in **Table 29**. The ROM costs for the Downtown and South Transit Centers are the same at this level of estimating because they have the same number of the chargers and the location of the service feeds and charger locations have not been finalized. A cost range of -20% to +30% was applied to the estimate due to the conceptual nature at this time.

Table 28 - ROM On-Route Charging Installation Costs for CSU Transit Center

Item	Units (EA)	Unit Cost ($)	Total Cost ($)	Source
Charger Purchase: Includes charger cabinets, charge pole, top-down pantograph, installation support and commissioning	1	385,000	385,000	ABB
Electrical and Charger Install: Includes 800A switchgear; 500KVA transformer; 3-phase feeders and breakers; DC charging power conduits; low voltage conduit; communication wiring; trenching	1	319,100	319,100	Hatch LTK
Indirect Costs (General Contractor): General Conditions; Mobilization/Demobilization; Overhead; Profit; Insurance & Bonding; Permits	1	150,200	150,200	Hatch LTK (30% of Construction Costs)
Design Fees	1	42,700	42,700	Engineer's Estimate (10% of Construction Costs)
Capacity Fees	1	84,000	84,000	Fort Collins Utilities
Service Feed Installation	1	18,000	18,000	Fort Collins Utilities
TOTAL			***$956,800***	
Cost Range (-20% to +30%)			***$765,400 - $1,243,800***	

Table 29 - ROM On-Route Charging Infrastructure Costs for Downtown and South Transit Centers

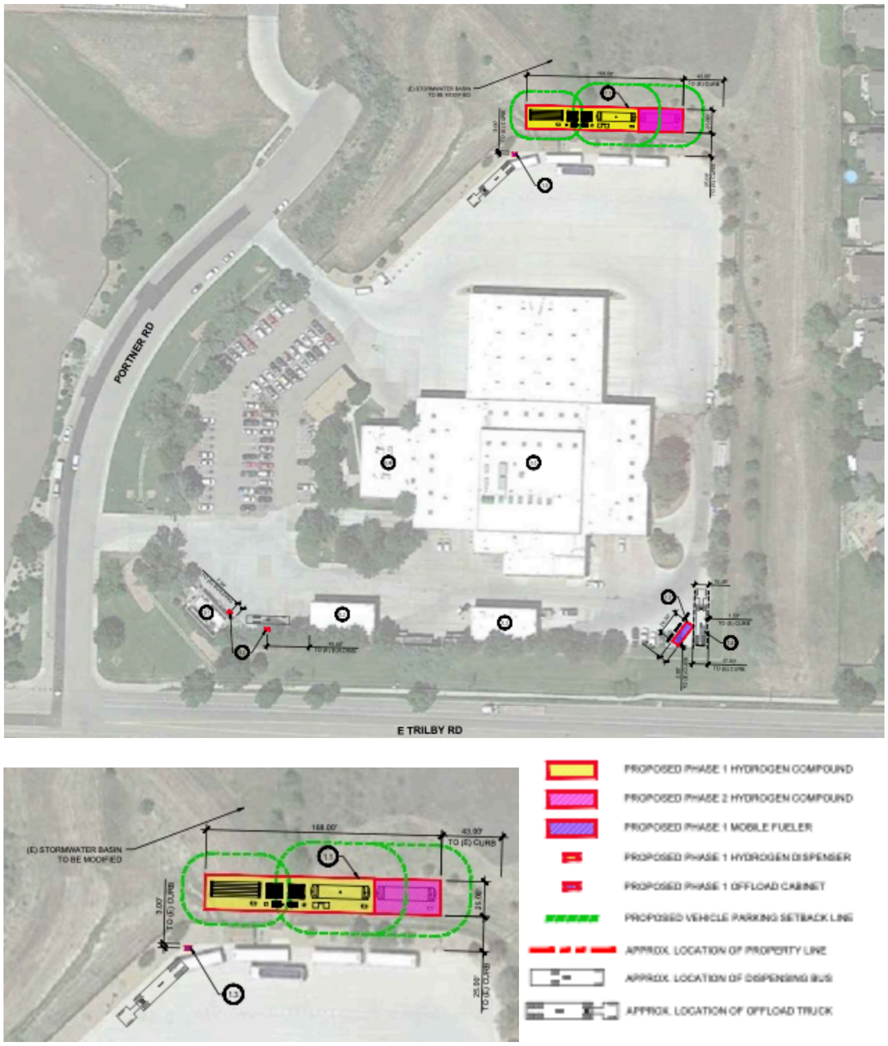
Item	Units (EA)	Unit Cost ($)	Total Cost ($)	Source
Charger Purchase: Includes charger cabinets, charge pole, top-down pantograph, installation support and commissioning	2	385,000	770,000	ABB
Electrical and Charger Install: Includes 1600A switchgear; 1000KVA transformers; 3-phase feeders and breakers; DC charging power conduits; low voltage conduit; communication wiring; trenching	1	538,200	538,200	Hatch LTK
Indirect Costs (General Contractor): General Conditions; Mobilization/Demobilization; Overhead; Profit; Insurance & Bonding; Permits	1	313,800	313,800	Hatch LTK (40% of Construction Costs)
Design Fees	1	72,100	72,100	Engineer's Estimate (10% of Construction Costs)
Capacity Fees	1	174,000	174,000	Fort Collins Utilities
Service Feed Installation	1	18,000	18,000	Fort Collins Utilities
TOTAL			***$1,755,300***	
Cost Range (-20% to +30%)			***$1,404,200 - $2,281,900***	

FCEB Infrastructure and Cost Assumptions

A primary advantage of FCEBs is that fueling operations with hydrogen are similar to CNG 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 fueling can be accomplished through delivery of either liquid or gaseous hydrogen or through on-site generation (electrolysis or steam methane reformation).

Fiedler Group developed a conceptual layout and associated ROM costs for incorporating hydrogen fueling in to the existing TMF. The conceptual layout assumes delivery and storage/dispensing of liquid hydrogen. Costs for completing an initial pilot project (up to 11 buses) were also evaluated. The conceptual layout developed for the existing TMF could also be used at a newly construction facility in the future. It would likely be less expensive to install the hydrogen storage and dispensing equipment at a new facility due to space constraints at the existing facility. The conceptual layout is included in **Figure 18.**

Figure 18 - Conceptual Layout for Hydrogen Storage and Dispensing



Hydrogen storage and dispenser equipment requirements for a pilot, current, and future cases are included in **Table 30.** Equipment sizing assumes a 4 day supply of hydrogen to fuel the buses based on the energy needs assessment. The equipment and associated equipment compound size and costs do not change if installed at the current facility or a new storage and maintenance facility.

Table 30 - Hydrogen Storage and Dispenser Requirements

Equipment	Pilot	Current	Future
Vehicles/Day	Up to 11	Up to 53	Up to 82
Liquid H2 Storage (15,000 gallons)	0	1	2
Vaporizers	0	2	2
Liquid H2 pumps	0	2	2
High pressure gaseous storage assembly	0	1	1
Dispensers	1	2	2
Equipment Compound Size	20’ x 75’	25’ x 123’	25’ x 170’

ROM costs associated with hydrogen infrastructure deployment are included in **Table 31**. The costs were developed by Fiedler Group based on experience on similar projects.

Table 31 - Estimated Costs for Hydrogen Fueling Infrastructure

Item	Pilot	Current	Future
Number of Buses	Up to 11	Up to 53	Up to 82
Engineering and Permitting Costs	$35,000	$300,000	$150,000
Fueling Equipment Costs	$72,000	4,600,000	$2,150,000
Installation Costs		$180,000	$400,000
Storage Capacity Incremental Costs		$300,000	$300,000
TOTAL	***Mobile Fueler Annual Lease Cost ~ $72,000***	***$7,000,000***	***$3,000,000****
Cost Range (-20% to +30%)		***$5.6M – $9.1M***	***$2.4M – $3.9M***

The future $3,000,000 cost is the estimate to expand the fueling infrastructure to increase the facility to accommodate up to 82 vehicles in the future. It is understood that the current TMF does not have the capacity to park 82 vehicles.

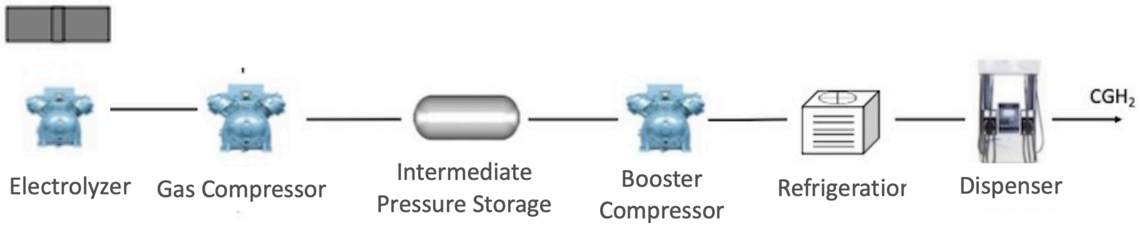
In addition to storage and fueling infrastructure, safety upgrades are required at the current storage and maintenance facility to accommodate hydrogen fueling. The current facility services CNG vehicles and upgrades are already planned as detailed in the Iconergy, LTD report dated March 29, 2021. As a result, the addition of hydrogen detection equipment is the primary additional safety requirement. Estimated costs to upgrade the facility for hydrogen detection equipment and the required ancillary support infrastructure, assuming all of the work to bring the current facility up to code for CNG operations, are included in **Table 32.**

Table 32 - Estimated Costs for Facility Upgrades to Support Hydrogen Fueling

Item	Units (EA)	Unit Cost ($)	Total Cost ($)
Hydrogen Sensors	24	3,000	72,000
Gas Detection commissioning	24	1,000	24,000
Programming of Gas Detection Panel	1	25,000	25,000
H2 Sensor Wiring	24	800	19,200
Building Finishes	1	2000	2,000
Indirect Costs – Mobilization, Demobilization, Supervision, Taxes (20% of equipment cost)	1	38,000	38,000
TOTAL			***$180,200***
Cost Range (-20% to +30%)			***$144,160 - $234,260***

As part of the hydrogen fueling analysis, on-site generation using electrolysis was modeled using the *Heavy-Duty Refueling Station Analysis Model* (HDRSAM) developed by Argonne National Laboratory. The model was used to estimate ROM costs associated with the use of electrolysis to generate sufficient hydrogen to fuel the Transfort fleet. A schematic of the process flow for the generating hydrogen for fuel supply through electrolysis is included in **Figure 19**.

Figure 19 - Electrolysis for Hydrogen Fuel Generation



The model was used to estimate the costs for the current fleet (53 vehicles) and future fleet (82 vehicles). Estimated costs are provided in **Table 33.**

Table 33 - Estimated Electrolysis Station Costs

Scenario	Capital Expense ($)	Total Refueling Cost ($/kg)
FCEB (Current)	$9.89 MM	$8.30
FCEB (Future)	$12.98 MM	$7.50

The costs are based on the infrastructure needs to support the fueling requirements for the fleet. The capital expense includes station design and engineering, permitting, construction, contingency, and all equipment including the electrolyzer and dispensing equipment. The Total Refueling Cost represents the operation, maintenance, and energy costs for the station on a per kilogram basis of hydrogen dispensed as well as the cost of the natural resources to produce the hydrogen (water). The estimated footprint of the electrolyzer would require between 5,800 and 6,900 square feet.

The total capital cost comparison between the evaluated ZEB transition scenarios for the current and future service is included in **Table 34** and **Table 35**, respectively.

Table 34 - Estimated Infrastructure Costs by Scenario (Current)

Scenario	% ZEB	Capital Cost (2021 $)
BEB Depot Only	39%	1,489,000
BEB Depot + On-Route	85%	5,956,400
Mixed Fleet*	85%	8,669,200
FCEB Only	85%	7,180,200

Table 35 - Estimated Infrastructure Costs by Scenario (Future)

Scenario	% ZEB	Capital Cost (2021 $)
BEB Depot Only	60%	6,452,000
BEB Depot + On-Route	92%	10,919,400
Mixed Fleet**	93%	13,632,200
FCEB Only	93%	10,180,200

The Mixed Fleet current scenario includes 21 depot-charged BEBs and 32 FCEBs while the Mixed Fleet future scenario includes 48 depot-charged BEBs and 34 FCEBs. The FCEB analysis assumes delivered hydrogen as the costs are currently lower than the cost for on-site generation through electrolysis. The analysis did not include costs to purchase and develop additional land for a new storage and maintenance facility although it is understood that the current facility is limited to a maximum of 53 vehicles. The costs are similar whether the work is completed at the current facility or a new facility other than potential costs associated with bringing in new electrical service.

Resilience and Redundancy

Electricity supply and energy resilience are important considerations for Transfort when transitioning to ZEBs. As a growing proportion of the fleet is electrified, the ability to provide service is dependent on access to reliable power. Climate change effects, such as more frequent extreme weather, coupled with growing demand pressures on the electric grid, is already affecting service reliability in some regions. These are motivating factors for Tranfort to consider on-site backup power.

There are three primary options to consider for backup power:
- On-site storage
- On-site generation (diesel, CNG)
- Redundant power feed

On-site storage

On-site storage option such as battery energy storage system (BESS) can provide backup in the case of loss of grid or local power supply to allow Transfort maintain partial or full service. However, energy storage system can be expensive if the storage requirement is high, which can be the case if the intent for the backup power is to support full service for a prolonged period. The storage capacity of the battery system also diminishes as the system ages. BESS has an added benefit in term of providing a buffer for intermittent supply from a renewable power source such as on-roof solar. Renewable energy options have the potential to lower operating costs but also can come with challenges such as intermittency.

A major goal of fleet electrification is reducing greenhouse gas (GHG) emissions. If charging energy is provided through connection to the local electrical grid, the GHG emissions reduction will be dependent on the carbon intensity of the energy mix feeding the grid. This is an added encouraging factor for considering on-site energy storage and renewable energy supply options supported by a local microgrid. Additionally, the system can be used to smooth out the load profile (peak shaving) to avoid peak demand charges and take advantage of time-of-use billing, resulting into significant operational cost savings.

On-site generation

On-site generation is a reliable option for prolonged outages. CNG and diesel generators are the most common equipment to support this application. They are widely used for backup power at industrial sites, factories, hospitals, hotels, airports, and many other places.

Diesel generators are typically cheaper to purchase and require less maintenance compared to the CNG generators. Diesel fuel is also typically stored on site which guarantees its availability during a power outage whereas CNG is typically supplied via gas line. Availability of continuous CNG supply is a major consideration while choosing this option. As CNG is already available at the current TMF, a backup CNG generator may be more feasible. CNG generators also provide significant environmental benefits over diesel generators as they are more efficient and produce lower GHGs. Regardless of the fuel type, the on-site generation system's advantage over on-site storage systems is its ability to provide continuous power for a prolonged period.

Redundant Power Feed

A third option would be to have redundant utility feed to the Transfort site(s). A redundant feed can be requested from the local utility to serve as a backup when there is an outage on the primary feed. Transfort’s current TMF is located immediately across the street from the utility substation which significantly reduces the probability of power outages. Transfort indicated that there has only been one minor outage at the current facility in the last five years. A redundant feed may be a preferable option at a new TMF that may not be located as close to a substation as the current facility.

Additional evaluation will be completed during Phase II of the ZEB Transition Study to align the strategy for resilience and redundancy with Transfort’s goals.

10 Total Cost Comparison

Capital Costs

The capital cost comparison includes the cost of replacing the current CNG vehicles with ZEBs based on block feasibility as well as the infrastructure costs to support the new fueling requirements. Estimated capital costs to support the current service and future service are included in **Table 36** and **Table 37**, respectively.

Table 36 - Capital Costs by Scenario (Current)

Scenario	% ZEB	Bus Capital Costs (2021 $)	Infrastructure Capital Cost (2021 $)	Total Capital Costs (2021 $)
BEB Depot Only	39%	42,500,000	1,489,000	43,989,000
BEB Depot + On-Route	85%	53,400,000	5,956,400	59,356,400
Mixed Fleet	85%	55,000,000	8,669,200	63,669,200
FCEB Only	85%	56,400,000	7,180,200	63,580,200

Table 37 - Capital Costs by Scenario (Future)

Scenario	% ZEB	Bus Capital Costs (2021 $)	Infrastructure Capital Cost (2021 $)	Total Capital Costs (2021 $)
BEB Depot Only	60%	74,400,000	6,452,000	80,852,00
BEB Depot + On-Route	92%	86,700,000	10,919,400	97,619,400
Mixed Fleet	93%	93,000,000	13,632,200	106,632,200
FCEB Only	93%	96,300,000	10,180,200	106,480,200

Operational Costs

The operational costs include the costs to fuel the vehicles as well as the maintenance costs to keep the vehicles serviced (including preventative maintenance and major services). These costs were estimated on a per mile basis for comparison as previously presented Section 7 and 8 of this report. Results for the Operational Cost analysis are for each scenario for current and future service are included in **Table 38** and **Table 39**, respectively.

Table 38 - Operational Costs by Scenario (Current)

Scenario	% ZEB	Fuel Cost ($)/Mile	Maintenance Cost ($) /Mile	Total Operational Cost ($)/Mile
BEB Depot Only	39%	0.45	0.40	0.85
BEB Depot + On-Route	85%	0.69	0.40	1.09
Mixed Fleet	85%	1.23	0.55	1.78
FCEB Only	85%	1.40	0.59	1.99

Table 39 - Operational Costs by Scenario (Future)

Scenario	% ZEB	Fuel Cost ($)/Mile	Maintenance Cost ($) /Mile	Total Operational Cost ($)/Mile
BEB Depot Only	60%	0.39	0.40	0.79
BEB Depot + On-Route	92%	0.54	0.40	0.94
Mixed Fleet	93%	0.99	0.49	1.48
FCEB Only	93%	1.40	0.59	1.99

Review of current operations indicates that the operational cost for CNG vehicles (including fuel and maintenance) is approximately $1.19/mile. By comparison, both the **BEB Depot Only and BEB Depot + On-Route options are estimated to be less expensive to operate on a per vehicle mile basis than CNG**, while the options including FCEB operations are more expensive. High FCEB operational costs are primarily impacted by the current cost for hydrogen fuel.

11 Emissions Analysis

A primary benefit of transitioning an entire fleet from fossil-fuel vehicles to zero-emission is the reduction of 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). 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 various classifications of 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*
- Transfort – data on existing fleet mileage and fuel economy

Net Carbon Emissions Reductions

There are three types of emissions generally referred to in the context of zero emission vehicle transportation: well-to-wheel (WTW) emissions, 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 energy used by the vehicle. WTW emissions are present for the generation of nearly all different fuels, be it diesel, gasoline, CNG, electricity, or hydrogen, 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 or green hydrogen).

Tailpipe emissions include all emissions generated by the vehicle during operation. It is assumed that BEBs 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.

These emissions are calculated using Argonne National Labs' AFLEET tool. Emissions for electricity production uses specific inputs based on the utility mix for the state of Colorado and estimated local upstream and vehicle emissions from the EPA to better estimate Transfort's impact.

The tables below show the estimated reduction of fuel quantity in diesel gallon equivalents (DGEs), the net GHG emissions reduction for each scenario compared to CNG buses, and the estimated annual equivalent vehicles removed from the road. Please note that all scenarios that utilize charging of BEBs at the depot assume use of a diesel fired auxiliary heater during the winter months at 5 gallons per day for each block operated for a period of 90 days. The emissions associated with the auxiliary heater are included in the emissions estimates. Hydrogen production is assumed to be completed off-site using steam methane reformation, as it is the primary method for industrial fuel production today, and transported to the site. The emission reduction would increase significantly if Transfort were able to produce hydrogen on-site using electrolysis and renewable energy or find a source of green hydrogen to be delivered. The emissions comparisons for each scenario compared to CNG operations for the current and future service are provided in **Table 40** and **Table 41**, respectively.

Table 40 - Emissions Estimates by Scenario (Current)

Scenario	% ZEB	Annual ZEB Mileage	DGEs Reduced	GHG Emissions Reduced (tons)	Equivalent Vehicles Removed from Road
BEB Depot Only	39%	399,884	96,790	909	180
BEB Depot + On-Route	85%	1,487,202	410,138	3,145	622
Mixed Fleet	85%	1,487,202	410,138	1,766	349
FCEB Only	85%	1,487,202	428,588	1,512	299

Table 41 - Emissions Estimates by Scenario (Future)

Scenario	% ZEB	Annual ZEB Mileage	DGEs Reduced	GHG Emissions Reduced (tons)	Equivalent Vehicles Removed from Road
BEB Depot Only	60%	1,626,903	450,398	3,699	732
BEB Depot + On-Route	92%	2,946,479	830,679	6,706	1,327
Mixed Fleet	93%	2,989,052	843,078	4,719	934
FCEB Only	93%	2,989,052	861,528	2,908	575

As expected, all of the scenarios that incorporate some level of ZEB operations reduce the WTW GHG emissions compared to CNG operations. The largest projected emissions reductions are associated with BEB Depot + On-Route charging for both the current and future operations.

Social Cost of Carbon

Externality costs of emissions can be quantified by their effect on agriculture, human health, property damage and other related factors. This estimate is widely known as the Social Cost of Carbon, or SCC. Using guidance developed by the Interagency Working Group on the Social Cost of Greenhouse Gases in the *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide* (United States Government, February 2021) for each ZEB scenario for the current and future service was calculated and provided in
Table *42* and **Table 43**.

Table 42 - Social Cost of Carbon by Scenario (Current)

Scenario	% ZEB	Annual ZEB Mileage	Carbon Savings from CNG (Metric Ton)	Savings (2021 $) @ $76/Metric Ton
BEB Depot Only	39%	399,884	660	50,138
BEB Depot + On-Route	85%	1,487,202	2,282	173,457
Mixed Fleet	85%	1,487,202	1,282	97,396
FCEB Only	85%	1,487,202	1,097	83,281

Table 43 - Social Cost of Carbon by Scenario (Future)

Scenario	% ZEB	Annual ZEB Mileage	Carbon Savings from CNG (Metric Ton)	Savings (2021 $) @ $76/Metric Ton
BEB Depot Only	60%	1,626,903	2,685	276,508
BEB Depot + On-Route	92%	2,946,479	4,702	484,318
Mixed Fleet	93%	2,989,052	3,425	352,725
FCEB Only	93%	2,989,052	2,110	217,364

12 Conclusions and Path Forward

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 replace internal combustion vehicles on a one for one basis. 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 a near operational equivalent to CNG, however, the incremental cost of buses, fueling infrastructure, and fuel places this technology at a serious disadvantage.

A review of the ZEB transition results indicates that BEB charging is more cost effective in the near term (current) and can meet the demands of a significant portion (estimated 39%) of Transfort's service. Based on the analysis conducted, Transfort is expected to be able to operate approximately 60% of the future blocks with depot-only BEB charging. As such, Transfort should consider building out the existing TMF to accommodate 100% depot charging to accommodate up to 53 vehicles in the future. If a new facility is constructed, the depot charging could be split to accommodate some level of charging (based on the location and routes/blocks). A new TMF would also be more preferred for development of hydrogen fueling capacity.

Transfort has already made the decision to purchase two depot-charged BEBs in 2021 with a third in 2022. In addition, Transfort has been awarded an FTA Low-No grant to deploy eight (8) additional BEBs. Phase II analysis should include a more detailed evaluation of on-route charging options and development of an Implementation Plan to continue to increase deployment and adoption of ZEBs in Transfort's fleet, with an initial focus on BEBs. Transfort should continue to monitor improvements in ZEB technology as the fleet may require BEBs and FCEBs to meet future operational requirements.

13 References

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Appendix A

Energy Requirements for On-Route Charging

Block Feasibility – CSU Layover

Block	Route(s)	On-Route Energy – Strenuous (kWh)	Energy Charged per Layover – Low (kWh)	Energy Charged per Layover – High (kWh)	Net Energy per Cycle – Low Charge	Net Energy per Cycle – High Charge
12	6	**35.8**	30.6	38.5	**-5.2**	2.7
13	2	**33.2**	48.1	60.5	14.9	27.3
22	7	**30.8**	48.1	60.5	17.3	29.7
25	702	**30.8**	48.1	60.5	17.3	29.7
27	32	**32.8**	39.4	49.5	6.6	16.7

Data presented is from Transfort block data

Block Feasibility – Downtown Layover

Block	Route(s)	On-Route Energy – Strenuous (kWh)	Energy Charged per Layover – Low (kWh)	Energy Charged per Layover – High (kWh)	Net Energy per Cycle – Low Charge	Net Energy per Cycle – High Charge
9	14-18-5	**82.6**	214.4	269.5	131.8	186.9
10	5-14-18	**82.6**	214.4	269.5	131.8	186.9
11	9-10	**32.6**	52.5	66.0	19.9	33.4
15	8	**25.7**	91.9	115.5	66.2	89.8
19	18-5-14	**82.6**	214.4	269.5	131.8	186.9
20	81	**25.9**	83.1	104.5	57.2	78.6

Data presented is from Transfort block data

Block Feasibility – South Layover

Block	Route(s)	On-Route Energy – Strenuous (kWh)	Energy Charged per Layover – Low (kWh)	Energy Charged per Layover – High (kWh)	Net Energy per Cycle – Low Charge	Net Energy per Cycle – High Charge
1	MAX-5	**42.0**	26.3	33.0	**-15.8**	**-9.0**
3	MAX-6	**42.0**	26.3	33.0	**-15.8**	**-9.0**
4	MAX-3	**42.0**	26.3	33.0	**-15.8**	**-9.0**
5	MAX-2	**42.0**	26.3	33.0	**-15.8**	**-9.0**
7	1602	**27.4**	87.5	110.0	60.1	82.6
14	16-11-12	**46.4**	118.1	148.5	71.7	102.1
18	11-12-16	**46.4**	118.1	148.5	71.7	102.1
21	MAX-4	**42.0**	26.3	33.0	**-15.8**	**-9.0**
28	19	**31.4**	35.0	44.0	3.6	12.6
36	MAX-1	**42.0**	26.3	33.0	**-15.8**	**-9.0**

Data presented is from Transfort block data

Appendix B

Conceptual Schematics for On-Route Charging Infrastructure

CSU Transit Center On-Route Charging

(1) 500 KVA transformer

(1) Outdoor Metal enclosed Power distribution switch board including METERING section.

(1) Outdoor Charging Cabinet.

location of pole and pantograph mount not shown

Measure distance
Click on the map to add to your path
Total area: 435.36 ft² (40.45 m²)
Total distance: 86.49 ft (26.36 m)

sketch drawn per scale using google maps measurement tool.

Location of charging equipment will require significant coordination with CSU (property owner)

South Transit Center On-Route Charging

(1) 1000 KVA transformer

(1) Outdoor Metal enclosed Power distribution switch board including METERING section.

(2) Outdoor Charging Cabinet.

location of pole and pantograph mount not shown

Measure distance

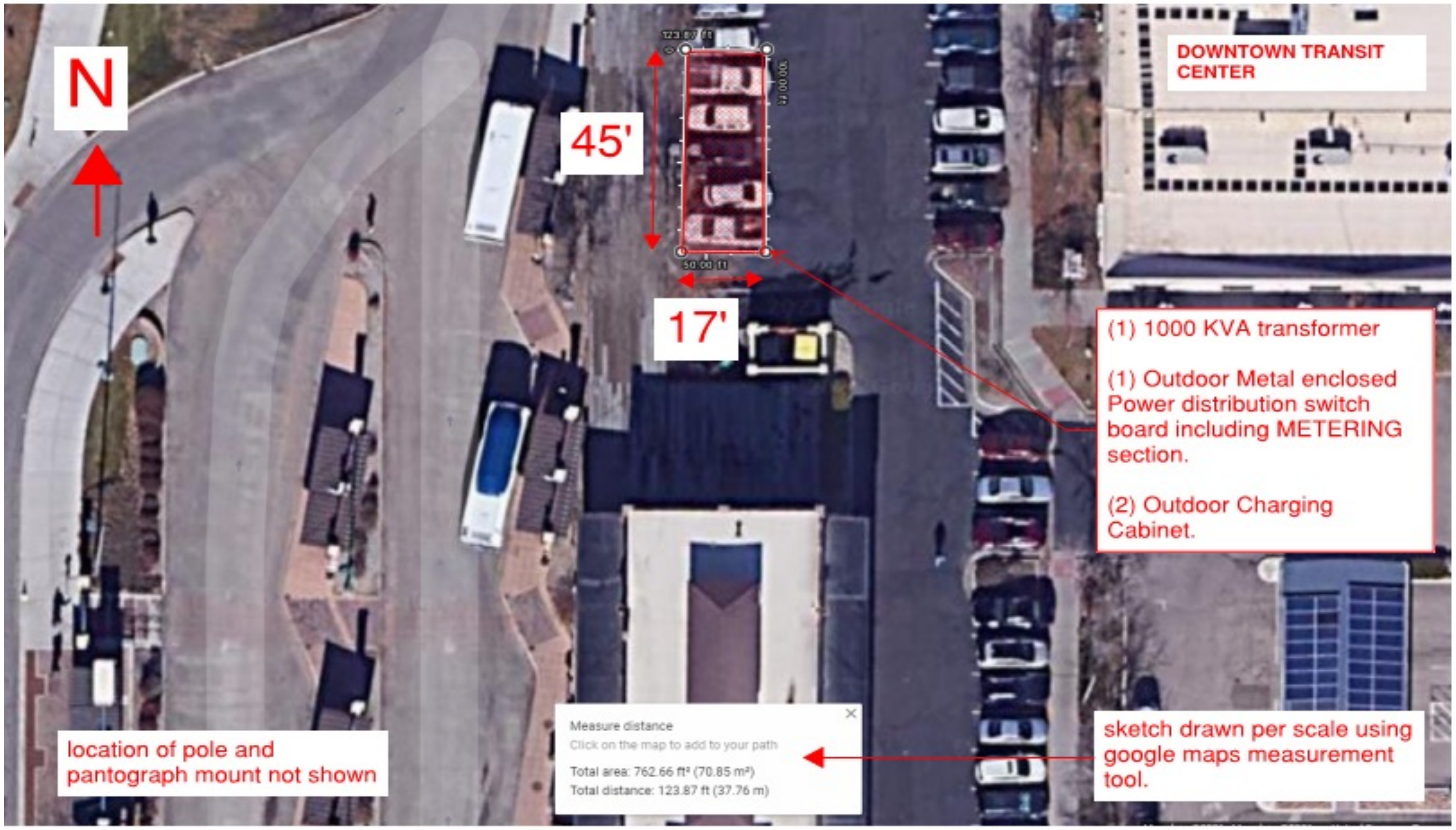
Click on the map to add to your path

Total area: 745.10 ft² (69.22 m²)

Total distance: 122.07 ft (37.21 m)

sketch drawn per scale using google maps measurement tool.

Downtown Transit Center – On-Route Charging



(1) 1000 KVA transformer

(1) Outdoor Metal enclosed Power distribution switch board including METERING section.

(2) Outdoor Charging Cabinet.

location of pole and pantograph mount not shown

Measure distance

Click on the map to add to your path

Total area: 762.66 ft² (70.85 m²)

Total distance: 123.87 ft (37.76 m)

sketch drawn per scale using google maps measurement tool.

- Potential issues with installation of charging equipment due to location in historical development area
- Location will cause loss of approximately 5-6 parking spaces
- Equipment could also be located on south side of building in current undeveloped green space