Zero-Emission Bus Fleet Transition Study

September 2020

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Executive Summary

MTS engaged the Center for Transportation and the Environment (CTE) to perform a zero-emission bus (ZEB) transition study in March 2018. The study's goal is to create a plan for a 100% zero-emission fleet by 2040 to be in compliance with the Innovative Clean Transit (ICT) regulation enacted by the California Air Resources Board (CARB). The results of the study will be used to inform MTS Board members and educate MTS staff of estimated costs, benefits, constraints, and risks to guide future planning and decision making. In addition to the ZEB transition study, MTS has initiated a pilot program to test ZEB technology in their service to better understand the technology and inform decision making. In 2019, MTS installed six (6) 62.5-kilowatt (kW) ChargePoint vehicle chargers at the Imperial Avenue Division (Imperial Ave) and deployed six (6) 40-foot New Flyer battery-electric buses (BEBs). In 2020, MTS installed an additional two (2) ChargePoint chargers each at South Bay Bus Maintenance Facility (South Bay), Kearny Mesa Division (Kearney Mesa), and the East County Bus Maintenance Facility (East County) to facilitate BEB pilot operations throughout the service area. Finally, two (2) 40-foot Gillig BEBs are scheduled for deployment in late 2020.

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

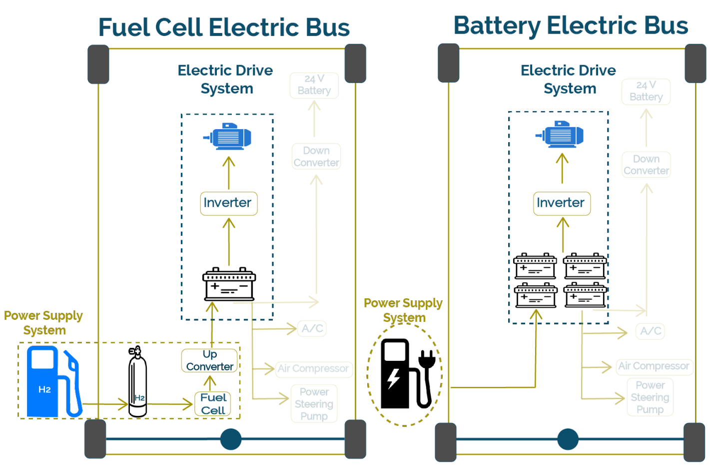


Figure ES-1 – Battery and Fuel Cell Bus Schematic

On December 14, 2018, CARB enacted the ICT regulation with a state wide goal, requiring all California public transit agencies to gradually transition to a 100 percent (%) zero-emission bus (ZEB) fleet. The ruling specifies the timeline for the required annual percentage of new bus procurements that must be zero-emission, starting with 25% of new bus purchases in 2023 and ramping up to 100% of new bus purchase in 2029. Following this schedule is intended to lead to a 100% zero-emission fleet in 2040. However, there are some waivers that allow for purchase deferrals in the event of economic hardships or if the technology has not matured to meet the service requirements of a given route. These concessions recognize that the technologies may cost more than current technologies on a life cycle basis and the technology may not currently meet all service requirements.

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

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

A primary assumption for the transition analysis is that MTS is unable to increase fleet size as a strategy to overcome BEB range limitations to achieve a 100% ZEB transition due to space constraints present at the current MTS depots. The Baseline scenario assumes that there are no changes to the current technology for bus procurements (e.g. compressed natural gas [CNG], gasoline, diesel, propane) 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.

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). The BEB Depot-Only Charging scenario meets the requirements of the CARB ICT regulation in that BEBs will be utilized for all service that meet the daily mileage requirements. The BEB Depot and On-Route Charging scenario was developed to mitigate the potential need for additional bus purchases when a one-for-one replacement with a depot-charged BEB was not possible. Finally, a Mixed BEB and FCEB scenario was developed with the underlying assumption that neither technology is suitable for 100% of the fleet replacement due to inherent constraints.

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

The underlying basis for the assessment is CTE's ZEB Transition Planning Methodology, which is a complete set of analyses used to inform agencies in converting their fleets to zero-emission that has been developed over the last decade. The methodology consists of data collection, analysis, and assessment stages; these stages are sequential and build upon findings in previous steps. The assessment allows CTE to develop engineering estimates for vehicle efficiency and energy consumption to project the range of given vehicle technologies in MTS service. CTE collected sample data from sixteen (16) MTS routes and used current ZEB specifications to estimate range and energy consumption on all MTS routes and blocks under varying environmental and passenger loading conditions. Once this information was established, CTE completed the following assessment to develop cost estimates for each transition scenario.

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

These assessments result in a total cost of ownership, inclusive of capital investments (ZEBs and fueling infrastructure) and operating expenses (fuel and maintenance) over the transition period (2019 – 2040) for each transition scenario. The table and figure below provide a side-by-side comparison of the cumulative transition costs for each scenario.

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

	Baseline	BEB Depot Only	BEB Depot + On Route	FCEB Only	Mixed BEB and FCEB
Fleet	$ 808,294,000	$ 1,086,465,000	$ 1,105,467,000	$ 1,355,484,000	$ 1,181,414,000
Fuel	$ 252,569,000	$ 298,234,000	$ 314,657,000	$ 462,731,000	$ 323,380,000
Infrastructure	-----	$ 120,305,000	$ 131,489,000	$ 73,394,000	$ 164,915,000
Maintenance	$ 762,263,000	$ 773,287,000	$ 782,339,000	$ 812,484,000	$ 804,691,000
Total	**$ 1,823,126,000**	**$ 2,278,291,000**	**$ 2,333,952,000**	**$ 2,704,093,000**	**$ 2,474,400,000**
Incremental Cost Over Baseline		**$ 455,165,000**	**$ 510,826,000**	**$ 880,967,000**	**$ 651,274,000**
% ZEB in 2040	**2%**	**77%**	**84%**	**95%**	**95%**

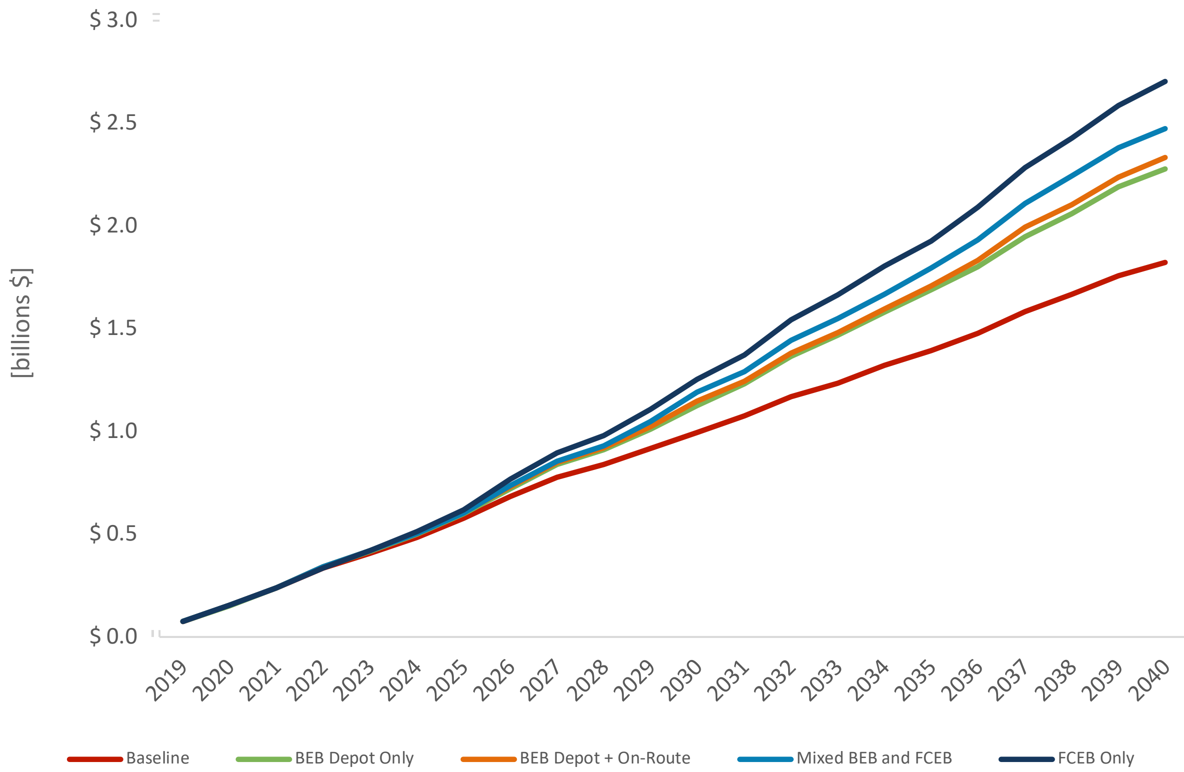


Figure ES-2 – Total Cost of Ownership, by Scenario

If MTS selects an all BEB strategy, incremental ZEB transition costs are likely to fall between approximately $455 million for the BEB Depot-Only Charging scenario, where approximately 77% of MTS' fleet is replaced with BEBs by 2040, to $511 million for the BEB Depot and On-Route Charging scenario, where approximately 84% of MTS' fleet is replaced with BEBs by 2040. The difference in incremental cost for these scenarios is a result of more vehicles being transitioned due to the use of on-route charging infrastructure, the incremental cost of the on-route charging infrastructure, as well as higher utility charges as a result of on-route charging because higher demand charges are incurred throughout the on-peak when on-route charging will occur. It should be noted that this analysis includes all vehicle lengths and types (40', 45', 60', and cutaways/minibus). While manufacturers have produced BEBs for each of the vehicle lengths and types used at MTS, only 40' and 60' BEBs have completed Altoona testing and are applicable under the CARB ICT regulation. The BEB Depot-Only Charging scenario meets the CARB ICT regulation requirements assuming a waiver for depot-charged technology that does not meet service requirements is granted as is clearly detailed in the rule.

If MTS selects an FCEB Only strategy, incremental ZEB transitional costs are estimated at approximately $881 million for replacement of approximately 95% of the fleet with FCEBs by 2040. The remaining 5% would be replaced during the next vehicle replacement cycle after 2040, as it is anticipated that by 2040, FCEB technology will have advanced such that all MTS service could be completed using FCEBs. A primary assumption for the FCEB analysis is that FCEB vehicles will be available for all vehicle types and lengths during the transition period. Currently, FCEBs have only been produced in 40' and 60' models. In addition, due to the limited deployment of FCEBs in service in the United States, FCEB and hydrogen fuel costs remain high. These costs are expected to come down in the future as more vehicles are deployed and as hydrogen production ramps up; however, there is currently no basis for assuming future cost reductions. Also, the current experience with FCEB maintenance cost is high due to the fact that much of the data is based on older vehicles that are no longer under warranty and require the support of a European company. As such, there are more unknowns associated with the incremental costs for the FCEB scenarios, and costs are likely to be more subject to change. It is expected that the cost of the FCEB Only and Mixed Fleet scenarios will come down if a larger number of vehicles and infrastructure are sold within the U.S., but the extent is still unknown. Significant investments in hydrogen production and distribution infrastructure is required and will take years to develop to gain a better understanding of the long-term costs for FCEB Only deployment.

As expected, with an incremental cost of approximately $651 million, the Mixed BEB and FCEB scenario that transitions approximately 95% of MTS' fleet to ZEB by 2040, has an incremental cost that falls between an all BEB and all FCEB deployment. Though the costs are considerably cheaper for a mixed fleet deployment than FCEB Only, there are expected to be complexities with managing the fleet through the transition that would require maintaining existing internal combustion engine vehicle infrastructure (CNG, propane, and gasoline), installing new BEB infrastructure, and installing new FCEB fueling infrastructure. Space constraints at the depot will require careful planning if this path is selected.

MTS may accumulate ZEB credits from their procurement of ZEBs prior to 2023. These credits can be used in place of ZEB purchases to satisfy CARB's ZEB procurement requirements beginning in 2023. With the purchase of eight (8) BEBs to support the ZEB pilot operations in 2019 and 2020, and the purchase of twelve (12) BEBs to support a new service in 2022, MTS will have nineteen (19) ZEB credits that can be applied to ZEB purchase requirements in 2023 and beyond. The use of these ZEB credits is not considered in the analysis of the transition scenarios.

As a result, recommendations for MTS are as follows:

1. **Remain proactive with ZEB deployments:** MTS has been proactive in the purchase and deployment of BEBs through their ZEB Pilot Program. Significantly more development, data collection, and analyses are needed before the technology is ready for fleetwide deployment. For example, BEBs will require charge management software, hardware, and standards to manage the fleetwide transition. For FCEB deployment to be competitive, lower fuel costs that will evolve over time with the production of hydrogen at scale is required. MTS should move forward carefully, taking advantage of various grant and incentive programs to offset the incremental cost for ZEB deployment. Incentive programs may be eliminated in future years as ZEB procurements are required instead of being optional.
2. **Target specific routes and blocks for early ZEB deployments:** MTS should consider the strengths of given ZEB technologies and focus those technologies on routes and blocks that take advantage of their efficiencies and minimizes the impact of the constraints related to the respective technologies. For example, depot-charged BEBs for shorter

routes and blocks, on-route charged BEBs for mid-range routes with layovers at a transit center, and FCEBs for long routes or routes with higher speeds and/or heavier loads. These technologies cannot follow a "one-size-fits-all" approach from either a performance or cost perspective. Matching the technology to the service will be a critical best practice. Results from the ZEB Pilot Program will help to inform these decisions.

3. **Continue with BEBs and consider FCEBs:** At this stage, it is too early to tell which technology will dominate the market 10 to 20 years from now. Having capability to deploy both ZEB technologies creates an opportunity for MTS to fully assess BEBs and FCEBs to determine which technology can best meet the operational range requirements while being financially efficient and sustainable.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. The technology requires significant development before it is ready to support fleetwide transitions. However, it is only through a continual process of deployment with specific goals for advancement that the industry can achieve the goal of economically sustainable, zero-emission public transit. Ultimately, the ZEB technology that is most efficient and sustainable to operate will evolve into either the majority ZEB solution or the only ZEB solution. MTS, with endorsement and approval from their Board of Directors, has elected to pursue a mixed use scenario that will allow them to initially deploy BEBs and explore possible opportunities and funding mechanisms to deploy FCEBs in service where BEBs are not able to meet range requirements. MTS will continue to monitor technology improvements and funding availability to accelerate the transition to a 100% zero-emission fleet. Evaluation will be completed in annual updates provided to the MTS Board of Directors and CARB.

Introduction

Founded in 1975, the San Diego Metropolitan Transit System (MTS) provides bus and light rail services to the urban areas of San Diego County and rural parts of East County, generating over 92 million passenger trips per year.

MTS engaged the Center for Transportation and the Environment (CTE) to perform a zero-emission bus (ZEB) transition study in March 2018. The study's goal is to create a plan for a 100% zero-emission fleet by 2040 to be in compliance with the Innovative Clean Transit regulation enacted by California Air Resources Board (CARB). The results of the study will be used to inform MTS Board members and educate MTS staff of estimated costs, benefits, constraints, and risks to guide future planning and decision making. In addition to the ZEB transition study, MTS has initiated a pilot program to test ZEB technology in their service to better understand the technology and inform decision making. In 2019, MTS installed six (6) 62.5-kilowatt (kW) ChargePoint vehicle chargers at the Imperial Avenue Division (Imperial Ave) and deployed six (6) 40-foot New Flyer battery-electric buses (BEBs). In 2020, MTS installed an additional two (2) ChargePoint chargers each at South Bay Bus Maintenance Facility (South Bay), Kearny Mesa Division (Kearney Mesa), and the East County Bus Maintenance Facility (East County) to facilitate BEB pilot operations throughout the service area. Finally, two (2) 40-foot Gillig BEBs are scheduled for deployment in late 2020.

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

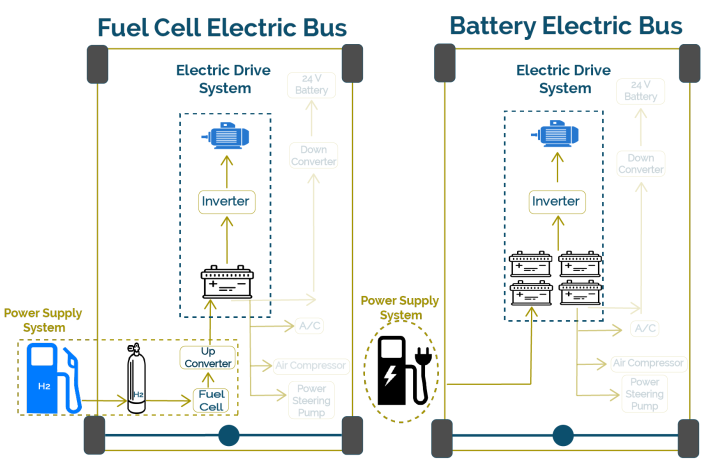


Figure 1 - Battery and Fuel Cell Electric Bus Schematic

CARB's Innovative Clean Transit Regulation

On December 14, 2018, CARB enacted the Innovative Clean Transit (ICT) regulation requiring all California public transit agencies with the state wide goal to gradually transition to a 100% ZEB fleet. The ruling specifies the timeline for the required annual percentage of new bus procurements that must be zero-emission, starting with 25% of new bus purchases in 2023 and ramping up to 100% of new bus purchase in 2029. This section summarizes key elements of the ICT.

ZEB Purchase Requirements

MTS' fleet exceeds 100 buses and, as such, is considered a "large" agency by CARB. All new bus purchases must include a specified percentage of ZEBs in accordance with the following schedule:

Table 1 – CARB Innovative Clean Transit (ICT) ZEB Transition Timeline.

Starting January 1	Percent of New Bus Purchases	Purchase Discharge Criteria
2023	25%	If 850 ZEBs by 12/31/2020
2024	25%	If 1250 ZEBs by 12/31/2020
2025	25%	-
2026	50%	-
2027	50%	-
2028	50%	-
2029	100%	-

New bus purchase requirements may be set-aside in 2023 and 2024 if a minimum number of buses are purchased in each respective year across all transit agencies in California. Purchase of cutaway/minibus, over-the-road, double-decker, or articulated buses may be deferred until the latter of either January 1, 2026 or until a model of a given type has passed the "Altoona" bus testing procedure and obtained a Bus Testing Report. As of the date of this report, only heavy-duty 30', 35', 40' and 60' ZEBs have passed Altoona bus testing.

ZEB Bonus Credits

Agencies may earn ZEB Bonus Credits for early acquisition that may be used against future compliance requirements. To earn bonus credits, ZEBs must be placed into service according to the following schedule. Bonus credits expire December 31, 2028.

Table 2 - ZEB Bonus Credits Applied to CARB ICT Transition Schedule

Technology	Placed in Service	ZEB Bonus Credit
BEB	As of January 1, 2018	1
FCEB	As of January 1, 2018	2
FCEB	January 1, 2018 to December 31, 2022	1

ZEB Credits

Although MTS is not expected to have ZEB Bonus Credits to utilize toward compliance, ZEBs purchased in advance of the new purchase requirements may be used as credits toward annual ZEB procurement compliance. As such, BEBs purchased in 2019 (6), 2020 (2), and planned for 2022 (12) represents nineteen (19) ZEB credits that may be applied toward purchase compliance with the ICT regulation in the early years of the transition.

ZEB Rollout Plan

MTS is required to submit a ZEB Rollout Plan that has been approved by their governing board by December 31, 2020. ZEB Rollout Plans must include all of the following components:

- A goal of full transition to ZEBs by 2040 with careful planning that avoids early retirement of conventional internal combustion engine buses;
- Identification of the types of ZEB technologies a transit agency is planning to deploy, such as BEBs and FCEBs;
- A schedule for construction of facilities and infrastructure modifications or upgrades, including charging, fueling, and maintenance facilities, to deploy and maintain ZEBs. This schedule must specify the general location of each facility, type of infrastructure, service capacity of an infrastructure, and a timeline for construction;
- A schedule for zero-emission and conventional internal combustion engine buses purchases and lease options. This schedule for bus purchases replacements must identify the bus types, fuel types, and number of buses;
- A schedule for conversion of conventional internal combustion engine buses to ZEBs, if any. This schedule for bus conversion must identify number of buses, bus types, the propulsion systems being removed and converted to;
- A description on how a transit agency plans to deploy ZEBs in disadvantaged communities as listed in the latest version of CalEnviroScreen at the time of the Rollout Plan is submitted;
- A training plan and schedule for ZEB operators and maintenance and repair staff; and
- Identification of potential funding sources.

A copy of the ZEB Rollout Plan is included in **Appendix A**.

Exemptions

Agencies may request exemption from ZEB purchase requirements in a given year due to circumstances beyond the transit agency's control. Acceptable circumstances include:

- Delay in bus delivery is caused by setback of construction schedule of infrastructure needed for the ZEB.
- Available depot-charged BEBs cannot meet a transit agency's daily mileage needs.
- Available ZEBs do not have adequate gradeability performance to meet the transit agency's daily needs
- When a required ZEB type for the applicable weight class based on gross vehicle weight rating (GVWR) is unavailable for purchase because the ZEB has not passed Altoona,

cannot meet ADA requirements, or would violate any federal, state, or local regulations or ordinances.

- When a required ZEB type cannot be purchased by a transit agency due to financial hardship and the agency can demonstrate that they have applied for applicable ZEB funding mechanisms.

Reporting Requirements

Starting March 31, 2021, and continuing every year thereafter through March 31, 2050, each transit agency must submit an annual ICT ZEB compliance report by March 31 for the prior calendar year. The initial report must be submitted by March 31, 2021, and must include the number and information of active buses in the transit agency's fleet as of December 31, 2017.

ZEB Transition Planning

ZEB Transition Planning Methodology

This study uses CTE's ZEB Transition Planning Methodology, which is a complete set of analyses used to inform agencies in converting their fleets to zero-emission that has been developed over the last decade. The methodology consists of data collection, analysis and assessment stages; these stages are sequential and build upon findings in previous steps. The work steps specific to this study are outlined below:

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

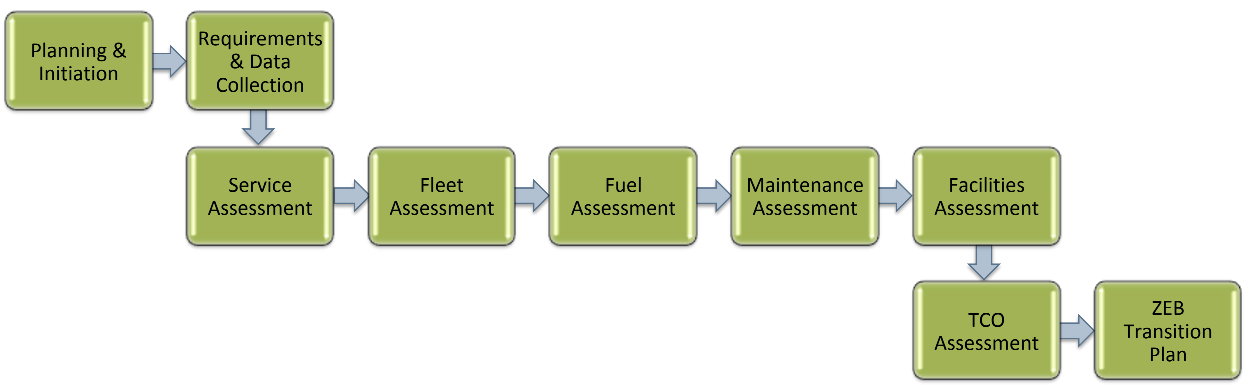


Figure 2 – CTE's ZEB Transition Study Methodology

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 MTS staff to plan the overall project scope and all deliverables throughout the full life of the study. CTE conducted an "Assumptions Workshop" to start the ***Requirements & Data Collection*** phase. The assumptions collected during this phase provide key parameters used in each of the Assessment phases that follow. CTE collected fleet, operational, maintenance, and facilities information to define the "As Is" or baseline scenario. CTE also collected route and block mileage and duty cycle information as the basis for the Service Assessment.

During the ***Service Assessment***, CTE worked with MTS staff to assess how MTS fleet vehicles are used and to identify service requirements. CTE leverages several different tools and methods, including route modeling and simulation software, and empirically-derived screening models based on real world operational data, to calculate expected energy efficiency, range, endurance, and energy consumption to identify any limitations or constraints to the application of electric vehicle technologies. Results from modeling were used to estimate achievability of every block in MTS' network using BEBs and FCEBs. The results from the Service Assessment were used to guide ZEB procurements in the Fleet Assessment and determine energy requirements (Depot Charging, On-Route Charging, and/or Hydrogen) in the Fuel Assessment.

The **Fleet Assessment** develops a projected timeline for replacement of current buses with ZEBs that is consistent with the agency's Fiscal Year 2019 fleet replacement plan. Multiple projection scenarios are created utilizing different combinations of ZEB technologies. This assessment also includes a projection of fleet capital cost over the transition lifetime and it can be optimized with regard to any state mandates, like CARB's ICT regulation, or to meet agency goals such as minimizing cost or maximizing service levels.

The **Fuel Assessment** merges the results of the Service Assessment and Fleet Assessment to determine annual fuel requirements and associated costs. The Fuel Assessment calculates energy costs through the full life of the transition for each scenario, including the agency's current internal combustion engine vehicles. To more accurately estimate BEB charging costs, a focused Charging Analysis is performed to simulate daily system-wide charging use. As current technologies are phased out in later years of the transition, the Fuel Assessment calculates the increasing energy requirements for ZEBs. The Fuel Assessment also provides a total energy cost over the transition lifetime.

The **Facilities Assessment** determines the necessary infrastructure to support the projected zero-emission fleet based on results from the Fleet Assessment and Fuel Assessment. The Facilities Assessment is calculated for each scenario used in the Fleet and Fuel Assessments. The result shows quantities of hydrogen and battery electric infrastructure and calculates associated costs.

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

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

Assessment 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 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 Baseline scenario assumes that there are no changes to the current technology for bus procurements (e.g. compressed natural gas [CNG], gasoline, diesel, propane) and is used for comparison to the other ZEB transition scenarios. The Baseline scenario includes the scheduled BEB purchases from 2019 to 2022 as previously discussed. 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). The BEB Depot-Only Charging scenario meets the requirements of the CARB ICT regulation in that BEBs will be utilized for all service that meet the daily mileage requirements on an single charge.

MTS is unable to increase fleet size to accommodate fleet expansion potentially needed to support a 100% ZEB transition due to space constraints present at the current depots. As a result, 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 MTS, and are as follows:

- Transition to a 100% ZEB fleet by 2040 to comply with the CARB ICT regulation
- No change in fleet size throughout the study period except for the addition of two (2) additional BEBs in 2020 support the ZEB Pilot Program and up to twelve (12) articulated vehicles to support service expansion from South Bay in 2022; the initial pilot buses (6) and buses scheduled for purchase in 2021 were used for vehicle replacement and did not add to the fleet size.
- Due to space constraints at the MTS depots, it is not feasible to increase fleet size to support ZEB deployment. Costs for a new depot, estimated at $185 million are not included in the analysis.
- Current fleet composition (Fiscal Year 2019 Fleet Plan) used for the baseline scenario
- Current planned fleet replacement cycles
- 12-year bus lifespan assumed for future heavy duty transit buses
- 7-year lifespan for cutaway vehicles
- Costs expressed in 2019 dollars with no escalation
- Current battery sizes for BEBs and fuel tank sizes for FCEBs are based on existing specifications for vehicles that have completed Altoona testing

- A 5% improvement in battery capacity (for BEB) and efficiency (FCEB) every two years
- A battery replacement with occur at the mid-life of each heavy-duty transit BEB (6 years)
- A battery replacement and fuel-cell overhaul will occur at the mid-life of each heavy-duty transit FCEB (6 years)

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 resiliency 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.

Requirements Analysis

Baseline Data Collection

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

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

Fleet

At the time of the study, the MTS bus fleet totaled 823 vehicles that provide service on nearly 105 fixed routes with additional, complementary, on-demand paratransit service. A breakdown of size and fuel type is shown in **Table 3** and **Table 4**. Bus services operate out of five divisions, all of which include operations, maintenance and fueling functions: Imperial Avenue Division (Imperial Ave), Kearney Mesa Division (Kearney Mesa); South Bay Bus Maintenance Facility (South Bay); East County Bus Maintenance Facility (East County); and Copley Park Maintenance Facility (Copley). MTS' fixed route mini buses and on-demand paratransit buses operate from Copley.

Table 3 - Fleet Breakdown by Division and Length

Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	215	0	0	0	**215**
East County	3	51	24	0	**78**
Kearny Mesa	0	85	0	42	**127**
Imperial Ave	0	111	0	44	**155**
South Bay	0	221	0	27	**248**
Totals	**218**	**468**	**24**	**113**	**823**

Table 4 - Fleet Breakdown by Division and Fuel Type

Division	Fuel Type					Totals
	CNG	Diesel	Propane	Gasoline	Electric	
Copley	0	0	77	138	0	**215**
East County	51	24	0	3	0	**78**
Kearny Mesa	127	0	0	0	0	**127**
Imperial Ave	149	0	0	0	6	**155**
South Bay	248	0	0	0	0	**248**
Totals	**575**	**24**	**77**	**141**	**6**	**823**

Routes and Blocks

MTS’ current service consists of 105 routes run on 1189 blocks as detailed in **Table 5**.

Table 5 - Count of Blocks by Division and Bus Length

Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	183	0	0	0	**183**
East County	6	71	33	0	**110**
Kearny Mesa	0	168	0	59	**227**
Imperial Ave	0	189	0	105	**294**
South Bay	19	344	0	12	**375**
Totals	**208**	**772**	**33**	**176**	**1189**

Fuel

MTS’ current fuel use was collected and used to estimate energy costs throughout the study period. Cost escalation is not assumed throughout the study. Annual fleet mileage and fuel use is shown in **Table 6**, **Table 7**, and **Table 8**.

Table 6 - Annual Service Miles by Division and Bus Length

Division	Bus Length [ft]				Totals
	22, 29, 32	40	45	60	
Copley	7,317,895	-	-	-	**7,317,895**
East County	35,724	1,696,686	797,770	-	**2,530,180**
Kearny Mesa	-	3,347,629	-	2,394,070	**5,741,699**
Imperial Ave	-	4,221,607	-	1,639,506	**5,861,113**
South Bay	-	8,834,534	-	835,484	**9,670,018**
Totals	**7,353,619**	**18,100,456**	**797,770**	**4,869,060**	**31,120,905**

Table 7 - Annual Diesel, Gasoline, and Propane Fuel Consumption by Division and Bus Length [DGE]

Division	Bus Length [ft]				Totals [DGE]
	22, 29, 32	40	45	60	
Copley	1,341,232	-	-	-	**1,341,232**
East County	4,401	-	-	-	**4,401**
Kearny Mesa	-	-	-	-	**-**
Imperial Ave	-	-	-	-	**-**
South Bay	-	-	-	-	**-**
Totals [DGE]	**1,345,633**				**1,345,633**

Table 8 - Annual CNG Fuel Consumption by Division and Bus Length [Therms]

Division	Bus Length [ft]				Totals [Therms]
	22, 29, 32	40	45	60	
Copley	-	-	-	-	**-**
East County	-	683,935	-	-	**683,935**
Kearny Mesa	-	1,438,836	-	1,011,100	**2,449,936**
Imperial Ave	-	1,756,221	-	986,864	**2,743,085**
South Bay	-	3,887,292	-	139,509	**4,026,801**
Totals [Therms]		**7,766,283**		**2,137,473**	**9,903,756**

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 MTS' system to complete the assessment.

The first task in the Service Assessment is to develop route and bus models to run operating simulations for representative MTS routes. CTE uses Autonomie, a powertrain simulation software program developed by Argonne National Labs for the heavy-duty trucking and automotive industry. CTE has modified software parameters specifically for electric buses to assess energy efficiencies, energy consumption, and range projections. CTE collected GPS data from sixteen (16) MTS routes. GPS data includes time, distance, vehicle speed, vehicle acceleration, GPS coordinates, and roadway grade that is used to develop the route model. CTE used component level specifications and the collected route data to develop a baseline performance model by simulating the operation of an electric bus on each route. Ideally it would be best to collect data and model every route in MTS' network; however, this is impractical due to the amount of time and labor this approach would require. Instead, a sampling approach is used where sample routes are identified with respect to topography and operating profile (e.g. average speeds, etc.). The modeling results of the sample routes are then applied to the routes and blocks that share the same characteristics. Routes selected for the analysis are included in **Table 9** below.

Table 9 - Selected Routes for Modeling

Division	Hills/ Low Speed	Hills/High Speed	Flat/Low Speed	Flat/High Speed	Count
Copley		838	84		**2**
East County	936	280	815	864	**4**
Kearny Mesa			237	120	**2**
Imperial Ave	2,10,13		7		**4**
South Bay	3	235	1	905	**4**
Count	**5**	**3**	**5**	**3**	**16**

The route modeling included analysis of several scenarios, varying passenger load, accessory load, and battery degradation, to estimate real-world vehicle performance, fuel efficiency, and range. The data from the routes, as well as the specifications for each of the bus types selected, was used to simulate operation of each type of bus on each type of route. The models were run with varying loads to represent "nominal" and "strenuous" loading conditions. Nominal loading conditions assume average passenger loads and moderate temperature over the course of the day, which places marginal demands on the motor and heating, ventilation, and air 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). Modeled operating scenarios are included in **Table 10** below.

Table 10 - Modeled Operating Scenarios

Bus Length [ft]	Load Case	Occupants	HVAC Load [kW]	Other Loads [kW]	Total Aux Load [kW]
22-32	Nominal	5	4	2	**6**
22-32	Strenuous	15	12	2	**14**
40	Nominal	9	3	2	**5**
40	Strenuous	39	10	2	**12**
45	Nominal	20	4.5	2	**6.5**
45	Strenuous	40	10	2	**12**
60	Nominal	10	5	3	**8**
60	Strenuous	55	15	3	**18**

Route modeling ultimately provides an average energy use per mile (kilowatt-hour/mile [kWh/mi]) associated with each route, bus size and load case. Using the results shown in **Table 11**, system-wide energy use, and costs, are estimated in the subsequent assessments.

Table 11 - Modeling Results Summary

Bus Length [ft]	Route	Nominal Efficiency [kWh/mi]	Strenuous Efficiency [kWh/mi]
40	1	1.9	2.8
	2	2.0	2.9
	3	2.1	3.1
	10	1.9	2.8
	13	1.8	2.6
	120	1.9	2.7
	237	2.1	2.7
	815	1.9	2.9
	864	1.8	2.7
	905	2.0	2.6
	936	2.0	2.9
45	280	2.7	3.0
60	7	3.2	4.5
	235	2.9	3.5
	905	2.8	3.6
22-32	84	1.4	2.1

Using vehicle performance predicted from route modeling, combined with educated assumptions for battery electric and fuel cell technology, CTE analyzed the expected performance and range needed on every block in MTS' network and assessed the "achievability" of each block by BEBs and FCEBs over time, as range improves. This assessment analyzes the feasibility of maintaining the MTS' current level of service with BEB and FCEB vehicles and does not plan for any expansions. The analysis focuses on bus endurance and range limitations to determine if the ZEBs could meet the service requirements of the blocks throughout the transition period. The energy needed to complete a block is compared to the available energy for the respective bus type that is planned for the block to determine if a BEB or FCEB can successfully operate on that block. This assessment also determines a timeline for when blocks become for eligible for zero-emission vehicles as technology improves. This information is used to then inform ZEB procurements in the Fleet Assessment.

Research suggests that battery density for electric vehicles has improved by an average of 5% each year.[1] For the purposes of this study, considering the extended period of a complete fleet transition (e.g. through 2040), CTE assumes a more conservative 5% improvement every two years. If the trend continues, it is expected that buses may continue to improve their ability to carry more energy without a weight penalty or reduction in passenger capacity. Over time, BEBs are expected to approach the capability to replace all of an agency's internal combustion engine buses one-for-one. FCEBs do not have the same range constraints as BEBs. Typically, FCEBs can more readily serve an agency's current blocks on a one-to-one basis with internal combustion engine buses; however, costs of hydrogen fuel and bus capital costs can create higher barriers to entry. There is also a significant amount of research going towards fuel cell technologies. We assume 5% bi-annual improvement in hydrogen tank size as a proxy for other component improvements such as battery capacity, motor efficiency, fuel cell efficiency, etc.

The block analysis, with the assumption of 5% improvement in battery capacity or improvement in hydrogen storage capacity every other year, is used to determine the timeline for when routes and blocks become achievable for BEBs and FCEBs, respectively, to replace internal combustion engine buses one-for-one. This information is used to then inform ZEB procurements in the Fleet Assessment. The results from the block analysis are used to 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.

Results from the block analysis that indicate the yearly block achievability by bus length throughout the transition period for BEBs and FCEBs are included in **Figure 3** and **Figure 4** below, respectively.

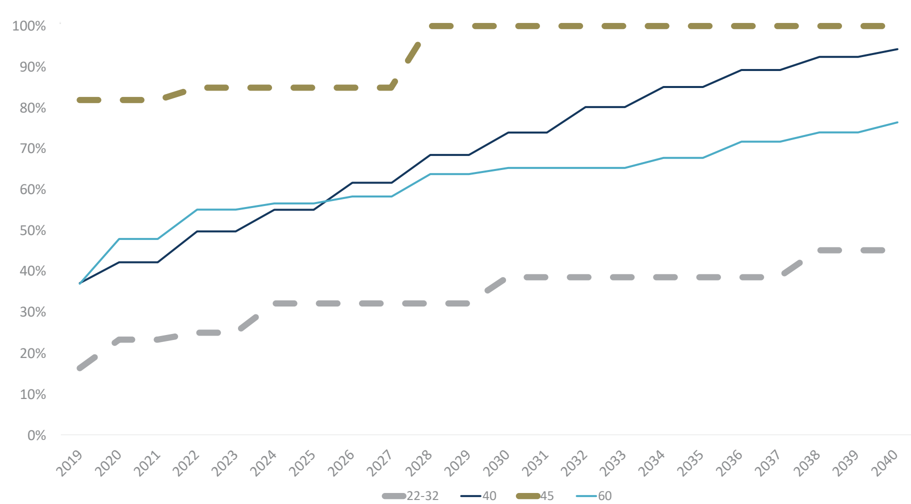


Figure 3 – BEB Block Achievability Percentage by Length

[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

The BEB achievability in **Figure 3** shows that by 2040, it is expected that nearly all 40’ and 45’ MTS blocks can be completed by BEBs. However, in 2040, 60’ and cutaway blocks (22’-32’) struggle, with only approximately 76% and 45% able to be completed by BEBs, respectively. Please note that the dashed lines indicate that, at the time of the study, there are no 45’or cutaway BEBs available on the market that have completed Altoona testing and the timeline for these to be available is uncertain.

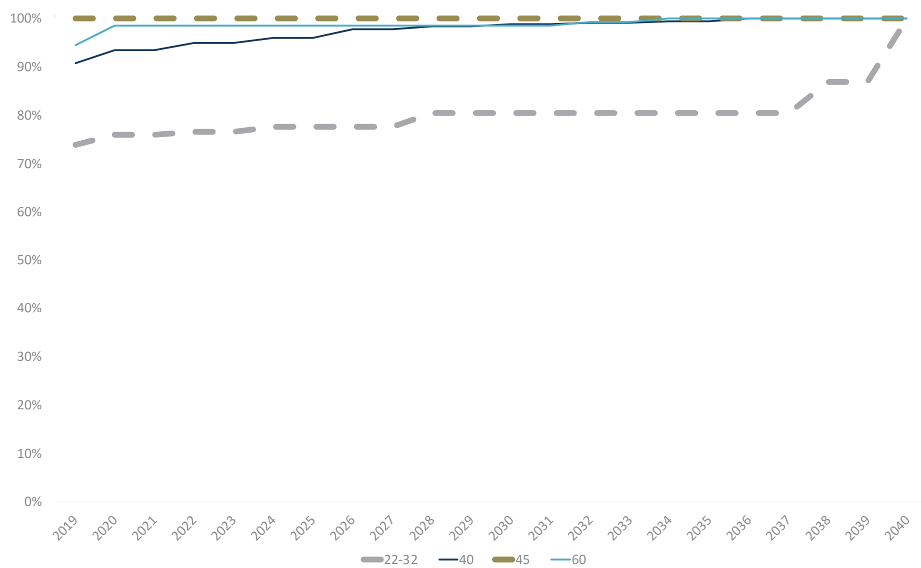


Figure 4 – FCEB Block Achievability Percentage by Bus Length

The FCEB achievability in **Figure 4** shows that by 2040, it is expected that 100% of MTS blocks can be completed by FCEBs. It is predicted that with the exception of cutaway buses (22’-32’), all other FCEB sizes can complete 90% or greater of MTS blocks starting in 2020. Please note that the dashed lines indicate that, at the time of the study, there are no 45’or cutaway BEBs available on the market that have completed Altoona testing and the timeline for these to be available is uncertain.

While routes and block schedules are unlikely to remain the same over the course of the transition period, these projections assume the blocks will retain a similar structure to what is in place today. 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.

It should be noted that BEB range is negatively impacted by battery degradation over time. A BEB may be placed in service on a given block with beginning-of-life batteries; however, it may not be able to complete the entire block at some point in the future before the batteries at are end-of-life (typically considered 80% of available service energy). Conceptually, older buses can be moved to shorter, less demanding blocks and newer buses can be assigned to longer, more demanding blocks. MTS can rotate the fleet to meet the demand assuming there is a steady procurement of BEBs each year to match service requirements. This could also be said for FCEBs, although the impact of degradation is assumed to be less.

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 the fleet to zero-emissions. Results from the Service Assessment are integrated with MTS' current fleet replacement plan and purchase schedule to produce two main outputs: a projected bus replacement timeline through the end of the projection period, and the associated total capital costs.

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

Cost Assumptions

CTE and MTS developed cost assumptions for this analysis for each bus length and technology type (e.g. CNG, gasoline, propane, BEB, FCEB). Key assumptions for bus costs for the MTS Transition Study are as follows:

- Bus costs are based on MTS procurements, industry quotes, and the State of California statewide procurement contract for BEBs and FCEBs executed in 2019
- Bus costs are inclusive of configurable options and taxes (7.75%)
- Bus costs are estimated where buses of a given configuration are not commercially available or where no quotes were available
- Future bus costs are based on year 2019 since the 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. Note that there is a program under development, known as the 100-Bus Fuel Cell Electric Bus Initiative, where multiple vendors have committed to a base price of $850k for a 40-foot FCEB based on a minimum bus order of 100 vehicles; however, the future of this initiative is uncertain. **Table 12** provides estimated bus costs used in the analysis.

Table 12 - Fleet Assessment Cost Assumptions

Length [ft]	CNG	Diesel	Gasoline	Propane	Electric	Hydrogen
22' Cutaway	-	-	$80,000	$110,000	$250,000	*$375,000*
29' Cutaway	-	-	$150,000	-	*$325,000*	*$487,000*
32' Cutaway	-	-	-	$177,000	*$325,000*	*$487,500*
40'	$549,962	-	-	-	$964,144	$1,147,515
45'	$800,000	$700,000	-	-	*$950,000*	*$1,400,000*
60'	$1,003,365	-	-	-	$1,374,333	$1,631,264

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

Baseline

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

Figure 5 presents the number of each bus type that is purchased each year to maintain MTS' current fleet composition through 2040. The number of buses purchased each year is based on the vehicle replacement schedule (Fiscal Year 2019) provided by MTS.

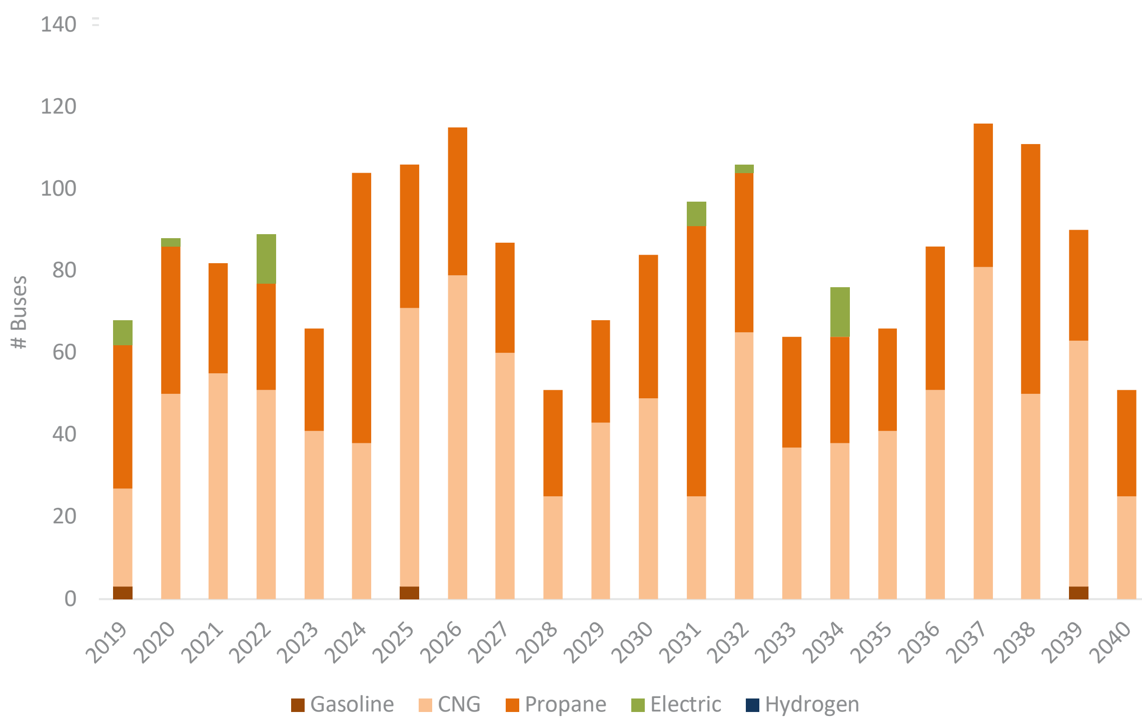


Figure 5 - Projected Vehicle Purchases, Baseline Scenario

Figure 6 depicts the annual baseline fleet composition through 2040. MTS phases out gasoline vehicles for propane from 2019 to 2021, and adds twelve (12) BEBs in 2022.

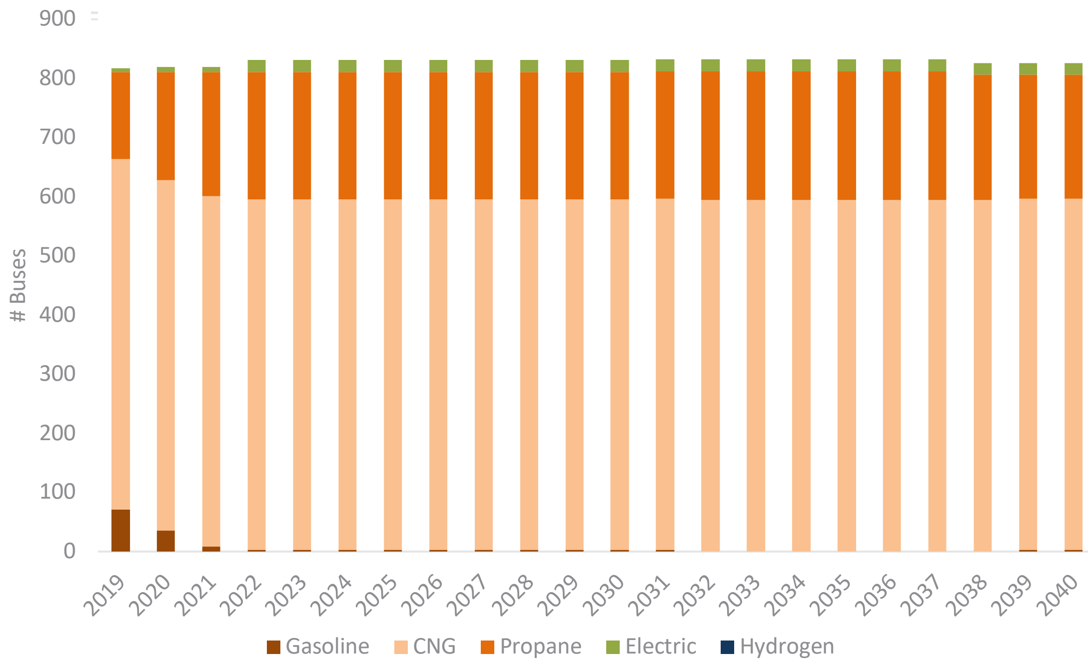


Figure 6 - Annual Fleet Composition, Baseline

Figure 7 shows the annual capital costs based on the purchase schedule and bus cost assumptions for the Baseline Scenario. Total bus purchases range from approximately $20 to $60 million each year.

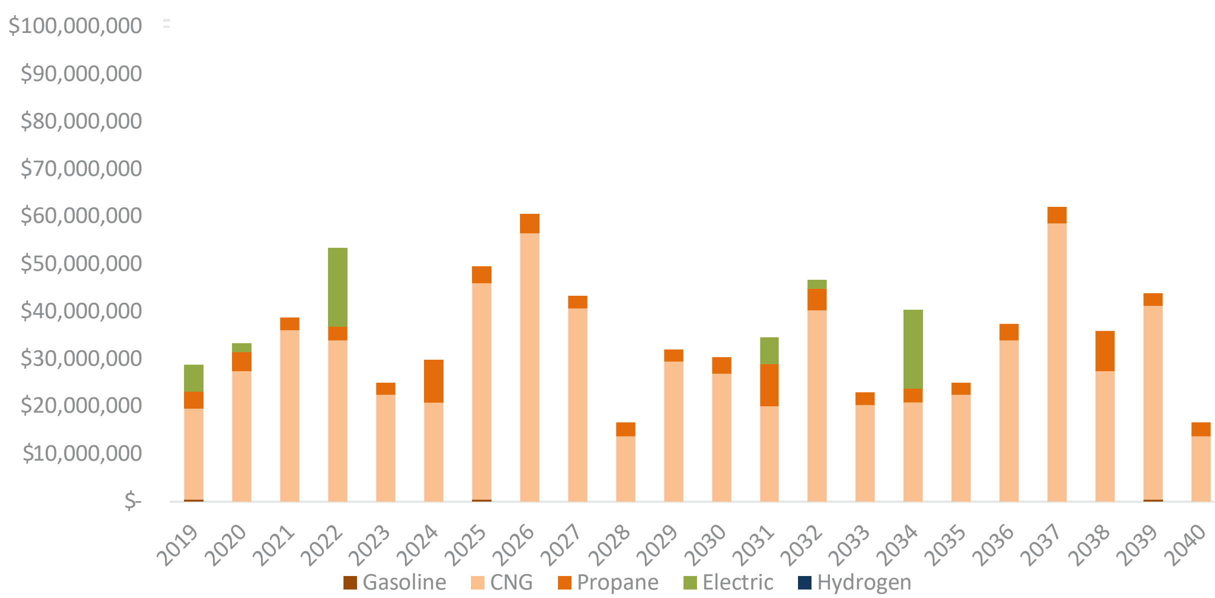


Figure 7 - Annual Capital Costs, Baseline

BEB Depot-Only Charging

The BEB Depot-Only Charging scenario assumes that depot-charged BEBs are used wherever possible; however, there may be instances where a depot-charged BEB cannot replace an internal combustion engine bus one-for-one due to insufficient range. As MTS has space constraints that limit their ability to increase the number of vehicles, replacement of a single internal combustion engine bus with multiple BEBs is not feasible. As a result, If vehicles cannot be replaced with a BEB because of the inability to complete the blocks, the vehicles are replaced with a internal combustion engine bus of the existing fuel type. The figures below show projected purchases, annual fleet composition, and annual total capital costs for the BEB Depot-Only Charging scenario. MTS phases out gasoline vehicles for propane from 2019 to 2021, and adds twelve (12) BEBs in 2022, but the fleet remains unchanged thereafter at a total of 835 buses. Note that by 2040, a total of approximately 77% of MTS fleet consists of BEBs. The fleet is unable to transition to 100% ZEB using depot-charged BEBs due to range limitations, primarily with the 60' and cutaway vehicles.

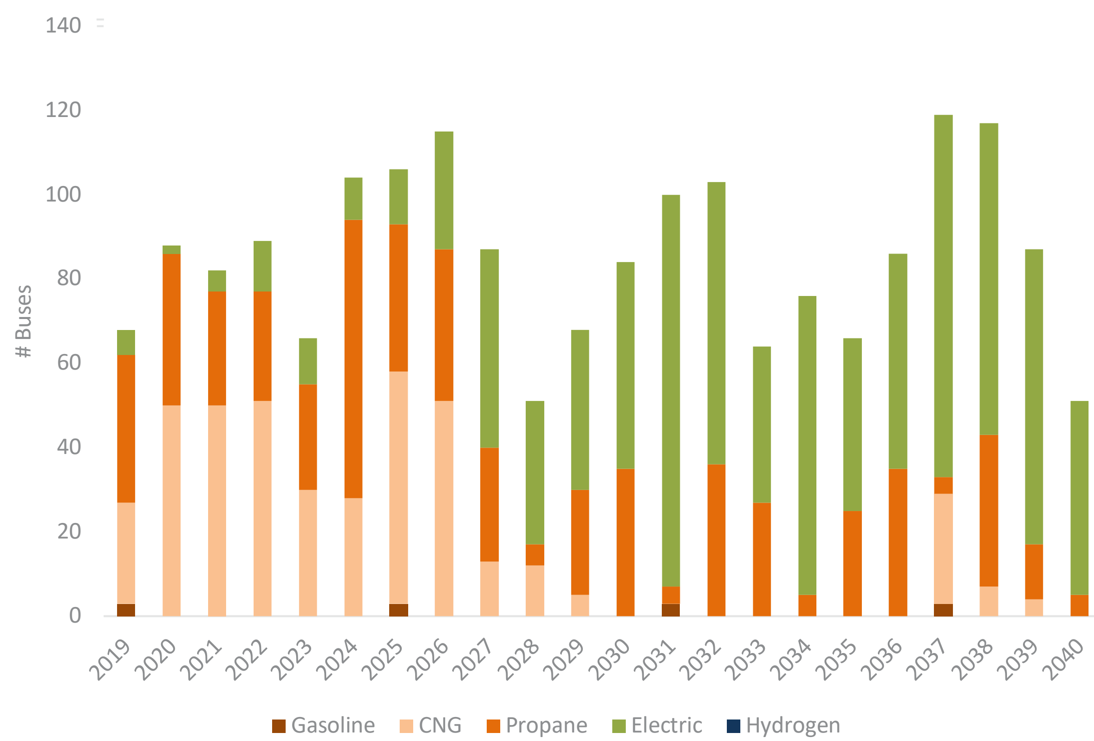


Figure 8 - Projected Vehicle Purchases, BEB Depot-Only Scenario

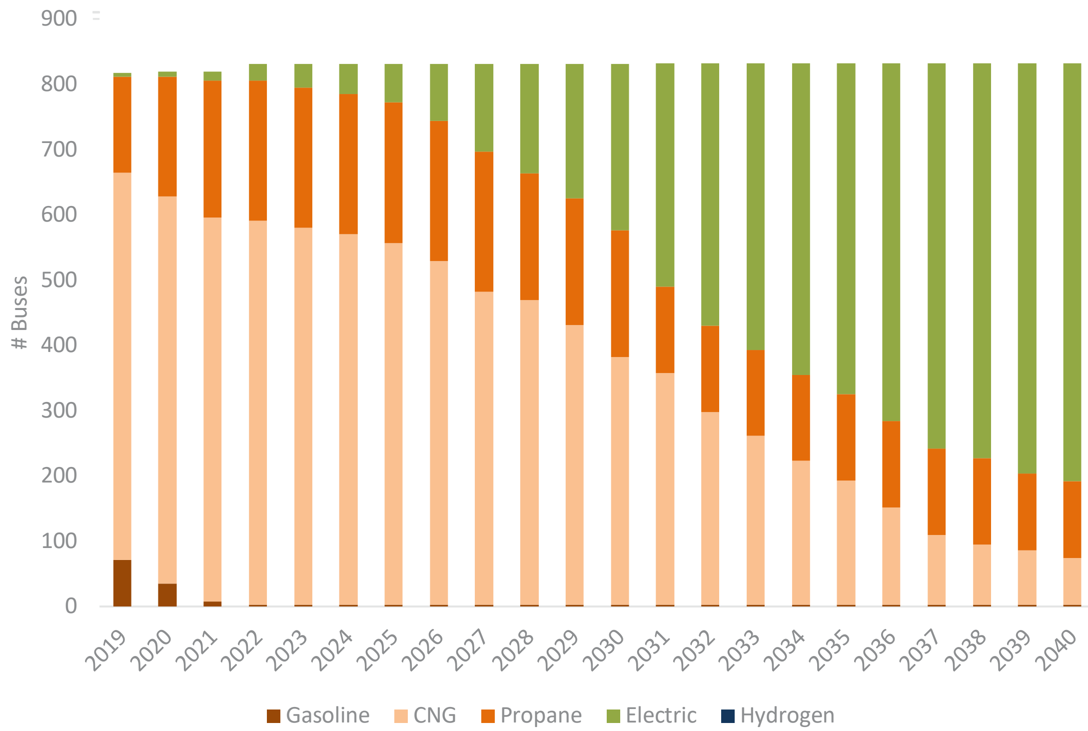


Figure 9 – Annual Fleet Composition, BEB Depot-Only Scenario

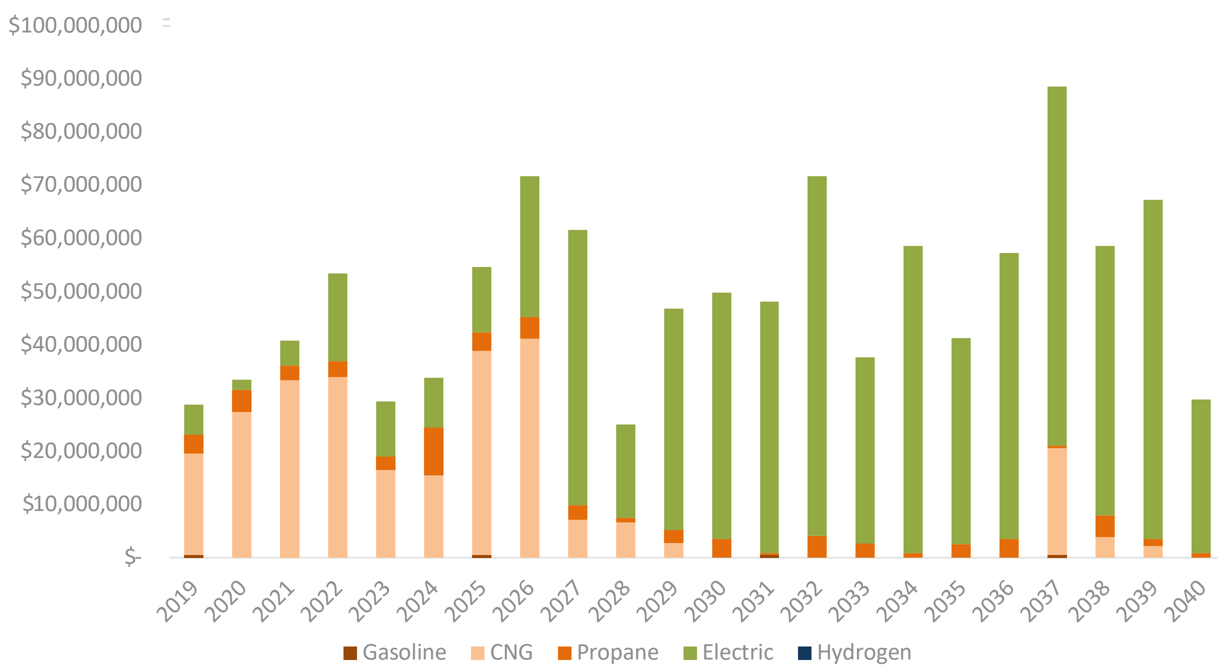


Figure 10 - Annual Capital Cost, BEB Depot-Only Scenario

BEB Depot and On-Route Charging

The BEB Depot and On-Route Charging scenario builds off of the analysis completed for the BEB Depot Only Charging scenario. Because bus replacements are based on block achievability found in the Service Assessment, there may be instances where block coverage is insufficient and depot-charged BEBs cannot meet service requirements. In that case, on-route charged BEBs can fill the gap. On-route charging allows an agency to add energy to buses while in service, providing the additional energy necessary to complete a block, without having to travel the extra distance and take the extra time to charge at a depot. Because MTS operates their Paratransit service as on-demand with no set routes or service area, the use of on-route charging is not feasible for these vehicles because they are unable to predict where a vehicle will be at a specific time of day when it needs to charge.

The figures below show projected purchases, annual fleet composition, and annual total capital costs for the BEB Depot and On-Route Charging scenario. By 2040, the addition of on-route charging allows MTS to replace approximately 84% of the fleet with BEBs. The fleet is unable to transition to 100% ZEB using depot-charged BEBs due primarily to the inability to operate the Paratransit fleet (cutaway/minibus) using on-route charging.

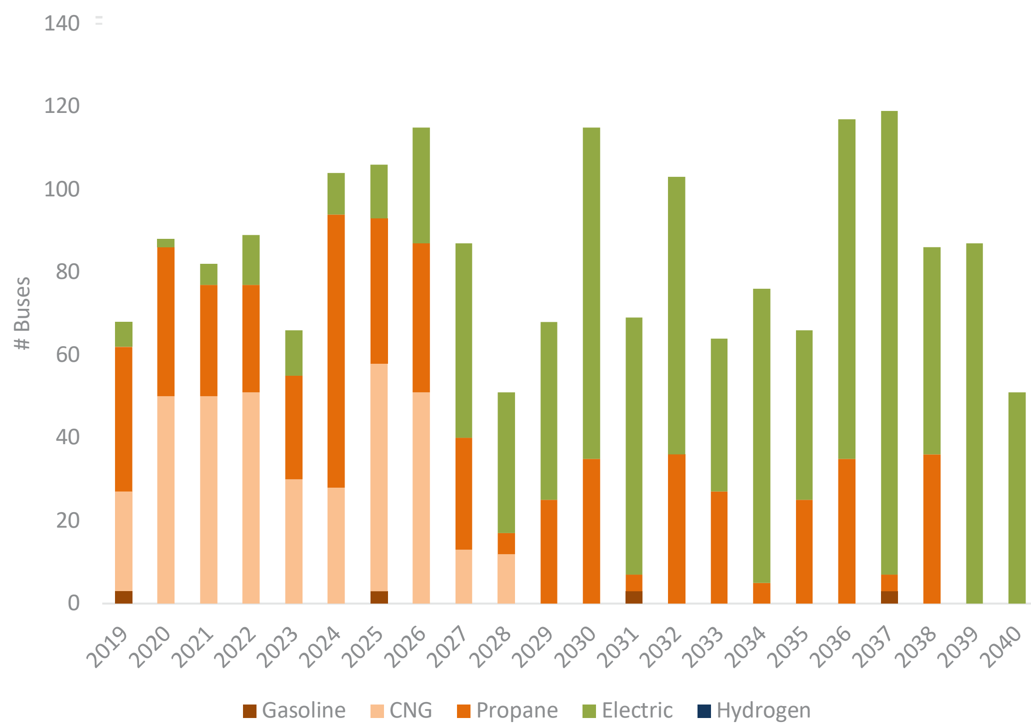


Figure 11 – Projected Vehicle Purchases, BEB Depot and On-Route Scenario

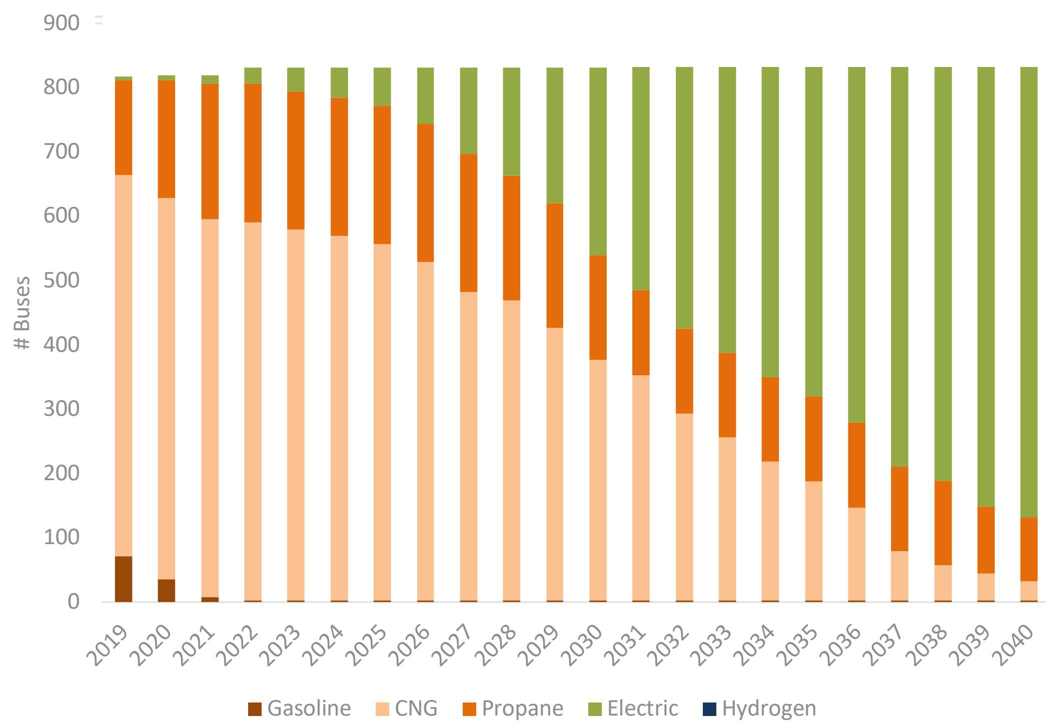


Figure 12 – Annual Fleet Composition, BEB Depot and On-Route Scenario

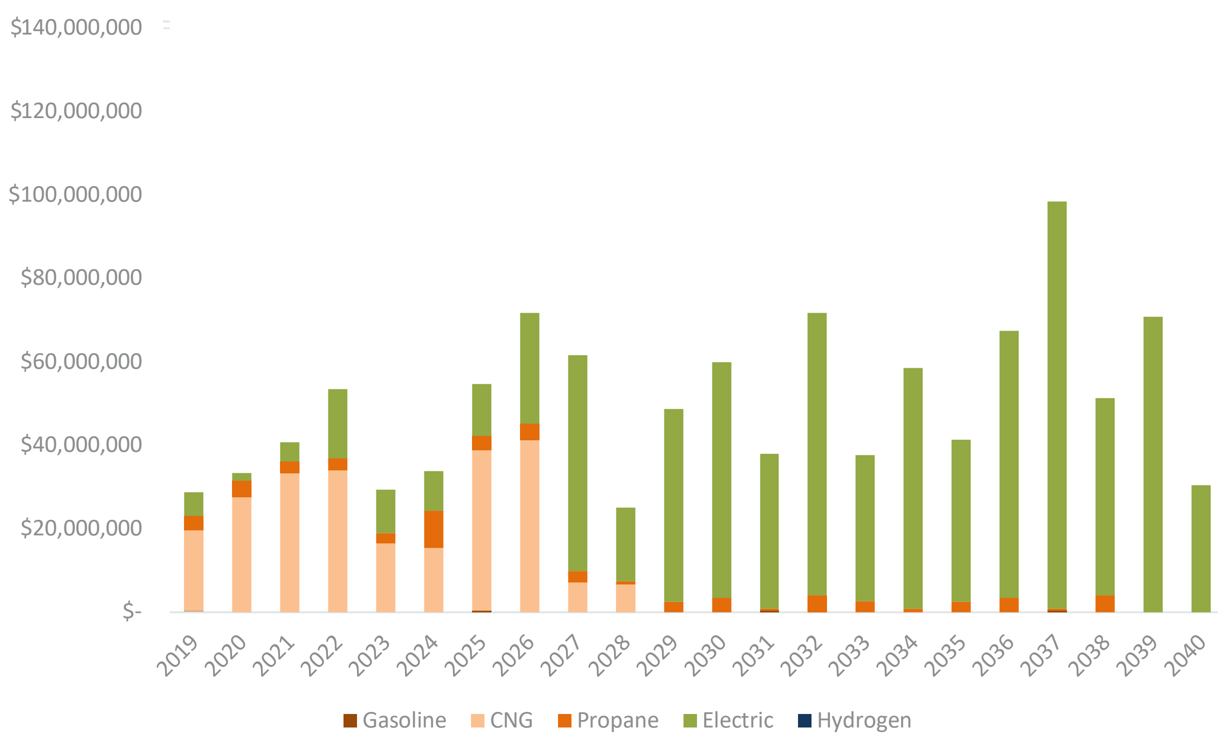


Figure 13 – Annual Capital Costs, BEB Depot and On-Route Scenario

FCEB Only

As discussed previously, FCEBs do not have the same range constraints as BEBs. Based on the analysis completed, by the end of the transition period, it is estimated that all of MTS blocks can be served by a FCEB on a one-for-one replacement basis (see **Figure 4**). There are significant assumptions that commercially available, Altoona tested 45' and cutaway FCEBs will be available during the transition period as well as improvements in range as previously discussed. The figures below show projected purchases, annual fleet composition and annual total capital costs for the FCEB Only scenario. By 2040, MTS is able to replace approximately 95% of its fleet with FCEBs. The remaining 5% of vehicles will be replaced with FCEBs when they reach their useful life after 2040. There is a lag between when FCEB technology can meet block energy requirements and when a vehicle is replaced due to the vehicle replacement schedule. Note that the hydrogen powered cutaway vehicles are differentiated from heavy-duty FCEBs due to the uncertainty associated with production of these vehicles in the future.

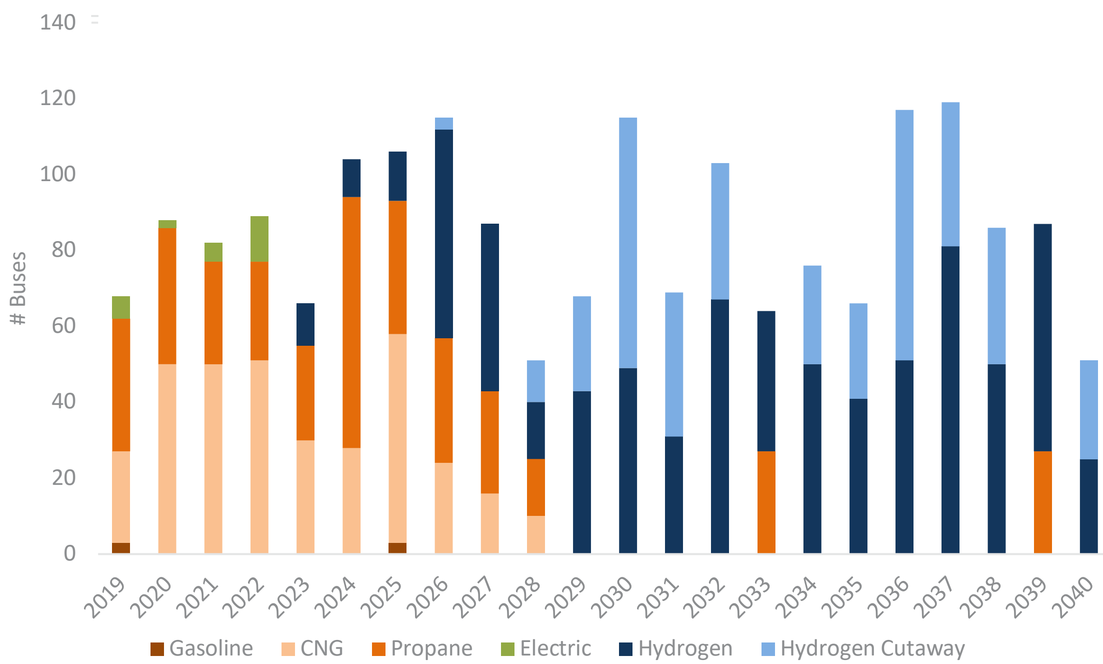


Figure 14 - Projected Vehicle Purchases, FCEB Only Scenario

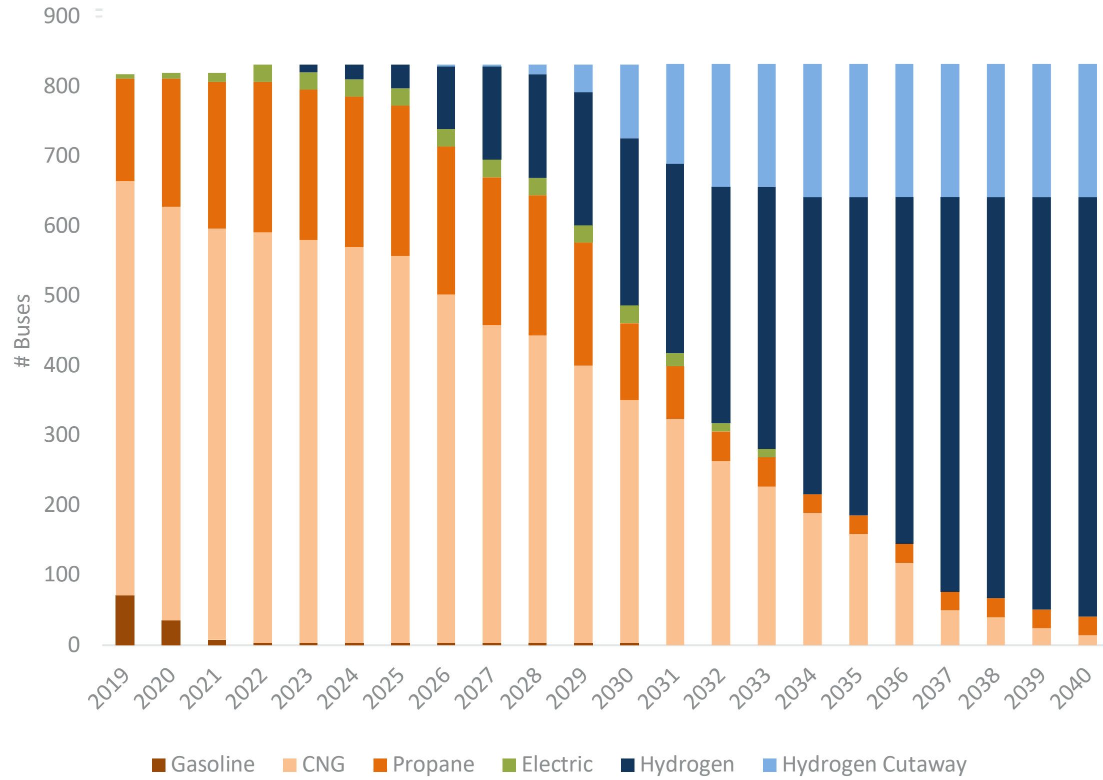


Figure 15 – Annual Fleet Composition, FCEB Only Scenario

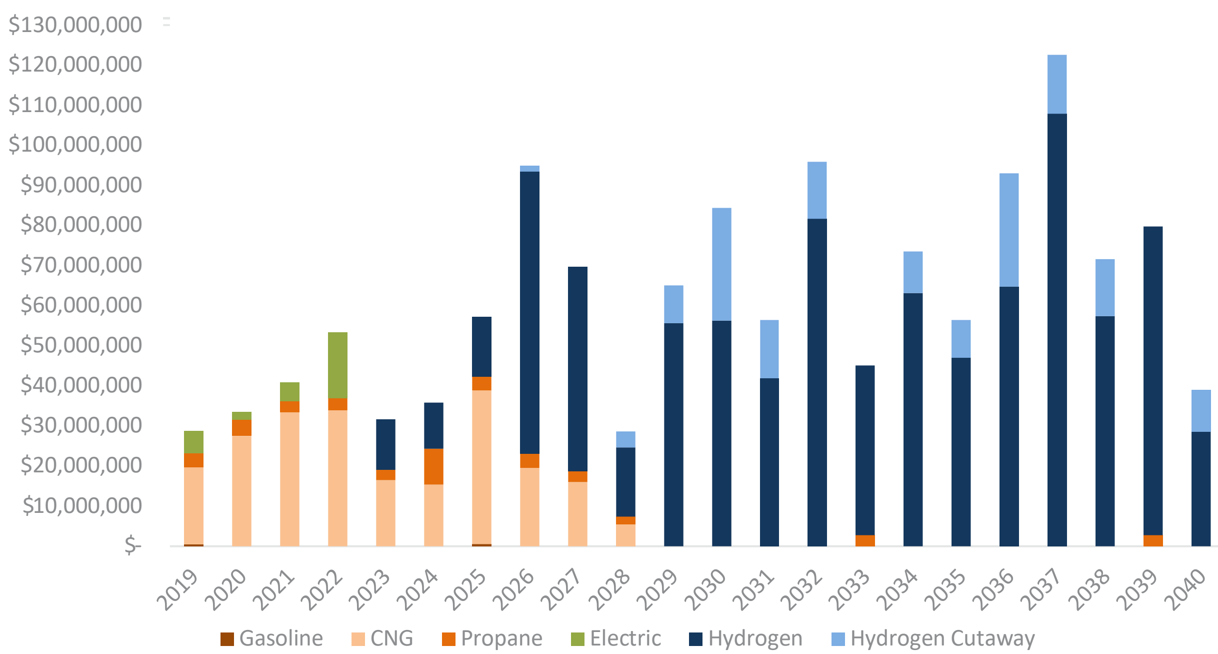


Figure 16 – Annual Capital Costs, FCEB Only Scenario

Mixed BEB and FCEB

In the Mixed BEB and FCEB scenario, depot-charged BEBs are utilized where they can replace internal combustion engine buses on a one-for-one basis. Since FCEBs have a greater range, they are used on the longer blocks and in Paratransit service where BEBs are not feasible. By the end of the transition period, any instance where block coverage is insufficient, a FCEB is used to replace MTS' original vehicle type. The figures below show projected purchases, annual fleet composition, and annual total capital costs for the Mixed BEB and FCEB fleet. By 2040, MTS is able to replace approximately 95% of its fleet with BEB and FCEBs. As in the FCEB Only scenario, the remaining 5% of vehicles will be replaced with FCEBs when they reach their useful life after 2040. There is a lag between when ZEB technology can meet block energy requirements and when a vehicle is replaced due to the vehicle replacement schedule. Note that the hydrogen powered cutaway vehicles are differentiated from heavy-duty FCEBs due to the uncertainty associated with production of these vehicles in the future.

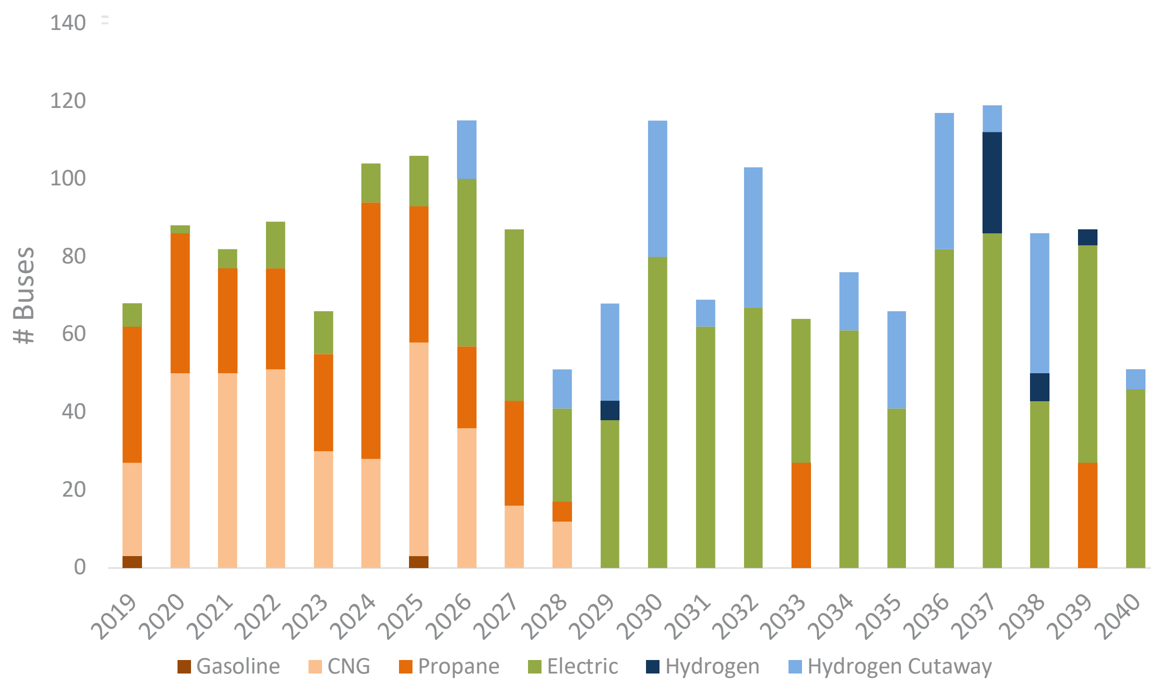


Figure 17 – Projected Vehicle Purchases, Mixed Scenario

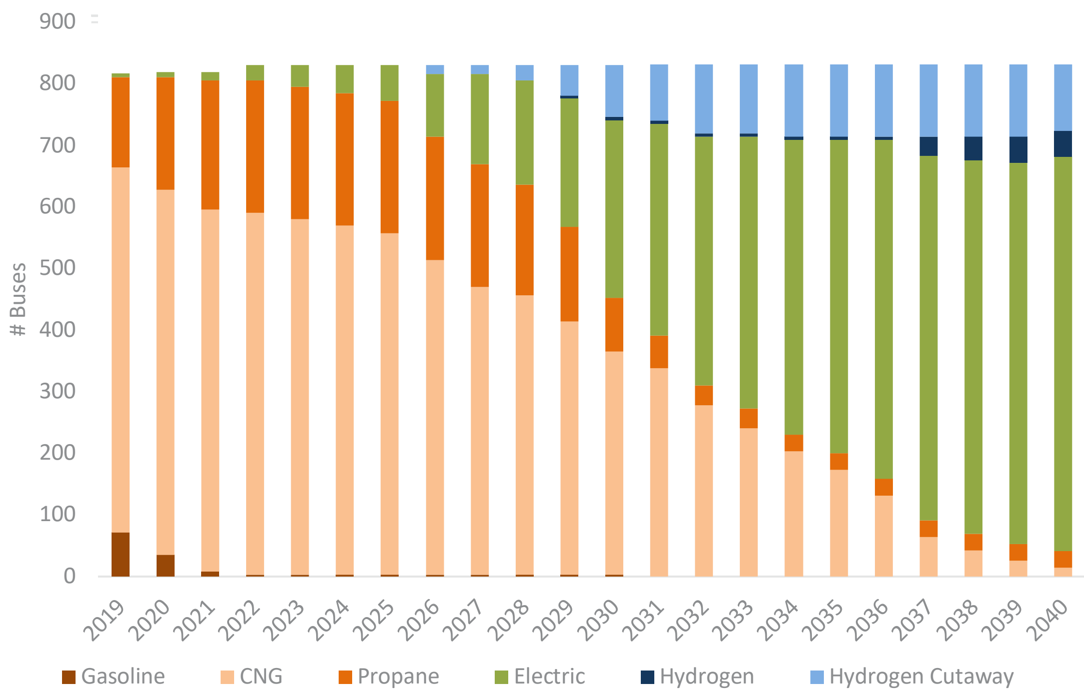


Figure 18 – Annual Fleet Composition, Mixed Scenario

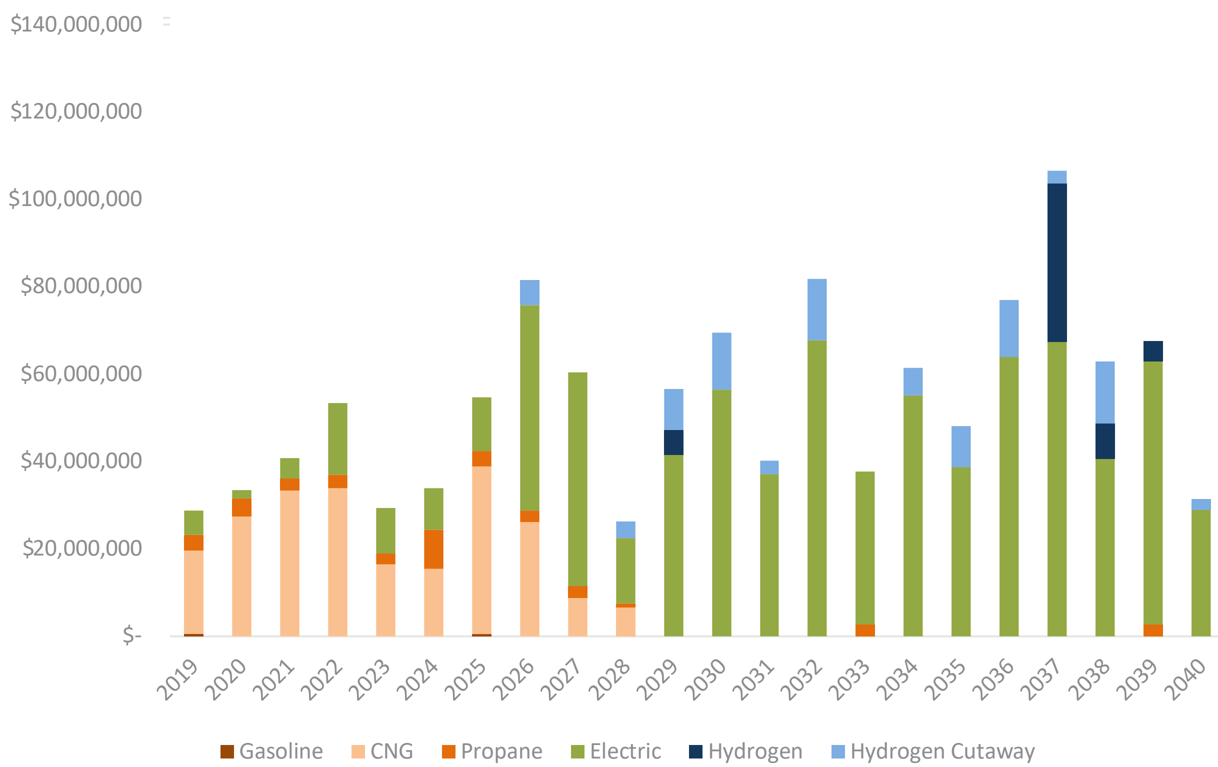


Figure 19 – Annual Capital Costs, Mixed Scenario

Fleet Assessment Cost Comparison

As discussed previously, the transition and fleet composition schedules were used to develop the total capital cost for vehicle purchases through the transition period. **Figure 20** shows the cumulative fleet purchase costs for each scenario.

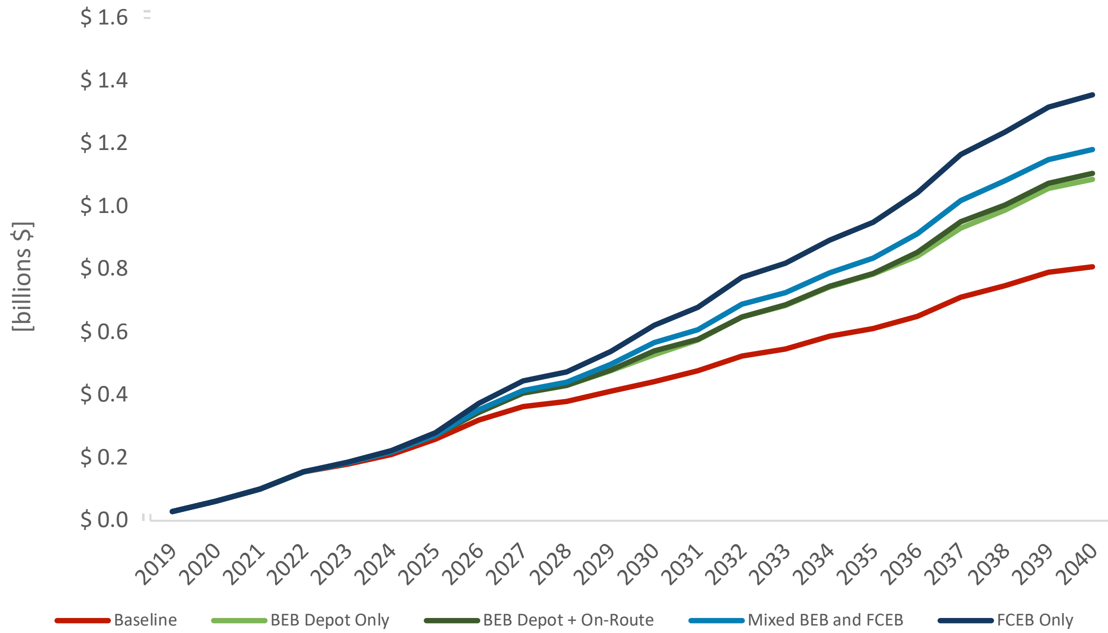


Figure 20 – Total Capital Costs, Fleet Assessment

By the end of the transition period, the cumulative vehicle costs vary substantially according to the technology selected as does the percentage of the fleet that can be transitioned to zero-emission by 2040. **Table 13** provides the combined total costs for each transition scenario, the percentage increase in cost above the baseline scenario, and the percentage of ZEBs present in the fleet in 2040 for the scenario.

Table 13 - Total Capital Costs, Fleet Assessment

Scenario	Cost	% Cost Increase Over Baseline	% ZEB in 2040
Baseline	$ 808,294,000	----	2%
BEB Depot Only	$ 1,086,465,000	34%	77%
BEB Depot + On-Route	$ 1,105467,000	37%	84%
FCEB Only	$ 1,355,484,000	68%	95%
Mixed BEB and FCEB	$ 1,181,414,000	46%	95%

Fuel Assessment

Using ZEB performance data from the bus modeling and route simulation, CTE analyzed the expected performance on each block in MTS' service network to calculate daily energy requirements. The five projection scenarios from the Fleet Assessment are used to estimate associated fuel and energy costs unique to each fleet projection throughout the study life. This assessment calculates energy costs using 2019 prices. The Fuel Assessment estimates quantities and costs for MTS' current and future internal combustion engine vehicles as well as electrical energy and hydrogen fuel quantities and costs for the future BEB and FCEBs projected in each scenario.

The terms "fuel" and "energy" are used interchangeably in this assessment, as ZEB technologies do not always require traditional liquid fuel. For clarity, in the case of BEBs, "fuel" is electricity and costs include energy, demand and other utility charges. FCEBs are more similar to internal combustion engine vehicles as they are fueled by a gaseous or liquid hydrogen fuel. In addition to the cost of the fuel itself, however, there are additional operational costs associated with the hydrogen fueling station that must be considered. Operation and maintenance costs to maintain fueling infrastructure for both BEBs and FCEBs are built into the Fuel Assessment. Fuel cost estimates are based on the assumptions shown in **Table 14** below.

Table 14 – Fuel Cost Assumptions

Fuel	Cost	Source
Gasoline	$2.73/gal	MTS contracted rate
CNG	$0.85/DGE	MTS contracted rate
Hydrogen (trucked)	$8.10/kg	Average of contracted rates for multiple CA transit agencies
Electricity	Varies	SDG&E AL-TOU and EV-HP Tariff Schedules

The primary source of energy for a BEB comes from the local electrical grid. Utility companies typically charge separate rates for total electrical energy used and the maximum electrical demand on a monthly basis. As more buses, and chargers, are added to a system, both the energy used and the demand increase. Rates also vary throughout the year and throughout the day; this makes costs highly variable. Costs not only depend on seasonal differences like temperature, but also the time of day buses are charged.

Table 15 shows the current San Diego Gas & Electric (SDG&E) rate schedule used in the Fleet Assessment to estimate electrical costs for BEBs. MTS' energy rates are Direct Access, meaning the energy is purchased outside the utility at a more competitive rate and supplied through SDG&E. These rates are averaged from monthly rates and are a summarized version of SDG&E's full schedule.

Table 15 – SDGE&E Rate Schedule

	Fee Type	Unit	AL TOU2	A6 TOU	A6 TOU
Demand Levels			0 - 499 kW	500 - 1200 kW	> 1200 kW
Service Type			Secondary	Primary	Substation
Customer Charge	Service Fee	per month	$ 310.34	$ 59.77	$ 30,722.49
Demand Charge	Non-Coincident Transmission & Distribution	per kW	$ 24.23	$ 23.66	$ 15.46
	Annual Peak Avg: Transmission & Distribution	per kW	$ 17.25	$ 17.11	$ 1.84
Energy Rates	Annual Super Off-Peak Avg	per kWh	$ 0.09892	$ 0.09865	$ 0.09865
	Annual Off-Peak Avg	per kWh	$ 0.11637	$ 0.11593	$ 0.11593
	Annual Peak Avg	per kWh	$ 0.13311	$ 0.13256	$ 0.13256

Charging Analysis

To accurately estimate energy use and electrical demand, and subsequent costs, due to BEB charging, charging was simulated at each depot, for each year of the transition. Electrical energy and demand were estimated based on current block schedules and BEB purchase projections and apply SDG&E tariff schedules to calculate an annual cost of charging. This annual cost is evaluated for each year of the study and at each depot to obtain a total BEB depot charging cost for the transition. This estimate is used as the total “fuel” cost for BEB depot charging in the subsequent assessment scenarios and it is incremental to on-route charging costs, hydrogen fuel costs and internal combustion engine costs.

The local utility, SDG&E, calculates total energy costs, measured per kWh, using three different Time-of-Use rates (TOU), as was shown in **Table 15.** Ideally, buses would all charge in the least expensive, Super Off-Peak time for the lowest overall cost, but because MTS is limited by space and by the available charge window to meet schedule requirements, this is not possible. To reduce overall energy and demand costs, charge management was modeled to optimize charging for MTS’ pull-out requirements.

Charge management reduces electricity costs by optimizing energy use (kWh) and maximum demand (kW) to occur during cheaper time windows. By managing charging, the total annual costs, using South Bay in 2040 as an example, are reduced by approximately $2.65 million, or by approximate 31%, as shown in **Table 16** below.

Table 16 - Charging Costs, South Bay, 2040

Fees	Annual Cost Unmanaged	Annual Cost Managed
Customer Charge	$ 717	$ 717
Noncoincident Demand	$ 3,288,020	$ 3,185,582
Demand Charge	$ 2,377,075	-
Demand Subscription	-	-
Energy	$ 2,749,706	$ 2,583,234
Total	**$ 8,415,519**	**$ 5,769,533**

Optimizing Energy Use

Figure 21 shows each weekday block's status at South Bay over a single day in 2040 (a weekday block is identical for each day of the week). Grey indicates the bus is in service; blue indicates setup time and delay; and gold indicates charging time. This unmanaged scenario assumes a standard 30-minute delay between pull-in and charge start. There are a significant number of charges occurring during On-Peak from 4pm to 9pm. This charging method incurs an annual total energy cost of approximately $2.75 million, shown in **Table 16**.

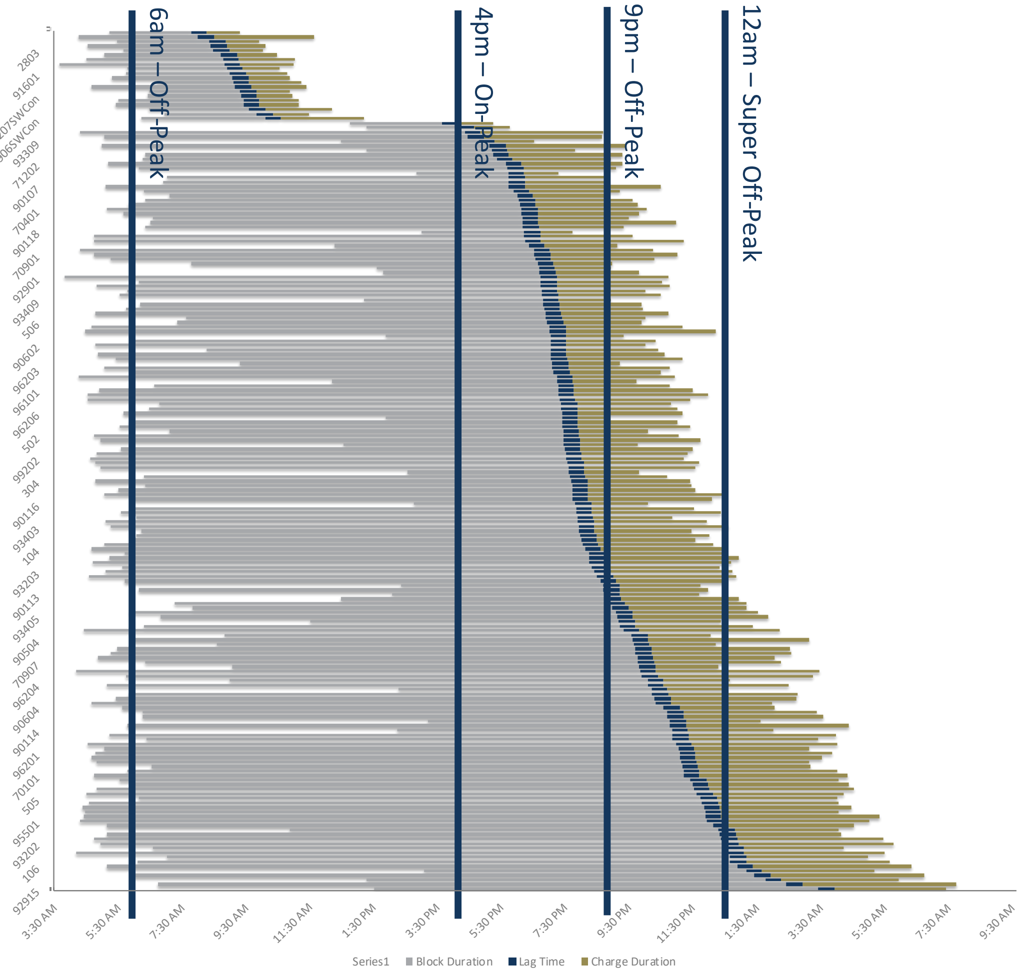


Figure 21 – Unmanaged Charging, South Bay, Weekday, 2040

Figure 22 shows the effect of actively managing charging on the same day shown in **Figure 21**. All the blocks that pull in between 4pm and 9pm now have extra delay time added so that the On-Peak time of use rate is avoided. This modification results in an energy cost savings of approximately $166,000 per year over the unmanaged case (**Table 16**).

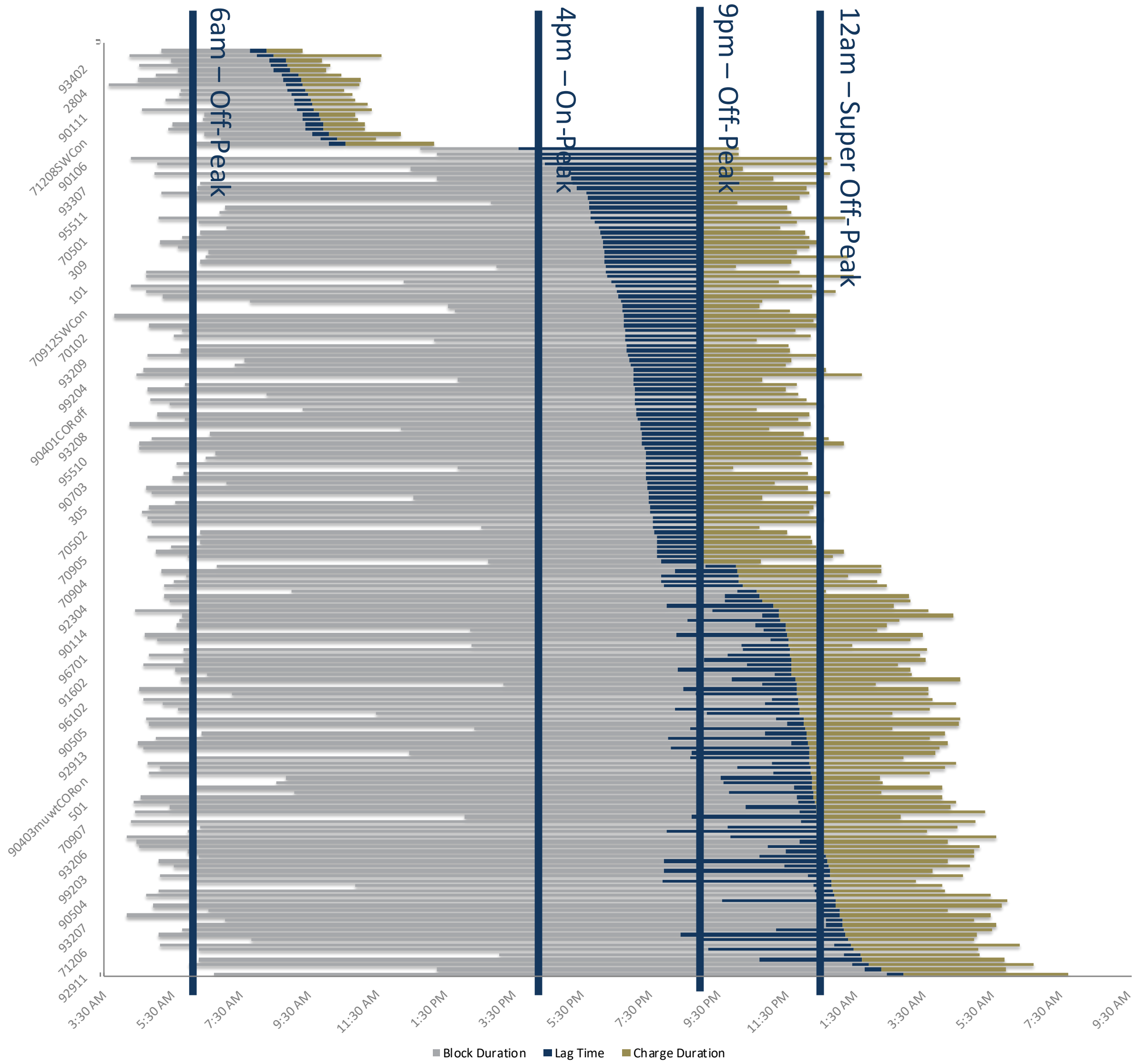


Figure 22 – Managed Charging, South Bay, Weekday, 2040

Minimizing Demand

The other main cost component of the utility bill is the demand charge, billed per kW. For a MTS operating BEBs, the number of chargers operating simultaneously is directly proportional to demand costs. By reducing the number of chargers running at any given time, demand costs are reduced. In this analysis, all chargers are assumed to provide 125 kW to the bus and pull approximately 132 kW from the grid.

In **Figure 23** below, managed charging eliminates the demand during the On-Peak by delaying charging to start only after 9pm. Charges that previously occurred On-Peak were spread to the Off-Peak and Super Off-Peak times. The Managed Off-Peak and Super Off-Peak windows do have a higher average demand than in the Unmanaged case, but demand costs are determined by the maximum, so overall, costs are still reduced, because the Managed peak demand is still lower than the peak in the Unmanaged case.

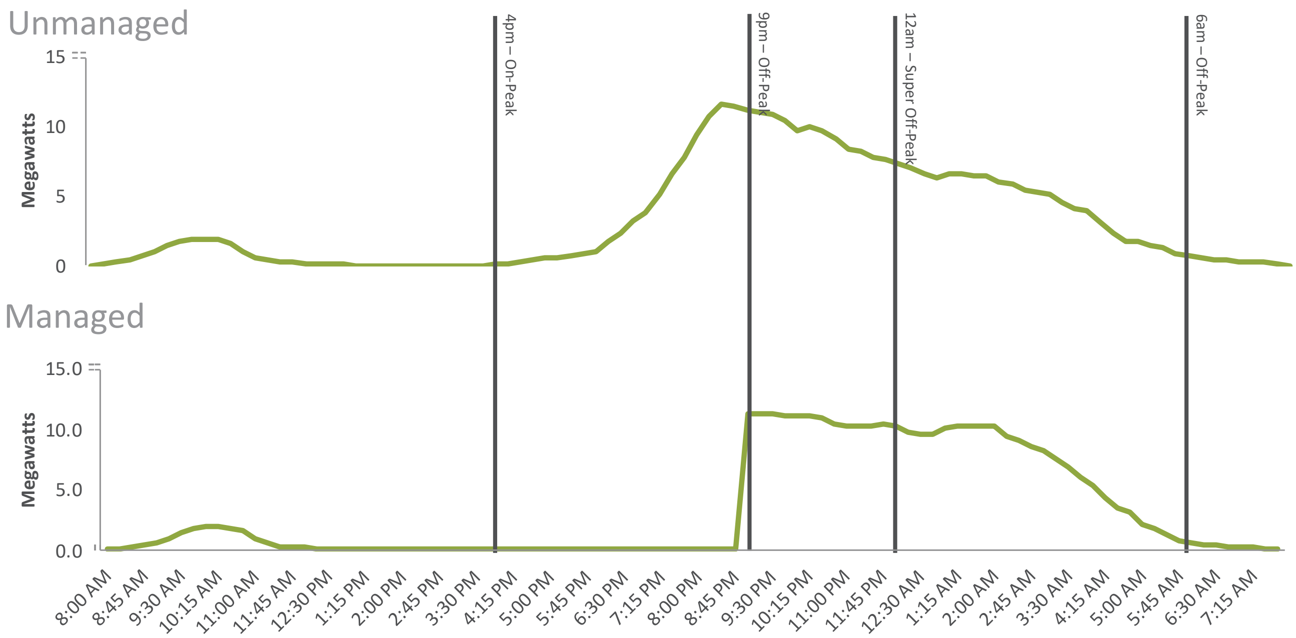


Figure 23 – Weekday Demand, South Bay, 2040

Table 17 provides more detail for the demand analysis. The Unmanaged case experiences a maximum demand of 11,580 kW during On-Peak; however, in the Managed case, all On-Peak demand is eliminated. This change eliminates SDG&E's demand charge, which is only based on On-Peak demand, saving $2.38 million annually (**Table 16**). In the Managed case, the max demand (11,220 kW) occurs during Off-Peak, and is still lower than the Unmanaged peak, therefore SDG&E's Noncoincident demand charge is reduced by approximately $100,000 annually (**Table 16**).

Table 17– Demand by Time of Use, South Bay, 2040

Time of Use	Unmanaged Peak Demand (kW)	Managed Peak Demand (kW)
On-Peak	11,580.8	0.0
Off-Peak	11,167.2	11,220.0
Super Off-Peak	7,312.8	10,331.2

Figure 24 shows the annual BEB depot charging costs based on managed charging as discussed previously in the charging analysis. These costs are inclusive of all divisions. The charging costs are applicable to the BEB Depot Only Charging scenario, the BEB Depot and On-Route Charging, and the Mixed BEB and FCEB scenario costs. Additional cost evaluation is completed for on-route charging to include the estimated fuel costs.

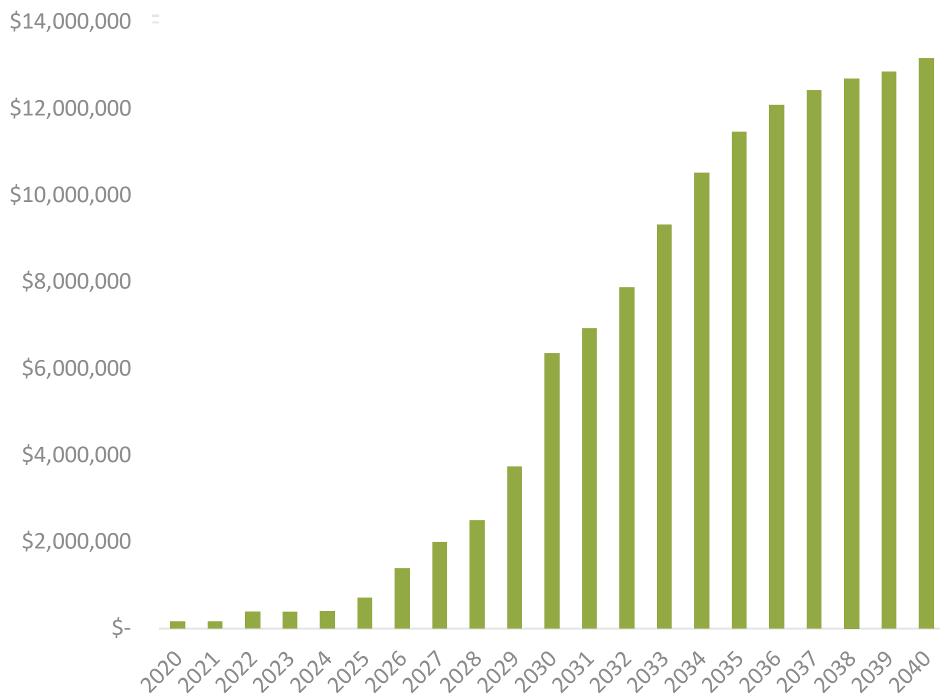


Figure 24 – Annual BEB Depot Charging Costs

The SDG&E Proposed EV Rate was also evaluated for comparison to the existing AL-TOU rates to determine potential costs savings over the life of the transition although the rate has yet to be approved. Results from the analysis indicate an approximate 26% savings in fuel costs over the transition period if the Proposed EV Rate is implemented and remains in effect for the duration of the transition. However, for the purposes of the transition analysis, the current AL-TOU rates were utilized for cost estimating and comparison to Baseline.

Baseline

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

Figure 25, below, depicts energy consumption for each fuel type over the transition period for the Baseline scenario. Fuel use is shown in diesel gallon equivalent (DGE) for all fuel types. It is assumed that the fuel economy for MTS' internal combustion engine vehicles remain constant over the study life.

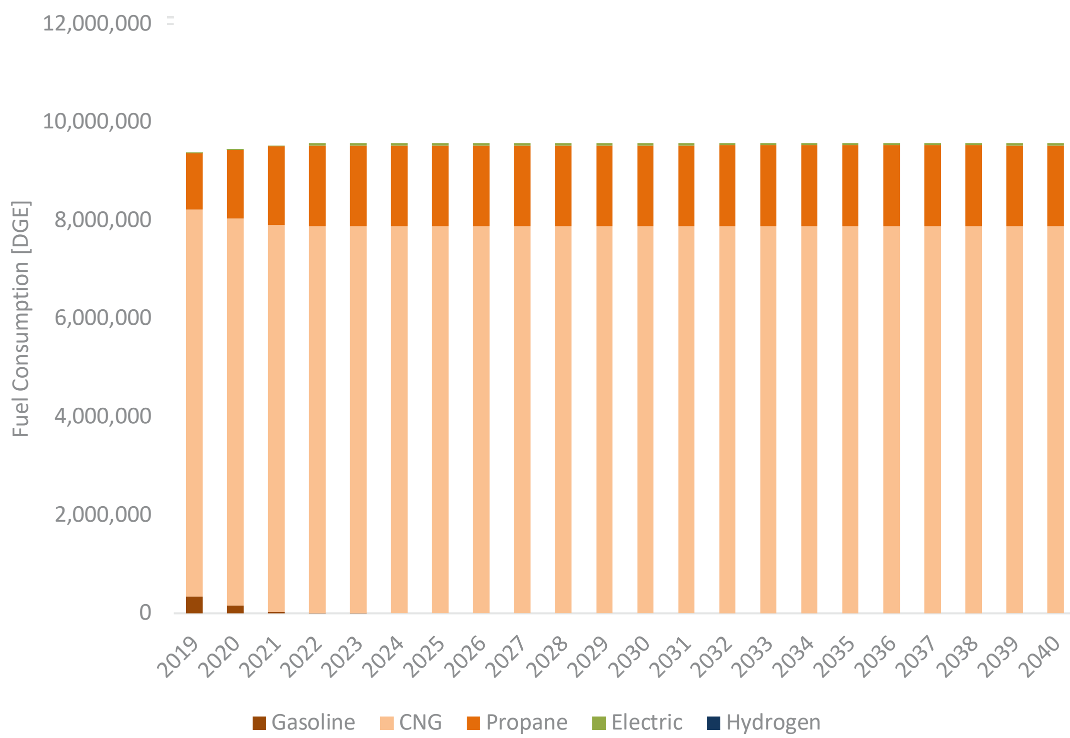


Figure 25 – Annual Fuel Consumption, Baseline

Figure 26 shows the calculated annual costs for each fuel type based on the quantities for the Baseline scenario.

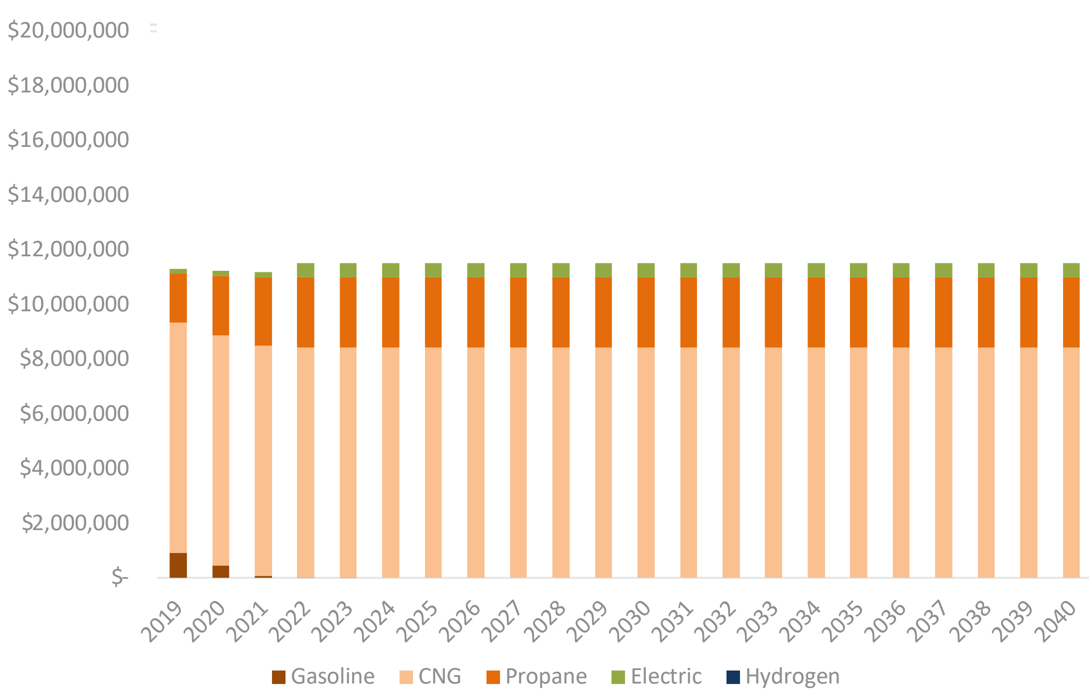


Figure 26 – Annual Fuel Costs, Baseline

BEB Depot-Only Charging

Figure 27 depicts energy consumption by fuel type over the transition period for the BEB Depot-Only Charging scenario. As one would expect, legacy fuels are phased out as electricity consumption increases, reflecting an increasing number of BEBs in the fleet. Electricity use by BEBs, measured in kWh, is converted to DGE for this analysis. Total energy use in 2040 is less than half of that in 2019 due to the improved efficiency of BEBs over internal combustion engine buses.

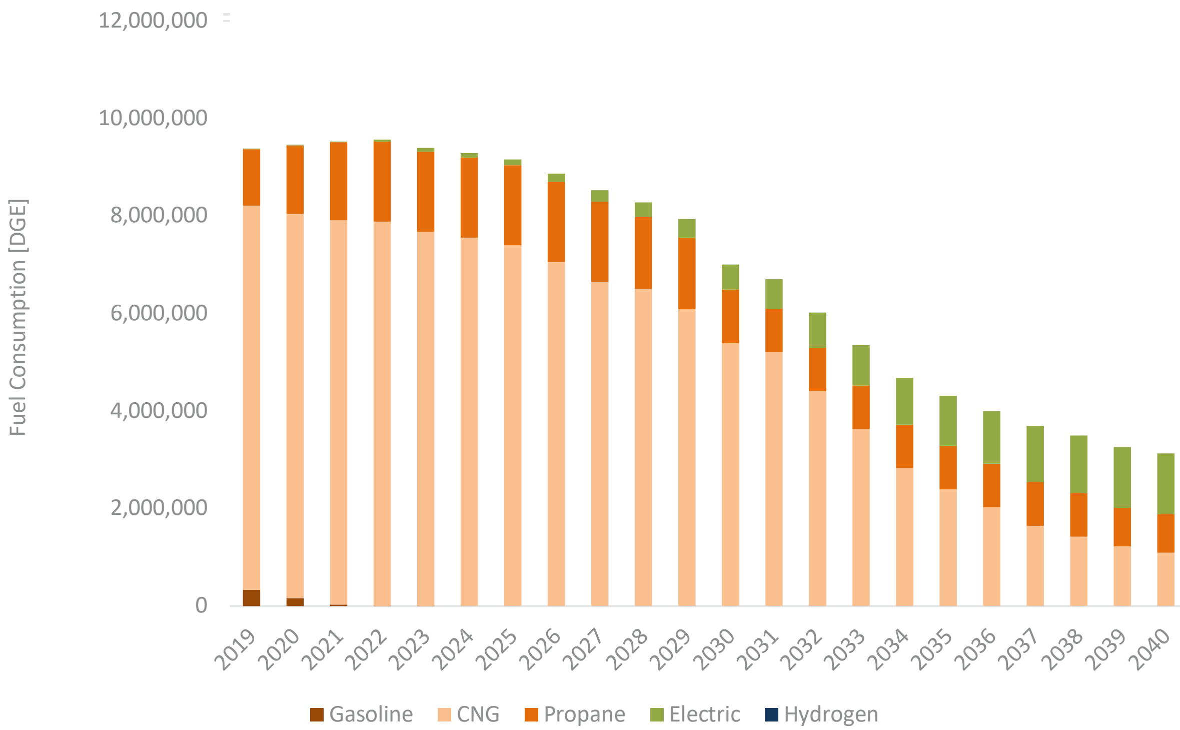


Figure 27 – Annual Fuel Consumption, BEB Depot-Only Scenario

Figure 28 shows the annual costs for each fuel type based on the quantities shown in **Figure 27**. Total estimated fuel costs in 2040 are approximately $16 million.

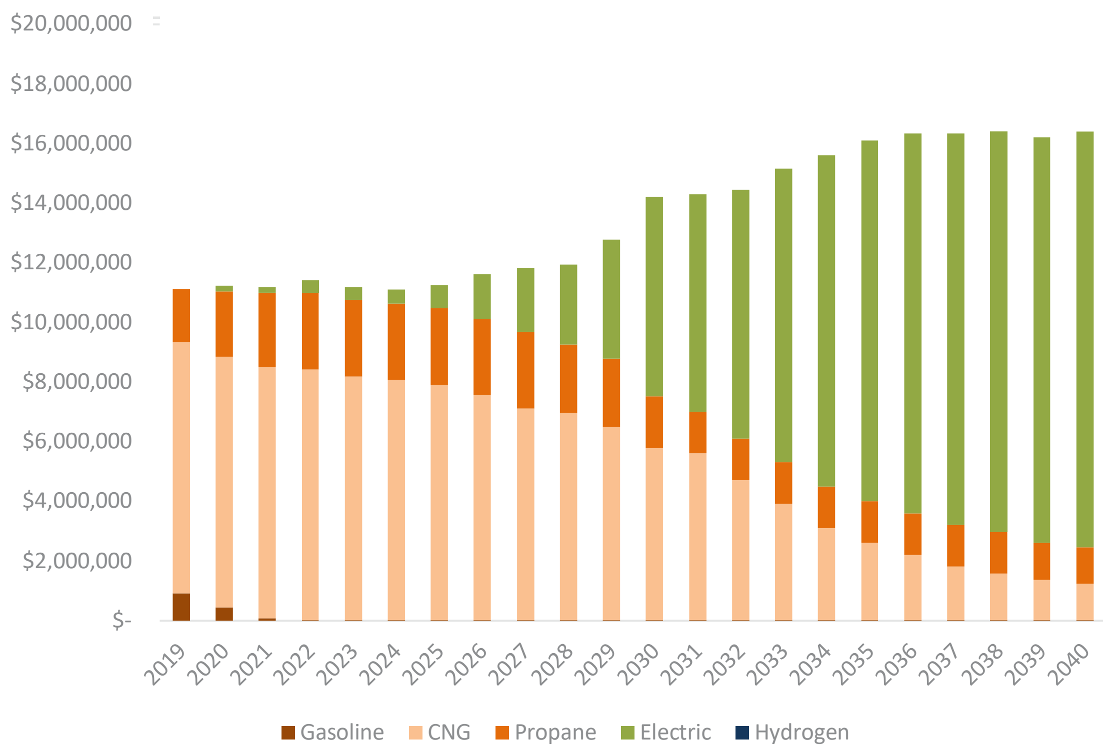


Figure 28 – Annual Fuel Costs, BEB Depot-Only Scenario

BEB Depot and On-Route Charging

Because bus replacements are based on block achievability, there may be instances where block coverage is insufficient and depot-charged BEBs cannot meet service requirements. On-route charged BEBs can be used to supplement depot charging to extend the range of vehicles and increase the feasibility for a 100% ZEB fleet. On-route charging allows an agency to add energy to buses while in service, providing the additional energy necessary to complete a block, without having to travel the extra distance and take the extra time to charge at a depot. Because MTS operates their Paratransit service as on-demand with no set routes or service area, the use of on-route charging is not feasible for these vehicles because they are unable to predict where a vehicle will be at a specific time of day when it needs to charge.

Figure 29, below, depicts energy consumption for each fuel type over the transition period assuming combination of depot and on-route charged BEBs. As expected, legacy fuels are phased out as electricity consumption increases, reflecting an increasing number of BEBs in the fleet. Total energy use in 2040 is approximately 20% of total energy use in 2019; this is representative of the improved efficiency of BEBs over internal combustion engine vehicles.

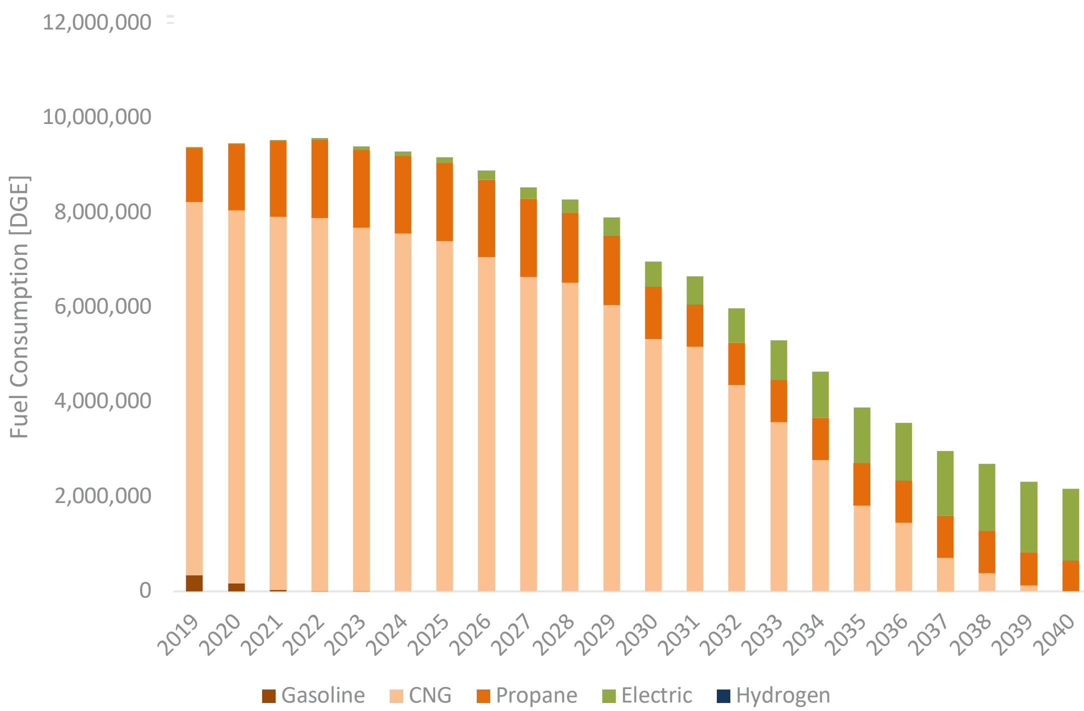


Figure 29 – Annual Fuel Consumption, BEB Depot and On-Route Scenario

Figure 30 shows the annual costs for each fuel type based on the quantities in **Figure 29**. Total estimated fuel costs in 2040 are approximately $20 million.

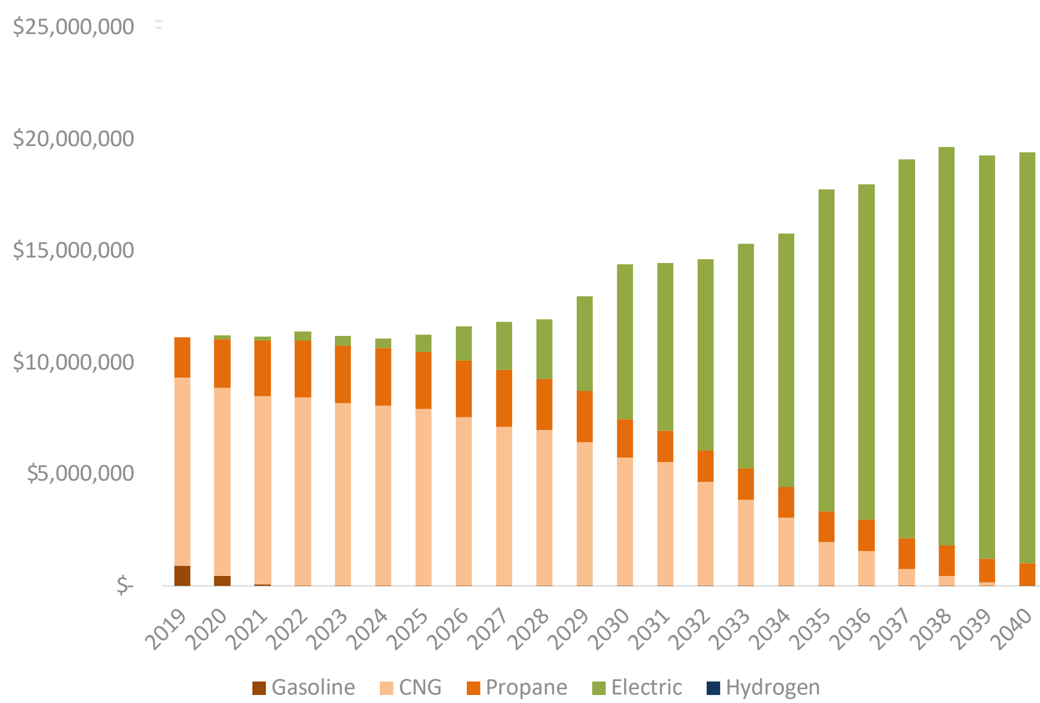


Figure 30 – Annual Fuel Costs, BEB Depot and On-Route Scenario

FCEB Only

Typically, FCEBs have greater range than a BEB, and are able to complete all of MTS's blocks by the end of the transition in 2040. **Figure 31** depicts fuel consumption for each fuel type over the transition period for the FCEB Only scenario. As expected, legacy fuels are phased out as hydrogen consumption increases, reflecting an increasing number of FCEBs in the fleet. Total energy use in 2040 is reduced by half from 2019.

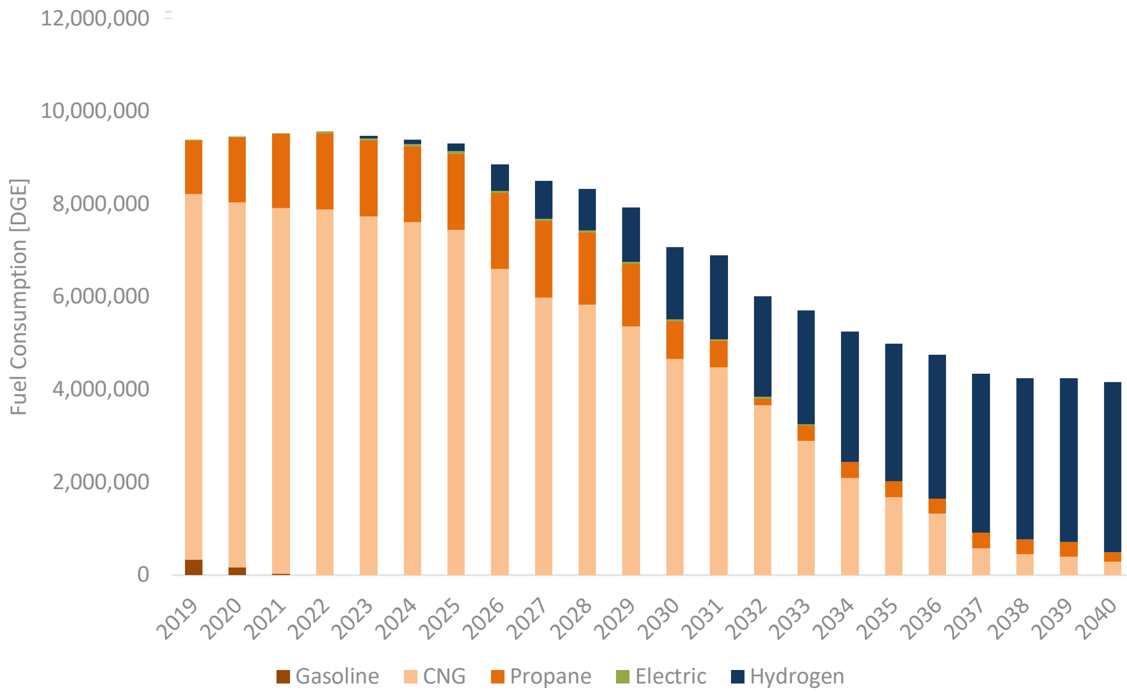


Figure 31 – Annual Fuel Consumption, FCEB Only Scenario

Figure 32 shows estimated annual costs for each fuel type based on the quantities shown in **Figure 31**. Total estimated fuel costs in 2040 are approximately $33 million, the bulk of which is from hydrogen.

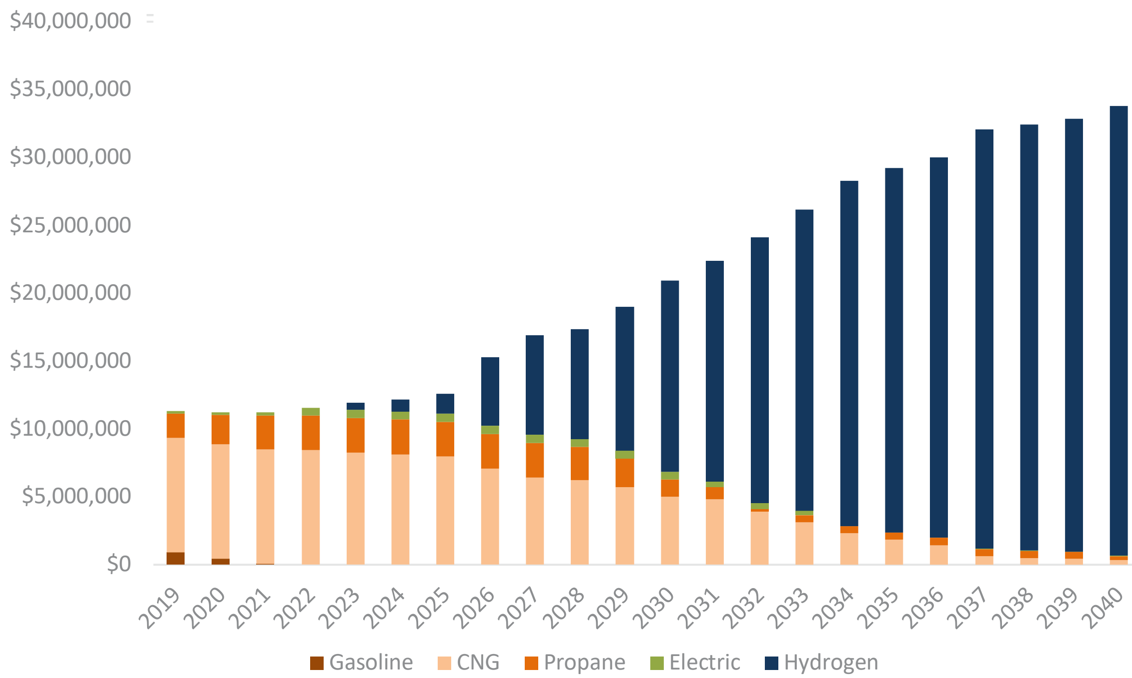


Figure 32 – Annual Fuel Costs, FCEB Only Scenario

Mixed BEB and FCEB

In the Mixed BEB and FCEB scenario, BEBs are utilized where they can replace internal combustion engine vehicles on a one-for-one basis. Since FCEBs have a greater range, they are used on the longer blocks and in Paratransit service where BEBs are not feasible. By the end of the transition period, any instance where block coverage was insufficient, a FCEB is used to replace the MTS' original vehicle type

Figure 33 depicts energy consumption for each fuel type over the transition period for the Mixed BEB and FCEB scenario. Legacy fuels are phased out as electricity and hydrogen consumption increases, reflecting an increasing number of BEBs and FCEBs in the fleet. Equivalent fleet energy use is reduced from nearly 10 million DGE in 2019 to just over 2 million DGE in 2040, an approximate 80% decrease.

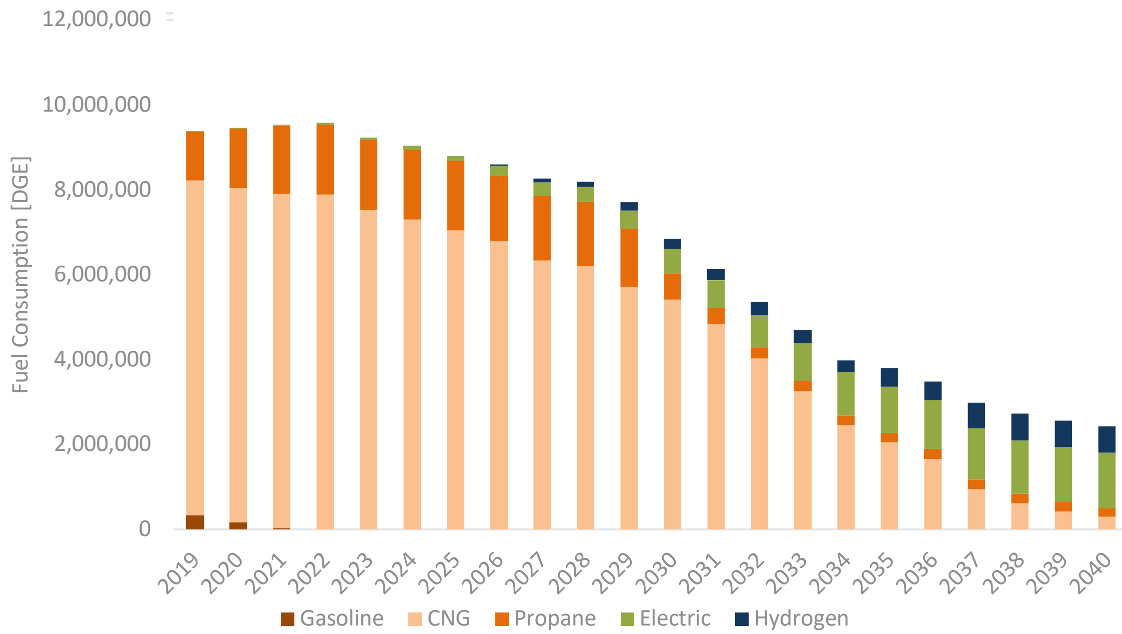


Figure 33 – Annual Fuel Consumption, Mixed Scenario

Figure 34 shows the estimated annual costs for each fuel type based on the quantities found in **Figure 33.** Total estimated fuel costs in 2040 are approximately $20 million, a majority of which are from electricity use for BEBs and to a lesser extent hydrogen fuel.

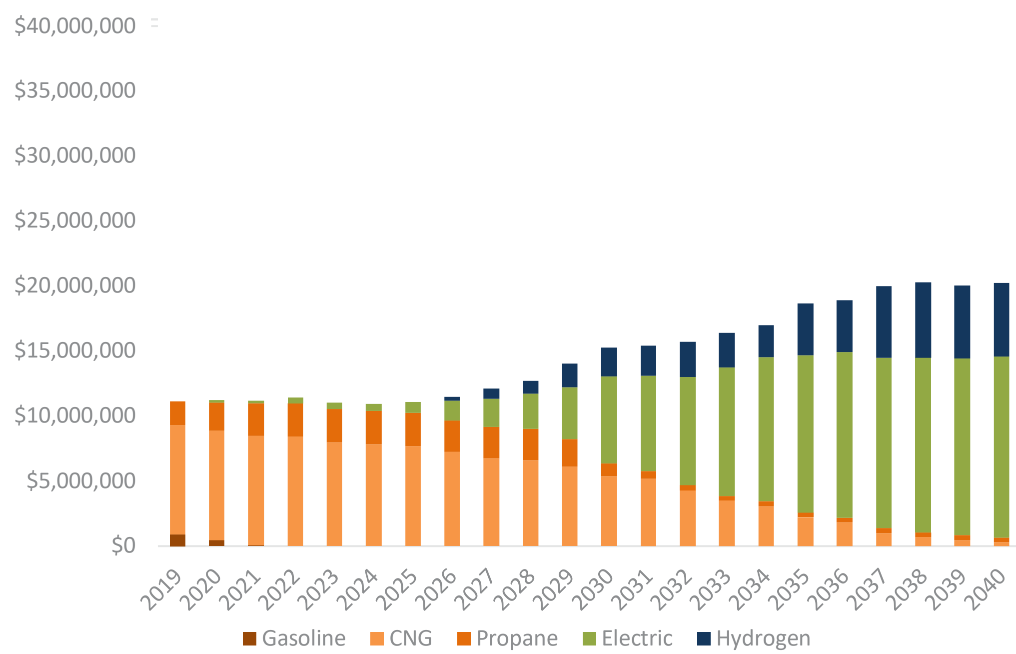


Figure 34 – Annual Fuel Costs, Mixed Scenario

Fuel Assessment Cost Comparison

The Fuel Assessment includes all electrical and fuel costs over the transition for each scenario. **Figure 35** shows the cumulative fuel costs for each scenario. **Table 18** shows the combined total costs, the incremental cost over the Baseline and the percentage of the fleet that is zero-emission in 2040.

Figure 35 - Total Costs, Fuel Assessment

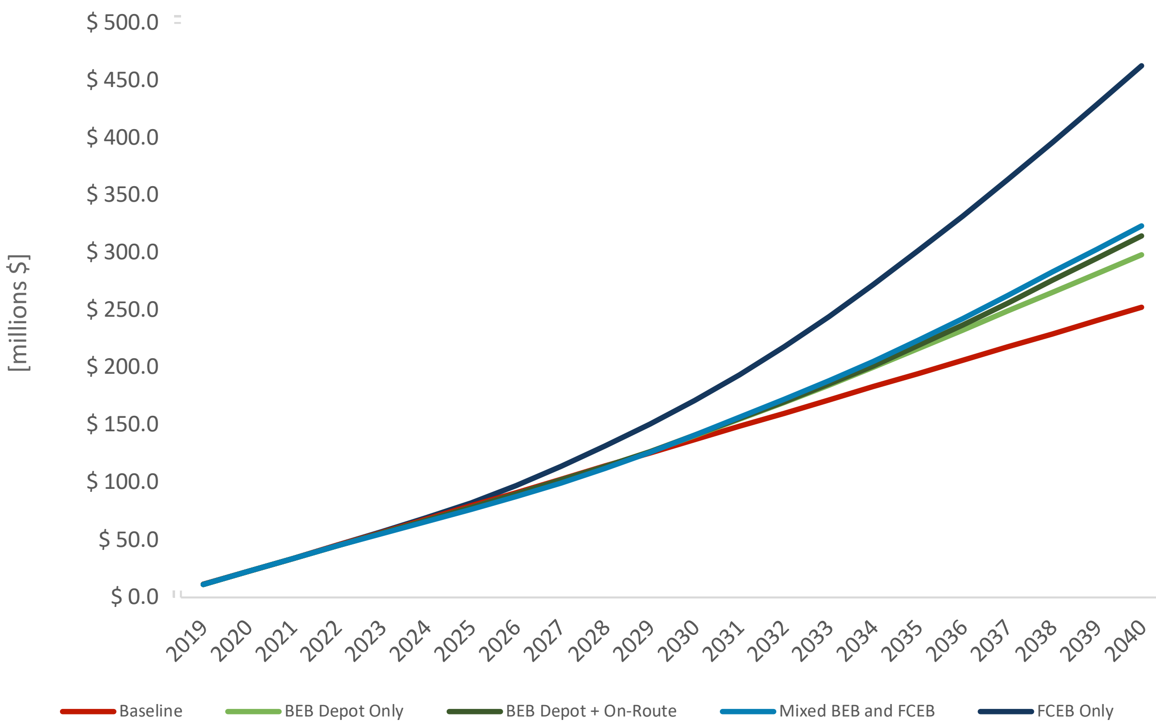


Table 18 - Total Costs, Fuel Assessment

Scenario	Cost	% Cost Increase Over Baseline	% ZEB in 2040
Baseline	$ 252,569,000	----	2%
BEB Depot Only	$ 298,234,000	18%	77%
BEB Depot + On-Route	$ 314,657,000	25%	84%
FCEB Only	$ 462,731,000	83%	95%
Mixed BEB and FCEB	$ 323,380,000	28%	95%

Facilities Assessment

Once bus and fueling requirements are understood for the ZEB transition, the requirements for supporting infrastructure can be determined including charging equipment for BEBs and 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 fleets' energy use estimated in the Fleet and Fuel Assessments, as well as all associated costs with installation of this infrastructure.

This section is divided between battery electric infrastructure and hydrogen fueling infrastructure. The scenarios shown below correspond with scenarios in the Fleet and Fuel Assessments.

Baseline

For the Baseline scenario, there are no additional costs associated with ZEB infrastructure because no ZEBs are added to the fleet. Although a total of nineteen (19) buses are scheduled to be added to the fleet between 2020 and 2022, these buses were already considered part of the baseline analysis as the infrastructure costs have already been programmed. No additional fueling infrastructure upgrades are required to support the Baseline scenario. Since the current internal combustion engine fueling infrastructure (CNG, gasoline, propane) must remain in place throughout the transition period, any upgrades or maintenance shall be required for each scenario. Related costs will be the same for each scenario and thus excluded from the analysis.

Battery-Electric Charging Infrastructure Scenarios

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 significantly different approach to charging and substantial infrastructure upgrades. Plug-in charging is no longer practical as charger dispenser cables can create hazards in the bus yard. Instead, the preferred approach is to use overhead pantograph or reel dispensers attached to gantries installed above bus parking lanes.

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. To define the timeline and costs to install the necessary charging equipment, the scope of work is broken into four key project types: planning, structural, power upgrades, and charger installation. Rather than building out the infrastructure all at once, projects are sized and scheduled to meet the near-term charging requirements.

CTE and AECOM developed estimates for components of each projects to build up a total cost estimate for each project. Assumptions used for BEB infrastructure are shown in **Table 19**. Conceptual BEB depot layouts, prepared by AECOM, are provided **Appendix B**.

Table 19 – BEB Infrastructure Planning Assumptions

Project	Cost Estimate Metrics	Source
Infrastructure Planning	$150k per division	Engineer's estimate
Structural Projects (Gantries, Conduit, duct banks, etc.)	Design/Construction: avg. $99k per bus	Engineer's estimate, includes 20% contingency
Power Upgrade Projects	Design, Construction, & Equip: $218k per MW	Engineer's estimate, includes 20% contingency
Charging Projects	Charging Equipment & Installation: $72k per bus	Quotes and estimates, includes 20% contingency

Key assumptions:

- Gantry structures used at each division except for Copley as depot plug-in charging will be utilized with cutaway vehicles
- One (1) plug-in reel or overhead pantograph per bus
- Two (2) buses per 125 kW charger except at Copley where four (4) per charger
- Two (2) charge windows, i.e., no more than half the buses charge at any given moment expect at Copley where four (4) charge windows
- Off-peak, overnight charging
- Charge management software to manage charging
- Dispenser capacity to serve up to 80% of the fleet at a time; No movement of buses overnight

Source: CTE

BEB Depot-Only Charging

Charging infrastructure to support 648 depot-charged BEBs in 2040 is required, as calculated in the Fleet Assessment.

Depot Planning Projects

The build-out of charging infrastructure will require planning at each division. Planning is assumed to cost approximately $150,000 at each division and will occur as shown in the table below. One planning project is expected at each of the five depots, which totals approximately $750,000 over the life of the transition.

Table 20 – Planning Projects, BEB Depot-Only Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Tota
Copley										1													1
East County								1															1
Kearny Mesa				1																			1
Imperial Ave										1													1
South Bay			1																				1
Total			**1**	**1**				**1**		**2**													**5**

Depot Structural Projects

Structural projects include (1) trenching and build out duct banks from the switchgear to the charger pads, (2) construction of charger pads (i.e., foundation for charging equipment), (3) construction of gantry foundations and overhead gantry structures that hold the dispensers, and (4) installation of conduit from switchgear to charger pads and gantries. **Table 21** shows the detailed cost assumptions for structural projects. These cost assumptions also apply to other projection scenarios. Duct bank cost is incurred only once per division, other costs are on a per gantry basis.

Table 21 – Structural Project Cost Assumptions

Item	Cost	Unit
Initial Duct/Bank	$ 300,000	per division
Gantry & Foundation	$ 500,000	per gantry
Incremental Duct Bank/Conduit	$ 15,000	per gantry
Charger Pad (3 chargers per gantry)	$ 25,000	per gantry
Contingency	20%	on project costs
Design Engineering	6%	on project costs and contingency

Each entry in the table below indicate a structural project to add overhead gantry capacity to each depot. **Table 22** shows the number of gantries added in a given year at each depot. Each gantry can serve between five and eight buses, depending on the location and space constraints at the depots. Note, that gantries are not employed at Copley as the depot only services cutaway vehicles and it is expected that these vehicles will charge using plug-in charging.

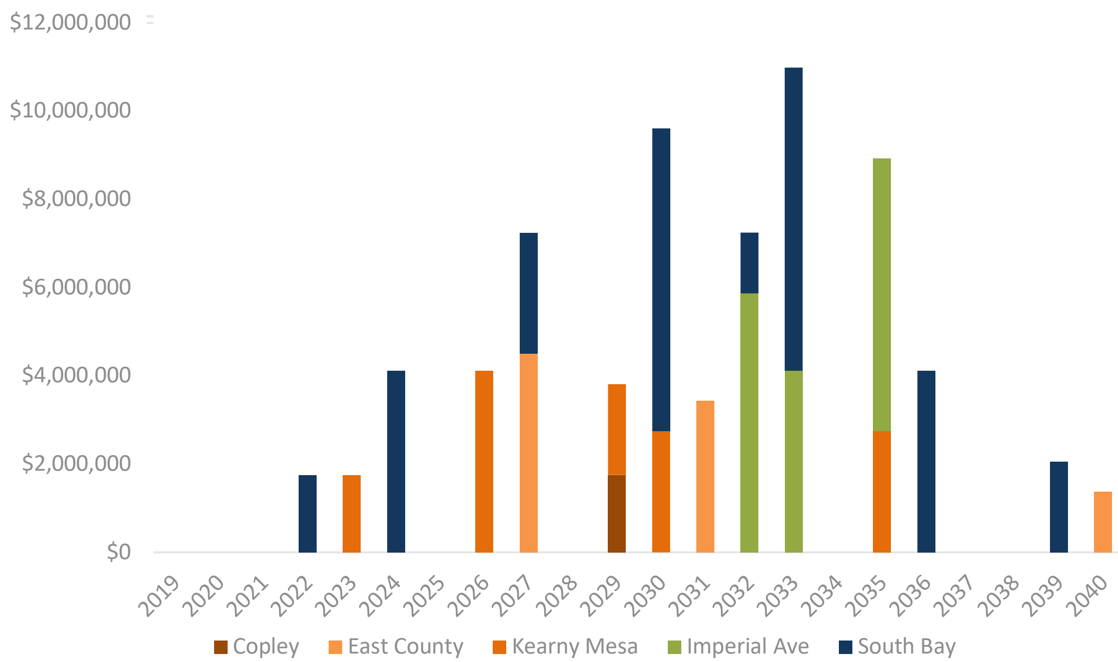
Table 22 – Incremental Gantries, BEB Depot-Only Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley											2												2
East County									6				5									2	13
Kearny Mesa					2			6			3	4					4						17
Imperial Ave														8	6		9						23
South Bay				2		6			4			10		2	10			6			3		43
Total				**2**	**2**	**6**		**6**	**10**		**5**	**14**	**5**	**10**	**16**		**13**	**6**			**3**	**2**	**98**

Figure 36 shows the total annual costs of structural projects by division for the BEB Depot-Only Charging scenario. These costs include the initial duct bank costs at each division, plus gantry and foundation costs, incremental duct bank/conduit costs and charger pad costs per gantry, sequenced in accordance with the above tables. On top of these costs, 20% contingency and 6% engineering cost is added. Although no gantries are proposed at Copley, there are still

structural projects that are required to support plug-in charger installation including duct bank installation, charger pad installation, and design services.

Figure 36 – Annual Structural Projects Cost, BEB Depot-Only Scenario



Depot Power Upgrade Projects

Power upgrade projects include construction of transformer foundations and installation of transformers. It is assumed that transformers will be modular and incremental power requirements are met over time. The table below shows the assumed costs for depot power upgrade projects.

Table 23 – Power Upgrade Cost Assumptions, BEB Depot-Only Scenario

Transformer/Switchback Pad	Cost	Unit
Transformer/Switchback Pad	$ 350,000	per division, up to 10 MW
Construction, Equipment (1 MW)	$ 200,000	per project
Construction, Equipment (2 MW)	$ 300,000	per project
Construction, Equipment (3 MW)	$ 350,000	per project
Construction, Equipment (4 MW)	$ 375,000	per project
Construction, Equipment (5 MW)	$ 400,000	per project
Contingency	20%	on project costs
Design Engineering	6%	on project costs and contingency

Table 24 shows incremental required electrical demand, in megawatts, for each division. Each entry indicates the minimum amount of power that must be added in a given year to meet the growing demand at a given facility as more BEBs are purchased. Please note that the incremental demand at Imperial Avenue noted in 2019. The additional demand associated with two 62.5 kW chargers at East County, Kearney Mesa, and South Bay is not included in this forecast to support the two year pilot program as no additional power upgrades were required to complete the installations.

Table 24 – Incremental Electrical Demand, BEB Depot-Only Scenario [MW]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley										0.7		0.8	0.8								0.4		2.8
East County									0.4	0.7	0.8		1.4									0.7	4.0
Kearny Mesa			0.1		0.8			0.7	0.6		1.3	0.7		0.7			0.3				0.4		5.6
Imperial Ave	0.4													2.1	0.7	0.7	1.4	1.0	1.0				7.2
South Bay				0.7		0.6	0.7	0.8	0.7			2.4		0.8	2.1	2.1		0.7	0.7	1.0	1.0		14.2
Total	**0.4**		**0.1**	**0.7**	**0.8**	**0.6**	**0.7**	**1.5**	**1.7**	**1.4**	**2.1**	**3.9**	**2.2**	**3.6**	**2.8**	**2.8**	**1.7**	**1.7**	**1.7**	**1.0**	**1.8**	**0.7**	**33.8**

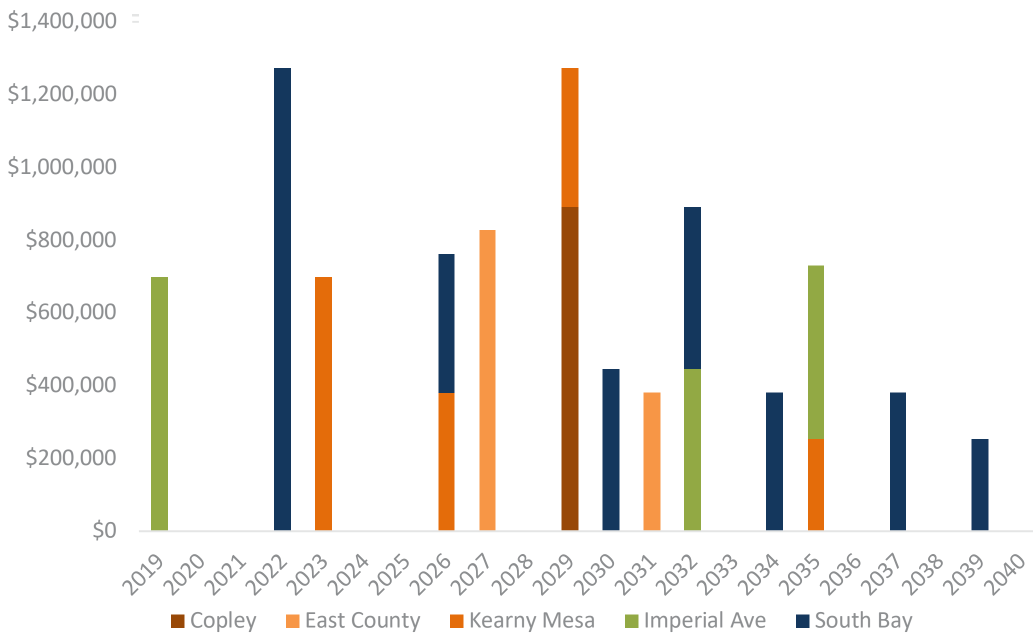
It is more economical, however, to increase power capacity in fewer projects that can meet power requirements for a longer period of time. Therefore, power upgrades are consolidated to occur in selected years, in accordance with the required demand in **Table 24**. These recommended upgrades are shown in **Table 25**. MTS will need to add an additional estimated 36 MW of capacity to its system by 2040 to accommodate charging for 640 BEBs.

Table 25 – Recommended Power Upgrade Projects, BEB Depot-Only Scenario [MW]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley											3.0												**3.0**
East County									2.0				2.0										**4.0**
Kearny Mesa					1.0			2.0			2.0						1.0						6.0
Imperial Ave	1.0													3.0			4.0						8.0
South Bay				2.0				2.0				3.0		3.0		2.0			2.0		1.0		**15.0**
Total	**1.0**			**2.0**	**1.0**			**4.0**	**2.0**		**5.0**	**3.0**	**2.0**	**6.0**		**2.0**	**5.0**		**2.0**		**1.0**		**36.0**

The total cumulative cost of Power Upgrade projects, in 2019 dollars, is provided in **Figure 37.** Total estimated power upgrade costs over the project life are approximately $10 million.

Figure 37 – Annual Power Upgrade Project Costs, BEB Depot-Only Scenario



Depot Charger Installation Projects

Charging projects include purchase and installation of 125 kW chargers and dispensers. Each bus will require one dispenser. Every two (2) buses (40' and larger) will require one (1) charger, while buses at Copley (all smaller, cutaway-style buses) which are assigned four (4) buses to one charger. Please note that six (6) 62.5 kW plug-in chargers with one dispenser each at Imperial Avenue and two (2) 62.5 kW plug-in chargers with one dispenser each at East County, Kearney Mesa, and South Bay have already been installed to support the pilot program. Dispensers for future installation are expected to be either overhead reel or pantograph style except for Copley where plug-in chargers are assumed. **Table 26** provides the costs assumed for charger and dispenser installs.

Table 26 – Dispenser and Charger Project Cost Assumptions

Item	Cost	Unit
Charger	$ 80,000	per 125 kW charger
Charger Installation	$ 10,000	per 125 kW charger
Dispenser/Pantograph	$ 10,000	per dispenser
Dispenser Installation	$ 5,000	per dispenser
Contingency	20%	on project costs

Table 27 and **Table 28** show the annual dispensers and charger installations by division for each year of the project.

Table 27 – Annual Dispenser Installations, BEB Depot-Only Scenario

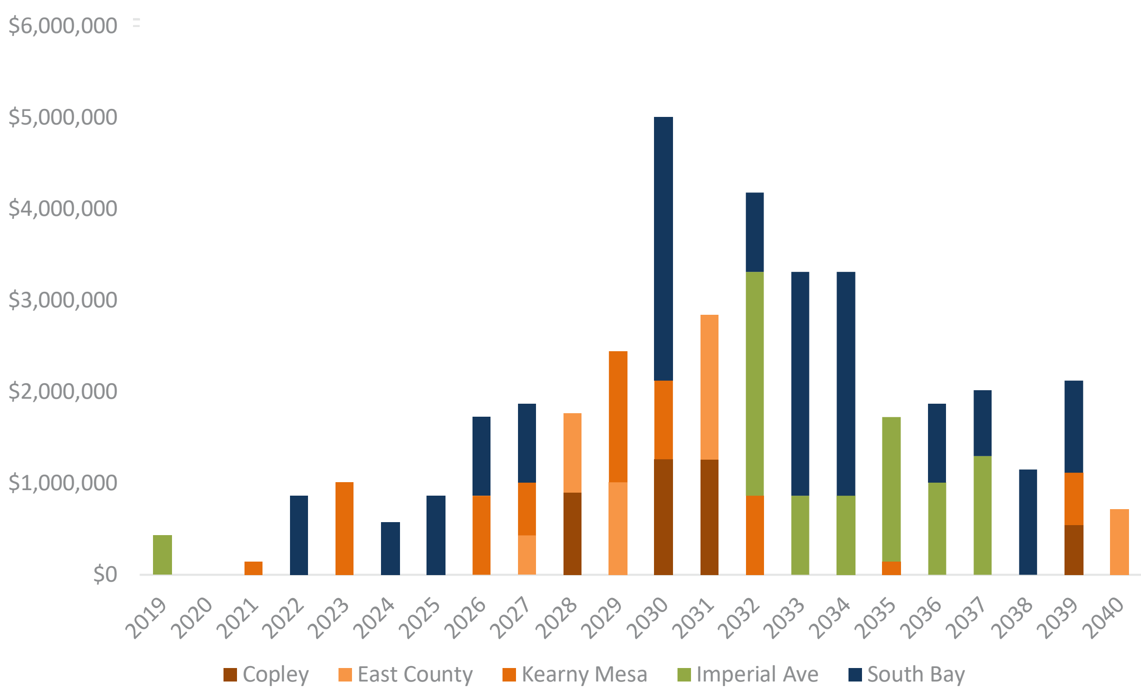
	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Tota
Copley										20		28	28								12		88
East County									6	12	14		22									10	64
Kearny Mesa			2		14			12	8		20	12		12			2				8		90
Imperial Ave	6													34	12	12	22	14	18				118
South Bay				12		8	12	12	12			40		12	34	34		12	10	16	14		228
Total	6		2	12	14	8	12	24	26	32	34	80	50	58	46	46	24	26	28	16	34	10	588

Table 28 – Annual Charger Installations, BEB Depot-Only Scenario

Division	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Tota
Copley										5		7	7								3		22
East County									3	6	7		11									5	32
Kearny Mesa			1		7			6	4		10	6		6			1				4		45
Imperial Ave	3													17	6	6	11	7	9				59
South Bay				6		4	6	6	6			20		6	17	17		6	5	8	7		114
Total	3		1	6	7	4	6	12	13	11	17	33	18	29	23	23	12	13	14	8	14	5	272

Figure 38 shows the annual cost of charger and dispenser installations based on these cost assumptions and the above estimated charger and dispenser quantities.

Figure 38 – Annual Cost of Charger and Dispenser Installations, BEB Depot-Only Scenario



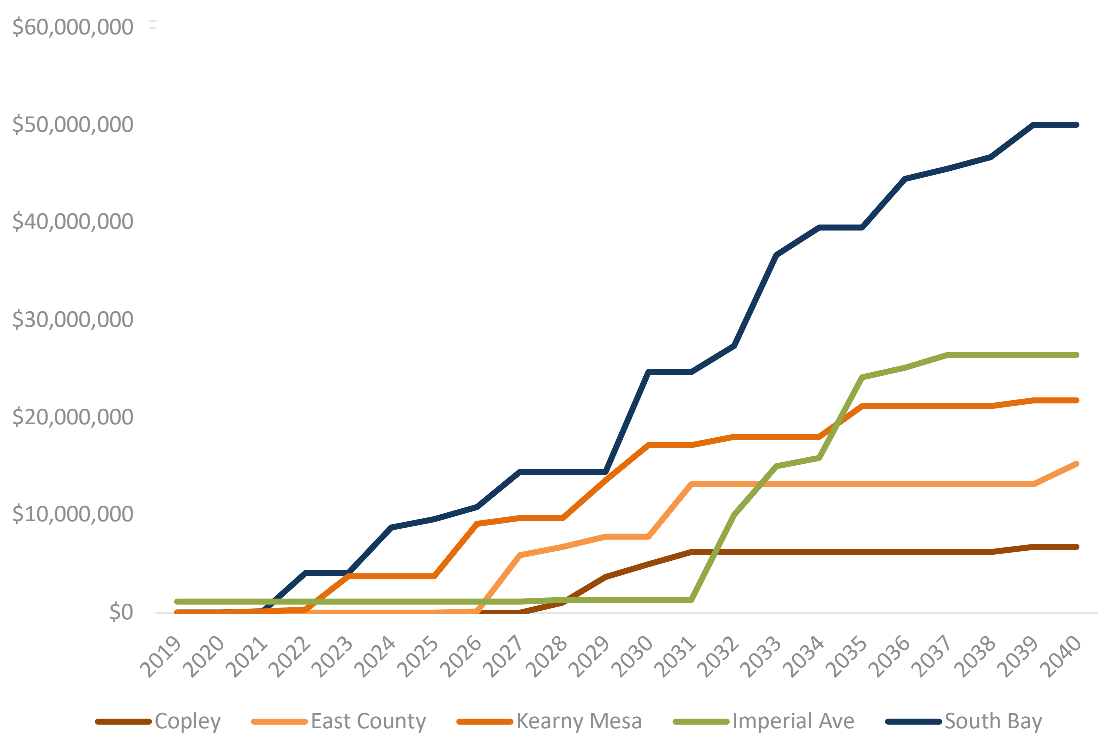
BEB Depot-Only Charging Infrastructure Cost Summary

Table 29 summarizes all costs for charging infrastructure by division for the BEB Depot-Only Charging scenario. **Figure 39** provides the cumulative total cost breakdown by division. The estimated total infrastructure costs for the BEB Depot-Only Charging scenario are approximately $120 million; this includes, at all divisions: all gantry structural projects, all power upgrade projects, all charger and dispenser installations, all planning projects, design engineering costs and added 20% contingency on all costs. Costs for a new facility to accommodate overflow due to reduced bus capacity at existing facilities due to infrastructure space requirements has not been incorporated in this analysis; however, there may be a need to construct a new facility as the build-out progresses. Estimated costs of $185 million for a new facility are not included in this analysis.

Table 29 – Total Infrastructure Costs, BEB Depot-Only Scenario

Division	Cost
Copley	$ 6,756,000
East County	$ 15,277,000
Kearny Mesa	$ 21,780,000
Imperial Ave	$ 26,448,000
South Bay	$ 50,045,000
Total	**$ 120,305,000**

Figure 39 – Cumulative Total Infrastructure Costs, BEB Depot-Only Scenario



BEB Depot and On-Route Charging

The BEB Depot and On-Route Charging scenario adds on-route charging infrastructure to the depot charging infrastructure already developed and presented in the previous section. The addition of on-route charging supports deployment of an additional 60 on-route-charged electric buses in addition to 640 depot-charged buses in 2040. All depot charging-related quantities, locations and costs are identical to BEB Depot-Only Charging scenario. The physical locations of the on-route chargers are not at the depot, but are referenced by depot to serve buses that operate out of the referenced depot. In this section, only costs related to the additional on-route infrastructure are shown; summarized at the end are the combined on-route and depot charging costs.

On-route chargers do not require any additional support structure to be built, such as gantries, and do not require any structural project planning as with depot chargers. Required infrastructure projects for on-route chargers include planning, power upgrade, and charger purchase and installation. **Table 30** shows the cost assumptions used in the following sections to estimate costs for on-route charging infrastructure.

Table 30 – On-Route Infrastructure Project Cost Assumptions

Item	Cost	Unit
Planning	$ 100,000	per site
Chargers	$ 350,000	per 450 kW charger
Charger Installation	$ 50,000	per 450 kW charger
Transformer/Switchback Pad	$ 50,000	per site
Construction, Equipment (1 MW)	$ 200,000	per MW
Contingency	20%	on project costs
Design Engineering	6%	on project costs and contingency

On-Route Planning Projects

The build-out of on-route charging infrastructure will require planning for each site. It is assumed that each on-route charging planning project will cost $100,000 per site with additional 20% contingency costs applied. The planning projects will occur at each location as shown in **Table 31**, below. A total of 8 on-route charging sites will be required to serve the additional 67 on-route-charged buses. Note, because Copley exclusively houses on-demand paratransit buses, on-route charging is not feasible for these buses because they do not run fixed routes.

Table 31 – Planning Projects, BEB Depot and On-Route Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley																							
East County											1												1
Kearny Mesa																	3						3
Imperial Ave																			3				3
South Bay																				1			1
Total											**1**						**3**		**3**	**1**			**8**

Total planning costs are approximately $1 million over the life of the transition.

On-Route Power Upgrade Projects

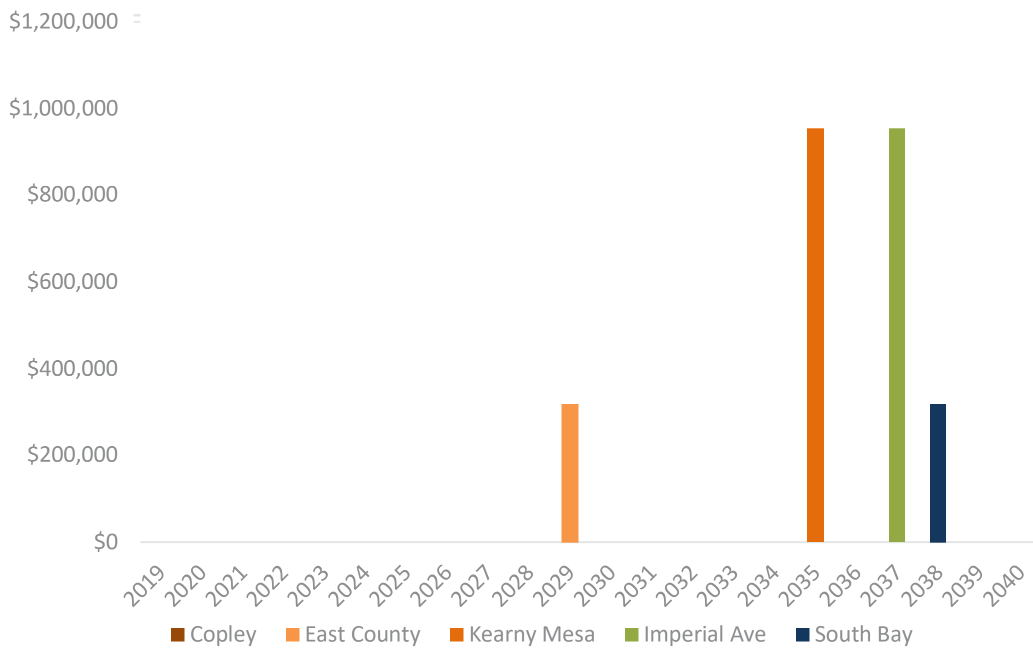
Power upgrade projects include construction of transformer foundations and installation of transformers. Each on-route charging site requires approximately 1 MW of power for two 450 kW chargers. **Table 32** shows a total of 8 MW of additional power required to serve the 67 on-route charged buses, 1 MW each for the 8 required site locations. Power upgrades are in addition to depot power upgrade projects from the BEB Depot-Only Charging scenario.

Table 32 – On-Route Power Upgrade Projects, BEB Depot and On-Route Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley																							
East County											1.0												1.0
Kearny Mesa																	3.0						3.0
Imperial Ave																			3.0				3.0
South Bay																				1.0			1.0
Total											**1.0**						**3.0**		**3.0**	**1.0**			**8.0**

The total annual cost of on-route power upgrade projects, in 2019 dollars, is provided in **Figure 40**. From **Table 30**, each power upgrade project is assumed to cost $250k per site (at 1 MW each), plus 20% contingency costs. In 2040, total power upgrade costs are approximately $2.5 million over the life of the transition.

Figure 40 – Annual Power Upgrade Project Cost for On-Route Charging, BEB Depot and On-Route Scenario



On-Route Charger Installation Projects

Table 33 shows assumed costs for on-route charger procurement and installation projects.

Table 33 – On-Route Charger Project Cost Assumptions

Item	Cost	Unit
Chargers	$ 350,000	per 450 kW charger
Charger Installation	$ 50,000	per 450 kW charger
Contingency	20%	of project costs

On-route chargers require purchase and installation of 450 kW chargers and pantograph dispensers. For on-route charging, one dispenser per charger is assumed, and is included in the charger cost.

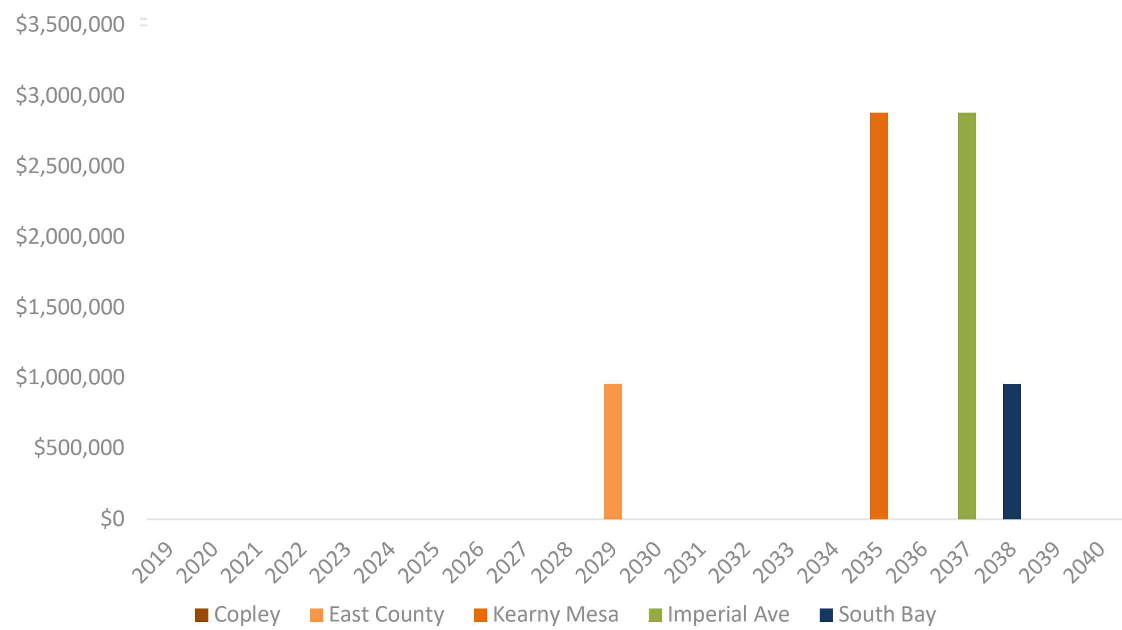
Table 34 shows on-route charger installations. Like planning and power upgrade projects, all site charger installations for each depot occur in a single year. Each charging site requires two chargers. For 8 sites, a total of 16 chargers are required.

Table 34 – Charger Installation Projects, BEB Depot and On-Route Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley																							
East County											2												**2**
Kearny Mesa																	6						**6**
Imperial Ave																			6				**6**
South Bay																				2			**2**
Total											**2**						**6**		**6**	**2**			**16**

Figure 41 shows the total annual costs of on-route charger installations for the BEB Depot and On-Route Charging scenario. Total charger procurement and installation costs are approximately $8 million over the life of the project.

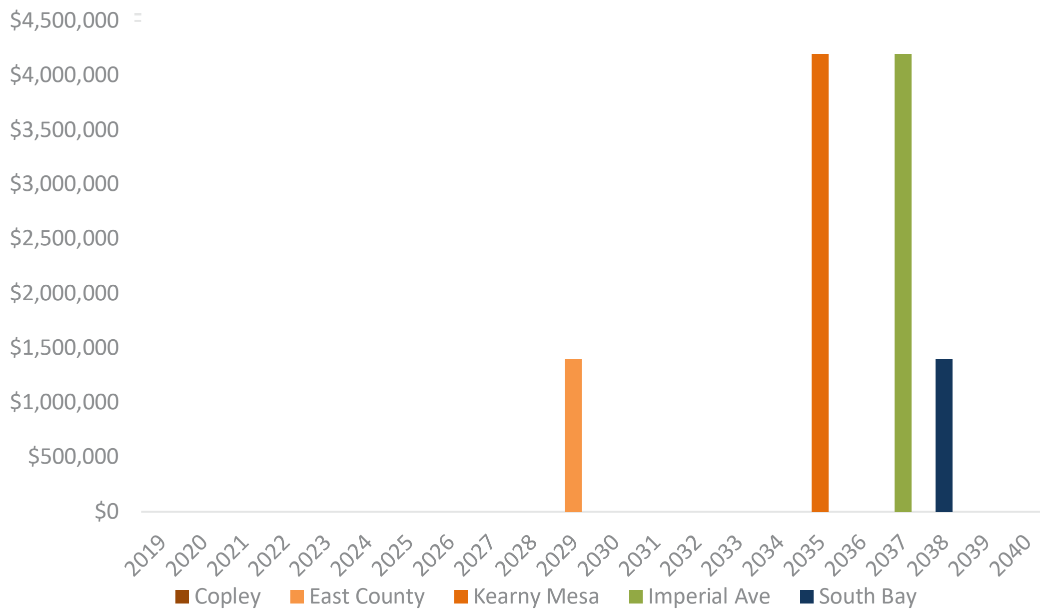
Figure 41 – Annual Charger Install Costs for On-Route Chargers, BEB Depot and On-Route Scenario



BEB Depot and On-Route Charging Infrastructure Summary

Estimated total annual costs for on-route charging infrastructure are shown in **Figure 42**. Total cumulative on-route charger infrastructure costs are approximately $11 million over the transition period.

Figure 42 – Total On-Route Infrastructure Costs, BEB Depot and On-Route Charging Scenario

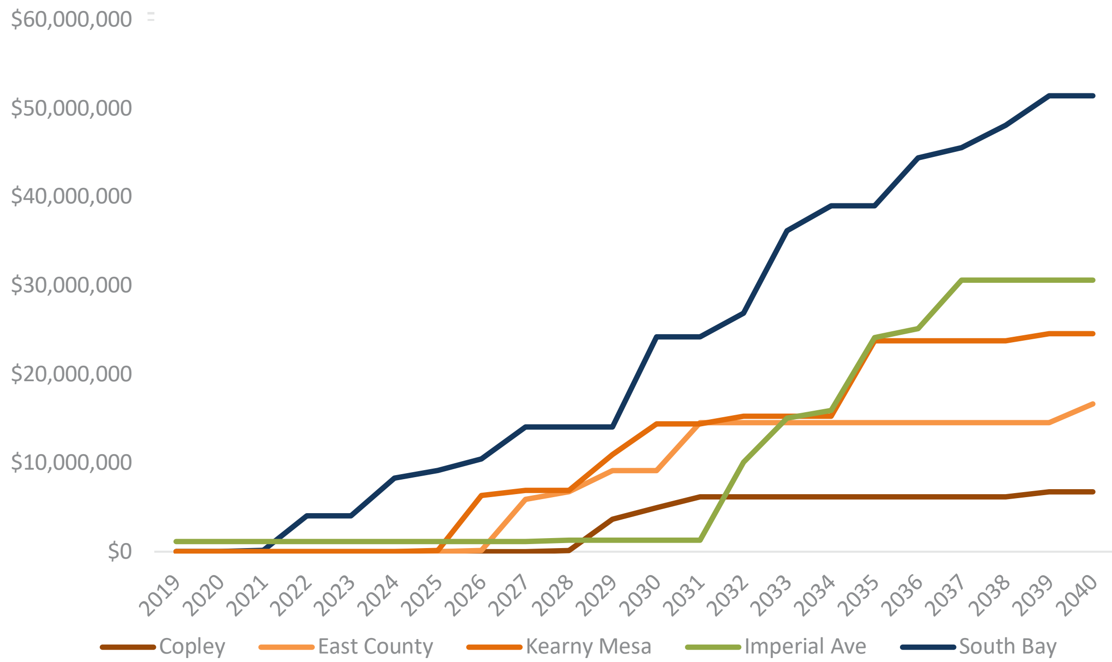


On-route charging infrastructure costs are incremental to depot charging infrastructure costs. The total combined on-route and depot charging infrastructure costs are shown in **Table 35** and cumulative annual infrastructure costs for the BEB Depot and On-Route Charging Scenario are shown in **Figure 43**. The total combined infrastructure costs for the BEB Depot and On-Route Charging scenario is approximately $131 million.

Table 35 – Total Infrastructure Costs, BEB Depot and On-Route Charging Scenario

Division	Cost
Copley	$ 6,756,000
East County	$ 16,675,000
Kearny Mesa	$ 25,974,000
Imperial Ave	$ 30,642,000
South Bay	$ 51,443,000
Total	**$ 131,489,000**

Figure 43 – Cumulative Total Infrastructure Costs, BEB Depot and On-Route Charging



Hydrogen Fuel Cell Infrastructure Scenarios

To define the timeline and costs to build-out hydrogen fueling infrastructure, we break the scope of work into four key project types: (1) planning, (2) structural, (3) maintenance bay upgrades, and (4) fueling. Rather than building out the infrastructure all at once, projects are sized and scheduled to meet the near-term fueling requirements.

CTE worked with Fiedler Group to develop the cost assumptions for FCEB infrastructure, summarized in the table below. Proposed depot layouts and the final report for depot upgrades prepared by Fiedler Group, is provided in **Appendix C.**

Table 36: FCEB Infrastructure Planning Assumptions

Project	Cost Estimate	Source
Infrastructure Planning	$150,000 per division	Engineer's estimate
50-Bus Incremental Mechanical Equipment and Installation Package	Varies by facility; Includes design, permitting, and installation for two (2) dispensers; all mechanical process equipment; electrical utilities and switchgear. Excludes storage tanks.	Engineer's estimate, vendor quotes
Incremental Addition of 15,000 Liquid Hydrogen Tank	$290,000 per tank for installation	Engineer's estimate, vendor quotes
Maintenance Upgrades	Electrical, Lighting, Ventilation, and Gas Detection - $125,000 per bay for depots that do not service CNG - $50,000 per bay for depots that currently service CNG	Engineer's estimate

FCEB Only

The FCEB scenario assumes that FCEBs are utilized where based, on analysis, they meet daily service requirements. The following estimates calculate necessary hydrogen infrastructure costs to support a fleet of 791 FCEBs in 2040, including 191 hydrogen powered cutaways. See **Appendix C**, which includes proposed site plans, detailed breakdown of required equipment and project phasing.

Planning Projects

The build-out of hydrogen infrastructure will require planning at each division. It is assumed that each planning project will cost $150,000, occurring as shown in the table below, and only once per division. Total planning projects for five divisions total approximately $750,000.

Table 37 – Planning Projects, FCEB Only Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley										1													1
East County								1															1
Kearny Mesa							1																1
Imperial Ave				1																			1
South Bay					1																		1
Total				1	1		1	1		1													5

50-Bus Mechanical Projects

For hydrogen fueling equipment, it is economical to package projects in 50-bus increments with all necessary mechanical and fueling components included, except for liquid hydrogen storage tanks. Storage tanks can be added in a modular fashion as demand increases, separately from other fueling components The 50-bus mechanical projects include:

1. Two dispensers, though additional dispensers may be added
2. All mechanical process equipment and hydrogen wetted components
3. Design, engineering, and permitting
4. Construction costs
5. Demolition of existing pavement, and excavation
6. Installation of new equipment foundations
7. All electrical conduit, conductors and termination
8. Emergency Shut Down and Notification system
9. Mechanical installation
10. Electrical utilities and switchgear

Table 38 shows the estimated mechanical project costs by year and division. Costs vary per project in a given year due to the scale of the implementation at each division. Buildout of mechanical infrastructure at each division are grouped into no more than three phases to minimize disruption of service and capital expenses. The total cost of mechanical projects to support the FCEB Only scenario is approximately $63 million, spread over 12 different projects.

Table 38 – 50-Bus Mechanical Projects Cost, FCEB Only Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley												8.6				3.6							**12.3**
East County										4.3				3.6									**7.9**
Kearny Mesa									4.3				3.6										**7.9**
Imperial Ave						4.3									6.5				4.3				**15.1**
South Bay							8.6									6.5						4.3	**19.4**
Total						**4.3**	**8.6**		**4.3**	**4.3**		**8.6**	**3.6**	**3.6**	**6.5**	**10.1**			**4.3**			**4.3**	**62.6**

Storage Capacity Projects

Storage capacity projects include the incremental addition of one or more 15,000-gallon liquid hydrogen storage tanks. Tanks are sized at 15,000 gallons to accommodate one truckload of liquid hydrogen, or approximately 3,000 kg. Storage capacity projects can be built in conjunction with a 50-bus mechanical project wherever possible, but can also occur on their own as necessary as the FCEB fleet grows at a given division. The required capacity of hydrogen storage at a given depot is sized to accommodate an approximate 4-day supply of average daily fuel use. **Table 39** shows the planned storage capacity projects and costs by year and division. Costs shown include installation when not accompanied by a mechanical project. A standalone, single-tank project costs approximately $290,000. The total storage capacity projects will cost approximately $5 million over the life of the study.

Table 39 – Storage Capacity Projects Cost, FCEB Only Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Copley												0.58											**0.58**
East County										0.29				0.29									**0.58**
Kearny Mesa									0.29				0.29					0.44					**1.02**
Imperial Ave						0.29									0.58				0.58				**1.45**
South Bay							0.87									0.58							**1.45**
Total						**0.29**	**0.87**		**0.29**	**0.29**		**0.58**	**0.29**	**0.29**	**0.58**	**0.58**		**0.44**	**0.58**				**5.08**

Maintenance Bay Upgrade Projects

Maintenance bays at each depot will require hydrogen detection and exhaust equipment to ensure safety. **Table 40** indicates the timing and location of upgrade projects, as well as the number of bays that require upgrades at each division. A total of 84 maintenance bays will require upgrades.

Table 40 – Hydrogen Maintenance Bay Upgrade Projects, FCEB Only Scenario

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Totals
Copley											10												**10**
East County									12														**12**
Kearny Mesa								20															**20**
Imperial Ave					15																		**15**
South Bay						27																	**27**
Total					**15**	**27**		**20**	**12**		**10**												**84**

Table 41 shows the associated project costs for the upgrades. A total of approximately $5 million is required to upgrade all 84 maintenance bays. We assume a cost of $50,000 per maintenance bay to retrofit CNG facilities for hydrogen buses at East County, Imperial Avenue, Kearny Mesa and South Bay. At Copley, which does not currently service any CNG buses, we assume $125,000 per bay for the required upgrades. This cost comes from requirement of additional ventilation systems; CNG facilities have the required ventilation systems already installed.

Table 41 – Maintenance Bay Upgrade Project Costs, FCEB Only Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Totals
Copley												1.3											**1.3**
East County										0.6													**0.6**
Kearny Mesa									1.0														**1.0**
Imperial Ave						0.8																	**0.8**
South Bay							1.4																**1.4**
Total						**0.8**	**1.4**		**1.0**	**0.6**		**1.3**											**5.0**

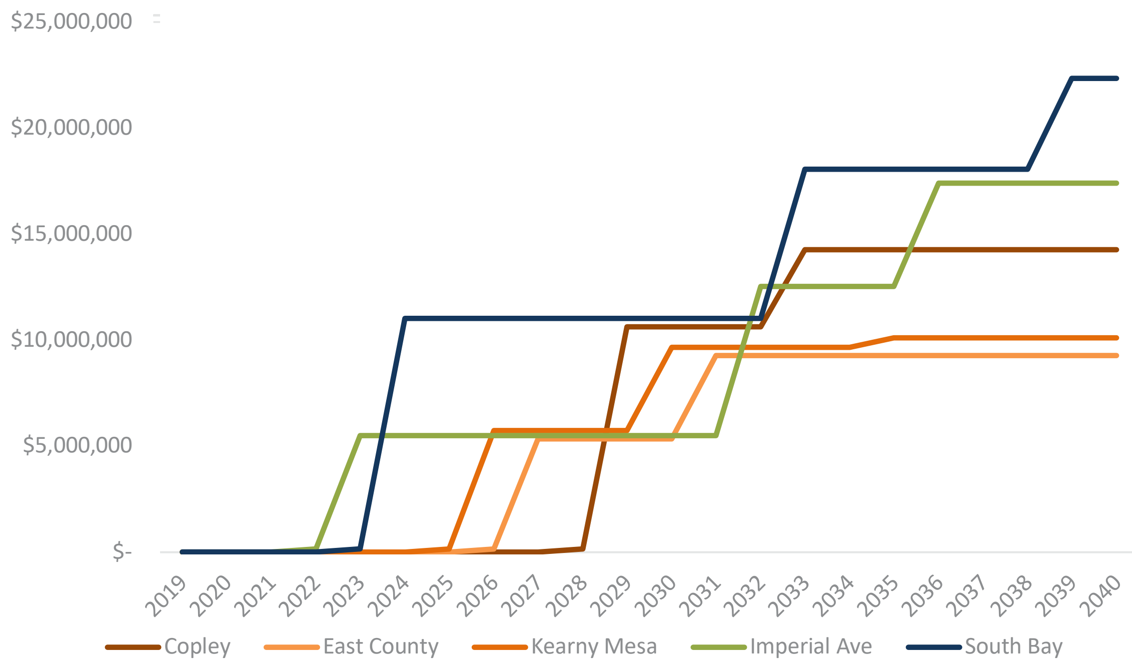
FCEB Only Infrastructure Summary

Table 42 provides the total infrastructure costs for the FCEB Only scenario for the transition. The total buildout of required FCEB infrastructure will require approximately $73 million for the FCEB Only scenario. **Figure 44** shows a cumulative summary by year and division.

Table 42 – Total Infrastructure Costs, FCEB Only Scenario

Division	Cost
Copley	$ 14,265,000
East County	$ 9,274,000
Kearny Mesa	$ 10,109,000
Imperial Ave	$ 17,403,000
South Bay	$ 22,344,000
Total	**$ 73,394,000**

Figure 44 – Cumulative Infrastructure Costs, FCEB Only Scenario

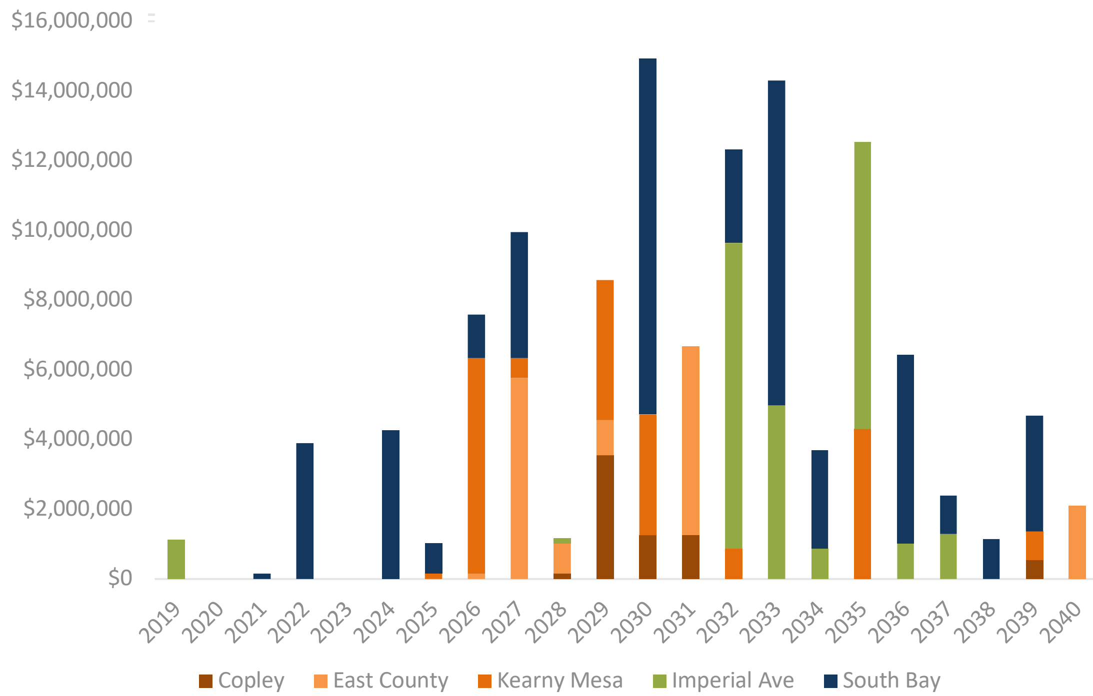


Mixed BEB and FCEB Scenario

In the Mixed BEB and FCEB scenario, charging infrastructure is required to service a total of 640 BEBs in addition to hydrogen fueling infrastructure to service 151 FCEBs across all five depots, including 108 hydrogen powered cutaways. A small number of vehicles will remain propane by 2040 but will ultimately transition to FCEB during the next replacement cycle.

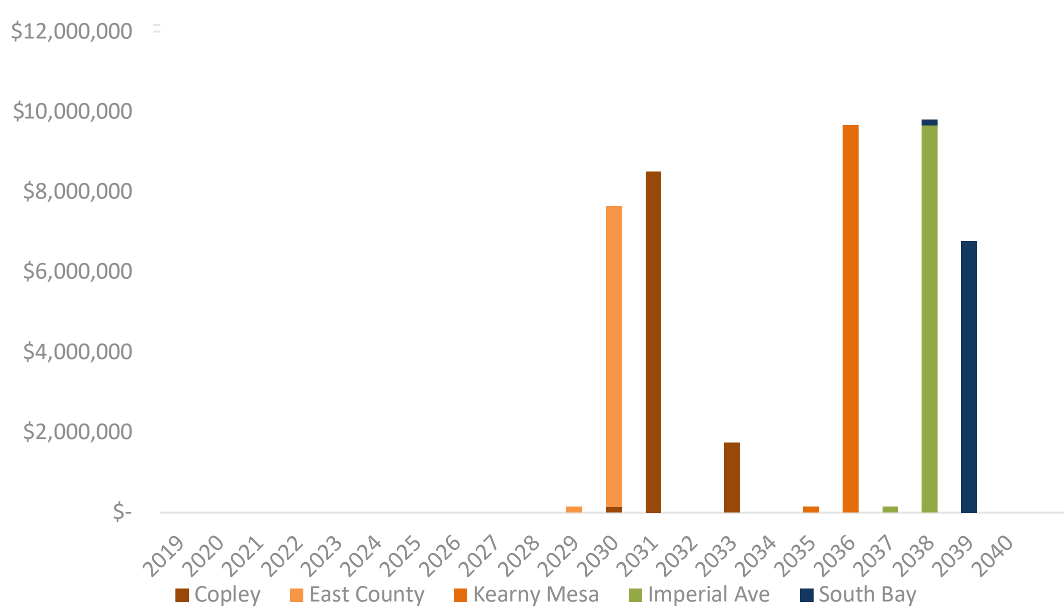
BEB charging infrastructure necessary to support the Mixed BEB and FCEB scenario mimics the costs provided in the BEB Depot-Only Charging scenario. The total infrastructure costs, by division and year, for BEB deployment are detailed on **Figure 45**.

Figure 45 - Annual BEB Infrastructure Costs, Mixed BEB and FCEB Scenario



In addition to BEB charging, hydrogen fueling is required to support the Mixed BEB and FCEB scenario. The FCEB fueling costs are developed as discussed in the FCEB Only scenario where the scope of work is broken into four (4) key project types: (1) planning, (2) structural, (3) maintenance bay upgrades, and (4) fueling. Infrastructure is built out over time as necessary to support FCEB deployment. Annual costs for the FCEB infrastructure portion of the mixed fleet are provided in **Figure 46**.

Figure 46 - Annual FCEB Infrastructure Costs, Mixed BEB and FCEB Scenario



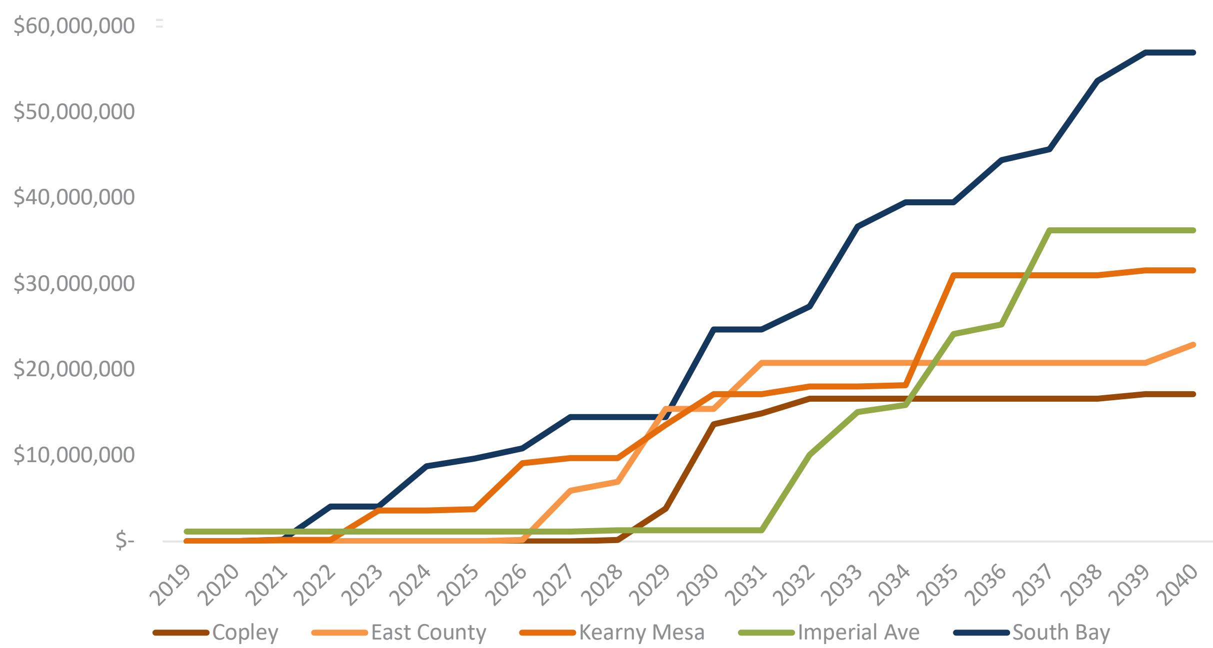
Mixed BEB and FCEB Infrastructure Summary

Table 43 provides the total infrastructure costs for the Mixed BEB and FCEB scenario for the transition. This total buildout of required BEB and FCEB infrastructure is expected to require approximately $165 million. **Figure 47** provides cumulative infrastructure costs for the Mixed BEB and FCEB scenario by year and division.

Table 43 - Total Infrastructure Costs, Mixed BEB and FCEB Scenario

Division	Cost
Copley	$ 17,166,000
East County	$ 22,927,000
Kearny Mesa	$ 31,590,000
Imperial Ave	$ 36,258,000
South Bay	$ 56,975,000
Total	**$ 164,915,000**

Figure 47 - Cumulative Infrastructure Costs, Mixed BEB and FCEB Scenario



Facilities Assessment Cost Comparison

The Facilities Assessment includes all infrastructure-related costs over the transition for each scenario. **Figure 48** shows the cumulative infrastructure costs for each scenario. **Table 44** shows the combined total costs and percent ZEB fleet in 2040. Note that the percent increase over baseline is not provided in the table as the Baseline is assumed to be zero as additional infrastructure is not required to operate the fleet in the current makeup.

Figure 48 - Total Costs, Facilities Assessment

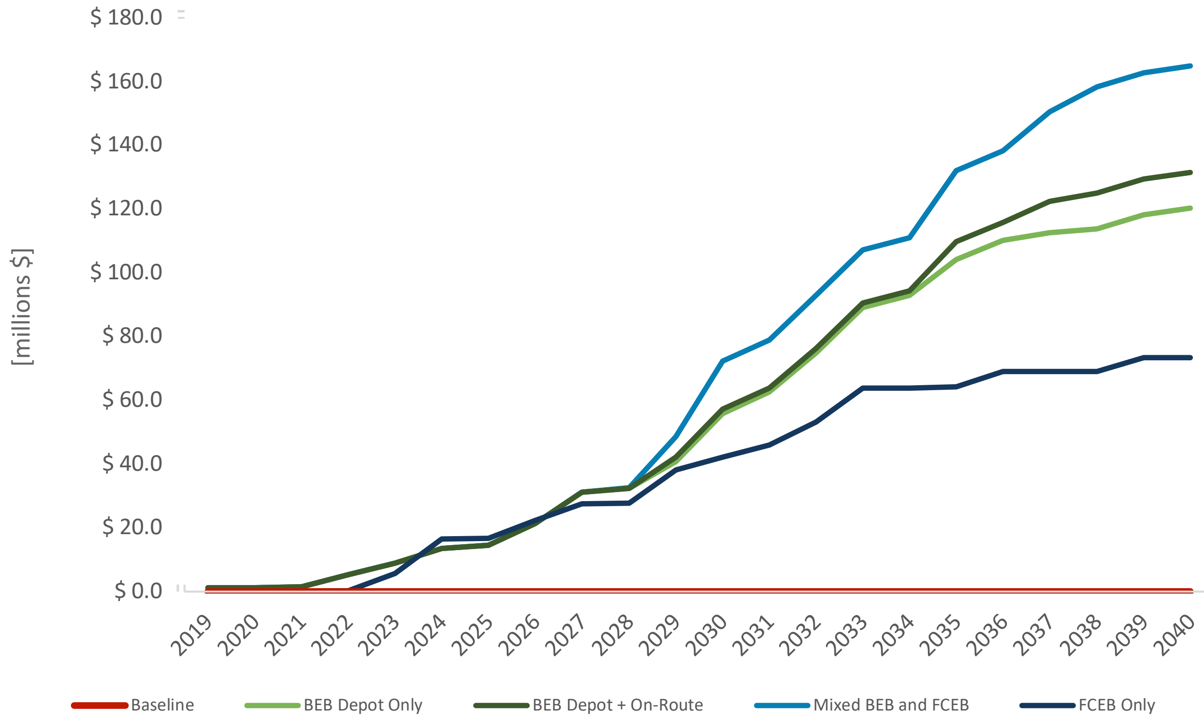


Table 44 - Total Costs, Facilities Assessment

Scenario	Cost	% Cost Increase Over Baseline	% ZEB in 2040
Baseline	$ ----	----	2%
BEB Depot Only	$ 120,305,000	NA	77%
BEB Depot + On-Route	$ 131,489,000	NA	84%
FCEB Only	$ 73,394,000	NA	95%
Mixed BEB and FCEB	$ 164,915,000	NA	95%

Maintenance Assessment

One of the anticipated benefits of moving to a BEB or FCEB fleet is maintenance costs. Conventional wisdom indicates that a transit agency may attain 30% to 50% in maintenance cost savings for a BEB. 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 an internal combustion engine bus. However, the savings in traditional maintenance costs may be offset by the cost of battery or fuel-cell replacements over the life of the vehicles.

There is limited data available on early deployments and many early deployments are from new manufacturers where production quality issues manifest as maintenance issues. Internal combustion engine vehicle labor and maintenance costs includes CNG, Propane and Diesel and is provided by MTS. BEB labor and maintenance cost comes from analysis completed by the U.S. DOE National Renewable Laboratory (NREL). There is limited information available regarding maintenance costs for FCEBs due to the limited number of vehicles in operation in the United States. Much of the information comes from AC Transit, which is the largest FCEB fleet in the country. Unfortunately, these buses are older models that require a significant amount of maintenance. In addition, the buses are out of warranty and support from the European manufacturer is expensive. As a result, rather than use artificially high costs for older model FCEBs, maintenance costs associated with CNG buses were used as a replacement based on similarities between the vehicles. In addition to labor and materials, the cost impact of mid-life overhauls for major components for each type of bus is also estimated. **Table 45** shows the assumed costs of scheduled and unscheduled labor and maintenance used in this analysis.

Table 45 – Labor and Materials Cost Assumptions

Type	Estimate	Source
Internal combustion engine	$1.05/mi, including tires	MTS
BEB	$0.74/mi	U.S. DOE NREL
FCEB	$1.05/mi including tires	MTS/CTE

In addition to Labor and Maintenance, the cost impact of mid-life overhauls of major components for each type of bus are estimated. Assumptions used in this analysis are given in **Table** 46**.** These costs are from MTS for internal combustion engine buses and for BEB and FCEB, mid-life overhaul cost estimates are provided by vehicle OEMs.

Table 46 – Mid-Life Overhaul Cost Assumptions

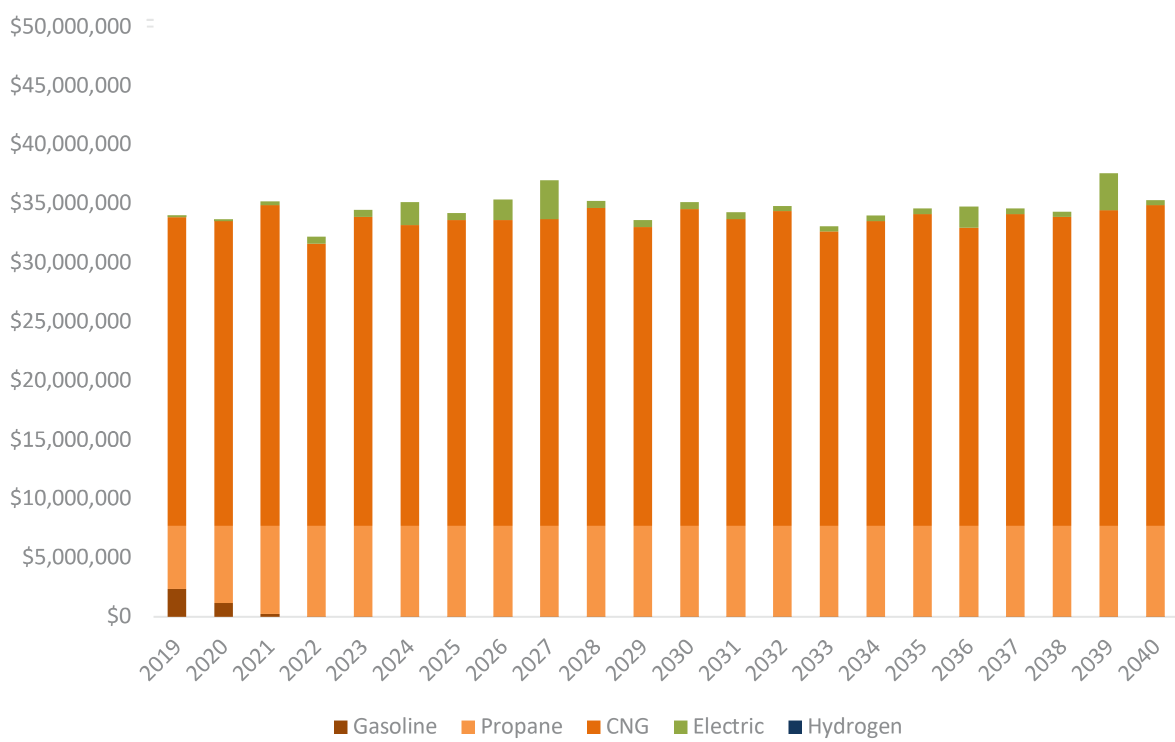
Type	Overhaul Scope	Estimate	Source
Internal combustion engine	Engine/Transmission Overhaul	$50k per bus	MTS
BEB	Battery Replacement	$500 per kWh	Bus OEM

FCEB	Battery Replacement Fuel Cell Overhaul	$500 per kWh $40k per bus	Bus OEM Fuel Cell OEM

Baseline

The baseline assumes no changes to MTS' current fleet configuration throughout the life of the study, i.e. no ZEB purchases other than those already planned, and is used for comparative analysis. **Figure 49** shows the combined labor, materials and mid-life overhaul costs for the Baseline scenario fleet projection for each year of the study, in 2019 dollars. Annual fleet maintenance costs average approximately $35 million per year.

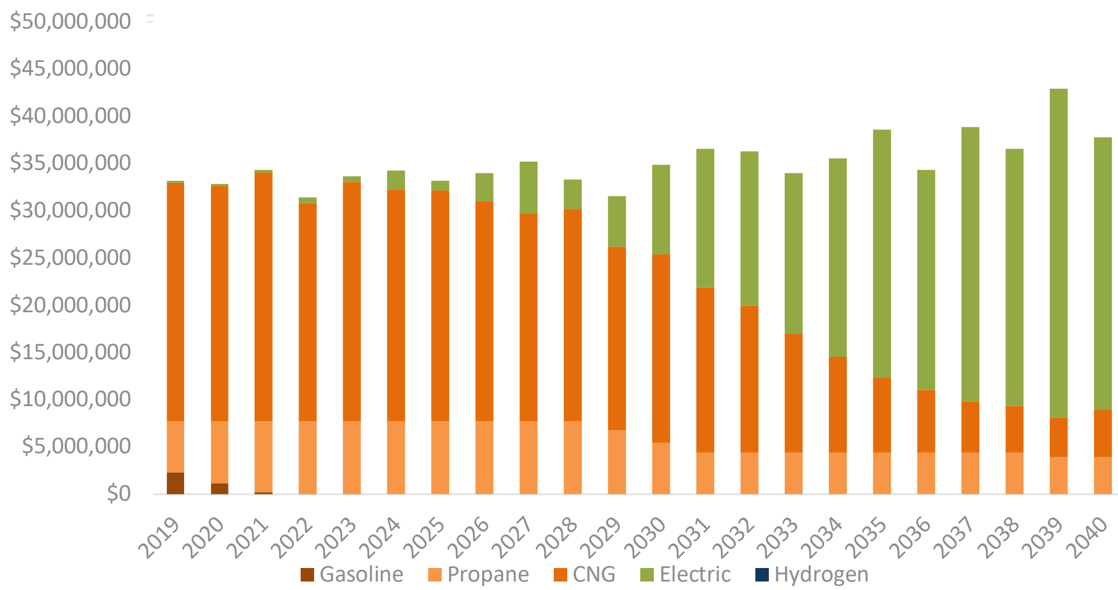
Figure 49 – Annual Fleet Maintenance Costs, Baseline



BEB Depot-Only Charging

Figure 50 shows the combined labor, materials and mid-life overhaul costs for the BEB Depot-Only Charging scenario for each year of the transition, in 2019 dollars.

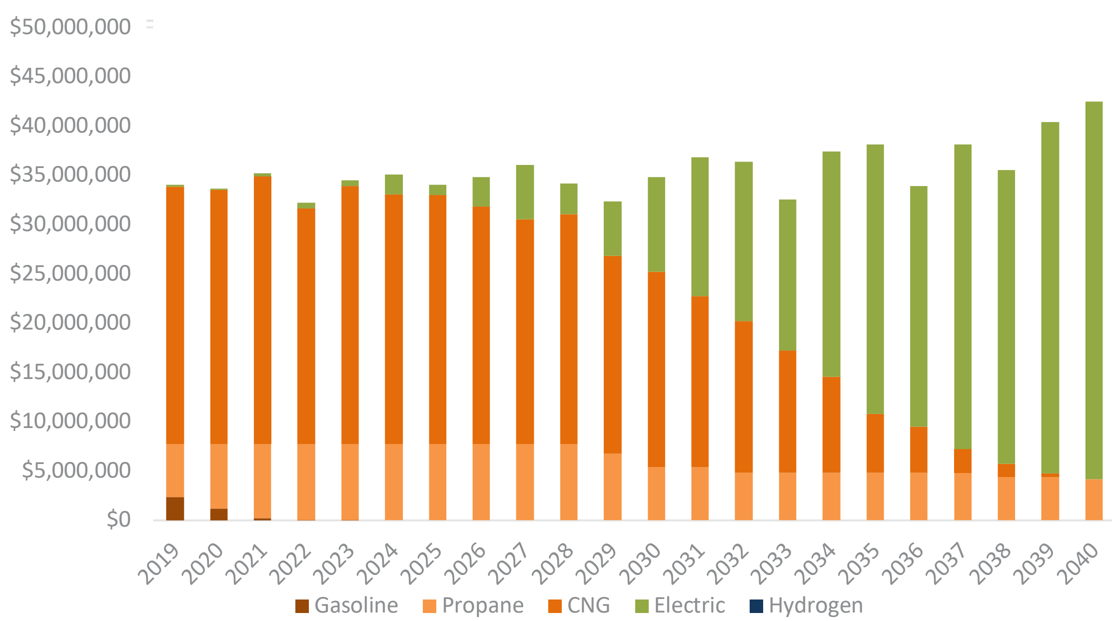
Figure 50 – Annual Fleet Maintenance Costs, BEB Depot-Only Scenario



BEB Depot and On-Route Charging

Figure 51 shows the combined labor, materials and mid-life overhaul costs for the BEB Depot and On-Route Charging scenario for each year of the transition, in 2019 dollars.

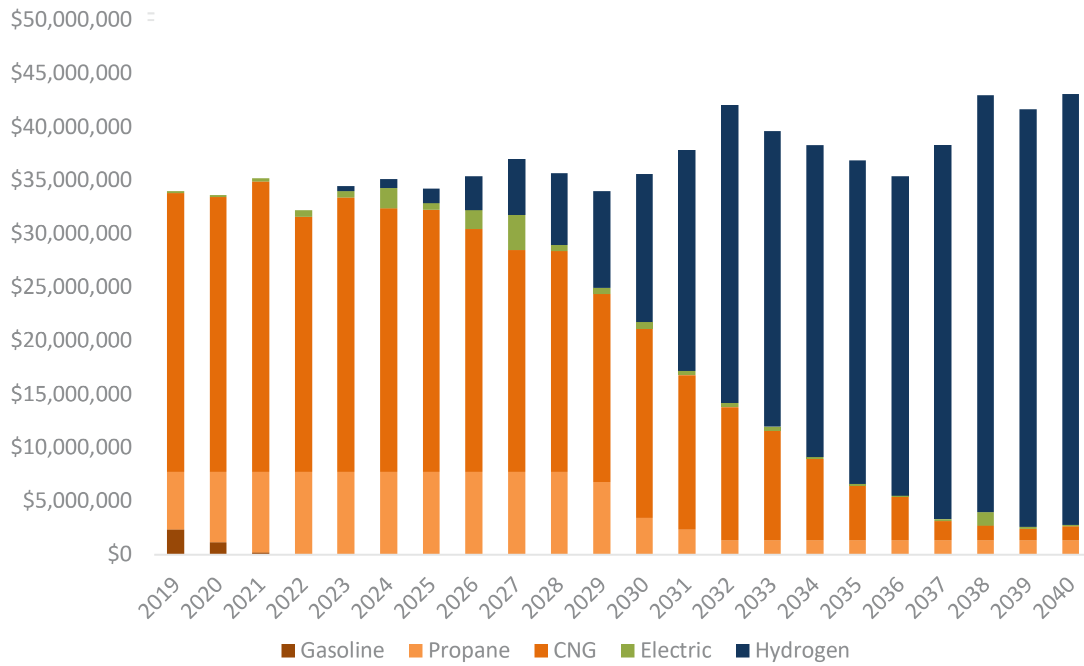
Figure 51 – Annual Fleet Maintenance Costs, BEB Depot and On-Route Scenario



FCEB Only

Figure 52 shows the combined labor, materials and mid-life overhaul costs for FCEB Only scenario for each year of the transition, in 2019 dollars.

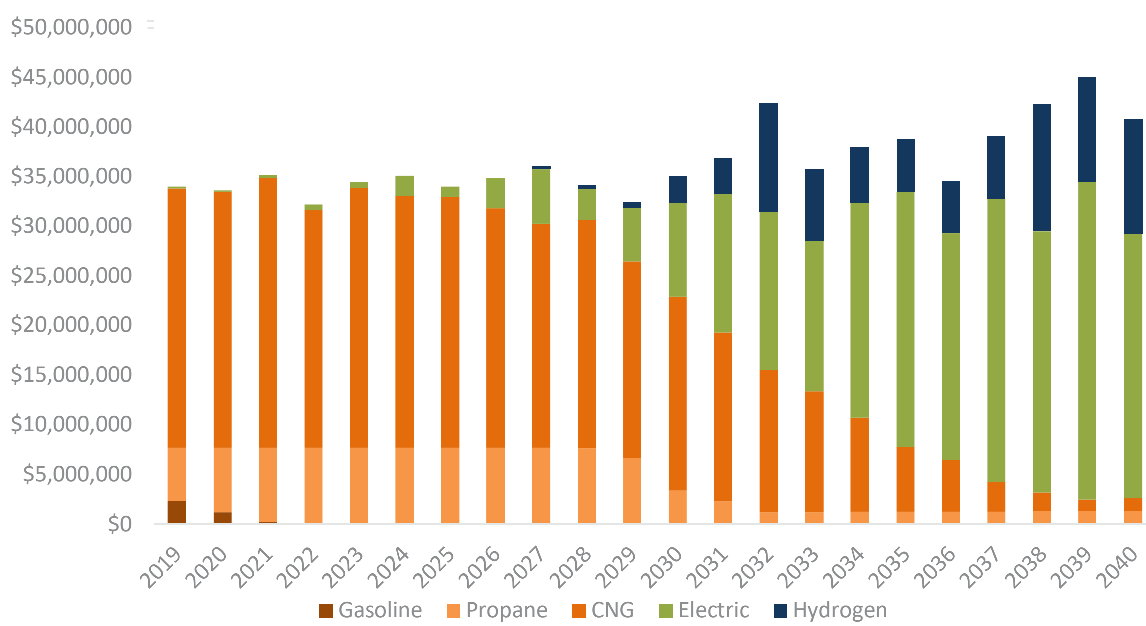
Figure 52 - Annual Maintenance Costs, FCEB Only Scenario



Mixed BEB and FCEB Scenario

Figure 53 shows the combined labor, materials and mid-life overhaul costs for the Mixed BEB and FCEB scenario for each year of the transition, in 2019 dollars.

Figure 53 – Annual Fleet Maintenance Costs, Mixed Scenario



Maintenance Assessment Cost Comparison

The Maintenance Assessment includes all labor, materials and overhaul costs over the transition for each scenario. **Figure 54** shows the cumulative maintenance costs for each scenario. **Table 47** shows the combined total costs and the incremental cost over the Baseline.

Figure 54 – Total Costs, Maintenance Assessments

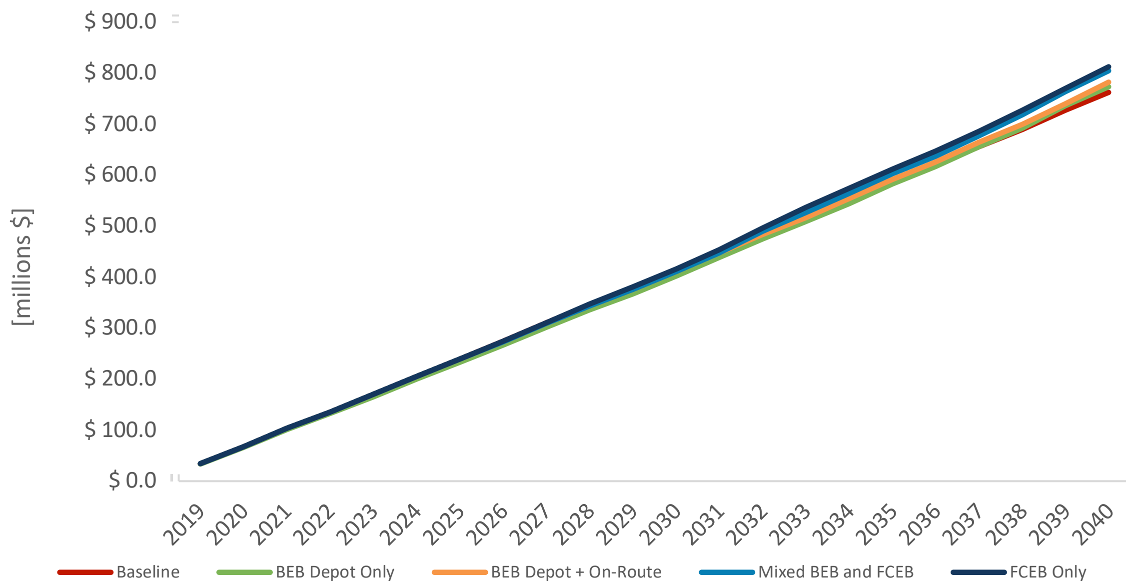


Table 47 – Total Costs, Maintenance Assessments

Scenario	Cost	% Cost Increase Over Baseline	% ZEB
Baseline	$ 762,263,000	----	2%
BEB Depot Only	$ 773,287,000	1%	77%
BEB Depot + On-Route	$ 782,339,000	3%	84%
FCEB Only	$ 812,484,000	7%	95%
Mixed BEB and FCEB	$ 804,691,000	6%	95%

Total Cost of Ownership Assessment

The Total Cost of Ownership Assessment compiles and organizes the results from the Fleet, Fuel, Facilities and Maintenance assessments to show total and annual costs throughout the transition. It includes selected capital and operating costs of each transition scenario over the transition timeline. There may be other costs incurred (i.e., incremental operator and maintenance training); however, these four assessment categories are the key drivers in ZEB transition decision-making. Redundancy, external battery storage, battery recycling, and potential costs associated with a new depot that may be required to support ZEB deployment are not included in this analysis but are important considerations that will also be factored in during the transition.

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

Costs by Scenario

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

Baseline

The Baseline scenario is used for comparative purposes only. It assumes no changes to the agency's current fleet configuration throughout the life of the study, i.e. no ZEB-related purchases. **Table 48** shows the fleet, fuel, facilities and maintenance costs for the Baseline scenario in 2019 dollars. MTS's total operating and capital costs are an estimated $1.82 billion from 2019 to 2040. There are no facilities costs for this scenario. Since we assume MTS will not be adding any additional buses (ZEB or internal combustion engine), other than those that are already included in the baseline scenario, no additional facilities are required.

Table 48 – Total Costs, Baseline [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Fleet	28.8	33.5	38.8	53.4	25.0	29.9	49.5	60.7	43.4	16.7	32.0	30.4	34.7	46.8	23.0	40.4	25.0	37.4	62.1	36.0	43.9	16.7	**808**
Fuel	11.3	11.2	11.2	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5	**253**
Facilities	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-
Maintenance	34.0	33.7	35.3	32.3	34.5	35.2	34.3	34.5	37.0	35.3	33.7	35.2	34.3	34.8	33.1	34.0	34.6	34.8	34.6	34.3	37.6	35.3	**762**
Total	**74.1**	**78.3**	**85.3**	**97.2**	**71.1**	**76.6**	**95.3**	**106.7**	**92.0**	**63.5**	**77.2**	**77.2**	**80.5**	**93.1**	**67.6**	**85.9**	**71.1**	**83.7**	**108.2**	**81.8**	**92.9**	**63.6**	**1,823**

BEB Depot-Only Charging

Table 49 shows the combined fleet, fuel, facilities and maintenance costs for the BEB Depot-Only Charging scenario in 2019 dollars. The total estimated combined cost is approximately $2.28 billion over the length of the transition, from 2019 to 2040. This scenario estimates a total of 640 BEBs in service by 2040.

Table 49 – Total Costs, BEB Depot-Only Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Fleet	28.8	33.5	38.8	53.4	29.4	33.8	54.7	71.8	61.6	25	46.8	49.9	48.1	71.7	37.7	58.6	41.3	57.3	88.5	58.7	67.3	29.8	1,086
Fuel	11.1	11.2	11.2	11.4	11.2	11.1	11.3	11.6	11.8	12	12.8	14.2	14.3	14.5	15.2	15.6	16.1	16.3	16.3	16.4	16.2	16.4	298
Facilities	1.1	0.0	0.3	3.9	3.5	4.7	1.0	6.8	9.9	1.2	8.4	15.1	6.7	12.3	14.3	3.7	11.4	6.0	2.4	1.2	4.4	2.1	120
Maintenance	33.2	32.8	34.4	31.5	33.7	34.3	33.3	33.2	35.3	33.4	31.7	35	36.6	36.3	34	35.6	38.6	34.4	38.9	36.6	42.9	37.8	773
Total	74.3	77.5	84.7	100	77.8	84	100	123	119	71.6	99.6	114	106	135	101	113	107	114	146	113	131	86	2,278

BEB Depot and On-Route Charging

Table 50 shows the combined fleet, fuel, facilities and maintenance costs for the BEB Depot and On-Route Charging scenario in 2019 dollars. The total estimated combined cost is approximately $2.33 billion over the length of the transition, from 2019 to 2040. The additional cost of approximately $56 million over the BEB Depot-Only Charging scenario is attributed to additional capital and operational expenses from the additional 60 on-route-charged buses; this scenario estimates a total of 700 total BEBs in service by 2040.

Table 50 – Total Costs, BEB Depot and On-Route Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Fleet	28.8	33.5	38.8	53.4	29.4	33.8	54.7	71.8	61.6	25	48.8	59.9	38	71.7	37.7	58.6	41.3	67.4	98.5	51.4	70.8	30.5	1,105
Fuel	11.1	11.2	11.2	11.4	11.2	11.1	11.3	11.6	11.8	11.9	13	14.4	14.5	14.6	15.3	15.8	17.7	18	19.1	19.7	19.3	19.4	315
Facilities	1.1	0.0	0.3	3.9	3.5	4.7	1.0	6.8	9.9	1.2	9.8	15.1	6.7	12.3	14.3	3.7	15.6	6.0	6.6	2.6	4.4	2.1	131
Maintenance	34	33.7	35.3	32.3	34.5	35.2	34.1	34	36.1	34.2	32.4	34.9	36.9	36.3	32.6	37.4	38.1	33.9	38.1	35.5	40.4	42.5	782
Total	75.1	78.3	85.6	101	78.6	84.8	101	124	119	72.4	104	124	96	135	99.9	115	113	125	162	109	135	94.5	2,334

FCEB Only

Table 51 shows the combined fleet, fuel, facilities and maintenance costs related to the FCEB Only scenario in 2019 dollars. The total estimated combined cost is approximately $2.70 billion over the length of the transition, from 2019 to 2040. This scenario estimates a total of 791 FCEBs in service by 2040.

Table 51 – Total Costs, FCEB Only Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Fleet	28.8	33.5	38.8	53.4	31.6	35.9	57.3	94.9	69.7	28.7	65	84.5	56.5	95.9	45.2	73.5	56.4	93	123	71.6	79.8	39	1,355
Fuel	11.3	11.2	11.2	11.6	11.9	12.2	12.6	15.3	16.9	17.4	19	20.9	22.4	24.1	26.2	28.3	29.2	30	32.1	32.4	32.8	33.8	463
Facilities	0.0	0.0	0.0	0.2	5.5	10.9	0.2	5.7	5.2	0.2	10.5	3.9	3.9	7.0	10.7	0.0	0.4	4.9	0.0	0.0	4.3	0.0	73
Maintenance	34	33.7	35.3	32.3	34.5	35.2	34.3	34.5	37	35.7	34.1	35.7	37.9	42.2	39.7	38.4	37	35.4	38.8	41.9	41.7	43.2	812
Total	74.1	78.3	85.3	97.4	83.6	94.1	104	150	129	82	129	145	121	169	122	140	123	163	193	146	159	116	2,704

Mixed BEB and FCEB

Table 52 shows the combined fleet, fuel, facilities and maintenance costs related to the Mixed BEB and FCEB scenario in 2019 dollars. The total estimated combined cost is approximately $2.47 billion over the length of the transition, from 2019 to 2040. This scenario estimates a total of 640 BEBs and 151 FCEBs (791 total ZEBs) in service by 2040.

Table 52 – Total Costs, Mixed Scenario [millions $]

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	Total
Fleet	28.8	33.5	38.8	53.4	29.4	33.8	54.7	81.4	60.4	26.3	56.6	69.6	40.1	81.8	37.7	61.4	48.2	77	107	62.9	67.6	31.3	1,181
Fuel	11.1	11.2	11.2	11.4	10.5	10.4	10.5	11.3	12	12.6	13.9	15.2	15.3	15.6	16.3	16.5	18.7	18.9	20	20.3	20	20.3	323
Facilities	1.1	0.0	0.3	3.9	3.5	4.7	1.0	6.8	9.9	1.3	16.1	23.6	6.7	14.1	14.3	3.8	21.0	6.1	12.2	7.9	4.4	2.1	165
Maintenance	34	33.7	35.3	32.3	34.5	35.2	34.1	34	36.1	34.2	32.5	35.1	36.9	42.5	35.8	37.9	38.8	34.6	39.1	42.3	45.1	40.8	805
Total	75.1	78.3	85.6	101	77.9	84.1	100	134	118	74.4	119	143	99.1	154	104	120	127	137	178	133	137	94.5	2,474

Total Estimated Costs

Figure 55 shows the combined total costs from the assessments above, broken down by scenario.

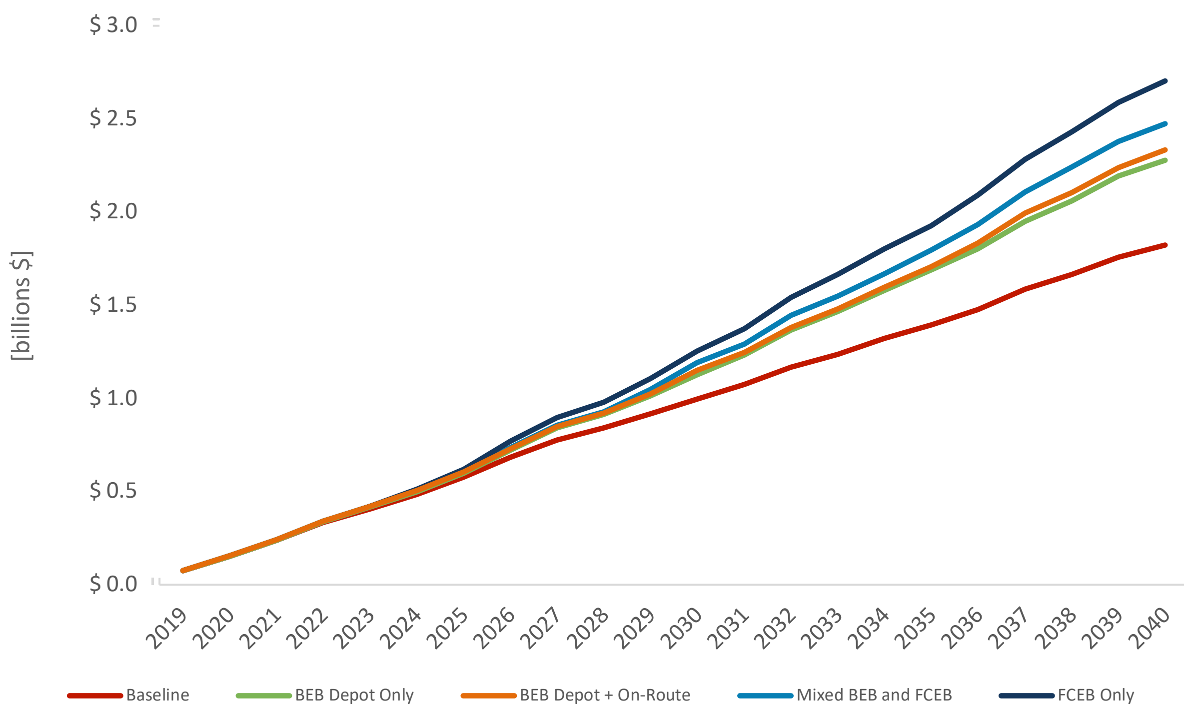


Figure 55 - Total Cost of Ownership, 2019-2040

Table 53 provides the detailed cost totals, total cost increase over Baseline, and the percent ZEBs in the fleet in 2040.

Table 53 – Total Cost of Ownership, by Scenario

	Baseline	BEB Depot Only	BEB Depot + On Route	FCEB Only	Mixed BEB and FCEB
Fleet	$ 808,294,000	$ 1,086,465,000	$ 1,105,467,000	$ 1,355,484,000	$ 1,181,414,000
Fuel	$ 252,569,000	$ 298,234,000	$ 314,657,000	$ 462,731,000	$ 323,380,000
Infrastructure	-----	$ 120,305,000	$ 131,489,000	$ 73,394,000	$ 164,915,000
Maintenance	$ 762,263,000	$ 773,287,000	$ 782,339,000	$ 812,484,000	$ 804,691,000
Total	**$ 1,823,126,000**	**$ 2,278,291,000**	**$ 2,333,952,000**	**$ 2,704,093,000**	**$ 2,474,400,000**
Incremental Cost Over Baseline		**$ 455,165,000**	**$ 510,826,000**	**$ 880,967,000**	**$ 651,274,000**

Emissions Assessment

A primary benefit of transitioning an entire fleet from internal combustion engine vehicles to zero-emission is the reduction of greenhouse gas (GHG) emissions. GHG emissions consist primarily of carbon dioxide (CO_2) but also include small amounts of methane (CH_4) and Nitrous Oxide (N_2O), emitted during fuel combustion[2]. In the transportation sector the vast majority of GHG emissions is from CO_2. For completeness, total GHG emissions are also calculated but the primary focus is on reduction of CO_2.

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

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

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

Carbon Emissions

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

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

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

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

Emissions from electricity production uses inputs from the Western Electricity Coordinating Council (WECC) as part of AFLEET's set of standard assumptions. The WECC energy mix is as follows: Renewable (41.1%), Natural Gas (25.5%), Coal (24.7%), Nuclear (8.3%), Residual Oil (0.2%), Biomass (0.1%).

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

Emissions analyses were performed for slightly different scenarios than in other previous assessments in this study. Two alternative purchase scenarios were created based on the Mixed BEB and FCEB scenario to demonstrate, at the request of stakeholders, potential emissions reductions from more aggressive ZEB purchasing schedules. The Early Purchasing scenario shifts purchases of ZEBs to begin immediately in 2020, instead of in 2023 as required by the CARB ICT regulation. The Mixed 2030 100% ZEB scenario alters purchases of ZEBs so that MTS' fleet is 100% zero-emission by 2030 rather than 2040 as required in the CARB ICT regulation. This includes replacing any existing internal combustion engine buses before the end of their useful life and replacing a single bus with multiple buses where necessary to maintain service levels. The BEB Depot and On-Route scenario was not analyzed due to marginal differences with the BEB Depot Only scenario.

1. Baseline (for comparison)
2. BEB Depot Only
3. Mixed BEB and FCEB
4. Mixed BEB and FCEB – Early Purchasing
5. Mixed BEB and FCEB – 2030 100% ZEB

Figure 56 compares the total estimated well-to-wheel greenhouse gas emissions for each scenario. The baseline scenario generates roughly 2.5 million tons of GHGs over the transition period (2019-2040). This scenario assumes "business as usual" and does not attempt to replace any internal combustion engine buses with zero emission buses. The BEB Depot Only, Mixed and Mixed Early Purchasing scenarios all result in similar cumulative GHG emissions of approximately 1.6 million tons. The Mixed 2030 100% ZEB scenario results in the lowest overall GHG emissions, around 1.2 million tons, since the conversion to ZEBs occurs sooner than in the other scenarios. That results in a 36% GHG savings over the baseline for the Depot Only, Mixed and Mixed Early Purchasing scenarios and a 52% savings for the Mixed 2030 100% ZEB scenario.

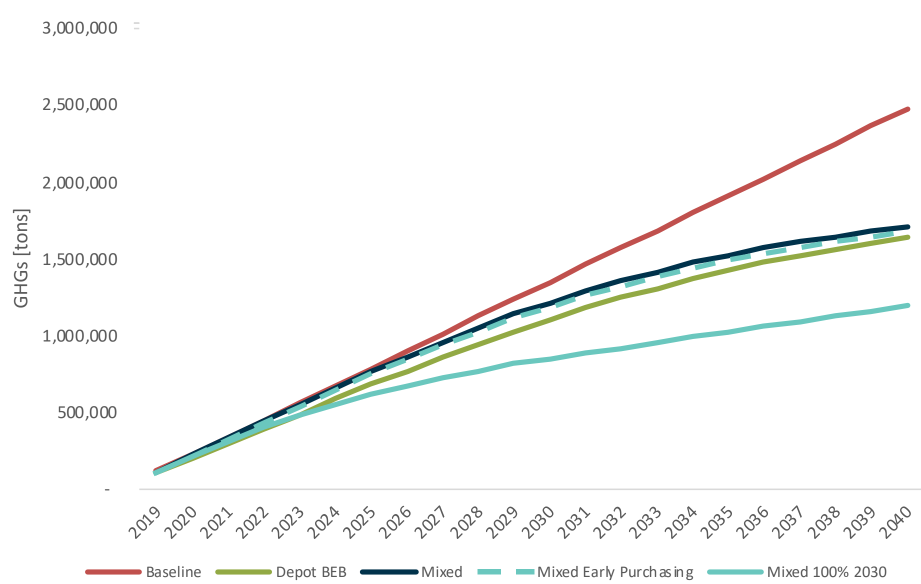


Figure 56 - Cumulative WTW GHGs, 2019-2040

Figure 57 shows the breakdown of well-to-wheel GHG emissions by scenario and emissions type. Again, this is the cumulative total emissions estimated through the transition period, 2019 to 2040. The Mixed 100% 2030 scenario has the lowest overall emissions, producing about 50% less emissions than the baseline scenario, whereas the other scenarios produce around 30% less emissions than the baseline scenario. The tailpipe and upstream emissions components of Depot BEB, Mixed and Mixed Early Purchasing scenarios are roughly the same at about 1.1 million tons of tailpipe and around 500,000 to 600,000 tons of upstream emissions. The Mixed 2030 100% ZEB scenario has highest amount of upstream emissions, approximately 680,000 tons but the lowest tailpipe emissions at 512,000 tons, ultimately resulting in the lowest overall emissions of all the alternate scenarios. This is a result of increased used of FCEBs early in the transition.

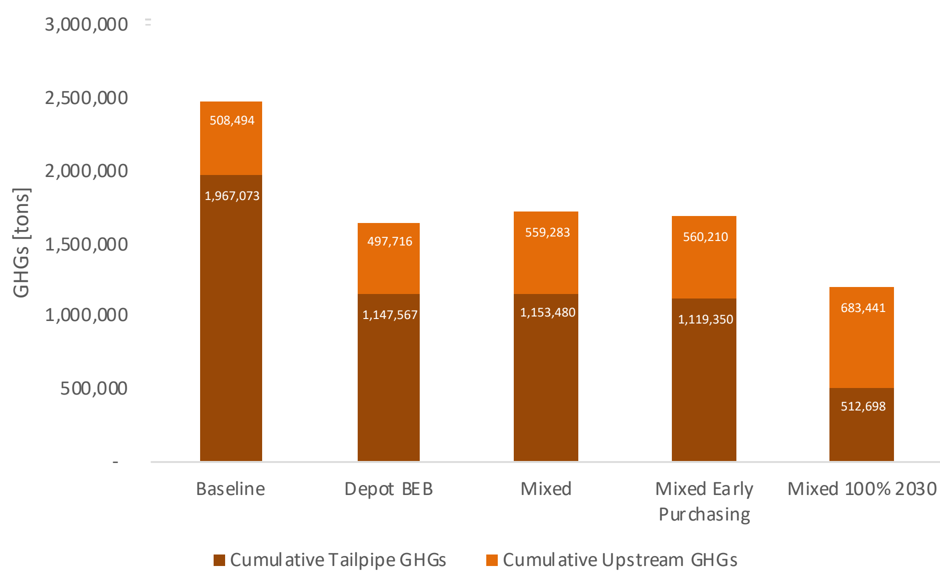


Figure 57 – Cumulative WTW GHGs Breakdown, 2019-2040

Criteria Pollutants

As discussed previously, criteria pollutants are compounds that are considered hazardous to human health. These include, but is not limited to, CO, VOCs, NOx, and PM10 and PM2.5. Fossil fuel vehicles produce these pollutants during combustion and as such, these emissions are emitted along roadways and near population centers, unlike upstream pollutants, which occur at the power plant or refinery. **Table 54** compares the projected total tailpipe criteria pollutants in each scenario; these estimates are cumulative over the transition period. Since ZEBs do not produce any tailpipe emissions, the reductions are a direct result of replacing of fossil fuel vehicles with zero-emission. For example, the Mixed 2030 100% ZEB scenario replaces the most internal combustion engine buses earlier in the study period, thereby reducing overall emissions the most. **Table 55** compares the emissions savings as a percentage over the baseline. The Mixed 2030 100% ZEB scenario also exhibits the highest cumulative savings in every pollutant category.

Table 54 –Tailpipe Criteria Pollutants, Cumulative, 2019-2040

Scenario	CO (lbs)	VOC (lbs)	NOx (lbs)	PM2.5 (lbs)	PM10 (lbs)
Baseline	9,755,782	110,096	1,674,260	4,249	6,071
Depot BEB	7,089,348	76,866	1,081,673	3,201	4,440
Mixed	5,640,795	66,027	989,595	2,493	3,521
Mixed Early Purchasing	5,560,730	64,615	958,607	2,469	3,474
Mixed 2030 100%	2,907,189	34,602	466,295	1,367	1,837

Table 55 – Criteria Pollutant Savings Over Baseline, Cumulative, 2019-2040

Scenario	CO (lbs)	VOC (lbs)	NOx (lbs)	PM2.5 (lbs)	PM10 (lbs)
Depot BEB	27%	30%	35%	25%	27%
Mixed	42%	40%	41%	41%	42%
Mixed Early Purchasing	43%	41%	43%	42%	43%
Mixed 2030 100%	70%	69%	72%	68%	70%

It should be noted that there are significant technical and financial challenges associated with meeting the Mixed 2030 100% ZEB scenario that have been documented separately and presented to MTS Board of Directors.

Conclusions and Recommendations

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

CARB's ICT regulation is an achievement toward addressing the challenges of climate change with a goal of 100% zero-emission transit fleets by 2040. However, as demonstrated in this analysis, there will be a substantial cost as well as technical challenges. Transit agencies may be challenged to meet this goal and provide the same level of passenger service. Fortunately, CARB's ruling provides waivers for economic hardship and in the event the current state of depot-charged bus technology does not meet service requirements.

A primary assumption for this analysis is that MTS is unable to increase fleet size due to significant space constraints at their depots and, as a result, vehicles must be replaced on a one-for-one basis. Analysis of additional land purchase and construction of new depot facilities was not part of this analysis, though it is expected to cost approximately $185 million to complete if required. If MTS selects an all BEB strategy, incremental ZEB transitional costs are likely to fall between $455 million for the BEB Depot-Only Charging scenario, where approximately 77% of MTS' fleet is replaced with BEBs by 2040, to $511 million for the BEB Depot and On-Route Charging scenario, where approximately 84% of MTS' fleet is replaced with BEBs by 2040. The difference in incremental cost for these scenarios is a result of more vehicles being transitioned due to the use of on-route charging infrastructure, the incremental cost of the on-route charging infrastructure, as well as higher utility charges as a result of on-route charging because higher demand charges are incurred throughout the on-peak when on-route charging will occur. It should be noted that this analysis includes all vehicle lengths and types (40', 45', 60', and cutaways); however, currently only 40' and 60' BEBs have completed Altoona testing. The BEB Depot-Only Charging scenario meets the CARB ICT regulation requirements assuming a waiver for depot-charged technology that does not meet service requirements is granted as is clearly detailed in the regulation.

If MTS selects an FCEB Only strategy, incremental ZEB transitional costs are estimated at approximately $881 million for replacement of approximately 95% of the fleet with FCEBs by 2040. The remaining 5% would be replaced during the next vehicle replacement cycle after 2040, as it is anticipated that by 2040, FCEB technology will have advanced such that all MTS service could be completed using FCEBs. A primary assumption for the FCEB analysis is that FCEB vehicles will be available for all vehicle types and lengths during the transition period. In addition, due to the limited deployment of FCEBs in service in the United States, capital costs for vehicles and fuel costs remain high. These costs are expected to come down in the future as more vehicles are deployed; however, there is no basis at this time to make assumptions as to how much they may be reduced. Also, the current experience with FCEB maintenance cost is high due to the fact that much of the data is based on older vehicles that are no longer under warranty and require the support of a European company. As such, there are more unknowns associated with the incremental costs for the FCEB Only scenario, and costs are likely to be more subject to change. It is expected that the cost of the FCEB Only scenario will come down if a larger number of vehicles and infrastructure is deployed but to what extent is unknown. Significant investments in hydrogen infrastructure will be required and will take years to develop to gain a better understanding of the long-term costs for FCEB Only deployment.

As expected, with an incremental cost of approximately $651 million, the Mixed BEB and FCEB scenario that transitions approximately 95% of MTS' fleet to ZEB by 2040, has an incremental cost that falls between an all BEB and all FCEB deployment. Though the costs are considerably cheaper for a mixed fleet deployment than FCEB Only, there are expected to be complexities with managing the fleet through the transition that would require maintain existing internal combustion engine vehicle infrastructure (CNG, propane, and gasoline), installing new BEB infrastructure, and installing new FCEB fueling infrastructure. Space constraints at the depot will require careful planning if this path is selected. MTS may also experience additional benefits as a result of the transition to ZEBs.

MTS may accumulate ZEB credits from their procurement of ZEBs prior to 2023, although these ZEB credits are not considered in this analysis. These credits can be used in place of ZEB purchases to satisfy CARB's ZEB procurement requirements beginning in 2023. With the purchase of eight (8) BEBs to support the ZEB pilot operations in 2019 and 2020, and the purchase of twelve (12) BEBs to support a new service in 2022, MTS will have twenty (20) ZEB credits that can be applied to ZEB purchase requirements in 2023 and beyond. By early adoption, MTS will be able to better assess BEB technology in their own service and will also be able to monitor the progress in FCEB vehicle and infrastructure development and pricing.

As a result, recommendations for MTS are as follows:

1. **Remain proactive with ZEB deployments:** MTS has been proactive in the purchase and deployment of BEBs through their ZEB Pilot Program. Significantly more development, data collection, and analyses are needed before the technology is ready for fleetwide deployment. For example, BEBs will require charge management software, hardware, and standards to manage the fleetwide transition. For FCEB deployment to be competitive, lower fuel costs that will evolve over time with the production of hydrogen at scale will be required. MTS should move forward carefully, taking advantage of various grant and incentive programs to offset the incremental cost for ZEB deployment. Incentive programs may be eliminated in future years as ZEB procurements are required instead of being optional.
2. **Target specific routes and blocks for early ZEB deployments:** MTS should consider the strengths of given ZEB technologies and focus those technologies on routes and blocks that take advantage of their efficiencies and minimizes the impact of the constraints related to the respective technologies. For example, depot-charged BEBs for shorter routes and blocks, on-route charged BEBs for mid-range routes with layovers at a transit center, and FCEBs for long routes or routes with higher speeds and/or heavier loads. These technologies cannot follow a "one-size-fits-all" approach from either a performance or cost perspective. Matching the technology to the service will be a

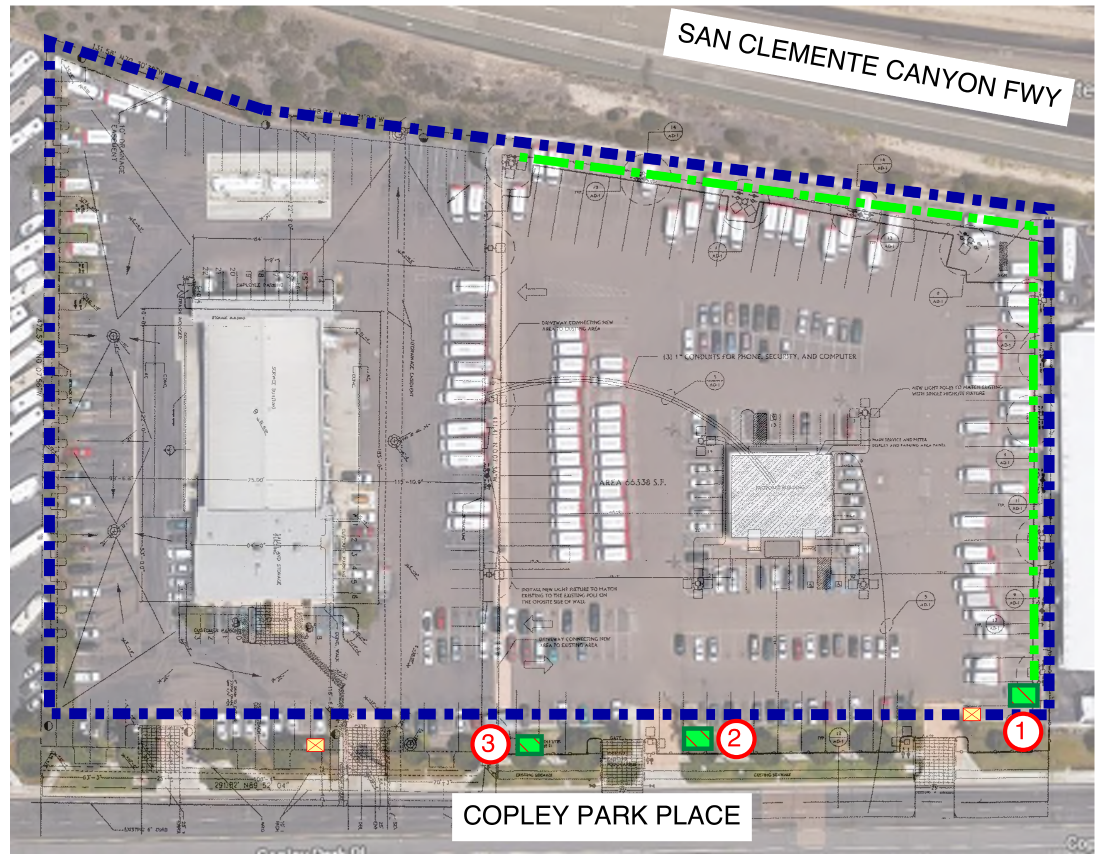
critical best practice. Results from the ZEB Pilot Program will help to inform these decisions.

3. **Continue with BEBs and consider FCEBs:** At this stage, it is too early to tell which technology will dominate the market 10 to 20 years from now. Having capability to deploy both ZEB technologies creates an opportunity for MTS to fully assess BEBs and FCEBs to determine which technology can best meet the operational range requirements while being financially efficient and sustainable.

The transition to ZEB technologies represents a paradigm shift in bus procurement, operation, maintenance, and infrastructure. The technology requires significant development before it is ready to support fleetwide transitions. However, it is only through a continual process of deployment with specific goals for advancement that the industry can achieve the goal of economically sustainable, zero-emission public transit. Ultimately, the ZEB technology that is most efficient and sustainable to operate will evolve into either the majority ZEB solution or the only ZEB solution. MTS, with endorsement and approval from their Board of Directors, has elected to pursue a mixed use scenario that will allow them to initially deploy BEBs and explore possible opportunities and funding mechanisms to deploy FCEBs in service in the future where BEBs are not able to meet range requirements. MTS will continue to monitor technology improvements and funding availability to accelerate the transition to a 100% zero-emission fleet. Evaluation will be completed in annual updates provided to the MTS Board of Directors and CARB.

A copy of the ZEB Rollout Plan is included in **Appendix A**.

Appendix B – Depot Site Plans, BEB Infrastructure



LEGEND

- EXISTING TRANSFORMER
- POTENTIAL GROUND CHARGER LOCATION (36/35 REQUIRED CHARGING STALLS)
- PROPERTY LINE
- 1 NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)

N

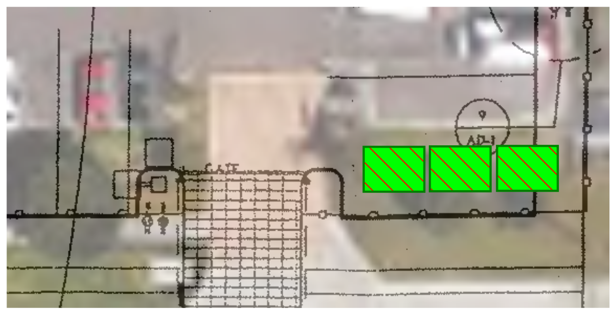
SITE PLAN - COPLEY BUS MAINTENANCE FACILITY

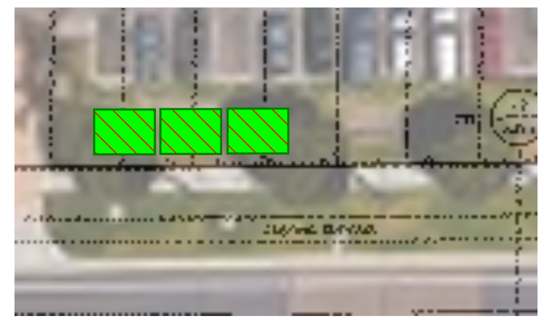
1" = 100'

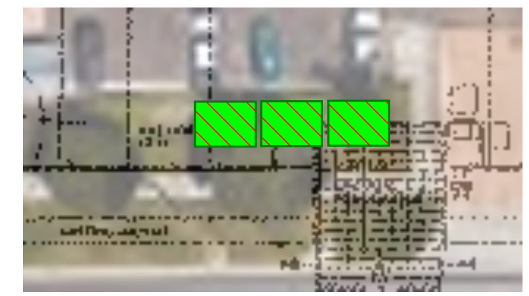
Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019







N COPLEY - OPPORTUNITY AREA 1
1" = 50'

N COPLEY - OPPORTUNITY AREA 2
1" = 50'

N COPLEY - OPPORTUNITY AREA 3
1" = 50'

LEGEND

15'-0" X 20'-0" CONCRETE PAD FOR NEW TRANSFORMER AND SWITCHGEAR.
3 REQUIRED FOR SITE

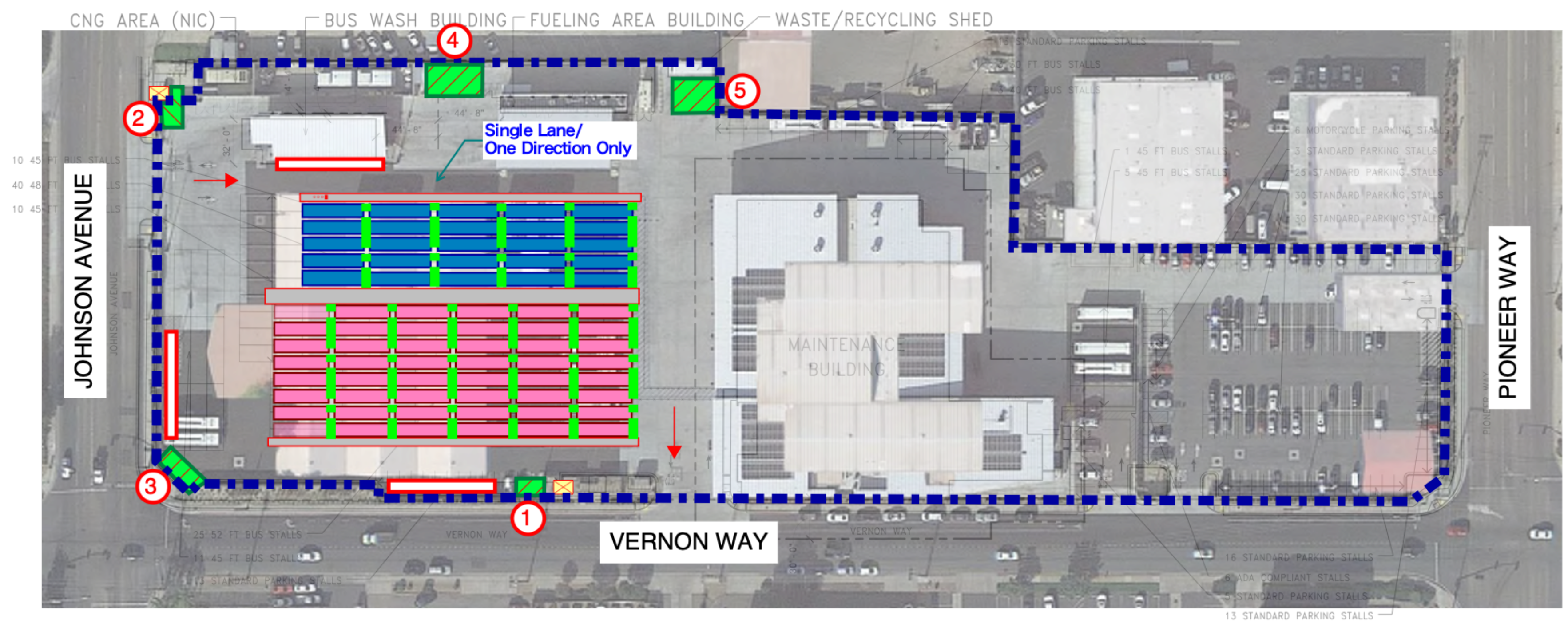
N ENLARGED SITE PLANS -
1" = 100'

Issue Status:
REPORT PACKAGE

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

Issue Status:
REPORT PACKAGE

AECOM



East County		
Bus Length (ft)	All Buses	BEBs in 2040
22	0	0
29	3	0
32	0	0
40	51	46
45	24	25
60	0	0
Totals	78	71

LEGEND

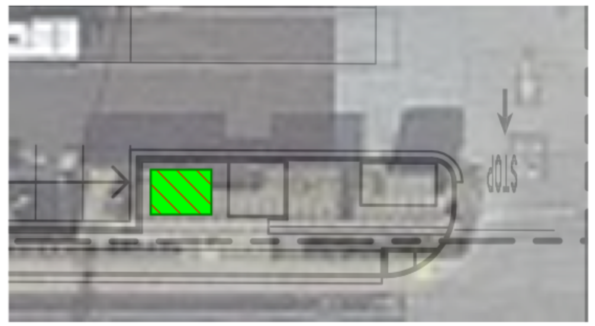
- EXISTING TRANSFORMER
- PROPERTY LINE
- 1 NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (6 GANTRIES/8 BUS SPAN, 5 GANTRIES/5 BUS SPAN, 73 CHARGING STALLS)
- 40' BUS PARKING (48 SPACES/46 REQUIRED)
- 45' BUS PARKING (25 SPACES/25 REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - EAST COUNTY BUS MAINTENANCE

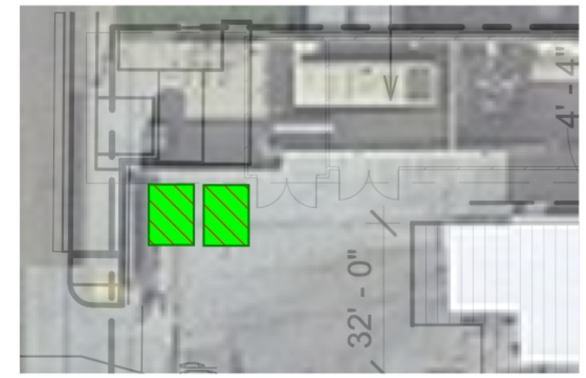
N

1" = 100'

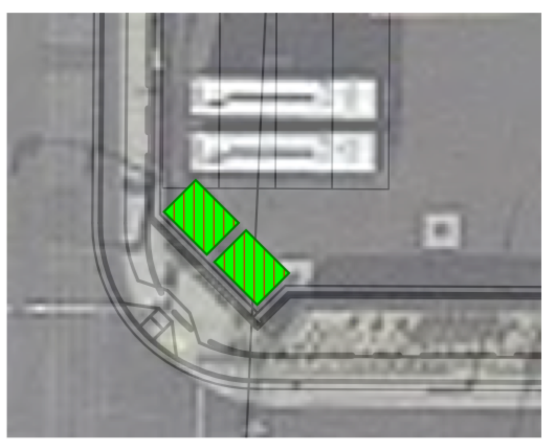
BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019



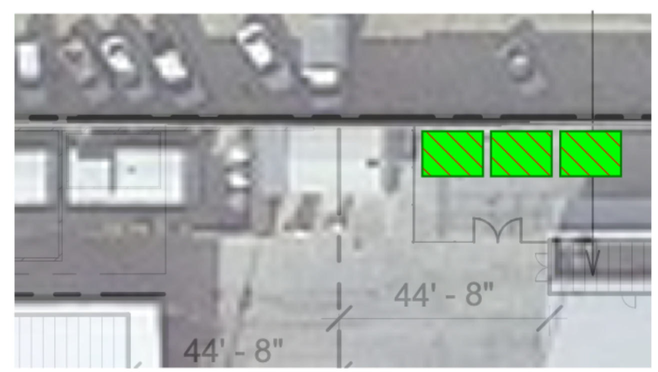
EAST COUNTY - OPPORTUNITY AREA 1
1" = 50'



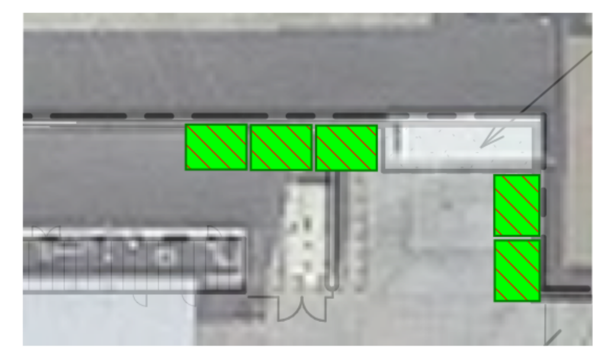
EAST COUNTY - OPPORTUNITY AREA 2
1" = 50'



EAST COUNTY - OPPORTUNITY AREA 3
1" = 50'



EAST COUNTY - OPPORTUNITY AREA 4
1" = 50'



EAST COUNTY - OPPORTUNITY AREA 5
1" = 50'

ENLARGED SITE PLANS - EAST COUNTY
1" = 100'

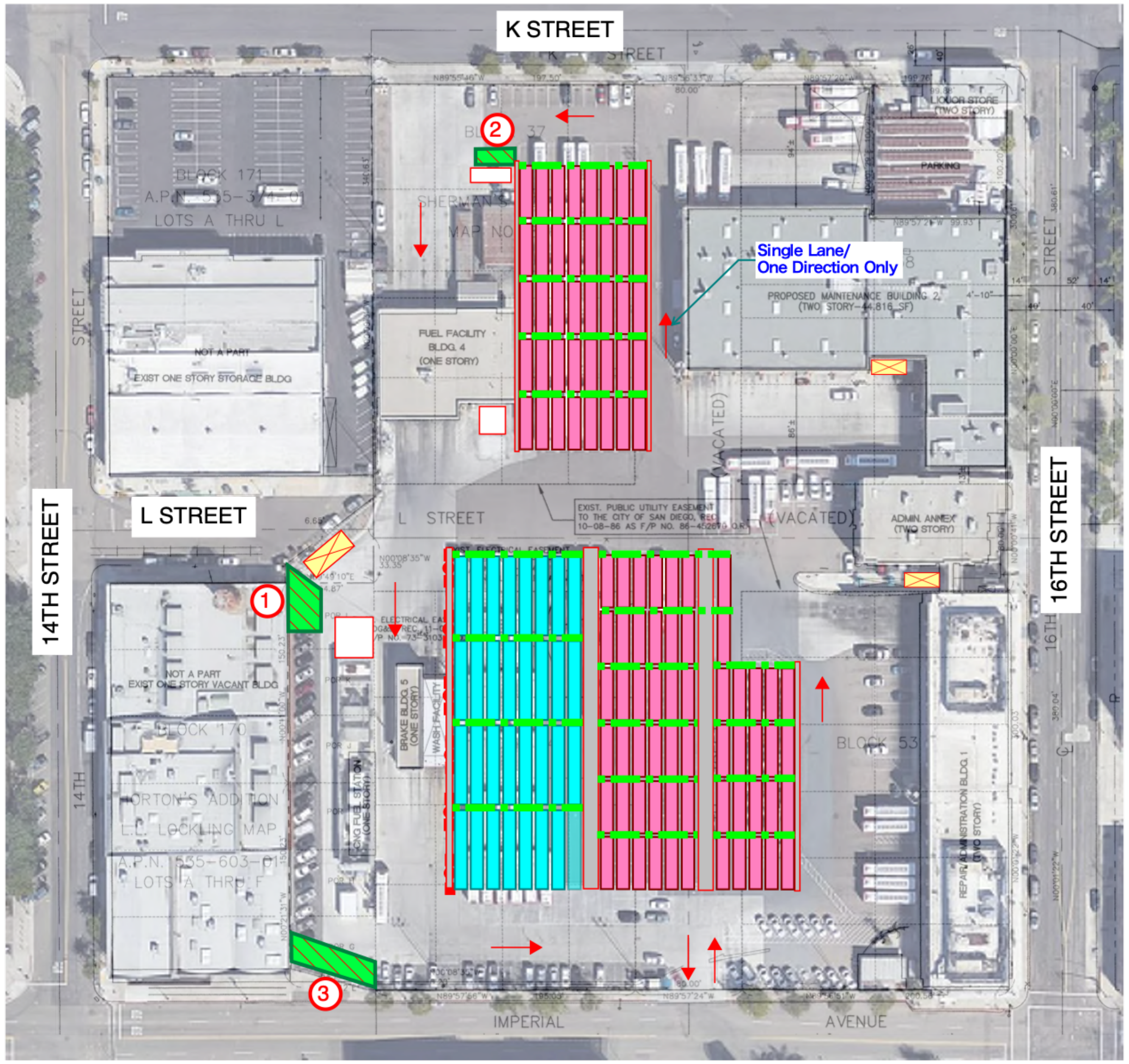
LEGEND

15'-0" X 20'-0" CONCRETE PAD FOR NEW TRANSFORMER AND SWITCHGEAR.
5 REQUIRED FOR SITE

Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019



Imperial Ave		
Bus Length (ft)	**All Buses**	**BEBs in 2040**
22	0	0
29	0	0
32	0	0
40	111	98
45	0	0
60	44	31
Totals	155	129

LEGEND

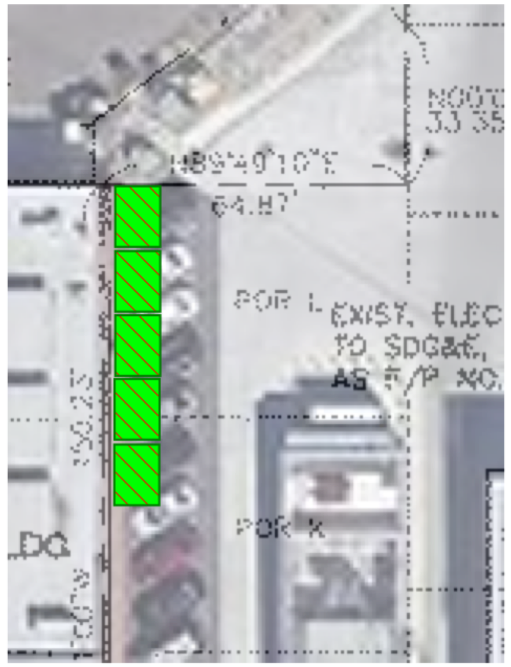
- EXISTING TRANSFORMER
- PROPERTY LINE
- 1 NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (9 GANTRIES/8 BUS SPAN, 4 GANTRIES/6 BUS SPAN, 2 GANTRIES/6 BUS SPAN w/ 1 STALL CANTILEVER, 4 GANTRIES/5 BUS SPAN, 130 CHARGING STALLS)
- 40' BUS PARKING (98 SPACES/98 REQUIRED)
- 60' BUS PARKING (32 SPACES/31REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - IMPERIAL AVENUE DIVISION

N

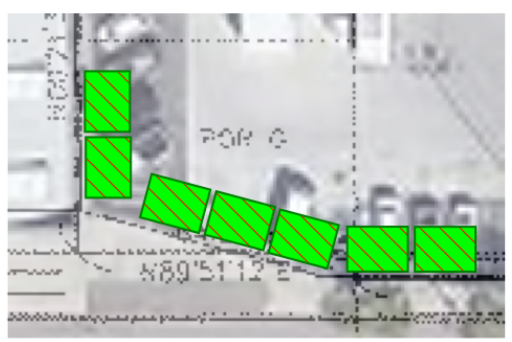
1" = 100'

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

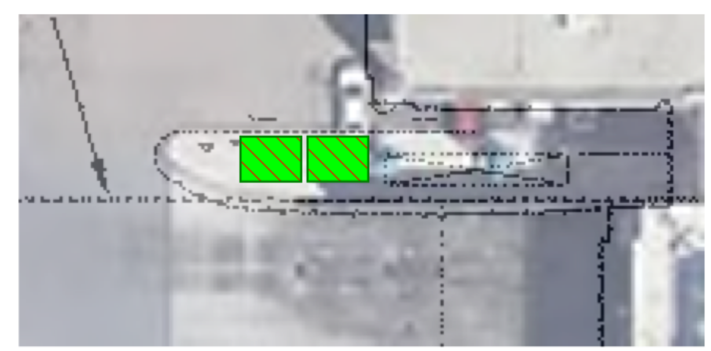


IMPERIAL AVENUE - OPPORTUNITY AREA 1
1" = 50'

IMPERIAL AVENUE - OPPORTUNITY AREA 2
1" = 50'



IMPERIAL AVENUE - OPPORTUNITY AREA 3
1" = 50'



IMPERIAL AVENUE - OPPORTUNITY AREA 4
1" = 50'

ENLARGED SITE PLANS - IMPERIAL AVENUE

1" = 100'

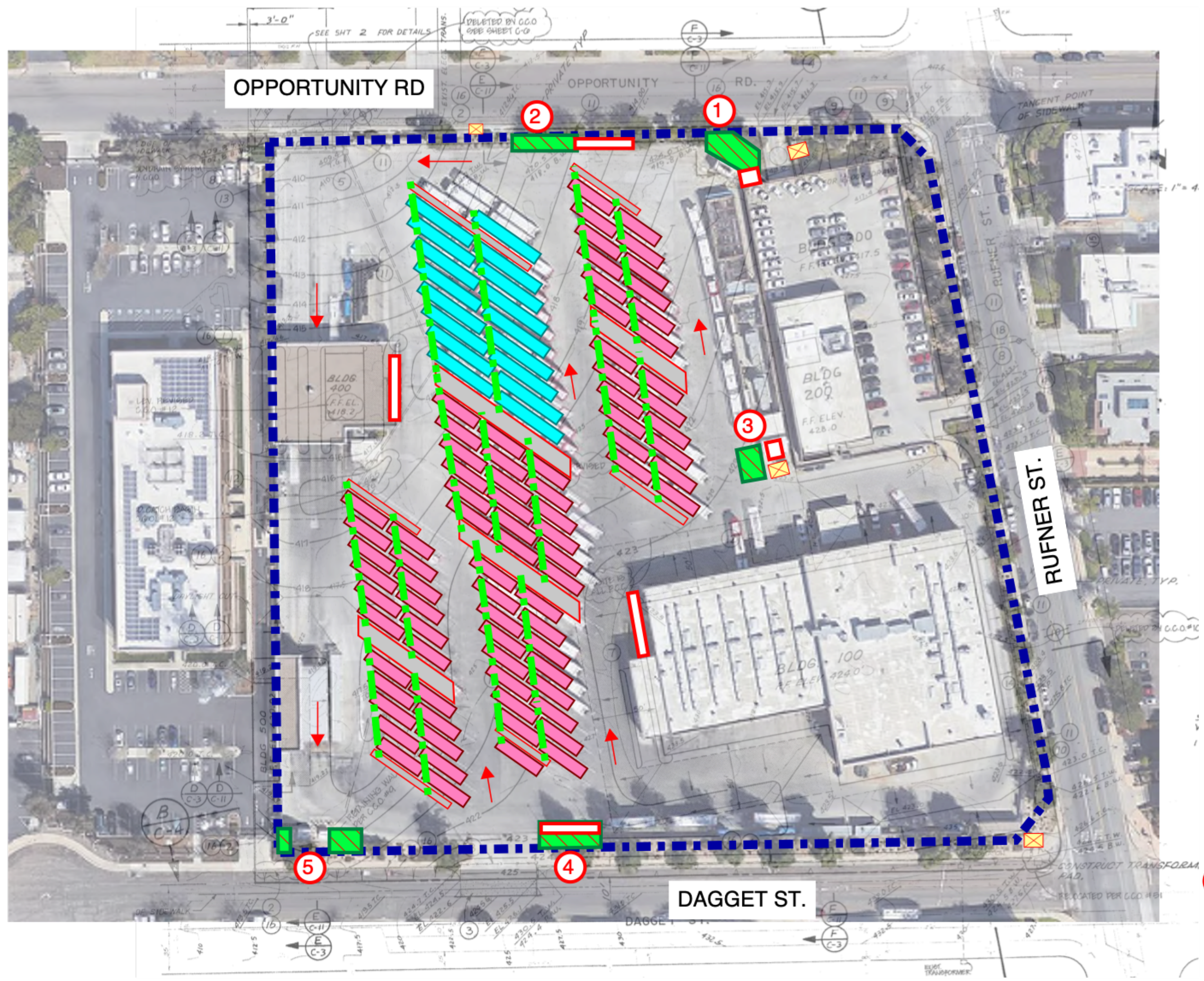
LEGEND

15'-0" X 20'-0" CONCRETE PAD FOR NEW TRANSFORMER AND SWITCHGEAR.
11 REQUIRED FOR SITE

Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019



Kearny Mesa - Option 1		
Bus Length (ft)	All Buses	BEBs in 2040
22	0	0
29	0	0
32	0	0
40	85	81
45	0	0
60	42	17
Totals	127	98

LEGEND

- EXISTING TRANSFORMER
- PROPERTY LINE
- NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (2 GANTRIES/8 BUS SPAN, 2 GANTRY/8 BUS SPAN w/ 1 BUS CANTILEVER, 9 GANTRIES/6 BUS SPAN, 2 GANTRIES/5 BUS SPAN- 98 CHARGING STALLS)
- 40' BUS PARKING (81 SPACES/81 REQUIRED)
- 60' BUS PARKING (17 SPACES/17 REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - KEARNY MESA DIVISION
OPTION 1

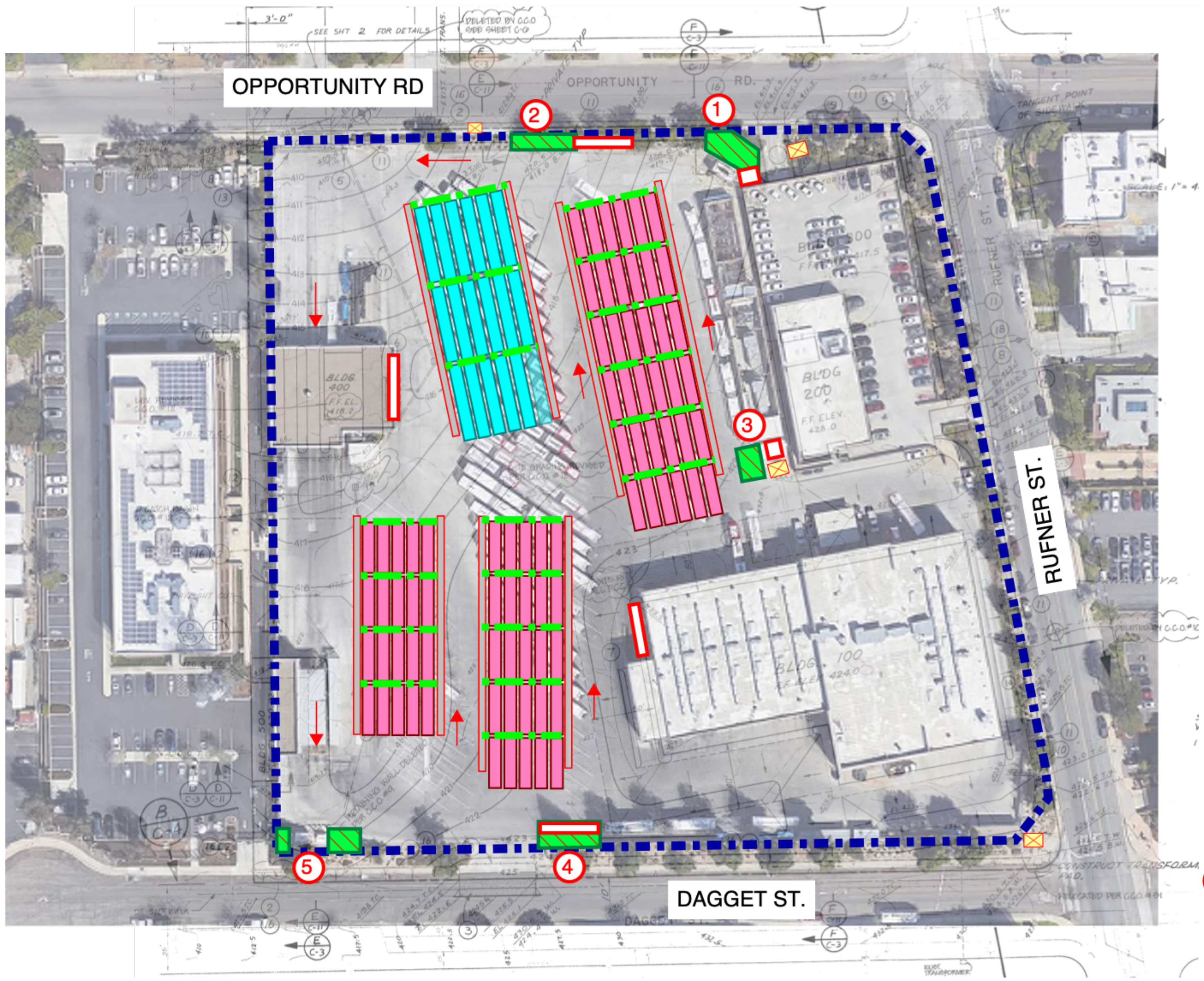
N

1" = 100'

Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019



Kearny Mesa - Option 2		
Bus Length (ft)	All Buses	BEBs in 2040
22	0	0
29	0	0
32	0	0
40	85	81
45	0	0
60	42	17
Totals	127	98

LEGEND

- EXISTING TRANSFORMER
- PROPERTY LINE
- 1 NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (14 GANTRIES/6 BUS SPAN, 4 GANTRIES/4 BUS SPAN, - 98 CHARGING STALLS)
- 40' BUS PARKING (81 SPACES/81 REQUIRED)
- 60' BUS PARKING (18 SPACES/17 REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - KEARNY MESA DIVISION
OPTION 2

N

1" = 100'

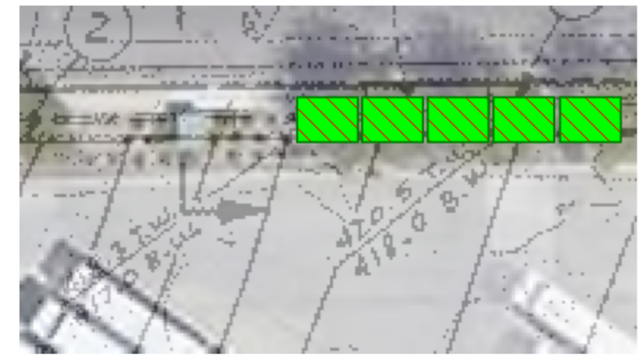
Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

KEARNY MESA - OPPORTUNITY AREA 1

1" = 50'

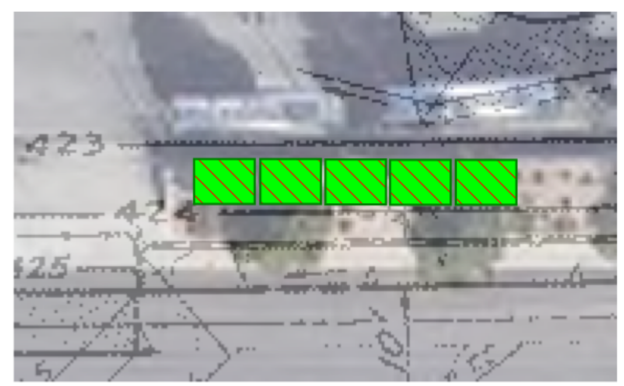


KEARNY MESA - OPPORTUNITY AREA 2

1" = 50'

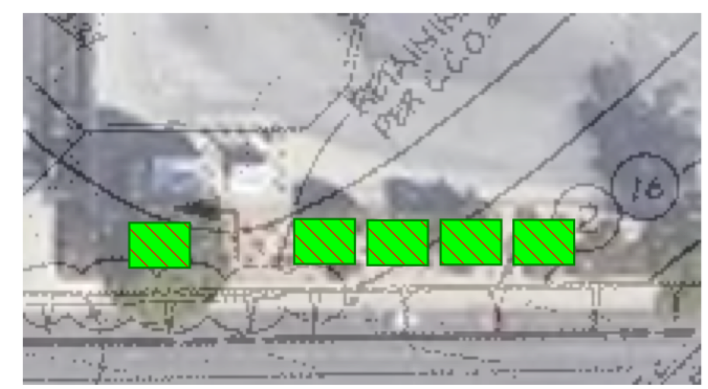
KEARNY MESA - OPPORTUNITY AREA 3

1" = 50'



KEARNY MESA - OPPORTUNITY AREA 4

1" = 50'



KEARNY MESA - OPPORTUNITY AREA 5

1" = 50'

LEGEND

15'-0" X 20'-0" CONCRETE PAD FOR NEW TRANSFORMER AND SWITCHGEAR.
4 REQUIRED FOR SITE

ENLARGED SITE PLANS - KEARNY MESA

1" = 100'

Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

South Bay		
Bus Length (ft)	All Buses	BEBs in 2040
22	0	0
29	0	0
32	0	0
40	221	214
45	0	0
60	39	39
Totals	260	253

LEGEND

- EXISTING TRANSFORMER
- PROPERTY LINE
- 1 NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (13 GANTRIES/8 BUS SPAN, 7 GANTRIES/7 BUS SPAN, 17 GANTRIES/6 BUS SPAN, 255 CHARGING STALLS)
- 40' BUS PARKING (215 SPACES/214 REQUIRED)
- 60' BUS PARKING (40 SPACES/39 REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - SOUTH BAY BUS MAINTENANCE FACILITY OPTION 1

N

1" = 100'

Issue Status:
REPORT PACKAGE

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

South Bay		
Bus Length (ft)	All Buses	BEBs in 2040
22	0	0
29	0	0
32	0	0
40	221	214
45	0	0
60	39	39
Totals	260	253

LEGEND

- EXISTING TRANSFORMER
- PROPERTY LINE
- NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (13 GANTRIES/8 BUS SPAN, 7 GANTRIES/7 BUS SPAN, 17 GANTRIES/6 BUS SPAN, 255 CHARGING STALLS)
- 40' BUS PARKING (215 SPACES/214 REQUIRED)
- 60' BUS PARKING (40 SPACES/39 REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - SOUTH BAY BUS MAINTENANCE FACILITY OPTION 2

1" = 100'

Issue Status:
REPORT PACKAGE

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

South Bay		
Bus Length (ft)	All Buses	BEBs in 2040
22	0	0
29	0	0
32	0	0
40	221	214
45	0	0
60	39	39
Totals	260	253

LEGEND

- EXISTING TRANSFORMER
- PROPERTY LINE
- 1 NEW TRANSFORMER OPPORTUNITY (WITH RECOMMENDED PRIORITY)
- ALTERNATE CHARGER OPPORTUNITY
- 6' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- 12' WIDE GANTRY SUPPORT STRUCTURE & CHARGER AREA
- POTENTIAL CHARGER GANTRY LOCATION (5 GANTRIES/8 BUS SPAN, 7 GANTRIES/7 BUS SPAN, 17 GANTRIES/6 BUS SPAN, 255 CHARGING STALLS)
- 40' BUS PARKING (215 SPACES/214 REQUIRED)
- 60' BUS PARKING (40 SPACES/39 REQUIRED)
- DIRECTION OF TRAFFIC

SITE PLAN - SOUTH BAY BUS MAINTENANCE FACILITY
OPTION 3

N

1" = 100'

Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
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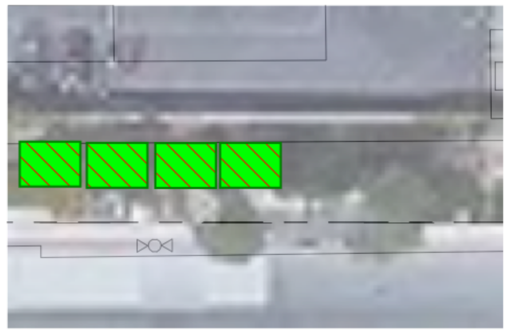
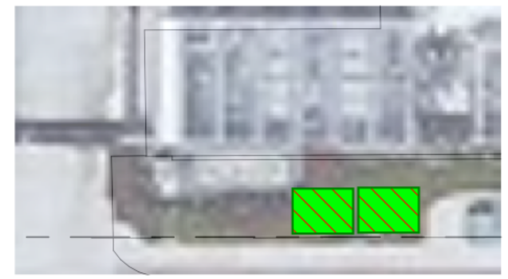


SOUTH BAY - OPPORTUNITY AREA 1

1" = 50'

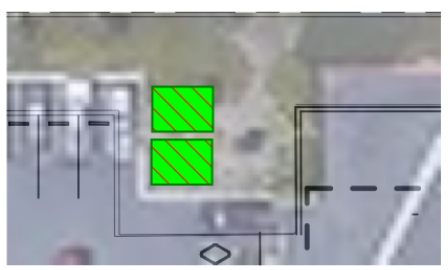


SOUTH BAY - OPPORTUNITY AREA 2

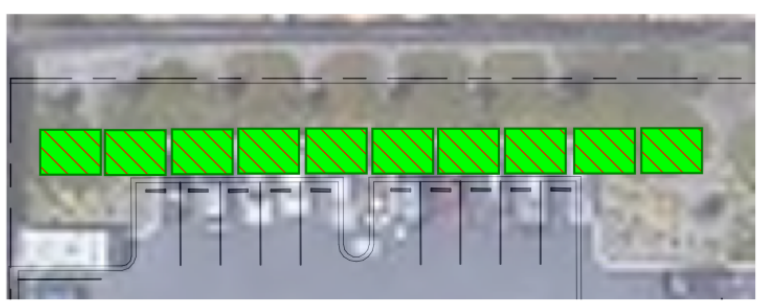
1" = 50'

SOUTH BAY - OPPORTUNITY AREA 3

1" = 50'



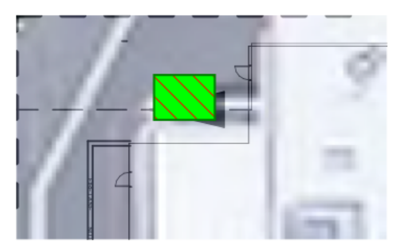
OPTION 1



OPTION 2

SOUTH BAY - OPPORTUNITY AREA 4

1" = 50'



SOUTH BAY - OPPORTUNITY AREA 5

1" = 50'

SOUTH BAY - OPPORTUNITY AREA 6

1" = 50'

ENLARGED SITE PLANS - SOUTH BAY

1" = 100'

LEGEND

15'-0" X 20'-0" CONCRETE PAD FOR NEW TRANSFORMER AND SWITCHGEAR.
16 REQUIRED FOR SITE

Issue Status:
REPORT PACKAGE

AECOM

BATTERY ELECTRIC BUS FEASIBILITY STUDY
CONSTRUCTION PHASING SITE PLAN
SAN DIEGO METROPOLITAN TRANSIT SYSTEM,
SAN DIEGO, CA
PROJ. NO.: 60579290
OCTOBER 2019

Appendix C – Depot Site Plans, FCEB Infrastructure, and Fiedler Group Report

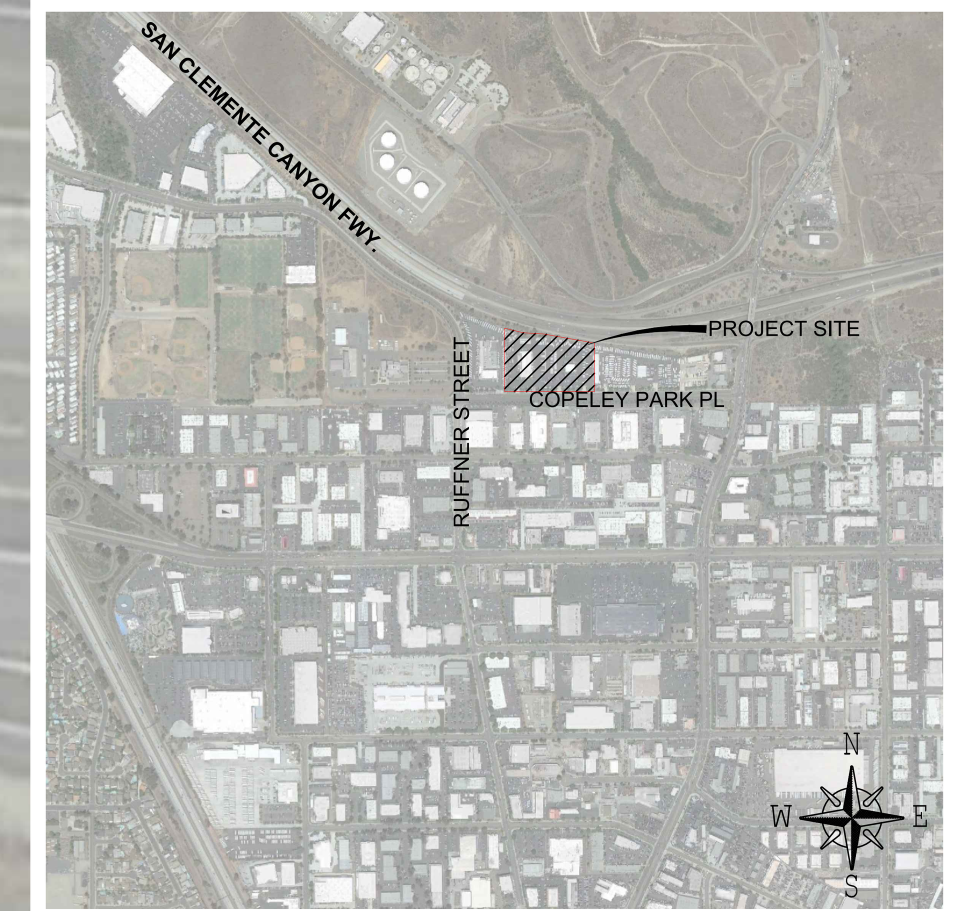
N
W E
S

PRELIMINARY HYDROGEN FUELING SITE PLAN

30' 0 30' 60' 90'

GRAPHIC SCALE: 1" = 30'

VICINITY MAP



SITE NOTES

#	NOTE
	EXISTING ITEMS
0.1	CNG STATION
0.2	DIESEL STATION
0.3	OFFICE/MAINTENANCE BLDG
0.4	MAINTENANCE BLDG
	NEW ITEMS
1.0	(N) HYDROGEN DISPENSER
1.1	(N) HYDROGEN EQUIPMENT COMPOUND

PARKING INFORMATION

	PHASE 1		PHASE 2	
	CAR	BUS	CAR	BUS
EXISTING REMOVED	0	-18	0	0
PROPOSED	0	0	0	0
NET CHANGE	0	-18	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2
TOTAL COMPOUND SIZE:	50' X 110'	50' X 120'
TOTAL # OF DISPENSER:	4	5
TOTAL # OF 15,000-GAL LH2 VESSELS	2	2

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

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DEVELOPMENT INFORMATION:

MTS
COPLEY PARK MAINTENANCE FACILITY (CPMF)

SITE ADDRESS:

7490 COPLEY PARK PL.
SAN DIEGO, CA 92111

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 09/27/2019	PROJECT NO.: 16231

DRAWING TITLE:

PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:

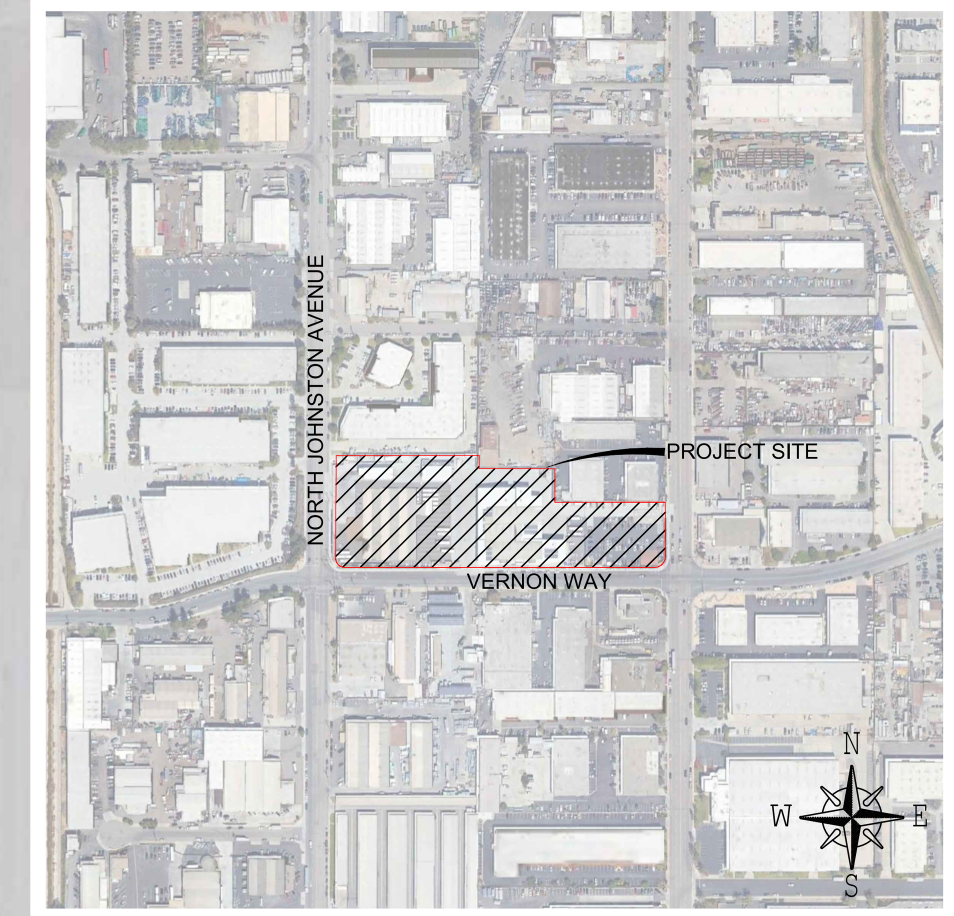
SP-1

\\fiedler-project\data\projects\16231\Design\100 Preliminary Designs\Preliminary Site Plans\SP\SP-1\01-Copley Park Maintenance Facility\16231-Copley Park-SP-1.dwg - PLOTTED: Feb 18, 2020 - 8:51am

PRELIMINARY HYDROGEN FUELING SITE PLAN

GRAPHIC SCALE: 1" = 40'

VICINITY MAP



SITE NOTES

#	NOTE	QUANTITY	REFERENCE
	EXISTING ITEMS		
0.1	(E) CNG FACILITY		
0.2	(E) BUS WASH		
0.3	(E) FUEL AREA BUILDING		
0.4	(E) BUS MAINTENANCE BUILDING		
0.5	(E) BUS PARKING TO BE REMOVED		
	NEW ITEMS		
1.0	(N) DISPENSER		
1.1	(N) HYDROGEN EQUIPMENT COMPOUND		
1.2	(N) FIRE RATED WALL		

PARKING INFORMATION

	PHASE 1			PHASE 2		
	CAR	40' BUS	45' BUS	CAR	40' BUS	45' BUS
EXISTING REMOVED	0	0	-10	0	0	0
PROPOSED	0	0	0	0	0	0
NET CHANGE	0	0	-10	0	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2
TOTAL COMPOUND SIZE:	25' X 121'	25' X 170'
TOTAL # OF FUELING POSITION:	2	2
TOTAL # OF 15,000-GAL LH2 VESSELS	1	2

LEGEND

PROPOSED PHASE 1 HYDROGEN COMPOUND

PROPOSED PHASE 2 HYDROGEN COMPOUND

PROPOSED PHASE 1 HYDROGEN DISPENSER

PROPOSED PHASE 2 HYDROGEN DISPENSER

PROPOSED VEHICLE PARKING SETBACK LINE

APPROX. LOCATION OF PROPERTY LINE

APPROX. LOCATION OF DISPENSING BUS

APPROX. LOCATION OF OFFLOAD TRUCK

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DEVELOPMENT INFORMATION:

MTS
EAST COUNTY BUS MAINTENANCE FACILITY (ECBMF)

SITE ADDRESS:

1213 N. JOHNSON AVE
@ VERNON STREET
EL CAJON, CA 92020

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 9/27/2019	PROJECT NO.: 16231

DRAWING TITLE:

PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:

SP-1

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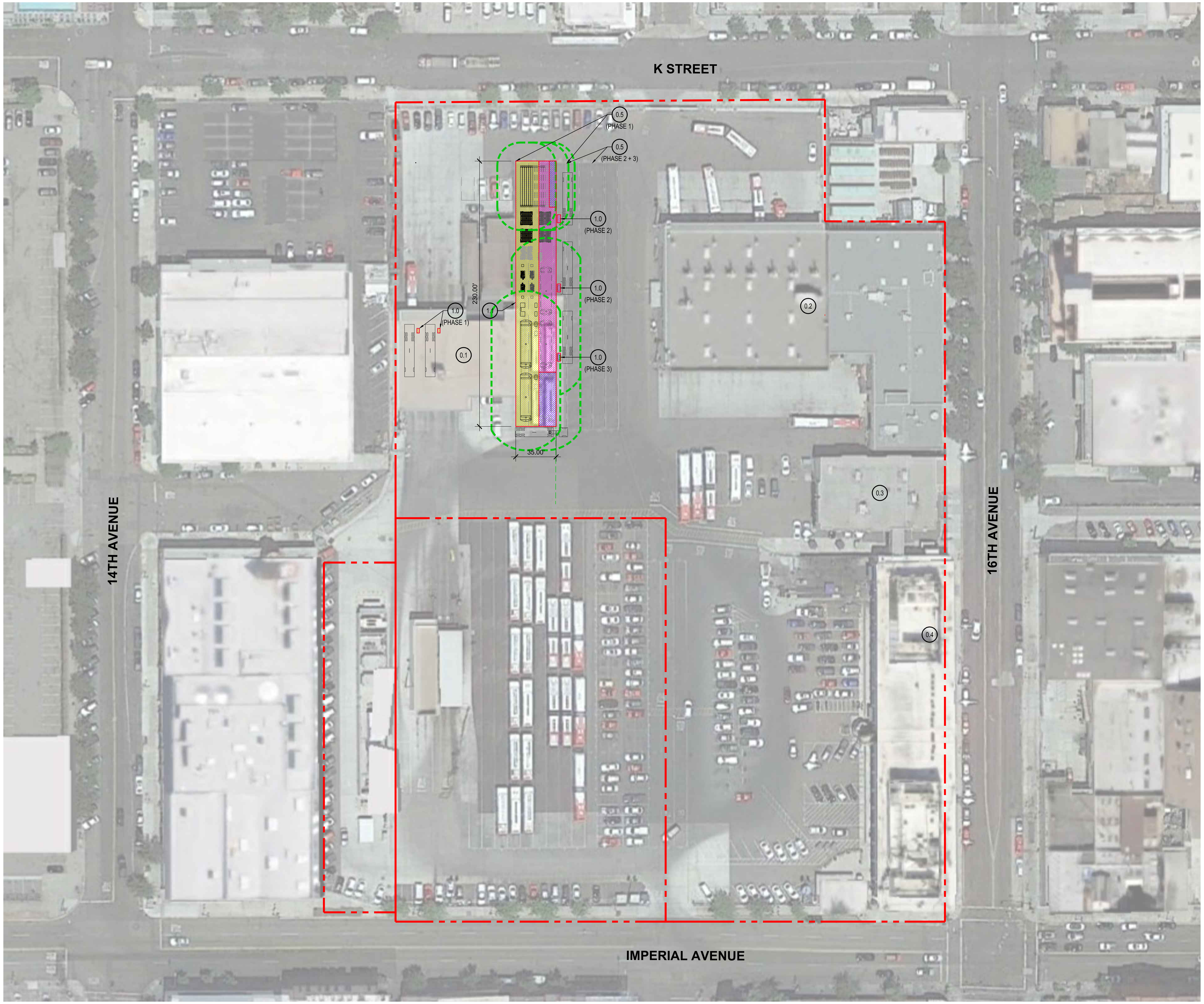

PRELIMINARY HYDROGEN FUELING SITE PLAN

GRAPHIC SCALE: 1" = 40'

VICINITY MAP

SITE NOTES

(#) NOTE

EXISTING ITEMS

- 0.1 (E) FUEL FACILITY
- 0.2 (E) MAINTENANCE BUILDING
- 0.3 (E) ADMIN ANEX
- 0.4 (E) REPAIR ADMIN BLDG. 1
- 0.5 (E) BUS PARKING TO BE REMOVED

NEW ITEMS

- 1.0 (N) DISPENSER
- 1.1 (N) HYDROGEN EQUIPMENT COMPOUND

PARKING INFORMATION

	PHASE 1		PHASE 2		PHASE 3	
	CAR	BUS	CAR	BUS	CAR	BUS
EXISTING REMOVED	-2	-20	0	-10	0	0
PROPOSED	0	0	0	0	0	0
NET CHANGE	-2	-20	0	-10	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2	PHASE 3
TOTAL COMPOUND SIZE:	20' X 230'	35' X 230'	35' X 230'
TOTAL # OF FUELING POSITION:	2	4	5
TOTAL # OF 15,000-GAL LH2 VESSELS	2	4	5

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 3 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED PHASE 3 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

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DEVELOPMENT INFORMATION:
MTS
IMPERIAL AVENUE DIVISION (IAD)

SITE ADDRESS:
100 16TH STREET
@ IMPERIAL AVENUE
SAN DIEGO, CA 92101

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 9/27/2019	PROJECT NO.: 16231

DRAWING TITLE:
PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:
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PRELIMINARY HYDROGEN FUELING SITE PLAN

N S E W

40' 20' 0 40' 80' 120'

GRAPHIC SCALE: 1" = 40'

VICINITY MAP

SITE NOTES

(#) NOTE

EXISTING ITEMS

0.1	MAINTENANCE (BLDG 100)
0.2	BUILDING 200
0.3	BUILDING 300
0.4	DIESEL FUEL (BLDG 400)
0.5	BUILDING 500
0.6	(E) BUS PARKING TO BE REMOVED

NEW ITEMS

1.0	(N) DISPENSER
1.1	(N) HYDROGEN EQUIPMENT COMPOUND
1.2	(N) FIRE RATED WALL

PARKING INFORMATION

	PHASE 1		PHASE 2		PHASE 3	
	CAR	BUS	CAR	BUS	CAR	BUS
EXISTING REMOVED	0	-5	0	0	0	-1
PROPOSED	0	0	0	0	0	0
NET CHANGE	0	-5	0	0	0	-1

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2	PHASE 3
TOTAL COMPOUND SIZE:	25' X 121'	25' X 168'	25' X 215'
TOTAL # OF FUELING POSITION:	2	2	2
TOTAL # OF 15,000-GAL LH2 VESSELS	1	2	3

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 3 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED PHASE 3 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

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DEVELOPMENT INFORMATION:

MTS
KEARNY MESA DIVISION (KMD)

SITE ADDRESS:

4630 RUFFNER ST
SAN DIEGO, CA 92111

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 09/27/2019	PROJECT NO.: 16231

DRAWING TITLE:

PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:

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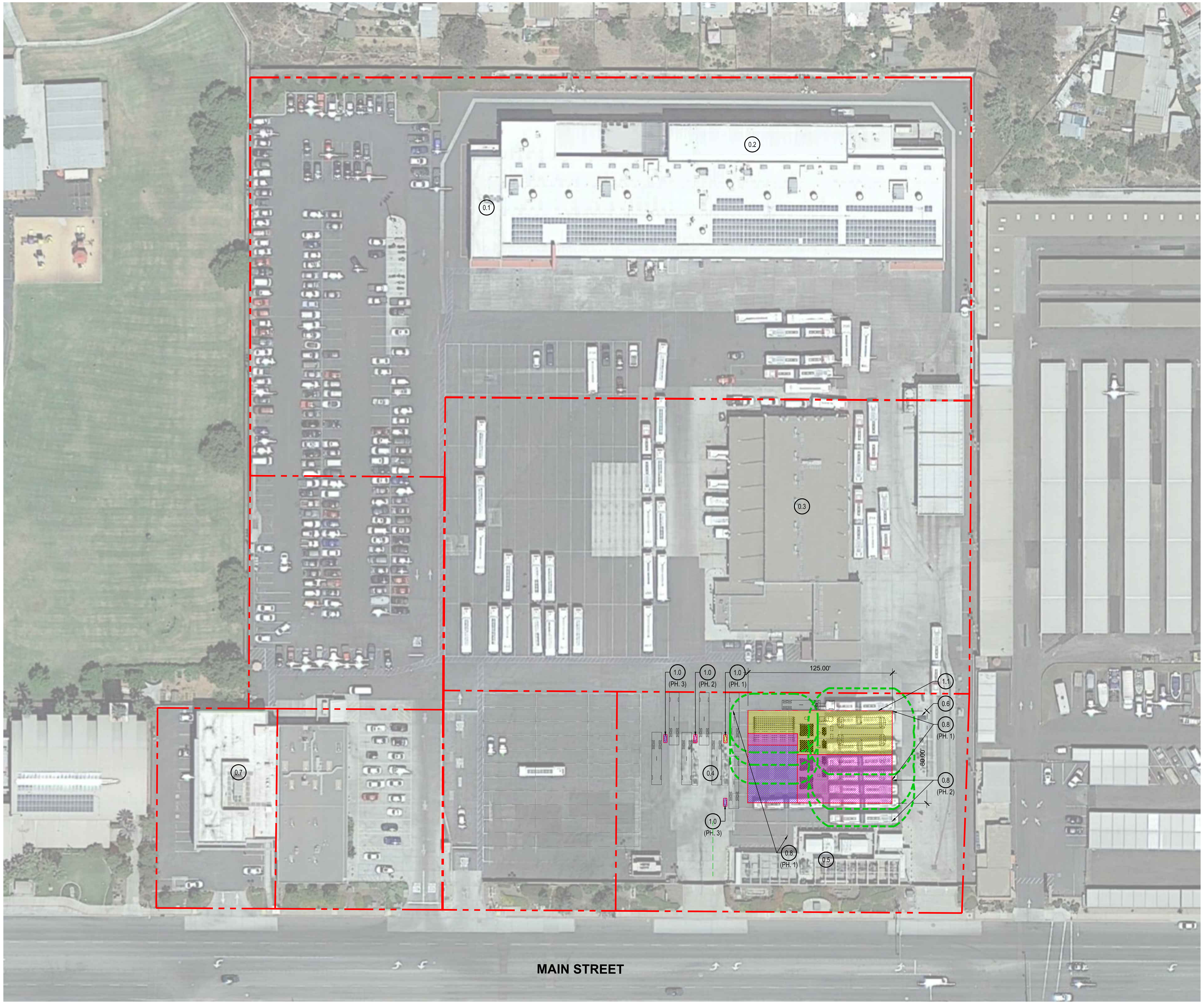

PRELIMINARY HYDROGEN FUELING SITE PLAN

N S E W

40' 20' 0 40' 80' 120'

GRAPHIC SCALE: 1" = 40'

VICINITY MAP

SITE NOTES

(#) NOTE

EXISTING ITEMS

- 0.1 (E) CHASSIS WASH AREA
- 0.2 (E) MAINTENANCE FACILITY
- 0.3 (E) MAINTENANCE
- 0.4 (E) CNG DISPENSERS
- 0.5 (E) CNG EQUIPMENT COMPOUND
- 0.6 (E) DIESEL DISPENSER
- 0.7 (E) ADMINISTRATION BUILDING
- 0.8 (E) BUS PARKING TO BE REMOVED

NEW ITEMS

- 1.0 (N) HYDROGEN DISPENSER
- 1.1 (N) HYDROGEN EQUIPMENT COMPOUND

PARKING INFORMATION

	PHASE 1		PHASE 2		PHASE 3	
	CAR	BUS	CAR	BUS	CAR	BUS
EXISTING REMOVED	0	-19	0	-6	0	0
PROPOSED	0	0	0	0	0	0
NET CHANGE	0	-19	0	-6	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2	PHASE 3
TOTAL COMPOUND SIZE:	125' X 38'	125' X 80'	125' X 80'
TOTAL # OF FUELING POSITION:	2	4	7
TOTAL # OF 15,000-GAL LH2 VESSELS	2	4	5

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 3 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED PHASE 3 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

PREPARED FOR (IMAGE):

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DEVELOPMENT INFORMATION:

MTS
SOUTH BAY BUS MAINTENANCE FACILITY (SBMF)

SITE ADDRESS:

3650A MAIN STREET
CHULA VISTA, CA 91911

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 9/27/2019	PROJECT NO.: 16231

DRAWING TITLE:

PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:

SP-1

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Design & Engineering

San Diego Metropolitan Transit System (MTS)

Fuel Cell Vehicle Fueling and Maintenance Facility Upgrade

Fuel Cell Bus Migration Plan

February 28, 2020

299 N. Euclid Ave., Ste 550 • Pasadena, CA 91101 • Phone (213) 381-7891

TABLE OF CONTENTS

Introduction

The purpose of this report is to provide San Diego Metropolitan Transit System (MTS) with an assessment and analysis of five (5) existing Maintenance Facilities for the purposes of deploying Fuel Cell Electric (FCE) buses. The report covers both the required modifications to enable hydrogen fuel cell buses to be serviced at the facility as well as the fueling infrastructure needed to fuel the buses with hydrogen.

The first section of the assessment details the maintenance facility modifications required at each division for servicing of Fuel Cell Buses. The latter section provides the fueling recommendations and phasing of supply equipment to accommodate additional Fuel Cell Buses at each division.

Existing Facilities and Fleet

San Diego Metropolitan Transit System (MTS) has five maintenance divisions located throughout San Diego County in order to support the operation of their fleet of buses. Each facility includes offices, maintenance, wash, and fueling facilities along with vehicle parking areas (both cars and buses). The current fleet size is approximately 800 buses: 483 are powered by compressed natural gas, 12 are gasoline/electric hybrid and the remaining are gasoline or diesel-powered.

The five Divisions are located at:

Copley Park Maintenance Facility (CPMF) - 7490 Copley Park Pl., San Diego, CA 92111

CPMF - is a 19,000 square-foot facility that supports a fleet of over 200 buses and does not include a CNG fueling station.

East County Bus Maintenance Facility (ECBMF) - 1213 N. Johnson Ave., El Cajon, CA 92020

ECBMF is a 57,500 square-foot facility that supports a fleet of 120 buses and includes a CNG fueling station.

Imperial Avenue Division (IAD) - 100 16th St., San Diego, CA 92101

IAD is an 86,300 square-foot facility located in Downtown San Diego and supports a fleet of 200 buses and can fuel CNG, diesel and gasoline buses.

Kearny Mesa Division (KMD) - 4630 Ruffner St., San Diego, CA 92111

KMD is a 54,166 square-foot division in Kearny Mesa supports 100 buses and includes both diesel and CNG fueling stations, as well as a body and paint shop.

South Bay Bus Maintenance Facility (SBMF) - 3650A Main St., Chula Vista, CA 91911

SBMF is a 48,000 square-foot facility that supports up to 250 buses and includes a CNG fueling station.

Analysis Approach

The scope of work for this analysis consists of both the maintenance facility upgrades that would be required to support a fleet of hydrogen fuel cell buses and the phased approach to build-out the hydrogen fueling infrastructure.

The applicable codes and standards that are the basis of the analysis include:

- PART 1 - CALIFORNIA ADMINISTRATIVE CODE
- PART 2 - CALIFORNIA BUILDING CODE
- PART 3 - CALIFORNIA ELECTRICAL CODE
- PART 4 - CALIFORNIA MECHANICAL CODE
- PART 5 - CALIFORNIA PLUMBING CODE
- PART 6 - CALIFORNIA ENERGY CODE
- PART 9 - CALIFORNIA FIRE CODE
- PART 10 - CALIFORNIA EXISTING BUILDING CODE
- PART 11 - CALIFORNIA GREEN BUILDING STANDARDS CODE
- PART 12 - CALIFORNIA REFERENCED STANDARDS CODE
- 2020 National Fire Protection Association (NFPA) 2 - Hydrogen Technologies
- 2018 National Fire Protection Association (NFPA) 30A - Code for Motor Fuel Dispensing Facilities and Repair Garages
- 2014 National Fire Protection Association (NFPA)70, National Electrical Code (NEC)

The Maintenance Facilities were evaluated to determine what would be the typical modifications needed to introduce hydrogen fuel cell buses into the serviceable fleet. The three main areas of review were:

Ventilation Systems:

NFPA-2 Code requires that the minimum air flow exhaust ventilation shall be not less than 1 scfm/ft^2 (0.028 Nm^3/min/m^2) of floor area. This calculation represents five (5) air changes per hour (ACH) and is the volumetric flow rate baseline for design when evaluating the flow performance for each ventilation fan.

Heating Systems:

NFPA-2 Code requires open-flame heaters or heating equipment with exposed surfaces having a temperature in excess of 752°F (400°C) shall not be permitted in areas subject to ignitable concentrations of gas.[1]

Gas Detection System:

NFPA-2 also requires that a gas detection system be provided. Major repair garages shall be provided with an approved hydrogen gas detection system such that gas can be detected where vehicle hydrogen fuel storage systems are serviced.

[1] 2020 NFPA 2 Section 18.3.4.4.2

The Fueling Facilities were evaluated to determine what would be the typical modifications needed to integrate the storage and dispensing equipment of hydrogen fuel into the existing buses maintenance facilities. The main areas of review were:

Hydrogen Storage:

- **HYDROGEN STORAGE:**

  The hydrogen storage has been sized in phases for the number of buses being fueled with a four-day supply. The hydrogen will be cryogenically stored in a liquid state outdoors in above ground insulated tanks. The hydrogen storage and dispensing require protection in the form of physical space or barriers, and the exclusion of certain electronic equipment and other potential sources of ignition.

- **SITING LOCATIONS - PHYSICAL PROTECTION MINIMUM DISTANCES**:

  Hydrogen storage is required to be protected from accidental discharge per NFPA 2 8.3.2.3.1.2 with physical barriers (bollards, fencing, grade separations walls, etc.) and setbacks. NFPA-2 8.3.2.3.1.6(A) Bulk Liquified Hydrogen Setback distances defines the required separation distances based on three exposure groups. Appendix C includes the Preliminary Site Plans with the proposed locations of the hydrogen fueling equipment and dispensers.

- **SITING LOCATIONS - ALTERNATIVE MINIMUM DISTANCES**:
  Insulated portions of the system can reduce the set-back distances by 2/3 (66.6%) but not less than 5 feet for items 1, 7, 8, 10, 11, and 12 (Column 4). Refer to Appendix F – Code Reference Table – Minimum Separation Distances.

  Fire barrier walls of >2-hour rating can reduce the set-back distances to 0 feet for items 1, 7, 8, 10, 11, and 12 (Column 5). Zero-foot setback is only applicable to the exposures that are blocked from the line-of-sight of the exposure to the bulk liquid hydrogen storage.

  Offloading Transfer Connection Modifications can reduce the set-back distances to 50 feet for Group 1 and 2 exposure types through active mitigation methods [8.3.2.3.1.6(B)] (Column 6).

Hydrogen Dispensing:

Sources of ignition shall not be permitted within 10 ft (3.0 m) of any filling connection during a transfer operation per NFPA-2 10.3.1.13.9. Electrical classifications do not permit unclassified electronics in the classified areas.

For dispensing hydrogen, the electrical classifications are as follows (NFPA 2 Table 11.2.12.1):

- Class 1 Div. 1:
    - Pits, trenches, or sumps located in or adjacent to Div. 1 or 2 areas – entire area.
    - Discharge from relief valves, drains - <5 feet from discharge.
    - Vehicle/cargo transfer area, outdoors in open air at or above grade - <3 feet of connection.
- Class 1, Div. 2:
    - Discharge from relief valves, drains - >5 feet and <25 feet from discharge in all directions.
    - Points where connections to the hydrogen system are regularly made and disconnected - >3 feet and <25 feet from connection.

Recommended Maintenance Facility Upgrades

Copley Park Maintenance Facility (CPMF)

- **ELECTRICAL AND LIGHTING SYSTEMS:** Lighting fixtures and electrical fittings will need to be evaluated and either replaced or relocated out of the 18" Class 1 / Division 2 area located at the underside of the roof deck.
- **MECHANICAL SYSTEMS:** Verification of current exhaust fan operation to confirm that the required number of air changes per hour is provided and adjust system as needed. Additional exhaust fans may be needed to ensure compliance with the required air changes per hour.
- **GAS DETECTION SYSTEM:** Gas detectors will need to be installed in each of the maintenance bays and a gas detection panel added.

East County Bus Maintenance Facility (ECBMF)

- **MECHANICAL SYSTEMS:** The existing facility is currently servicing Compressed Natural Gas (CNG) buses. Verification of current exhaust fan operation to confirm that the required number of air changes per hour is provided and adjust system as needed.
- **GAS DETECTION SYSTEM:** Gas detectors will need to be installed in each of the maintenance bays and a gas detection panel added and integrated into the operation of the existing methane gas detection system.

Imperial Avenue Division (IAD)

- **MECHANICAL SYSTEMS:** The existing facility is currently servicing Compressed Natural Gas (CNG) buses. Verification of current exhaust fan operation to confirm that the required number of air changes per hour is provided and adjust system as needed.
- **GAS DETECTION SYSTEM:** Gas detectors will need to be installed in each of the maintenance bays and a gas detection panel added and integrated into the operation of the existing methane gas detection system.

Kearny Mesa Division (KMD)

- **MECHANICAL SYSTEMS:** The existing facility is currently servicing Compressed Natural Gas (CNG) buses. Verification of current exhaust fan operation to confirm that the required number of air changes per hour is provided and adjust system as needed.
- **GAS DETECTION SYSTEM:** Gas detectors will need to be installed in each of the maintenance bays and a gas detection panel added and integrated into the operation of the existing methane gas detection system.

South Bay Bus Maintenance Facility (SBMF)

- **MECHANICAL SYSTEMS:** The existing facility is currently servicing Compressed Natural Gas (CNG) buses. Verification of current exhaust fan operation to confirm that the required number of air changes per hour is provided and adjust system as needed.
- **GAS DETECTION SYSTEM:** Gas detectors will need to be installed in each of the maintenance bays and a gas detection panel added and integrated into the operation of the existing methane gas detection system.

Fueling Facility Phasing

Introduction:

The phasing of the fueling facility design is driven by the migration of existing fleet buses at each division to FCEV buses. With a yearly migration plan increasing the number of FCEV per division, an equipment package must be designed to also upgrade in kind. Equipment design falls into two categories: vehicle dispensing capacity, and bulk on-site fuel capacity.

Equipment

Overview

1) Dispensing Capacity
    a. Driven by number of buses undergoing fueling per incremental time available
    b. Drives capacity and quantity of dispensing equipment
        i. Dispensers
        ii. Liquid Hydrogen (LH2) pumps
        iii. Liquid-to-Gas vaporizers
        iv. Gaseous Hydrogen (H2) temperature conditioning (Chilling)
2) Bulk On-Site Fuel Capacity
    a. Driven by daily LH2 consumption, and desired buffer capacity
    b. Sized appropriately to accept a minimum of one complete offload

Dispensers:

The number of dispensers necessary per division is calculated with the following given data and assumptions

- Each bus requires one fueling event per day.
- Each dispenser is capable of fueling one vehicle at a time. Also referred to as a "single-hose dispenser"
- Each bus will experience an average of 27kg of fuel dispensed at one time, within an average time of 12 minutes. Commercially available FCEV Buses can fuel up to 36kg from near-empty, however we assume each bus is only 75% empty at fueling.
- All buses must be filled within a 8-hour window per day
- Industry available H2 bus technology is limited to 350bar maximum pressure.
- Minimum quantity of two dispensers per division irrespective of demand, for the purpose of redundancy.

Utilizing the above metrics, the number of dispensers required per division is as follows:

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Copley	0	0	0	0	0	0	2	3	4	4	5	5	5	5	5	5	5	5
East County	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2
Imperial Ave	2	2	2	2	2	2	2	2	2	2	2	3	3	4	5	5	5	5
Kearny Mesa	0	0	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
South Bay	0	2	2	2	2	2	2	3	3	3	4	5	6	6	6	6	7	7

The above data however must be compared to existing operations. Based on reconnaissance data, each division consists of the following existing fueling positions (dispensers):

Copley: **4;** East County: **2;** Imperial Avenue: **3;** Kearny Mesa: **5;** South Bay: **4**

When comparing with the above table, additional dispensing positions will be necessary for all but two sites. This can be achieved by revisiting our initial assumptions, or adding new fueling positions:

<u>Copley:</u> Extension of the fueling window by two hours will accommodate the existing four fueling positions.

<u>East County</u> and <u>Kearny Mesa</u> can maintain the existing number of fueling positions.

<u>Imperial Ave:</u> The addition of a fourth fueling position in addition to a two-hour extension of the fueling window can meet the needs of the full migration from 2037 on.

<u>South Bay:</u> Possessing the highest bus demand of any location, an addition of one fueling positions beyond what exists today will be necessary. In addition, the fueling window should be extended by two hours.

<u>Balance of Dispensing Equipment:</u>

Each equipment manufacturer will pair liquid H2 pumping capacity, liquid-to-gas vaporization capacity, and gaseous H2 temperature conditioning (chilling) to the number of simultaneous fills necessary to meet the demand. The quantity and capacity of this equipment often varies between each equipment manufacturer and is dependent on product offerings of each respective sub-vendor. For example, a single LH2 pump may provide sufficient flow for multiple simultaneously fueling dispensers.

<u>Liquid H2 Storage:</u>

The most efficient capacity for a bulk storage tank will at a minimum accept one complete offload from a mobile LH2 tanker, while maximized to cost effectively ship to the prospective location. A 15,000 gallon (nominal) cryogenic LH2 vessel will accept the full delivery trailer capacity, while maintaining a diameter just under the maximum on-road transport width allowed by DOT (12') for a non-escorted "wide-load". When factoring LH2 volume expansion due to environmental and pump heat transfer, the net fuel anticipated to be offloaded to the permanent storage vessel is approximately 3000 Kg's.

As a result, we recommend a single 15,000-gallon tank as the minimum for bulk LH2 capacity at each division. Increased bulk LH2 capacity can be attained by deploying additional 15,000-gallon vessels as necessary.

In order to evaluate the number of vessels necessary per division, we utilized the projected fuel consumption calculated by CTE staff. We understand MTS desires liquid storage capacity equaling four days of service, which was reflected in the fuel capacity requirement.

Below is a projection of the recommended quantity of 15,000-gallon LH2 vessels per division, per year.

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Copley	0	0	0	0	0	0	1	2	2	2	2	2	2	2	2	2	2	2
East County	0	0	0	0	1	1	1	1	2	2	2	2	2	2	2	2	2	2
Imperial Ave	1	1	1	1	1	1	1	1	1	2	2	3	3	4	5	5	5	5
Kearny Mesa	0	0	0	1	1	1	2	2	2	2	2	2	3	3	3	3	3	3
South Bay	0	1	1	2	2	2	2	3	3	3	4	5	5	5	5	5	5	5

Cost Analysis

Our philosophy for the development of our cost model is as follows:

1) 50-bus incremental mechanical equipment package and installation
   a. Inclusive of two dispensers
   b. Excludes LNG storage tank (to be incrementally added based on fuel demand)
   c. Includes all mechanical process equipment and hydrogen wetted components
   d. Includes design, engineering, and permitting
   e. Includes construction cost
      i. Demolition of existing pavement, and excavation
      ii. Installation of new equipment foundations
      iii. All electrical conduit, conductors and termination
      iv. Emergency Shut Down and Notification system
      v. Mechanical installation
      vi. Electrical utilities estimate and switchgear
2) Incremental addition of 15,000-gallon LH2 tank
   a. Cost includes installation when not accompanied by station expansion.

In order to reasonably phase the expansion of fueling capacity, we are limiting the number of phases for each division to three. This will result in higher capital expenses during the initial installation and expansions; however, we feel this is ultimately more practical. Expansion will inevitably interfere with existing operations of both FCE buses and non-FCE buses on-site. In addition, there is considerable capital expenditure savings by developing a larger footprint at one time. For example, design and permitting costs is nearly identical for a 50 vs. 100-bus-capacity station design.

For the development of three distinct phases, we evaluated the number of buses per year, in combination with yearly projected fuel throughput. In most cases, storage capacity was added alongside dispenser and pump/vaporizer capacity. In a few limited cases, the addition of dispensers or LH2 storage were disjointed. If a division's final build-out would only utilize a small fraction of volume of the last tank, this tank was eliminated. We believe the marginal use of a storage tank to be an inefficient use of capitol, if fewer tanks can nearly meet the four-day storage requirement.

One special consideration is electrical utility service. In our direct experience, this cost can swing wildly as it is highly dependent on existing infrastructure present and adjacent to the subject property. This topic should be investigated early with the local electrical power utility to determine budget impacts.

Below is a breakdown of incremental cost for the phasing of fueling infrastructure per division:

Copley Fueling Facility Yearly Incremental Cost Estimate

Division	2019	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Number of Buses	0	0	0	0	0	0	0	21	112	147	177	204	215	215	215	215	215	215	215
50-bus Incremental								$8,635,070				$3,649,924							
Storage Capacity Incremental Cost								$580,000											
Yearly Facility Expansion Cost								$9,215,070				$3,649,924							

East County Fueling Facility Yearly Incremental Cost Estimate

Division	2019	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Number of Buses	0	0	0	0	0	6	21	41	41	66	69	69	69	69	69	69	69	69	79
50-bus Incremental						$4,294,028				$3,649,924									
Storage Capacity Incremental Cost						$290,000				$290,000									
Yearly Facility Expansion Cost						$4,584,028				$3,939,924									

Imperial Ave. Fueling Facility Yearly Incremental Cost Estimate

Division	2019	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Number of Buses	0	11	11	11	11	11	11	21	21	21	77	90	103	133	149	193	193	193	193
50-bus Incremental		$4,294,028									$6,464,549				$4,294,028				
Storage Capacity Incremental Cost		$290,000									$580,000				$580,000				
Yearly Facility Expansion Cost		$4,584,028									$7,044,549				$4,874,028				

Kearny Mesa Fueling Facility Yearly Incremental Cost Estimate

Division	2019	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Number of Buses	0	0	0	0	12	35	35	48	60	60	60	60	60	89	89	89	89	89	89
50-bus Incremental					$4,294,028				$3,649,924										
Storage Capacity Incremental Cost					$290,000				$290,000					$435,000					
Yearly Facility Expansion Cost					$4,584,028				$3,939,924					$435,000					

South Bay Fueling Facility Yearly Incremental Cost Estimate

Division	2019	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Number of Buses	0	0	10	23	51	69	69	69	112	119	134	171	209	221	233	244	254	267	267
50-bus Incremental			$8,635,070									$6,464,549						$4,294,028	
Storage Capacity Incremental Cost			$870,000									$580,000							
Yearly Facility Expansion Cost			$9,505,070									$7,044,549						$4,294,028	

Recommended Fueling Facility Upgrades

Copley Park Maintenance Facility (CPMF)

- **HYDROGEN STORAGE AND ASSOCIATED SYSTEMS:**
    - In the initial phase of hydrogen integration, a hydrogen storage and associated equipment compound to be located in the bus parking area as indicated on Preliminary Site Plan SP-1.
    - Property line set back is reduced to 0 feet with recommended installation of a 2-hour fire-rated barrier wall constructed in accordance with NFPA 2 8.3.2.3.1.6(A). Recommended location complies.
    - Set-back from equipment air intakes, wall openings, and any other ignition sources is 50 feet with active mitigation methods for offloading bulk liquid hydrogen transfer as outlined in NFPA 2 8.3.2.3.1.6(B). Recommended location complies.
    - Set-back to public assembly areas (e.g. emergency evacuation assembly area, etc.) is 50 feet with mitigation methods for offloading bulk liquid hydrogen transfer. Recommended location complies.
    - Set-back to parked cars is 25 feet. Given the required separation distances from parking, buildings and property lines, a reduction in parking is necessary to comply. The recommended location for the hydrogen compound will result in the removal of fifteen (15) car parking spaces to accommodate the hydrogen storage/equipment. With parking restriction, recommended location complies.
    - Building setbacks are between zero and 25 feet depending on construction type. Recommended location complies.
    - All additional setbacks comply per NFPA 2 Table 8.3.2.3.1.6(A)

- **DISPENSING SYSTEMS:**
    - The existing fueling area is comprised of four (4) fueling positions adjacent to above ground storage tanks. In the initial phase of hydrogen integration, two (2) hydrogen fueling lanes will be constructed. In the second phase of integration, a third and fourth hydrogen fueling lanes will be constructed. Flame and gas detection sensors will be added to each of the fueling lanes.

East County Bus Maintenance Facility (ECBMF)

- **HYDROGEN STORAGE AND ASSOCIATED SYSTEMS:**
  - In the initial phase of hydrogen integration, a hydrogen storage and associated equipment compound to be located in the bus parking area as indicated on Preliminary Site Plan SP-1.
  - Property line set back is reduced to 0 feet with recommended installation of a 2-hour fire-rated barrier wall constructed in accordance with NFPA 2 8.3.2.3.1.6(A). Recommended location complies.
  - Set-back from equipment air intakes, wall openings, and any other ignition sources is 50 feet with active mitigation methods for offloading bulk liquid hydrogen transfer as outlined in NFPA 2 8.3.2.3.1.6(B). Recommended location complies.
  - Set-back to public assembly areas (e.g. emergency evacuation assembly area, etc.) is 50 feet with mitigation methods for offloading bulk liquid hydrogen transfer. Recommended location complies.
  - Set-back to parked cars is 25 feet. Given the required separation distances from parking, buildings and property lines, a reduction in parking is necessary to comply. The recommended location for the hydrogen compound will result in the removal of five (5) bus and thirteen (13) car parking spaces to accommodate the hydrogen storage/equipment. With parking restriction, recommended location complies.
  - Building setbacks are between zero and 25 feet depending on construction type. Recommended location complies.
  - All additional setbacks comply per NFPA 2 Table 8.3.2.3.1.6(A)

- **DISPENSING SYSTEMS:**
  - The existing fueling area is comprised of three (3) fueling lanes. In the initial phase of hydrogen integration, two (2) hydrogen dispensers will be added to two of the fueling lanes. Flame and gas detection sensors will be added to each of the fueling lanes.

Imperial Avenue Division (IAD)

- **HYDROGEN STORAGE AND ASSOCIATED SYSTEMS:**
  - In the initial phase of hydrogen integration, a hydrogen storage and associated equipment compound to be located in the bus parking area as indicated on Preliminary Site Plan SP-1.
  - Property line set back is reduced to 0 feet with recommended installation of a 2-hour fire-rated barrier wall constructed in accordance with NFPA 2 8.3.2.3.1.6(A). Recommended location complies.
  - Set-back from equipment air intakes, wall openings, and any other ignition sources is 50 feet with active mitigation methods for offloading bulk liquid hydrogen transfer as outlined in NFPA 2 8.3.2.3.1.6(B). Recommended location complies.
  - Set-back to public assembly areas (e.g. emergency evacuation assembly area, etc.) is 50 feet with mitigation methods for offloading bulk liquid hydrogen transfer. Recommended location complies.
  - Set-back to parked cars is 25 feet. Given the required separation distances from parking, buildings and property lines, a reduction in parking is necessary to comply. The recommended location for the hydrogen compound will result in the removal of twenty-six (26) bus and four (4) car parking spaces to accommodate the hydrogen storage/equipment. With parking restriction, recommended location complies.
  - Building setbacks are between zero and 25 feet depending on construction type. Recommended location complies.
  - All additional setbacks comply per NFPA 2 Table 8.3.2.3.1.6(A)

- **DISPENSING SYSTEMS:**
  - The existing fueling area is comprised of three (3) fueling lanes. In the initial phase of hydrogen integration, two (2) hydrogen dispensers will be added to two of the fueling lanes. In the second phase of integration a third hydrogen dispenser and a fourth fueling lane will be added so all fueling lanes can fuel hydrogen fuel cell buses. Flame and gas detection sensors will be added to each of the fueling lanes.

Kearny Mesa Division (KMD)

- **HYDROGEN STORAGE AND ASSOCIATED SYSTEMS:**
  - In the initial phase of hydrogen integration, a hydrogen storage and associated equipment compound will be located in the bus parking area as indicated on Preliminary Site Plan SP-1.
  - Property line set back is reduced to 0 feet with recommended installation of a 2-hour fire-rated barrier wall constructed in accordance with NFPA 2 8.3.2.3.1.6(A). Recommended location complies.
  - Set-back from equipment air intakes, wall openings, and any other ignition sources is 50 feet with active mitigation methods for offloading bulk liquid hydrogen transfer as outlined in NFPA 2 8.3.2.3.1.6(B). Recommended location complies.
  - Set-back to public assembly areas (e.g. emergency evacuation assembly area, etc.) is 50 feet with mitigation methods for offloading bulk liquid hydrogen transfer. Recommended location complies.
  - Set-back to parked cars is 25 feet. Given the required separation distances from parking, buildings and property lines, a reduction in parking is necessary to comply. The recommended location for the hydrogen compound will result in the removal of eleven (11) bus parking spaces to accommodate the hydrogen storage/equipment. With parking restriction, recommended location complies.
  - Building setbacks are between zero and 25 feet depending on construction type. Recommended location complies.
  - All additional setbacks comply per NFPA 2 Table 8.3.2.3.1.6(A)

- **DISPENSING SYSTEMS:**
  - The existing fueling area is comprised of three (3) fueling lanes. In the initial phase of hydrogen integration, two (2) hydrogen dispensers will be added to two of the fueling lanes. Flame and gas detection sensors will be added to each of the fueling lanes.

South Bay Bus Maintenance Facility (SBMF)

- **HYDROGEN STORAGE AND ASSOCIATED SYSTEMS:**
    - In the initial phase of hydrogen integration, a hydrogen storage and associated equipment compound will be located in the bus parking area as indicated on Preliminary Site Plan SP-1.
    - Property line set back is reduced to 0 feet with recommended installation of a 2-hour fire-rated barrier wall constructed in accordance with NFPA 2 8.3.2.3.1.6(A). Recommended location complies.
    - Set-back from equipment air intakes, wall openings, and any other ignition sources is 50 feet with active mitigation methods for offloading bulk liquid hydrogen transfer as outlined in NFPA 2 8.3.2.3.1.6(B). Recommended location complies.
    - Set-back to public assembly areas (e.g. emergency evacuation assembly area, etc.) is 50 feet with mitigation methods for offloading bulk liquid hydrogen transfer. Recommended location complies.
    - Set-back to parked cars is 25 feet. Given the required separation distances from parking, buildings and property lines, a reduction in parking is necessary to comply. The recommended location for the hydrogen compound will result in the removal of thirty-five (35) bus parking spaces to accommodate the hydrogen storage/equipment. With parking restriction, recommended location complies.
    - Building setbacks are between zero and 25 feet depending on construction type. Recommended location complies.
    - All additional setbacks comply per NFPA 2 Table 8.3.2.3.1.6(A)

- **DISPENSING SYSTEMS:**
    - The existing fueling area is comprised of four (4) fueling lanes. In the initial phase of hydrogen integration, two (2) hydrogen dispensers will be added to two of the fueling lanes. In the second phase of integration a third hydrogen dispenser will be added so each fueling lane can fuel hydrogen fuel cell buses. In the third phase of integration, a fourth and fifth hydrogen dispenser will be added. Flame and gas detection sensors will be added to each of the fueling lanes.

Appendix A – Budgetary Cost Estimate for Maintenance Facility Upgrades

The budgetary costs to modify the existing maintenance facilities to service the fuel cell buses were developed utilizing data from recent deployment programs. The per bay budgetary costs for a facility that has already been previously modified to service CNG buses is $50,000.00 per bay. For facilities that have not been previously modified to service CNG buses, the budgetary cost per bay is $125,000.00.

Division	# of Bays	$ / Bay	Budget
Copley Park Maintenance Facility (CPMF)	10	$125,000	$ 1,250,000
East County Bus Maintenance Facility (ECBMF)	12	$ 50,000	$ 600,000
Imperial Avenue Division (IAD)	15	$ 50,000	$ 750,000
Kearny Mesa Division (KMD)	20	$ 50,000	$ 1,000,000
South Bay Bus Maintenance Facility (SBMF)	27	$ 50,000	$ 1,350,000

Appendix B – Budgetary Cost Estimate for Fueling Facility Migration

Division	Phase 1 Budget	Phase 2 Budget	Phase 3 Budget
Copley Park Maintenance Facility (CPMF)	$ 9,215,070	$ 3,939,924	N/A
East County Bus Maintenance Facility (ECBMF)	$ 4,584,028	$ 3,939,924	N/A
Imperial Avenue Division (IAD)	$ 4,584,028	$ 6,754,549	$ 4,584,028
Kearny Mesa Division (KMD)	$ 4,584,028	$ 3,939,924	$ 435,000
South Bay Bus Maintenance Facility (SBMF)	$ 9,215,070	$ 7,044,549	$ 4,294,028

Appendix C – Conceptual Fueling Migration Site Plans

- **Copley Park Maintenance Facility (CPMF Imperial Avenue Division (IAD)**
- **East County Bus Maintenance Facility (ECBMF)**
- **Imperial Avenue Division (IAD)**
- **Kearny Mesa Division (KMD)**
- **South Bay Bus Maintenance Facility (SBMF)**

Copley Park Maintenance Facility (CPMF)

The Hydrogen Equipment Compound at Copley Park Division will be located at the West end of the property. The Equipment Compound will be built in two phases: Phase I and Phase II. The Equipment Compound will be 39’ W x 145” L.

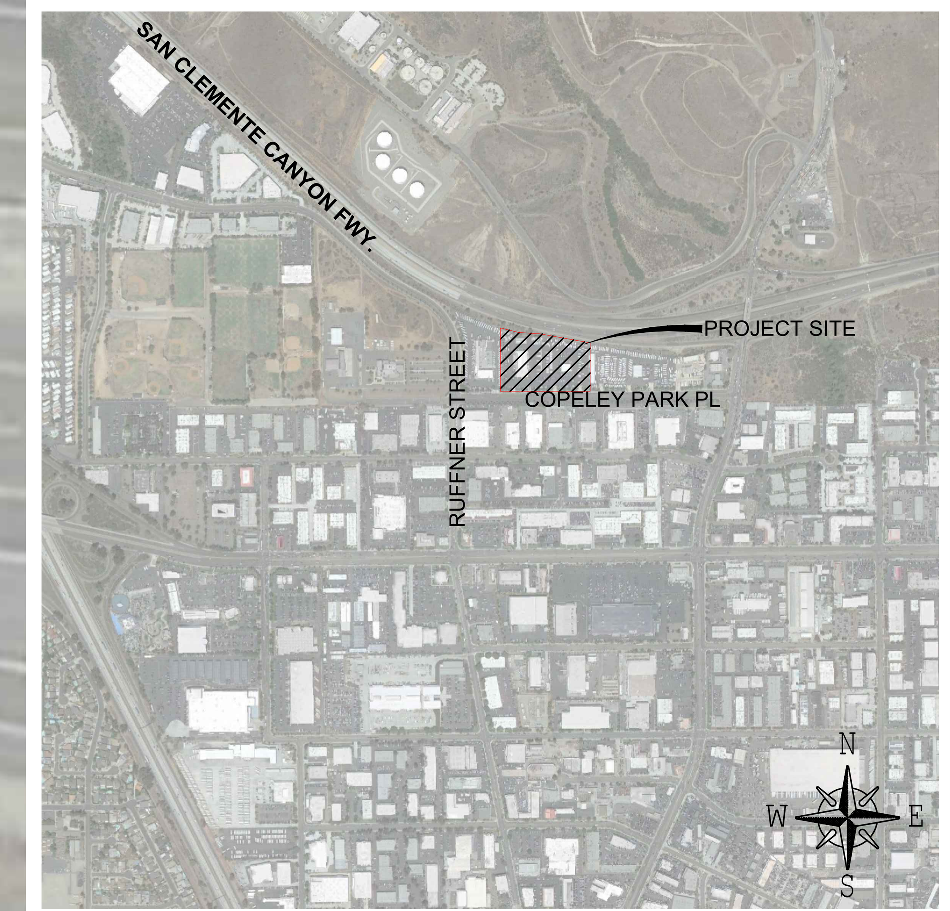
- **Phase I:**
  To include 2 LH_2 tanks, 4 vaporizers, 4 pumps, and 4 assemblies of high-pressure gaseous hydrogen storage vessels.

- **Phase II:**
  To include 1 vaporizers, 1 pumps, and 1 assembly of high-pressure gaseous hydrogen storage vessels.

PRELIMINARY HYDROGEN FUELING SITE PLAN

GRAPHIC SCALE: 1" = 30'

VICINITY MAP



SITE NOTES

#	NOTE
	EXISTING ITEMS
0.1	CNG STATION
0.2	DIESEL STATION
0.3	OFFICE/MAINTENANCE BLDG
0.4	MAINTENANCE BLDG
	NEW ITEMS
1.0	(N) HYDROGEN DISPENSER
1.1	(N) HYDROGEN EQUIPMENT COMPOUND

PARKING INFORMATION

	PHASE 1		PHASE 2	
	CAR	BUS	CAR	BUS
EXISTING REMOVED	0	-18	0	0
PROPOSED	0	0	0	0
NET CHANGE	0	-18	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2
TOTAL COMPOUND SIZE:	50' X 110'	50' X 120'
TOTAL # OF DISPENSER:	4	5
TOTAL # OF 15,000-GAL LH2 VESSELS	2	2

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

MTS

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DEVELOPMENT INFORMATION:
MTS
COPLEY PARK MAINTENANCE FACILITY (CPMF)

SITE ADDRESS:
7490 COPLEY PARK PL.
SAN DIEGO, CA 92111

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 09/27/2019	PROJECT NO.: 16231

DRAWING TITLE:
PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:
SP-1

\\fiedler-project\data\projects\16231\Design\100 Preliminary Designs\Preliminary Site Plans\SP\SP-1\01-Copley Park Maintenance Facility\16231-Copley Park-SP-1.dwg - PLOTTED: Feb 18, 2020 - 8:51am

East County Bus Maintenance Facility (ECBMF)

The Hydrogen Equipment Compound at East County Division will be located at the South end of the property. The Equipment Compound will be built in two phases: Phase I and Phase II. The Equipment Compound will be 39' W x 115" L.

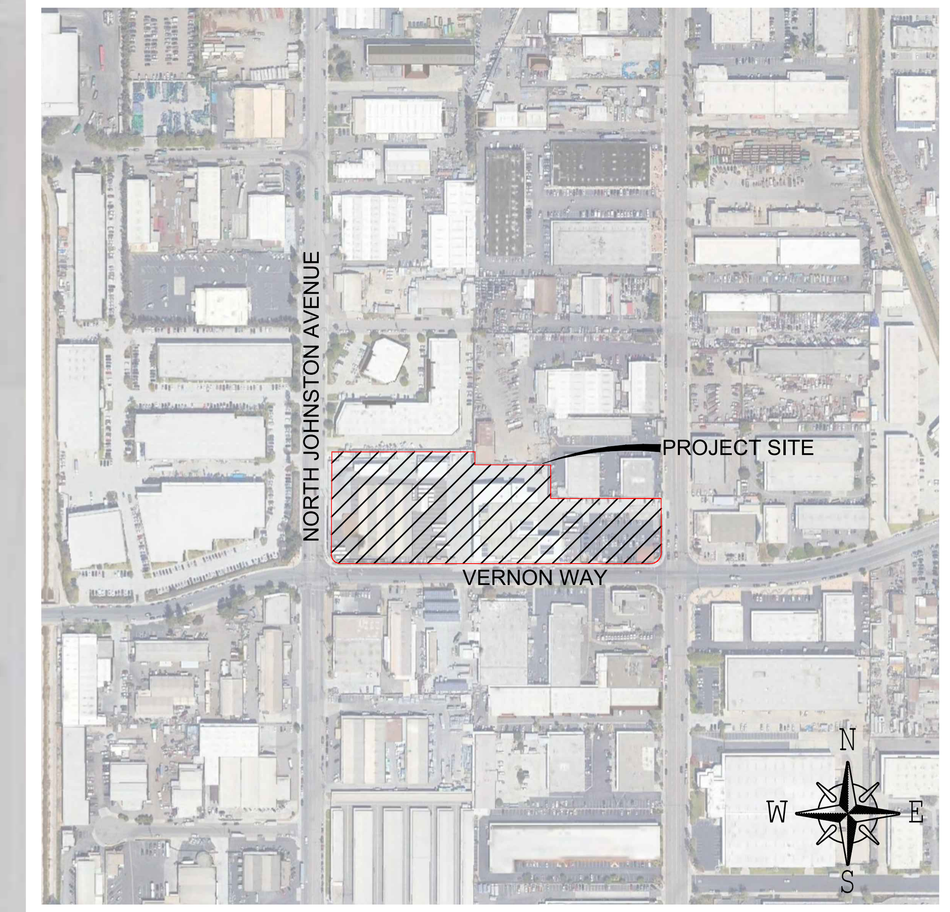
- **Phase I:**
  To include 1 LH_2 tank, 2 vaporizers, 2 pumps, and 1 assembly of high-pressure gaseous hydrogen storage vessels.

- **Phase II:**
  To include 1 LH_2 tank

PRELIMINARY HYDROGEN FUELING SITE PLAN

GRAPHIC SCALE: 1" = 40'

VICINITY MAP



SITE NOTES

#	NOTE	QUANTITY	REFERENCE
	<u>EXISTING ITEMS</u>		
0.1	(E) CNG FACILITY		
0.2	(E) BUS WASH		
0.3	(E) FUEL AREA BUILDING		
0.4	(E) BUS MAINTENANCE BUILDING		
0.5	(E) BUS PARKING TO BE REMOVED		
	<u>NEW ITEMS</u>		
1.0	(N) DISPENSER		
1.1	(N) HYDROGEN EQUIPMENT COMPOUND		
1.2	(N) FIRE RATED WALL		

PARKING INFORMATION

	PHASE 1			PHASE 2		
	CAR	40' BUS	45' BUS	CAR	40' BUS	45' BUS
EXISTING REMOVED	0	0	-10	0	0	0
PROPOSED	0	0	0	0	0	0
NET CHANGE	0	0	-10	0	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2
TOTAL COMPOUND SIZE:	25' X 121'	25' X 170'
TOTAL # OF FUELING POSITION:	2	2
TOTAL # OF 15,000-GAL LH2 VESSELS	1	2

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

MTS

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DEVELOPMENT INFORMATION:

MTS
EAST COUNTY BUS MAINTENANCE FACILITY (ECBMF)

SITE ADDRESS:

1213 N. JOHNSON AVE
@ VERNON STREET
EL CAJON, CA 92020

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 9/27/2019	PROJECT NO.: 16231

DRAWING TITLE:

PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:

SP-1

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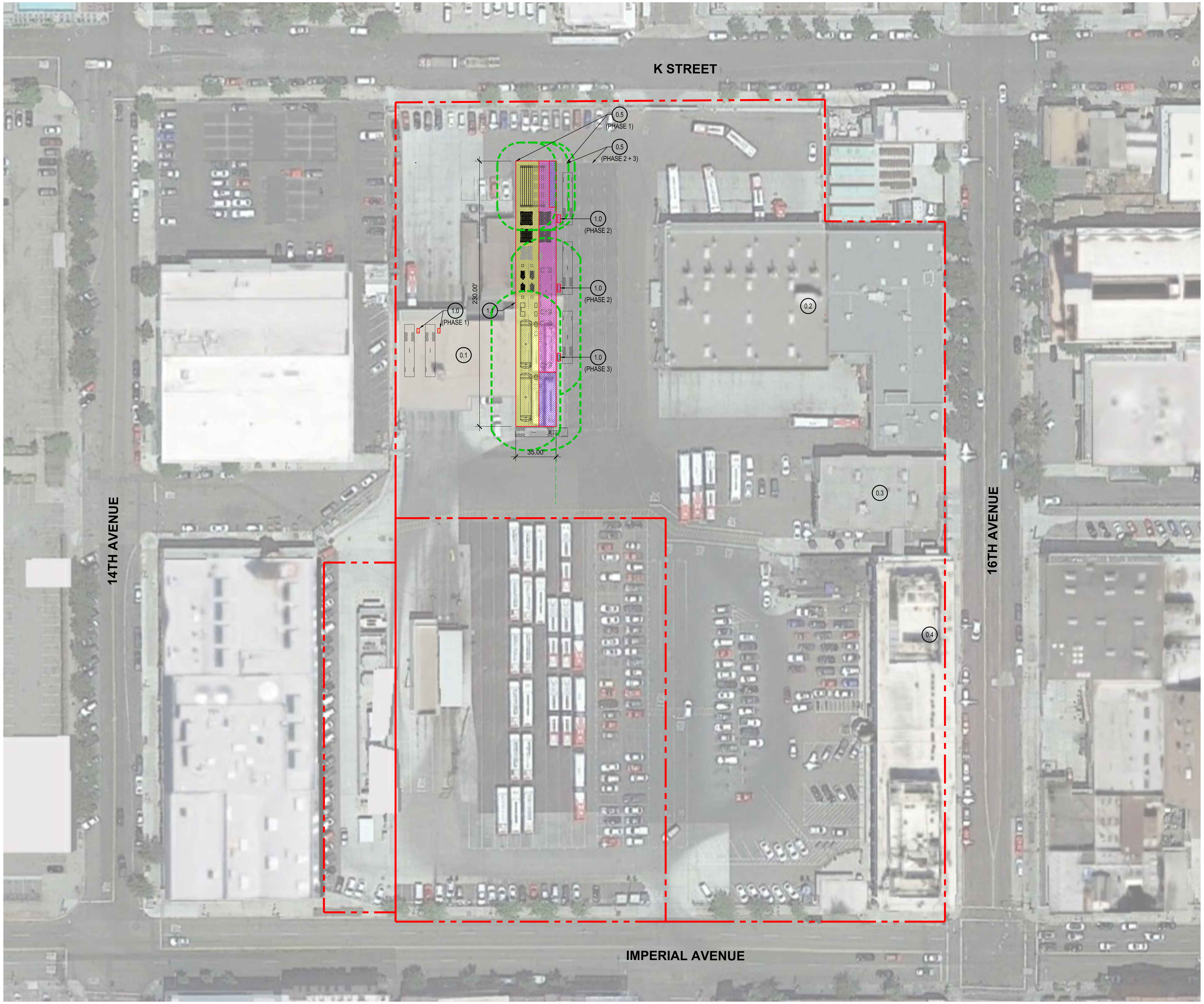
Imperial Avenue Division (IAD)

The Hydrogen Equipment Compound at Imperial Avenue Division will be located at the North end of the property. The Equipment Compound will be built in three phases: Phase I, Phase II and Phase III. The Equipment Compound will be 39’ W x 180’ L.

- **Phase I:**
  To include 2 LH_2 tank, 2 vaporizers, 2 pumps, and 2 assembly of high-pressure gaseous hydrogen storage vessels.

- **Phase II:**
  To include 2 LH_2 tank, 2 vaporizers, 2 pumps, and 2 assemblies of high-pressure gaseous hydrogen storage vessels.

- **Phase III:**
  To include 1 LH_2 tank, 1 vaporizers,1 pumps, and 1 assembly of high-pressure gaseous hydrogen storage vessels.



PRELIMINARY HYDROGEN FUELING SITE PLAN

40' 20' 0 40' 80' 120'

GRAPHIC SCALE: 1" = 40'

VICINITY MAP

SITE NOTES

(#) NOTE

EXISTING ITEMS

- 0.1 (E) FUEL FACILITY
- 0.2 (E) MAINTENANCE BUILDING
- 0.3 (E) ADMIN ANEX
- 0.4 (E) REPAIR ADMIN BLDG. 1
- 0.5 (E) BUS PARKING TO BE REMOVED

NEW ITEMS

- 1.0 (N) DISPENSER
- 1.1 (N) HYDROGEN EQUIPMENT COMPOUND

PARKING INFORMATION

	PHASE 1		PHASE 2		PHASE 3	
	CAR	BUS	CAR	BUS	CAR	BUS
EXISTING REMOVED	-2	-20	0	-10	0	0
PROPOSED	0	0	0	0	0	0
NET CHANGE	-2	-20	0	-10	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2	PHASE 3
TOTAL COMPOUND SIZE:	20' X 230'	35' X 230'	35' X 230'
TOTAL # OF FUELING POSITION:	2	4	5
TOTAL # OF 15,000-GAL LH2 VESSELS	2	4	5

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 3 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED PHASE 3 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

MTS

fiedlergroup
Design & Engineering

299 N. Euclid Ave., Ste 550
Pasadena, CA 91101

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DEVELOPMENT INFORMATION:

MTS

IMPERIAL AVENUE DIVISION (IAD)

SITE ADDRESS:

100 16TH STREET
@ IMPERIAL AVENUE
SAN DIEGO, CA 92101

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 9/27/2019	PROJECT NO.: 16231

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PRELIMINARY HYDROGEN FUELING SITE PLAN

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Kearny Mesa Division (KMD)

The Hydrogen Equipment Compound at Kearny Mesa Division will be located at the North end of the property. The Equipment Compound will be built in three phases: Phase 1, Phase II and Phase III. The Equipment Compound will be 39' W x 140' L.

- **Phase I:**
  To include 1 LH_2 tank, 2 vaporizers, 2 pumps, and 1 assembly of high-pressure gaseous hydrogen storage vessels.

- **Phase II:**
  To include 1 LH_2 tank.

- **Phase III:**
  To include 1 LH_2 tank.

PRELIMINARY HYDROGEN FUELING SITE PLAN

GRAPHIC SCALE: 1" = 40'

VICINITY MAP

SITE NOTES

(#) NOTE

EXISTING ITEMS

0.1	MAINTENANCE (BLDG 100)
0.2	BUILDING 200
0.3	BUILDING 300
0.4	DIESEL FUEL (BLDG 400)
0.5	BUILDING 500
0.6	(E) BUS PARKING TO BE REMOVED

NEW ITEMS

1.0	(N) DISPENSER
1.1	(N) HYDROGEN EQUIPMENT COMPOUND
1.2	(N) FIRE RATED WALL

PARKING INFORMATION

	PHASE 1		PHASE 2		PHASE 3	
	CAR	BUS	CAR	BUS	CAR	BUS
EXISTING REMOVED	0	-5	0	0	0	-1
PROPOSED	0	0	0	0	0	0
NET CHANGE	0	-5	0	0	0	-1

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2	PHASE 3
TOTAL COMPOUND SIZE:	25' X 121'	25' X 168'	25' X 215'
TOTAL # OF FUELING POSITION:	2	2	2
TOTAL # OF 15,000-GAL LH2 VESSELS	1	2	3

LEGEND

- PROPOSED PHASE 1 HYDROGEN COMPOUND
- PROPOSED PHASE 2 HYDROGEN COMPOUND
- PROPOSED PHASE 3 HYDROGEN COMPOUND
- PROPOSED PHASE 1 HYDROGEN DISPENSER
- PROPOSED PHASE 2 HYDROGEN DISPENSER
- PROPOSED PHASE 3 HYDROGEN DISPENSER
- PROPOSED VEHICLE PARKING SETBACK LINE
- APPROX. LOCATION OF PROPERTY LINE
- APPROX. LOCATION OF DISPENSING BUS
- APPROX. LOCATION OF OFFLOAD TRUCK

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DEVELOPMENT INFORMATION:
MTS
KEARNY MESA DIVISION (KMD)

SITE ADDRESS:
4630 RUFFNER ST
SAN DIEGO, CA 92111

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 09/27/2019	PROJECT NO.: 16231

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PRELIMINARY HYDROGEN FUELING SITE PLAN

SHEET NO.:
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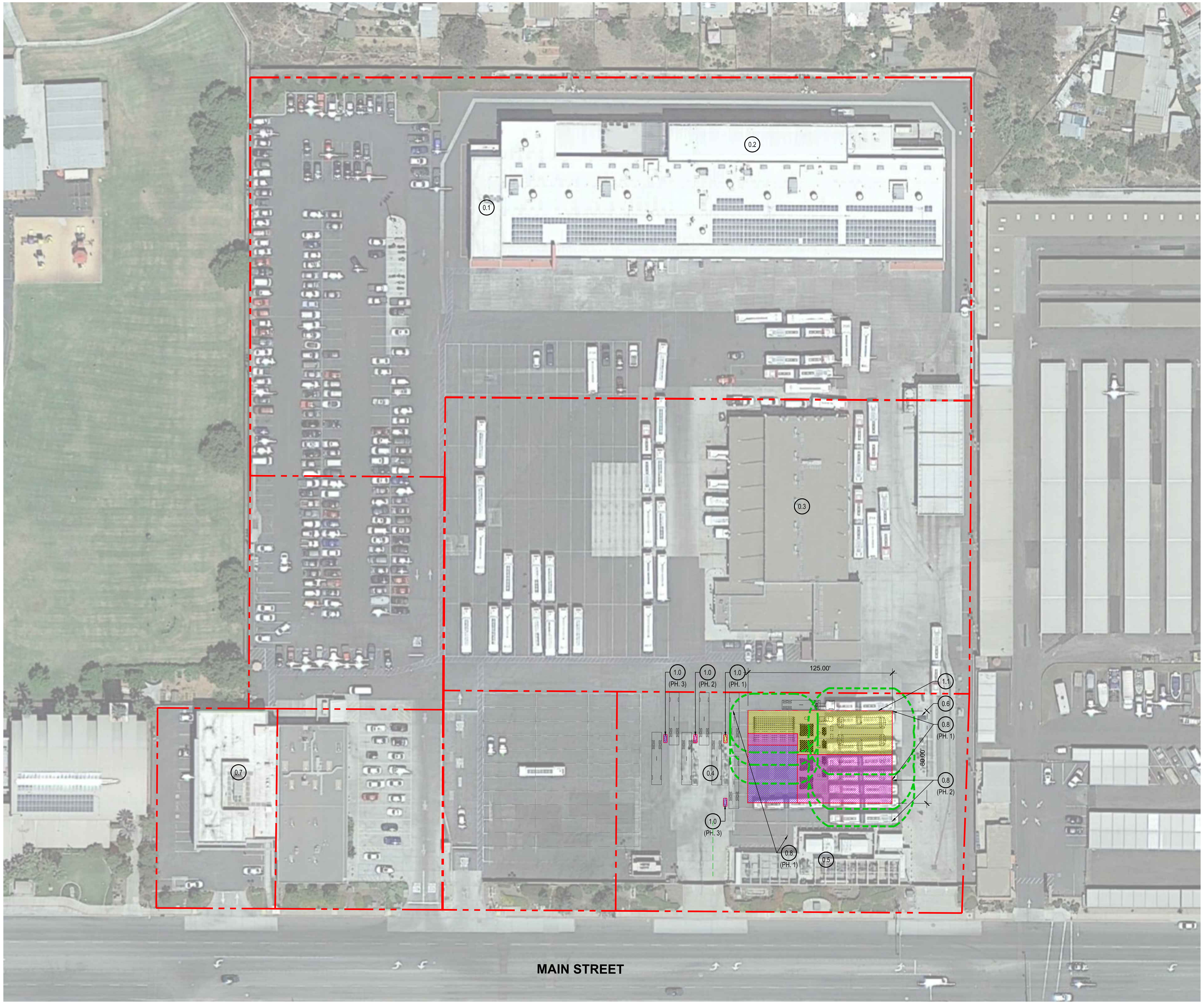
South Bay Bus Maintenance Facility (SBMF)

The Hydrogen Equipment Compound at South Bay Division will be located at the South end of the property. The Equipment Compound will be built in three phases: Phase I, Phase II and Phase III. The Equipment Compound will be 78' W x 145' L.

- **Phase I:**
  To include 2 LH_2 tanks, 2 vaporizers, 2 pumps, and 2 assemblies of high-pressure gaseous hydrogen storage vessels.

- **Phase II:**
  To include 2 LH_2 tanks, 2 vaporizers, 2 pumps, and 2 assembly of high-pressure gaseous hydrogen storage vessels.

- **Phase III:**
  To include 1 LH2 tank, 3 vaporizers, 3 pumps, and 3 assembly of high-pressure gaseous hydrogen storage vessels.



PRELIMINARY HYDROGEN FUELING SITE PLAN

GRAPHIC SCALE: 1" = 40'

VICINITY MAP

SITE NOTES

#	NOTE
	EXISTING ITEMS
0.1	(E) CHASSIS WASH AREA
0.2	(E) MAINTENANCE FACILITY
0.3	(E) MAINTENANCE
0.4	(E) CNG DISPENSERS
0.5	(E) CNG EQUIPMENT COMPOUND
0.6	(E) DIESEL DISPENSER
0.7	(E) ADMINISTRATION BUILDING
0.8	(E) BUS PARKING TO BE REMOVED
	NEW ITEMS
1.0	(N) HYDROGEN DISPENSER
1.1	(N) HYDROGEN EQUIPMENT COMPOUND

PARKING INFORMATION

	PHASE 1		PHASE 2		PHASE 3	
	CAR	BUS	CAR	BUS	CAR	BUS
EXISTING REMOVED	0	-19	0	-6	0	0
PROPOSED	0	0	0	0	0	0
NET CHANGE	0	-19	0	-6	0	0

HYDROGEN EQUIPMENT INFORMATION

	PHASE 1	PHASE 2	PHASE 3
TOTAL COMPOUND SIZE:	125' X 38'	125' X 80'	125' X 80'
TOTAL # OF FUELING POSITION:	2	4	7
TOTAL # OF 15,000-GAL LH2 VESSELS	2	4	5

LEGEND

PROPOSED PHASE 1 HYDROGEN COMPOUND

PROPOSED PHASE 2 HYDROGEN COMPOUND

PROPOSED PHASE 3 HYDROGEN COMPOUND

PROPOSED PHASE 1 HYDROGEN DISPENSER

PROPOSED PHASE 2 HYDROGEN DISPENSER

PROPOSED PHASE 3 HYDROGEN DISPENSER

PROPOSED VEHICLE PARKING SETBACK LINE

APPROX. LOCATION OF PROPERTY LINE

APPROX. LOCATION OF DISPENSING BUS

APPROX. LOCATION OF OFFLOAD TRUCK

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DEVELOPMENT INFORMATION:

MTS
SOUTH BAY BUS MAINTENANCE FACILITY (SBMF)

SITE ADDRESS:

3650A MAIN STREET
CHULA VISTA, CA 91911

DESIGNED BY: PDM	FG PM: PDM
CHECKED BY: POF	MEP PM: -
DRAWN BY: POF	CONSULTANT PM: -
DATE: 9/27/2019	PROJECT NO.: 16231

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Appendix D – Code Reference Table – Building Modification

Code Item	Code Statement	Code Section
Required Sprinklers	**Automatic Sprinkler Systems.** Automatic sprinkler systems shall be provided in accordance with the building code and the fire code adopted by the AHJ.	NFPA 2 Section 18.3.2
Gas Detection System	**Gas Detection System**. Major repair garages shall be provided with an approved hydrogen gas detection system such that gas can be detected where vehicle hydrogen fuel storage systems are serviced, or indoor defueling occurs. The detection system shall be maintained and calibrated in accordance with the manufacturer's instructions on at least an annual basis, or more often, if required by the manufacturer. The repair garage operator shall maintain a record of detection system maintenance and calibration in good condition and accessible to an inspector. The hydrogen detection system shall be designed to activate when the level of hydrogen exceeds 25 percent of the lower flammable limit. **Location.** System shall provide coverage of the fuel cell vehicle service area. The hydrogen detection system shall have sensors in the following locations: (1) At inlets to exhaust systems (2) At high points in service bays with natural ventilation near vents (3) At the inlets to mechanical ventilation systems; where hydrogen vehicle fuel systems are serviced or defueled. **Operation**. Activation of hydrogen detection system shall result in all of the following: (1) Initiation of distinct audible and visual alarm signals in the repair garage (2) Deactivation of heating systems located in the repair garage (3) Activation of the exhaust system, unless the exhaust system is in continuous operation	NFPA 2 Section 18.3.3 through 18.3.3.5

<table>
<tr><th>Code Item</th><th>Code Statement</th><th>Code Section</th></tr>
<tr><td>Exhaust System</td><td>The exhaust system should be designed per the mechanical code adopted by the AHJ.</td><td>NFPA 2 Section 18.4.1</td></tr>
<tr><td>Exhaust System Requirements</td><td>Ventilation. Repair garages used for the repair of natural gas or hydrogen-fueled vehicles shall be provided with an approved mechanical ventilation system. The mechanical ventilation system shall be in accordance with the International Fire Code Section 2211.7
Exception: Repair garages with natural ventilation when approved.

Design. Indoor locations shall be ventilated utilizing supply inlets and exhaust outlets arranged to provide uniform air movement to the extent practical. Inlets shall be uniformly arranged on exterior walls near floor level. Outlets shall be located at the high point of the room in exterior walls of the roof.

Ventilation shall be by a continuous mechanical ventilation system or by a mechanical ventilation system activated by a continuously monitoring natural gas detection system or, for hydrogen, a continuously monitoring flammable gas detection system, each activating at a gas concentration of not more than 25 percent of the lower flammable limit (LFL). In all cases, the system shall shut down the fueling system in the event of failure of the ventilation system.

The ventilation rate shall be at least 1 cubic foot per minute per 12 cubic feet of room volume.

Operation. The mechanical ventilation system shall operate continuously.
Exception:
1. Mechanical ventilation systems that are interlocked with a gas detection system designed in accordance with Sections 2211.7.2 through 2211.7.2.3.
2. Mechanical ventilation in repair garages that are used only for repair of vehicles fueled by liquid fuels or odorized gases, such as CNG, where the ventilation is electronically interlocked with the lighting circuit.</td><td>2009 International Fire Code</td></tr>
</table>

Code Item	Code Statement	Code Section
Heat-Producing Appliances	18.5 Heat-Producing Appliances. 18.5.1 Heat-producing appliances shall be installed to meet the requirements of NFPA 31, NFPA 54, NFPA 82, NFPA 90A, and NFPA 211, as applicable, except as hereinafter specifically provided. [30A:7.6.9] 18.5.2 Heat-producing appliances shall be of an approved type. Solid- fuel stoves, improvised furnaces, salamanders, or space heaters shall not be permitted in major repair garages or where indoor refueling occurs. 18.5.3 Heat-producing appliances in major repair garages shall be permitted to be installed in a special room that is separated from the repair area by walls that are constructed to prevent the transmission of hydrogen, that have a fire resistance rating of at least 1 hour, and that have no openings in the walls that lead to a classified area. Specific small openings through the wall, such as for piping and electrical conduit, shall be permitted, provided the gaps and voids are filled with a fire-resistant material to resist transmission of hydrogen. All air for combustion purposes shall be taken from outside the building. 18.5.4 Heat-producing appliances using gas or oil fuel shall be permitted to be installed in a major repair garage provided the combustion chamber is at least 18 in. (455 mm) below the ceiling. 18.5.5 In major repairs garages, open-flame heaters or heating equipment with exposed surfaces having a temperature **in excess of 750°F (399°C) shall not be permitted in areas subject** to ignitable concentrations of gas. 18.5.6 Electrical heat-producing appliances shall meet the requirements of Chapter 6.	NFPA 2 Section 18.5
De-classification of Ceiling Area	The ceiling area shall be un-classified where ventilation is provided, from a point not more than 18 in. from the highest point in the ceiling, to exhaust the ceiling area at a rate of not less than 1 cfm/ft^2 of ceiling area at all times that the building is occupied or when vehicles using lighter-than-air gaseous fuels are parked below this area.	NEC 511.3(C)(2)(a)

Code Item	Code Statement	Code Section
Parking Garage	17.1 Scope. This chapter shall apply to open and enclosed parking garages used to store self-propelled vehicles powered by GH2 or LH2. This chapter shall also apply to storage of self-propelled vehicles powered by GH2 or LH2 within the residential garages of one- and two-family dwellings. 17.1.1 Application. This chapter shall apply to buildings and parking structures that store self-propelled vehicles powered by GH2 or LH2. This chapter does not apply to dispensing of GH2 or LH2 or to storage or use of GH2 or LH2 in parking garages. 17.1.2 Storage or use of GH2 or LH2 other than within the fuel and propulsion systems of vehicles being stored shall not be allowed unless specifically approved by the AHJ. 17.2* Parking Garages. 17.2.1 The storage of self-propelled vehicles powered byGH2 or LH2 in parking garages or residential garages associated with one- or two-family dwellings shall be subject to the same requirements applicable to vehicles powered by traditional fuels.	NFPA 2 Section 17

Appendix E – Code Reference Table – Storage and Fueling

Code Item	Code Statement	Code Section
Outdoor Storage	General. [LH2] in stationary or portable containers stored outdoors shall be in accordance with 8.2.2.3. Distance to Exposures. [LH2] containers and systems in storage or use shall be separated from materials and conditions that present exposure hazards to or from each other in accordance with 8.2.2.3.2. Separation Distance. Non-bulk portable containers of liquefied hydrogen shall be separated from exposure hazards in accordance with Table 8.2.2.3.4.	NFPA 2 Section 8.2.2.3
Fire Barriers	A 2-hour fire barrier wall shall be permitted in lieu of the distances specified by Table 8.2.2.3.4 when in accordance with the provisions of 8.2.2.3.4.1 (A) through 8.2.2.3.4.1 (E). (A) The fire barrier wall shall be without openings or penetrations. (B) Penetrations of the fire barrier wall by conduit or piping shall be permitted provided that the penetration is protected with a firestop system in accordance with the building code. (C) The fire barrier wall shall be either an independent structure or the exterior wall of the building adjacent to the storage system. (D) The fire barrier wall shall be located not less than 5 ft from any exposure. (E) The fire barrier wall shall not have more than two sides at approximately 90-degree directions or not more than three sides with connecting angles of approximately 135 degrees.	NFPA 2 Section 8.2.2.3.4.1
Air Intakes	Storage and use of [LH2] shall not be located within 50ft of air intakes.	NFPA 2 Section 8.2.2.3.4.2
Building Openings	Storage and use of [LH2] outside of buildings shall also be separated from building openings by 25 ft. Fire barriers shall be permitted to be used as a means to separate storage areas from openings or a means of egress used to access the public way.	NFPA 2 Section 8.2.2.3.4.3

Grading, Drainage, and LH_2 Spill Protection	8.3.2.1.2 Diking shall not be used to contain a [LH_2] spill. 8.3.2.1.3 [LH_2] diking or berms shall be permitted to direct the spill away from exposures. 8.2.2.3.9.1 The area surrounding stationary and portable containers shall be provided with a means to prevent accidental discharge of [LH_2] from endangering personnel, containers, equipment, and adjacent structures and from entering enclosed spaces in accordance with [the adopted fire prevention code]. 8.2.2.3.9.2 The stationary container shall not be placed where spilled or discharged LH_2 will be retained around the container. 8.2.2.3.9.4(A) The grade for a distance of not less than 50 feet from where [LH_2] storage or delivery systems are installed shall be higher than the grade on which flammable or combustible liquids are stored or used. (B) Drainage control. (1)Where the grade differential between the storage or delivery system and the flammable or combustible liquids storage or use area is not in accordance with 8.2.2.3.9.4(A), diversion curbs or other means of drainage control shall be used to divert the flow of flammable or combustible liquids away from the LH_2 system. (2) the means of drainage control shall prevent the flow of flammable or combustible liquid to a distance not less than 50 ft from all parts of the delivery system.	NFPA 2 Chapter 8
Areas Subject to Flooding	Stationary containers located in flood hazard areas shall be anchored to prevent flotation during conditions of the design flood as designated by the [adopted] building code.	NFPA 2 Section 8.2.2.3.8
Separation Distances for Outdoor Fueling	**Dispensing equipment** - Nearest important building or line of adjoining property that can be built upon or from any source of ignition: 10 feet **Dispensing equipment** - Nearest public street or public sidewalk: 10 feet **Dispensing equipment** - Nearest rail of any railroad main track: 10 feet **Point of transfer** - Any important building other than buildings of Type I or Type II construction with exterior walls having a fire resistance rating of not less than not less than 2 hours: 10 feet **Point of transfer** - Buildings of Type I or II construction with exterior walls having a fire resistance rating of not less than 2 hours or walls constructed of concrete or masonry, or of other material having a fire resistance rating of not less than 2 hours: No limit	NFPA 2 Table 10.5.2.2.1.4

Appendix F – Code Reference Table – Minimum Separation Distances

NFPA 2 provides a minimum distance that the hydrogen system can be from groups of exposure types that have been identified as requiring protection. The exposures are broken down into 16 items of 3 types, and a nominal distance from the liquid hydrogen systems and the exposure is given for each. Outside of those prescribed distances, there are active design methods that can be employed to decrease certain exposure distances. The first method is to insulate all piping and systems containing liquid hydrogen. Blast walls made of 2-hour or greater fire rating may be employed to reduce the set-back distances for certain exposure types to zero. Another mitigation method to reduce the set-back distances is to modify the offloading process from the mobile trailer to the onsite liquid storage. The final determination of the set-back distances is determined by specific on-site conditions, the design of the liquid hydrogen storage and hydrogen dispensing systems. For reference, Table 8.3.2.3.1.6(A), below, provides the setback distances for installations of over fifteen thousand to seventy-five thousand gallons of liquid hydrogen storage on site.

Table 8.3.2.3.1.6(A): Minimum Separation Distance from Bulk Liquid Hydrogen Systems to Exposures (15,000 Gallons to 75,000 Gallons)

Item	**Exposure**	**Min. Distance**	**Insulated**	**2-hour rated Fire Wall**	**Offloading Mod.**	**Best Design Case**
1	Property lines	75	25	0	50	0
2	Air intakes	75			50	50
3	Wall openings and windows	75			50	50
4	Ignition sources	50			50	50
5	Public Assembly Areas	75			50	50
6	Parked cars	25			50	25
7.(a)(1)	Non/limited-combustible construction Building, with sprinklers or incombustible contents	5	5	0		0

7.(a)(2) i.	Non/limited-combustible construction Building, no sprinklers or combustible contents, and an adjacent wall of <3-hour fire rating	75	25	0		0
7.(a)(2) ii.	Non/limited-combustible construction Building, no sprinklers or combustible contents, and an adjacent wall of 3-hour Fire rating or greater [*exclusive of windows and doors*]	5	5	0		0
7.(b)(1)	Combustible construction building - sprinklered	50	17	0		0
7.(b)(2)	Combustible construction building – no sprinklers	100	33	0		0
8	Flammable gas storage or systems above or below ground (other than hydrogen)	75	25	0		0
9	Between stationary liquified hydrogen containers	5				5
10	All classes of flammable and combustible liquids (above ground and vent or fill openings if below ground). [*Class IIIB combustible liquids shall be permitted to be reduced to 15 feet.*]	100	33	0		0
11	Hazardous materials storage or systems including liquid oxygen storage and other oxidizers, above or below ground	75	25	0		0
12	Heavy timber, coal, or other slow-burning combustible solids	100	33	0		0

13	Wall openings, unopenable openings in buildings and structures	50				50
14	Inlet to underground sewers	5				5
15.(a)	Utilities overhead, including electric power, building services, or hazardous materials from piping systems. Horizontal distance from the vertical plane below the nearest overhead wire 75of an electric trolley, train, or bus line	50				50
15.(b)	Utilities overhead, including electric power, building services, or hazardous materials from piping systems. Horizontal distance from the vertical plane below the nearest overhead electrical wire	25				25
15.(c)	Utilities overhead, including electric power, building services, or hazardous materials from piping systems. Piping containing other hazardous materials.	15				15
16	Flammable gas metering and regulating stations above grade	15				15