Zero-Emission Bus Technologies and Existing Conditions for E-tran

Overview of Existing Conditions and ZEB Technologies

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Prepared for:
The City of Elk Grove

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Executive Summary

As a small transit agency operating in the state of California, the City of Elk Grove’s transit service, e-tran, is required to submit a zero-emission bus rollout plan to the California Air Resources Board by July 1, 2023 as stated in the Innovative Clean Transit mandate. This document, the Overview of Zero-Emission Technologies and Existing Conditions Review, is the first step in the rollout plan process. This document provides a comprehensive overview of the CARB ICT mandate, a market scan and literature review on currently available zero-emission technologies for bus transit operations, and a review of Elk Grove current operations and finances. Specifically, this report includes:

- A review of the ICT regulation, including reporting requirements and required rollout plan elements
- An overview of ZEB technologies (including battery-electric and hydrogen fuel cell electric buses) that details current costs, manufacturers, maintenance considerations, facility infrastructure considerations, charging requirements, and considerations related to transitioning from conventional to zero-emission buses
- A review of Elk Grove’s current operations and services. This includes the current fleet composition and replacement schedule, operational characteristics that dictate the feasibility of a ZEB transition (including an analysis of block lengths and deadheading impacts and current daily service schedule), mean distance between failures, route and ridership analysis, and an analysis of current disadvantaged communities within the service area
- A literature review of relevant agency documents that may impact the ZEB transition, including the current operations and maintenance staff collective bargaining agreement the recent comprehensive operational analysis, and the transit fleet facility electric infrastructure project memo
- An assessment of the existing conditions of the Corporation Yard
- A financial analysis of Elk Grove’s current operations, including operating and existing costs as well as capital funding sources

Taken together, these steps lay the groundwork for Elk Grove’s transition to a zero-emission bus fleet, and the major findings and takeaways presented act as constraints and opportunities regarding the city’s future fleet composition and transition and implementation considerations.
Abbreviations

AC     Alternating Current
ATU    Amalgamated Transit Union
BEB    Battery Electric Bus
BTM    Behind the Meter
CalEPA California Environmental Protection Agency
CARB   California Air Resources Board
CBC    California Building Code
CCW    Complete Coach Works
CNG    Compressed Natural Gas
COA    Comprehensive Operational Analysis
CPUC   California Public Utilities Commission
CTE    Center for Transportation and the Environment
DC     Direct Current
EIA    U.S. Energy Information Agency
EV     Electric Vehicle
FCEB   Fuel Cell Electric Bus
FTIP   Federal Transportation Improvement Program
GHG    Greenhouse gas
H2     Hydrogen
ICT    Innovative Clean Transit
LCTOP  Low Carbon Transit Operations Program
LOTO   Lock-Out-Tag-Out
### ZERO-EMISSION BUS TECHNOLOGIES AND EXISTING CONDITIONS FOR E-TRAN

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>MOU</td>
<td>Memorandum of Understanding</td>
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<tr>
<td>MPO</td>
<td>Metropolitan planning organization</td>
</tr>
<tr>
<td>MTIP</td>
<td>Metropolitan Transportation Improvement Program</td>
</tr>
<tr>
<td>NREL</td>
<td>National Renewable Energy Laboratory</td>
</tr>
<tr>
<td>NRV</td>
<td>Non-Revenue Vehicle</td>
</tr>
<tr>
<td>SACOG</td>
<td>Sacramento Area Council of Governments</td>
</tr>
<tr>
<td>SacRT</td>
<td>Sacramento Regional Transit District</td>
</tr>
<tr>
<td>SMUD</td>
<td>Sacramento Municipal Utility District</td>
</tr>
<tr>
<td>SRTP</td>
<td>Short Range Transit Plan</td>
</tr>
<tr>
<td>OEHHA</td>
<td>Office of Environmental Health Hazard Assessment</td>
</tr>
<tr>
<td>RTP/SCS</td>
<td>Regional Transportation Plan/Sustainable Communities Strategy</td>
</tr>
<tr>
<td>SCADA</td>
<td>Supervisory control and data acquisition</td>
</tr>
<tr>
<td>ZEB</td>
<td>Zero-Emission Bus</td>
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</table>
1.0  ABOUT ELK GROVE E-TRAN

The City of Elk Grove, the second-largest city in Sacramento County, provides public transit services through e-tran, which provides local fixed-route public transit services within the community and commuter routes to large employment centers in downtown Sacramento and Rancho Cordova, as well as providing connections to other regional transit providers such as Sacramento Regional Transit District (SacRT) light rail stations. E-tran currently operates seven local routes and ten commuter routes. Commuter routes provide weekday trips during AM peak commuter periods with reverse PM trips, with local routes providing all-day weekday service (between 6 am and 10 pm) and some limited Saturday service. E-tran does not operate on Sundays.

After the City was incorporated in 2000, SacRT began to operate public transit services within city limits. In 2005, Elk Grove decided to create and operate its own public transit system, e-tran. Over time, e-tran has grown and evolved to incorporate new commuter and local services to enhance the mobility and accessibility of those living and working within the region. In 2019, the City entered into a contract with SacRT for SacRT to operate and maintain e-tran services and fleet vehicles.

With a service area population of 171,059 and fleet of 46 CNG-fueled fixed-route revenue service vehicles (which are all fueled at an off-site location within close proximity to the City’s Corporation Yard located in Elk Grove)\(^1\), Elk Grove’s e-tran system is classified as a small transit agency under Innovative Clean Transit (ICT) mandate and thus is required to submit a rollout plan to the California Air Resources Board (CARB) by July 1, 2023\(^2\). The entirety of Elk Grove’s service is located within the boundaries of the Sacramento Municipal Utility District.

2.0  WHY ZEBS? A PRIMER ON ICT REGULATION

2.1  INNOVATIVE CLEAN TRANSIT

CARB adopted the ICT regulation in December 2018, which requires all public bus transit agencies in the state to gradually transition to a completely zero-emission bus (ZEB) fleet by 2040. This regulation is in accordance with preceding state policies SB 375 and SB 350. SB 375, the Sustainable Communities and Climate Protection Program, creates initiatives for increased development of transit-oriented communities, better-connected transportation, and active transportation. Relatedly, SB 350 supports widespread transportation electrification through collaboration between CARB and the California Public Utilities Commission (CPUC).

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\(^1\) NTD 2018 agency profile
\(^2\) CARB ICT defines large transit agencies as operating in “an urbanized area with a population of at least 200,000 as last published by the Bureau of Census before December 31, 2017, and has at least 100 buses in annual maximum service.” Agencies that do not meet this definition are categorized as small transit agencies.
ICT also states that transit agencies are required to produce a ZEB rollout plan that describes how the agency is planning to achieve a full transition to a zero-emission fleet by 2040 as well as outlining reporting and record-keeping requirements. Specific elements required in the rollout plan include:

- A full explanation of how the agency will transition to ZEBs by 2040 without early retirement of conventional internal combustion engine buses
- Identification of the ZEB technology the agency intends to deploy
- How the agency will deploy ZEBs in disadvantaged communities
- Identification of potential funding sources
- A training plan and schedule for ZEB operators and maintenance staff
- Schedules for bus purchase and lease options (including fuel type, number of buses, and bus type)
- Construction of associated facilities and infrastructure (including location, type of infrastructure, and timeline)

Small Californian transit agencies, such as Elk Grove’s, are mandated to submit ZEB rollout plans by July 1, 2023 to CARB. ICT also outlines different ZEB purchase schedules that large and small agencies must adhere to. Beginning in 2021 and continuing annually through 2050, each transit agency will be required to provide a compliance report\(^3\). The initial report will outline the number of and information on active buses in the agency’s fleet as of December 31, 2017. Subsequent reports must include transit agency information, information on each bus purchased, owned, operated, leased, or rented (including make, model, curb weight, engine and propulsion system, bus purchases, and any information on converted buses), zero-emission mobility option information (if applicable), and information on renewable fuel usage (including date purchased, fuel contract number, and effective date, if applicable).

Table 1 below outlines the ZEB purchase schedule for small transit agencies for 40-ft. heavy duty transit vehicles. Specific vehicle types, such as motor coaches, cutaways, double decker, and 60-ft. vehicles, are exempt from this purchase schedule until 2026 or later (dependent on Altoona testing being completed). Whereas large agencies are required to start purchasing ZEBs in 2023, small agencies are exempt until 2026, when 25% of new bus purchases must be zero emission.

**Table 1: ZEB purchase schedule (as a percentage of total new bus purchases for small transit agencies) for standard 40-ft. buses.**

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage</th>
</tr>
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<tbody>
<tr>
<td>2023</td>
<td>-</td>
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\(^3\) [https://ww2.arb.ca.gov/sites/default/files/2019-10/ictfro-Clean-Final_0.pdf](https://ww2.arb.ca.gov/sites/default/files/2019-10/ictfro-Clean-Final_0.pdf)
ICT also outlines several flexibility options to comply with ZEB purchase requirements that transit agencies can take advantage of. These include receiving bonus credits for early ZEB purchases, zero-emission mobility options to encourage innovation, enhanced first/last mile connections and improved mobility, and the option to form a joint ZEB group, which entails transit agencies working together to collectively comply with ZEB purchase requirements and a joint ZEB rollout plan. Formation of joint ZEB groups is dependent on certain eligibility requirements (agencies must share infrastructure, be in the same air basin, air district, MPO, or RTPO).

The zero-emission mobility option outlined above specifically refers to a program that provides a zero-emission mobility service, such as a shared mobility bicycle program or any service operated by the agency that include zero-emission transportation, such as microtransit, demand-response service, or autonomous shuttles. The mobility option does not apply to larger buses or fixed-route transit services. Small transit agencies must achieve 180,000 zero-emission passenger miles per year to be eligible for a mobility credit. One mobility credit is the equivalent to having one ZEB in the fleet.

To account for circumstances beyond a transit agency’s control that may impact their ability to comply with ICT regulations, the mandate laid out specific provisions for exemptions. Exemptions will be permitted for the following circumstances:

- If the required ZEB type is unavailable
- Daily mileage needs cannot be met
- Gradeability needs cannot be met
- Delays in infrastructure construction
- A financial emergency is declared by the transit agency
- In circumstances where incremental capital or electricity costs for charging cannot be offset after applying for all available funding and incentive opportunities.
Specifically, the ZEB rollout plan required to be submitted to CARB by mid-2023 must include the following components, broken down by CARB into nine sections.

- Section A: Transit agency information
- Section B: Rollout plan general information
- Section C: Technology portfolio
- Section D: Current bus fleet composition and future bus purchases
- Section E: Facilities and infrastructure modifications
- Section F: Providing service in disadvantaged communities
- Section G: Workforce training
- Section H: Potential funding sources
- Section I: Start-up and scale-up challenges

### 3.0 OVERVIEW OF ZEB TECHNOLOGIES

To provide a primer on ZEB technologies, the section below reviews current ZEB technologies and the required infrastructure considerations. This section addresses technical, operational, and scheduling considerations when transitioning to a ZEB fleet as well as providing a scan of major manufacturers summarizing the pros and cons of commercially available electric bus technologies, both battery electric and hydrogen fuel cell.

### 3.1 OVERVIEW OF ZERO-EMISSION TRANSIT VEHICLES

Different configurations of battery electric buses (BEBs) and hydrogen fuel cell electric buses (FCEBs) are being considered today by transit agencies as a solution to replace fossil-based fuels with the goal to reduce criteria pollutant and greenhouse gas emissions, as well as within California to comply with future ICT regulations. Because each ZEB technology has different strengths and weaknesses, as well as unique operational requirements, the following sections present a brief overview of the commonly deployed ZEBs.

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4 All ZEBs referenced are 40-ft vehicles unless otherwise stated.
3.1.1 Depot-Charging BEBs

Depot-charging BEBs (also referred to as plug-in BEBs) have batteries with large energy storage capacity and only charge while out-of-service in the bus depot. Current models range between 444 kWh (Gillig)\(^5\), 466 kWh (New Flyer and BYD)\(^6\) to 660 kWh (Proterra)\(^7\), and therefore, these vehicles have expected driving ranges between 150-240 miles, depending on average fuel efficiency and route parameters. These types of buses are required to return to a garage and be connected to a charger to replenish the battery – a process that can take between four to six hours to achieve a full charge and range potential. There is different charging equipment that can be used at the depots, but 125-150 kW plug-in chargers (which can be connected to one to three dispensers) are commonly used for overnight charging or if buses return to the garage during the span of service. Table 2 presents an overview of depot-charging BEBs with advantages and disadvantages. Figure 1 shows an example of depot-charging BEBs recharging in Santa Monica’s Big Blue Bus facility.

Table 2: Overview of plug-in BEBs

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tr>
<td>- No traffic disruptions due to construction when installing charging equipment &lt;br&gt; - Control over charging schedules to minimize max power demand to mitigate grid connection upgrades, and to avoid demand charges during peak-hours &lt;br&gt; - Buses can be deployed on any route within 180-240 miles range of a garage &lt;br&gt; - Control over infrastructure deployment since equipment will be on transit property (no easements needed) &lt;br&gt; - Possible to integrate with facility renewable energy and energy storage systems</td>
<td>- More than one bus might be needed to provide the service one diesel or CNG bus can provide, depending on the block distance requirements &lt;br&gt; - Limitations on daily traveled distance &lt;br&gt; - Buses ending at a different division than the one they started, represent a challenge for power demand requirements and availability of charging equipment. This can set limitations and force changes in the bus dispatching dynamic &lt;br&gt; - High battery replacement cost at bus midlife &lt;br&gt; - Footprint constraints for charging equipment in garage and significant retrofit requirements at garage (significantly more electrical load) &lt;br&gt; - Need to develop charger-to-bus ratio that will dictate power requirements &lt;br&gt; - High peak charging demands can result in grid constraints and demand costs &lt;br&gt; - Need coordination with utility company for grid connection upgrade &lt;br&gt; - Heavier and larger batteries to maximize range may impact axle weight and passenger-load limitations</td>
</tr>
</tbody>
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Figure 1: BEBs with plug-in chargers at Santa Monica Big Blue Bus
Figure 2: SAE J1772 CCS-1 charging port on a New Flyer Xcelsior charge

Note: A BEB can have plug-in charging capabilities and equipment to use overhead pantographs. However, throughout this report, we term a BEB that can only charge in-depot as “depot BEB”.
3.1.2 On-Route Charging BEBs

On-route charging BEBs typically have a smaller battery (when compared to depot-only charging BEBs), between 106-320 kWh, that can translate to a reduction in purchase cost and weight. However, with a small battery size, the expected range with full charge is between 50 and 130 miles. Therefore, these types of buses need to recharge while on route to expand the range of service, and in theory, can operate indefinitely as long as they are able to recharge. The overhead-pantograph chargers are typically allocated along the route, usually at a bus stop that has a long layover such as a terminal, where the battery is charged, and the bus then continues its service. The on-route charging of the battery can take between five and ten minutes to extend range between 30 and 60 miles (using at least a 450-kW charger capacity). If the BEBs are exclusively on-route charging, then each bus would require between 15 and 40 minutes (depending on the battery size) to completely recharge the batteries at the end of its service before returning to base.

Furthermore, current manufacturers are now installing on-route charging equipment to BEBs that have significantly larger batteries, between 450 and 660 kWh. These BEBs have the capability to charge on-route, but they will also require charging equipment to charge at the depot (mostly occurring overnight). Therefore, the charging equipment for this type of BEB could include a combination of plug-in dispensers or slow-charging pantographs (for the depot charging), with strategically-located fast-charging pantographs (for opportunity charging while on-route).

Note: For the remainder of this report, vehicles that use opportunity charging and in-depot charging are termed “on-route charging BEBs”.

Table 3 presents an overview of on-route charging BEBs with advantages and disadvantages of this bus configuration, and Figure 3 shows an example of the roof of an on-route charging BEB to demonstrate the charging rails where the overhead pantograph establishes contact.
### Table 3: Overview of on-route charging BEBs

<table>
<thead>
<tr>
<th>On-route charging BEB Advantages</th>
<th>On-route charging BEB Disadvantages</th>
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<tbody>
<tr>
<td>- Smaller batteries on buses have lower purchase price, reduced bus weight, and reduced battery replacement cost at the bus midlife compared to other ZEB technologies (for battery packs of 320 kWh and lower)</td>
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<tr>
<td>- Potential better power to weight ratio for performance</td>
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<td>- Cost of on-route charging infrastructure may be able to be shared with other agencies with overlapping routes/blocks</td>
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<td>- Charging events of five to seven minutes after every roundtrip might be above layover times</td>
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<tr>
<td>- High infrastructure costs</td>
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<td>- Infrastructure along routes can disrupt traffic, during and after construction</td>
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<td>- Demand charges during the day and at peak hours</td>
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<tr>
<td>- Buses can only serve electrified routes where charging equipment is available or be assigned to other route/block where driving range will be limited</td>
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<tr>
<td>- Additional buses assigned to the same routes during a service expansion might require additional chargers to avoid increasing layover times</td>
<td></td>
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<tr>
<td>- Additional space requirements for adjacent charging infrastructure along the routes might require special city contracts</td>
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<tr>
<td>- If multiple roads converge at a terminal where chargers are located and are scheduled to arrive concurrently to facilitate passenger transfers, then multiple charging positions will be needed, and an acute peak draw will occur for a short time</td>
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<tr>
<td>- If charging protocol requires bus operators to stay with the vehicle while charging is occurring, schedules may further be compromised to allow operators a “short personal relief” if such facilities are located at this point</td>
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<tr>
<td>- Additional space requirements for adjacent charging infrastructure along the routes might require special city contracts, permits and rights of way</td>
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<tr>
<td>- If charging infrastructure needs repairs, it can compromise service of routes until repairs are completed</td>
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<tr>
<td>- Requires coordination with utility company</td>
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3.1.3 Fuel Cell Electric Buses

The only other type of zero-emission vehicle is the fuel cell electric bus (FCEB). This type of bus is also an electric vehicle; however, the way that the energy is stored is not just using batteries but using hydrogen as the energy carrier. Hydrogen in this sense works as any other fuel, but instead of an internal combustion engine to convert the energy into mechanical work, a fuel cell converts hydrogen's energy into electricity.

FCEBs have been the subject of several trials in California (Figure 4 and Figure 5 show FCEB fueling and defueling infrastructure for the Orange County Transportation Authority), Ohio, and British Columbia, Canada. FCEBs present operational advantages over BEBs including short refueling times, longer ranges, reliable service in inclement weather conditions without impact on range or performance, and similar refueling operations as traditional CNG and diesel buses. However, early deployments of this technology struggled to find economic benefit due to the high cost of producing hydrogen.
As hydrogen becomes more economical to produce and fuel cell prices drop, the economics for FCEB will improve, helping to justify the initial investment, especially for agencies that operate over large service areas and vehicles that operate long blocks.

Figure 4: OCTA's FCEB fueling station

Figure 5: OCTA's FCEB defueling station
Table 4 presents the advantages and disadvantages of FCEBs collected from information publicly available from past demonstration projects, including transit agencies like SunLine, OCTA, AC Transit and Anteater Express from the University of California, Irvine (UCI). Specific details about the bus performance from each transit agency can be found in the NREL reports\(^8\),\(^9\). Figure 6 shows an example of a FCEB from OCTA.

Table 4: Overview of hydrogen fuel cell buses

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Refueling process similar to CNG or diesel buses allows to continue other maintenance routines while refueling (e.g., interior cleaning, tire pressure, liquids check, etc.)</td>
<td>• High purchase price and investment for refueling infrastructure, as well as for leak detection systems in maintenance buildings</td>
</tr>
<tr>
<td>• Refueling time of 8-12 minutes</td>
<td>• Only buses from the garage with hydrogen infrastructure can serve the selected routes, setting limitations to the bus assignments</td>
</tr>
<tr>
<td>• Long driving range of around 330 miles, close to APTA White Book standards and closer to CNG or diesel bus range than BEBs</td>
<td>• Footprint constraints for hydrogen storage and fueling equipment in garage</td>
</tr>
<tr>
<td>• Buses can serve other routes besides the prioritized ones unlike on-route charged BEBs</td>
<td>• Difficult access to inexpensive hydrogen. Trucked-in hydrogen commodity cost can reach up to $13 per kilogram versus potential low prices of $7 per kilogram when on-site hydrogen production is available</td>
</tr>
<tr>
<td>• No disruptions to traffic due to construction</td>
<td>• Requires emergency response coordination (fire department) and other safety regulations</td>
</tr>
<tr>
<td>• Possible to avoid midlife fuel cell replacement since recorded hours of operation for the fuel cell power plant have reached 29,000 hours without repair or replacement, which is above the FTA ultimate performance target.</td>
<td>• Some common reason for downtime of the buses are air blowers, compressors and plumbing leaks</td>
</tr>
<tr>
<td>• If midlife fuel cell replacement is needed, its cost is lower than that of full BEB-battery replacement</td>
<td>• Getting replacement parts from the OEMs have worked well but the agencies might still have issues getting parts</td>
</tr>
<tr>
<td>• The overall availability percentage for FCEBs is 72% with a high of 88%. Only 25% of the unavailable time was attributed to fuel cell system issues but were not issues from the fuel cell stack</td>
<td>• Issues getting a full fill for the hydrogen tank when the station fill rate is high which requires topping off the fuel tanks in the morning</td>
</tr>
<tr>
<td>• Buying buses from North American OEMs that use the same platform as conventional bus technologies will improve the availability of replacement parts and lower parts costs</td>
<td>• Potential pump/compressor failure for hydrogen refueling station would require redundancy in the form of an additional pump/compressor</td>
</tr>
<tr>
<td>• Fuel economy between 5.83 and 7.82 mpg of diesel equivalent</td>
<td>• Fewer OEMs currently offer FCE buses (though this is expected to change)</td>
</tr>
</tbody>
</table>

3.2 ZEB MANUFACTURERS

This section provides an overview of the commercially available ZEBs and their manufacturers, including information about charging infrastructure.

Table 5 was obtained from a bus manufacturer review completed by the CTE in 2019\(^\text{10}\) and presents a summary of different body styles, length, and energy storage options offered by different bus manufacturers. The table includes BEBs and FCEBs. BYD offers the larger variety of BEBs, followed by Proterra and New Flyer. In total, at the time of this writing, there are over 45 different configurations of

\(^{10}\) Center for Transportation and the Environment, “Electric Bus Planning Workshop for the Colorado Department of Transportation”
BEBs and only three of FCEBs. ENC and New Flyer are the only manufacturers that offer BEBs and FCEBs.

Table 5: Commercially available ZEBs and their manufacturers

<table>
<thead>
<tr>
<th>Body Style</th>
<th>Length (ft)</th>
<th>Energy Storage (kWh)</th>
<th>BYD</th>
<th>CCW</th>
<th>ENC</th>
<th>GreenPower</th>
<th>NovBus</th>
<th>Proterra</th>
<th>New Flyer</th>
<th>Van Hool</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>BEB Low Floor</td>
<td>30</td>
<td>210 - 466</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>94 - 440</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>94 - 460</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>213 - 578</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>BEB Coach</td>
<td>40</td>
<td>352</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45*</td>
<td>446 - 660</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>BEB Total</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>7</td>
<td>3</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCEB Low Floor</td>
<td>40</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>FCEB Total</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>ZEB Total</td>
<td>8</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>12</td>
<td>9</td>
<td>5</td>
<td>44</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 shows the equipment specifications for plug-in chargers from different manufacturers. Currently, there are eleven manufacturers that provide charging equipment for ZEBs.

Table 6: Equipment specifications of depot and on-route chargers by different manufacturers

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>kW</th>
<th>Specs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siemens</td>
<td>120, 150, 600</td>
<td>2.6ft deep, large footprint. Both, overhead and ground mount</td>
</tr>
<tr>
<td>ABB</td>
<td>150</td>
<td>Remote dispenser pedestal (integrated)(^{11})</td>
</tr>
<tr>
<td>Heliox</td>
<td>50, 300, 600</td>
<td>Remote dispenser pedestal</td>
</tr>
<tr>
<td>Proterra</td>
<td>60 or 125</td>
<td>Remote dispenser pedalal</td>
</tr>
<tr>
<td>ChargePoint CPE Depot</td>
<td>156</td>
<td>Remote dispenser pedestal</td>
</tr>
<tr>
<td>ChargePoint CPE 250</td>
<td>62.5 or 125</td>
<td>1.3ft deep to fit between lanes</td>
</tr>
<tr>
<td>BYD</td>
<td>80</td>
<td>1.3ft deep to fit between lanes</td>
</tr>
<tr>
<td>BTC Power</td>
<td>50 or 100-200</td>
<td>Ground integrated and modular</td>
</tr>
<tr>
<td>Delta</td>
<td>100</td>
<td>DC city charger ground mount</td>
</tr>
<tr>
<td>Efacec</td>
<td>20, 150, 350</td>
<td>Ground mount, integrated and modular</td>
</tr>
<tr>
<td>Signet</td>
<td>100, 350</td>
<td>Ground mount, integrated and modular</td>
</tr>
<tr>
<td>Tritium</td>
<td>50, 175</td>
<td>Ground mount, integrated and modular</td>
</tr>
</tbody>
</table>

\(^{11}\) Footprint for remote dispenser pedestals is currently unavailable based on current literature review. The Stantec team has contacted several charger manufacturers and will provide further detail in subsequent task reports once more information has been obtained.
3.3 ZEB COST OVERVIEW

3.3.1 Bus Purchase Price

An overview of purchase prices of 40-ft. ZEBs by different manufacturers is shown below (see Table 7). The collected information includes different bus configurations and the location where the buses were deployed, in addition to the year of purchase. Purchase prices reported to the California eProcure Portal\textsuperscript{12} under state contracts from Proterra and New Flyer provide the most current values (shaded gray in the table below). For context, Elk Grove’s most recent procurement of 40-ft. CNG New Flyers in 2018 had a purchase price of $600,000.

Table 7: Purchase prices of a sample of ZEBs\textsuperscript{13}

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Battery Size</th>
<th>Bus Type</th>
<th>OEM - Operator</th>
<th>Bus Unit Price</th>
<th>Purchase Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYD</td>
<td>324 kWh</td>
<td>Depot-charging BEB</td>
<td>AVTA</td>
<td>$770,000</td>
<td>2016</td>
</tr>
<tr>
<td>BYD</td>
<td>324 kWh</td>
<td>Depot-charging BEB</td>
<td>UCI</td>
<td>$833,400</td>
<td>2017</td>
</tr>
<tr>
<td>Gillig</td>
<td>444 kWh</td>
<td>Depot-charging BEB</td>
<td>Santa Monica BBB</td>
<td>$990,500</td>
<td>2019</td>
</tr>
<tr>
<td>Green Power</td>
<td>320 kWh</td>
<td>Depot-charging BEB</td>
<td>N/A</td>
<td>$850,000</td>
<td>2018</td>
</tr>
<tr>
<td>Proterra</td>
<td>88 kWh</td>
<td>On-route charging BEB</td>
<td>Foothill Transit</td>
<td>$904,500</td>
<td>2014</td>
</tr>
<tr>
<td>Proterra</td>
<td>105 kWh</td>
<td>On-route charging BEB</td>
<td>King County</td>
<td>$798,000</td>
<td>2015</td>
</tr>
<tr>
<td>Proterra</td>
<td>106 kWh</td>
<td>On-route charging BEB</td>
<td>Foothill Transit</td>
<td>$879,900</td>
<td>2016</td>
</tr>
<tr>
<td>Proterra</td>
<td>220 kWh</td>
<td>Depot-charging BEB</td>
<td>California eProcurement</td>
<td>$699,000</td>
<td>2019</td>
</tr>
<tr>
<td>Proterra</td>
<td>440 kWh</td>
<td>Depot-charging BEB</td>
<td>California eProcurement</td>
<td>$799,000</td>
<td>2019</td>
</tr>
<tr>
<td>Proterra</td>
<td>660 kWh</td>
<td>Depot-charging BEB</td>
<td>California eProcurement</td>
<td>$899,000</td>
<td>2019</td>
</tr>
<tr>
<td>New Flyer</td>
<td>213 kWh</td>
<td>Depot-charging BEB</td>
<td>California eProcurement</td>
<td>$721,200</td>
<td>2019</td>
</tr>
<tr>
<td>New Flyer</td>
<td>311 kWh</td>
<td>Depot-charging BEB</td>
<td>California eProcurement</td>
<td>$733,800</td>
<td>2019</td>
</tr>
<tr>
<td>New Flyer</td>
<td>466 kWh</td>
<td>Depot-charging BEB</td>
<td>California eProcurement</td>
<td>$820,200</td>
<td>2019</td>
</tr>
<tr>
<td>New Flyer</td>
<td>100 kWh</td>
<td>FCEB 37.5 kg H\textsubscript{2}</td>
<td>California eProcurement</td>
<td>$994,300\textsuperscript{14}</td>
<td>2019</td>
</tr>
<tr>
<td>New Flyer</td>
<td>47 kWh</td>
<td>FCEB 40 kg H\textsubscript{2}</td>
<td>SunLine</td>
<td>$1,200,000</td>
<td>2009</td>
</tr>
<tr>
<td>Eldorado (ENC)</td>
<td>11 kWh</td>
<td>FCEB 50 kg H\textsubscript{2}</td>
<td>Irvine California</td>
<td>$1,846,200</td>
<td>2015</td>
</tr>
<tr>
<td>Eldorado (ENC)</td>
<td>11 kWh</td>
<td>FCEB 50 kg H\textsubscript{2}</td>
<td>SunLine</td>
<td>$2,100,000</td>
<td>2014</td>
</tr>
<tr>
<td>Eldorado (ENC)</td>
<td>11 kWh</td>
<td>FCEB 50 kg H\textsubscript{2}</td>
<td>OCTA</td>
<td>$1,400,000</td>
<td>2016</td>
</tr>
<tr>
<td>Van Hool</td>
<td>21 kWh</td>
<td>FCEB 50 kg H\textsubscript{2}</td>
<td>AC Transit</td>
<td>$2,500,000</td>
<td>2010</td>
</tr>
</tbody>
</table>

\textsuperscript{12} Cal eProcure is an online portal designed for businesses to sell products and services to the state of California. ZEB purchase contracts have been pre-approved for transit agencies in CA via eProcure.

\textsuperscript{13} Rounded to nearest hundred dollars

\textsuperscript{14} Price guaranteed only if order is higher than 49 FCEBs.
Note that the prices in Table 7 represent either historical purchase prices or prices from statewide contracting. As such, actual costs may differ depending on service elements and are subject to competitive bids during a procurement process.

### 3.3.2 Cost of Charging Infrastructure

Estimating the cost of charging infrastructure quickly becomes complex since the level of electrical modifications necessary to install equipment can widely vary depending on the garage location and current equipment. Additionally, different arrangements with local utility companies and equipment manufacturers have proven to drastically affect the investment cost.

Our literature review regarding the cost of charging infrastructure of different demonstration projects presents combined installation costs without distinguishing between the cost of labor or electrical equipment such as transformers, generators, etc. Furthermore, the data collection shows a lack of reporting on the cost of chargers for operators since often the purchase contract combines the cost of the buses and cost of chargers. The average cost per charger was estimated based on literature and data presented in Table 8 and Table 9. Additionally, Table 10 presents a summary of charging equipment cost by vendor that was collected via an RFI.

#### Table 8: Cost of depot charging infrastructure\(^{15}\) \(^{16}\)

<table>
<thead>
<tr>
<th>OEM - Operator</th>
<th>Equipment Cost per Depot Charger</th>
<th>Installation Cost per Depot Charger</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYD - AVTA</td>
<td>$19,100</td>
<td>$55,900</td>
</tr>
<tr>
<td>BYD - UCI</td>
<td>$40,600</td>
<td>$77,400</td>
</tr>
<tr>
<td>Proterra - King County</td>
<td>$60,500</td>
<td></td>
</tr>
<tr>
<td>Center for Transportation and the Environment (CTE)</td>
<td>$50,600</td>
<td>$17,600</td>
</tr>
</tbody>
</table>


\(^{16}\) Rounded to nearest hundred dollars

\(^{17}\) Information on the installation cost of on-route chargers was not provided by the source.
Table 9: Cost of on-route charging BEBs and charging infrastructure\textsuperscript{18}

<table>
<thead>
<tr>
<th>OEM - Operator</th>
<th>Bus Unit Price</th>
<th>Equipment Cost per on-route Charger</th>
<th>Installation Cost per on-route Charger</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYD - AVTA</td>
<td>$779,000</td>
<td>$353,900</td>
<td>$252,800</td>
</tr>
<tr>
<td>Proterra - King county</td>
<td>$806,600</td>
<td>$606,600</td>
<td>$244,200</td>
</tr>
<tr>
<td>Proterra - Foothill</td>
<td>$797,700</td>
<td>$505,500</td>
<td>$202,200</td>
</tr>
<tr>
<td>Center for Transportation and the Environment (CTE)</td>
<td>$897,100</td>
<td>$501,100</td>
<td>$205,100</td>
</tr>
</tbody>
</table>

\textsuperscript{18} Rounded to nearest hundred dollars

Table 10: Summary of charging equipment costs

<table>
<thead>
<tr>
<th>OEM</th>
<th>Charger Type</th>
<th>Rated Output (kW)</th>
<th>Type/ Interface</th>
<th>Max Disp’r per Charger</th>
<th>Max Active Disp’rs</th>
<th>Comments</th>
<th>$ Cost Ea.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABB</td>
<td>In-depot</td>
<td>150</td>
<td>J3105 / Mast down</td>
<td>1</td>
<td></td>
<td>One dispenser</td>
<td>$110,000</td>
</tr>
<tr>
<td>ChargePoint</td>
<td>In-depot</td>
<td>156</td>
<td>J1772 / CCS</td>
<td>8</td>
<td>2</td>
<td>Two dispensers</td>
<td>$120,000</td>
</tr>
<tr>
<td>Proterra</td>
<td>In-depot</td>
<td>125</td>
<td>J1772 / CCS</td>
<td>1</td>
<td>1</td>
<td>All in-depot chargers are 1:1</td>
<td>$65,000</td>
</tr>
<tr>
<td>Proterra</td>
<td>In-depot</td>
<td>125</td>
<td></td>
<td></td>
<td></td>
<td>Two dispensers</td>
<td>$79,500</td>
</tr>
<tr>
<td>Siemens</td>
<td>In-depot</td>
<td>150</td>
<td>J1772 / CCS</td>
<td>3</td>
<td>1</td>
<td>single dispenser</td>
<td>$130,000</td>
</tr>
<tr>
<td>ABB</td>
<td>In-depot or on-route</td>
<td>450</td>
<td>J3105 / Mast down</td>
<td>N/A</td>
<td>N/A</td>
<td>On-route</td>
<td>$339,000</td>
</tr>
<tr>
<td>Proterra</td>
<td>In-depot or on-route</td>
<td>500</td>
<td>J3105 / Mast down</td>
<td></td>
<td></td>
<td>Charger with pole, catenary down charge head and related wiring and</td>
<td>$349,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>controls</td>
<td></td>
</tr>
<tr>
<td>Siemens</td>
<td>In-depot or on-route</td>
<td>450</td>
<td>J3105 / Mast down</td>
<td>N/A</td>
<td>N/A</td>
<td>On-route</td>
<td>$500,000</td>
</tr>
<tr>
<td>Siemens</td>
<td>In-depot or on-route</td>
<td>600</td>
<td>J3105 / Mast down</td>
<td>N/A</td>
<td>N/A</td>
<td>On-route</td>
<td>$620,000</td>
</tr>
</tbody>
</table>
3.3.3 Cost of Hydrogen Fueling Infrastructure

The refueling process of a FCEB is similar to the refueling of a diesel or natural gas bus; a hose is connected to the fuel gauge and after eight to ten minutes the tank is full. However, hydrogen can be supplied through a variety of methods, including:

1. A tube trailer can be used to supply gaseous hydrogen,
2. A tube trailer delivering liquid hydrogen for storage onsite in cryogenic tank(s),
3. On-site generation of hydrogen gas using steam methane reformation (SMR), or
4. On-site generation of hydrogen using water electrolysis (which can be powered by grid electricity or using renewable electricity like from solar panels).

Table 11 summarizes the configurations and capital cost of hydrogen infrastructure for different FCEBs fleet sizes, obtained from Ballard’s “Hydrogen Refueling for Fuel Cell Bus Fleets” report. For context, Elk Grove’s 2018 fuel costs per mile for fixed-route service was $0.98/mile\textsuperscript{19}.

Table 11: Capital Cost and Specifications for Hydrogen Refueling Infrastructure

<table>
<thead>
<tr>
<th>Fleet size</th>
<th>Likely fuel supply</th>
<th>Average fleet consumption</th>
<th>Capital Costs</th>
<th>Delivered fuel costs</th>
<th>Fuel cost per mi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demo; less than 5 buses</td>
<td>Tube trailer delivery of hydrogen gas</td>
<td>125 kg/day</td>
<td>Tube trailer rental: $3,000 Compression, storage, and dispenser: $1 million</td>
<td>$10-12/kg</td>
<td>$3.20-3.90/mi</td>
</tr>
<tr>
<td>Pilot deployment (5-20 buses)</td>
<td>Liquid hydrogen storage</td>
<td>125-500 kg/day</td>
<td>Vaporizer, pump, storage, and dispenser: $3-5 million</td>
<td>$6-9/kg</td>
<td>$1.48-2.20/mi</td>
</tr>
<tr>
<td>Commercial deployment (&gt;20 buses)</td>
<td>Liquid hydrogen storage or on-site SMR</td>
<td>500-1,000 kg/day</td>
<td>On-site SMR: $2.5-3.5 million Vaporizer, cryopump, storage, and dispensers: $3-5 million</td>
<td>$3-7.6/kg</td>
<td>$0.98-1.94/mi</td>
</tr>
</tbody>
</table>

Independent from the hydrogen distribution system to the division is the size of the refueling station. The size and configuration of the hydrogen station depends on the number of buses that need to be filled overnight (usually in a seven-hour shift), and the average hydrogen dispensed to each bus (between 30 to 50 kg per bus). Therefore, the daily hydrogen demand and number of buses at each division will determine the proper configuration of the station, reflected in total number of hydrogen pumps and storage.  

\textsuperscript{19} NTD, 2018
number of dispensers (or refueling islands). Table 12 presents the estimated capital cost for different sizes of a hydrogen refueling station.

Table 12: Capital cost for hydrogen refueling stations of different capacities

<table>
<thead>
<tr>
<th>Station Capacity</th>
<th>Hydrogen Refueling Station Configuration</th>
<th>Capital Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Buses</td>
<td>Kg/day</td>
<td>No. of Pumps</td>
</tr>
<tr>
<td>55</td>
<td>1,600</td>
<td>1</td>
</tr>
<tr>
<td>110</td>
<td>3,300</td>
<td>2</td>
</tr>
<tr>
<td>165</td>
<td>5,000</td>
<td>3</td>
</tr>
</tbody>
</table>

3.3.4 Maintenance Cost of BEBs

The total cost of maintenance for BEBs was reported by CTE to be $0.23 per mile\textsuperscript{20}; this includes scheduled and unscheduled repairs. A similar value was reported by the National Renewable Energy Laboratory (NREL) for the BEB deployed at Foothill Transit\textsuperscript{21}. For comparison, maintenance cost of diesel buses has been reported to be between $0.25 and $0.68 per mile by transit agencies in the Bay Area\textsuperscript{22}. Table 13 presents the maintenance cost by system type. In Table 13, the propulsion-related repairs for the BEBs include low-voltage batteries, battery equalizer, cooling system, and DC-AC converter.

Table 13: Maintenance cost per mile by system component in battery electric buses\textsuperscript{23}

<table>
<thead>
<tr>
<th>System</th>
<th>Maintenance of BEB ($/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion-related</td>
<td>0.05</td>
</tr>
<tr>
<td>Cab, body, and accessories</td>
<td>0.13</td>
</tr>
<tr>
<td>PMI</td>
<td>0.03</td>
</tr>
<tr>
<td>Brakes</td>
<td>0.01</td>
</tr>
<tr>
<td>Frame, steering, and suspension</td>
<td>0.00</td>
</tr>
<tr>
<td>HVAC</td>
<td>0.01</td>
</tr>
<tr>
<td>Lighting</td>
<td>0.01</td>
</tr>
<tr>
<td>General air system repairs</td>
<td>0.01</td>
</tr>
<tr>
<td>Axles, wheels, and drive shaft</td>
<td>0.00</td>
</tr>
<tr>
<td>Tires</td>
<td>0.01</td>
</tr>
</tbody>
</table>

\textsuperscript{20} Matt Boothe - CTE, “Critical Answers for Smart Deployments.”
3.3.5 Maintenance Cost of FCEBs

The maintenance cost of FCEBs has been collected by NREL from different agencies under the report called “Fuel Cell Buses in U.S. Transit Fleets: Current Status 2018”\textsuperscript{24}. The average maintenance cost for FCEBs was reported as $0.10 per mile for scheduled maintenance and $0.38 per mile for unscheduled maintenance, yielding a total of $0.48 per mile. Table 14 presents the maintenance cost breakdown by system type. The systems with the highest percentage of maintenance costs for the FCEBs were (1) cab, body, and accessories; (2) PMI; and (3) propulsion.

For FCEBs, the parts costs make up only 14% of the total maintenance cost because most of the FCEBs are still under warranty or supported by the OEMs. Therefore, costs for high-dollar parts are currently not reflected in the cost breakdown, which limits the maintenance cost estimations.

Table 14: Maintenance cost per mile by system component in FCEBs\textsuperscript{25}

<table>
<thead>
<tr>
<th>System</th>
<th>Maintenance of FCEB ($/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Propulsion-related</td>
<td>0.09</td>
</tr>
<tr>
<td>Cab, body, and accessories</td>
<td>0.21</td>
</tr>
<tr>
<td>PMI</td>
<td>0.09</td>
</tr>
<tr>
<td>Brakes</td>
<td>0.02</td>
</tr>
<tr>
<td>Frame, steering, and suspension</td>
<td>0.04</td>
</tr>
<tr>
<td>HVAC</td>
<td>0.02</td>
</tr>
<tr>
<td>Lighting</td>
<td>--</td>
</tr>
<tr>
<td>General air system repairs</td>
<td>--</td>
</tr>
<tr>
<td>Axles, wheels, and drive shaft</td>
<td>--</td>
</tr>
<tr>
<td>Tires</td>
<td>0.01</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.48</strong></td>
</tr>
</tbody>
</table>

3.4 TRANSITION TO ELECTRIFICATION CONSIDERATIONS

Diesel re-fueling is quick and can be done within scheduled layovers and maintenance. To refuel an electric bus, the on-board batteries must be charged. This can take anywhere from three minutes to many hours depending on the bus battery size and charging infrastructure type. When these considerations are taken together with electric utilities coordination, there may be restrictions on the number of vehicles that can charge concurrently at one location. Because of the substantially larger demand on electricity at

\textsuperscript{25} Ibid.
transit facilities, agencies need to transform their relationship with their utility from one that is based on electricity for typical industrial uses, to one a relationship where electricity is now ‘fuel’.

Early consultation with the electric utilities could help to mitigate this since they need to be active participants in the ZEB transition plan. In addition, when planned properly, the new electric load could represent a benefit to the local utilities since a high demand during the day is desirable to help balance the grid from intermittent renewable sources. During the day, solar and wind power generation are at their peak, but during such times the demand is traditional low; therefore, much of such produced electricity is then curtailed. Transit fleets tend to have fixed schedules, which create a reliable demand that can be satisfied by excess renewables, opening the door for an increase in the share of renewables in the local grid. For example, Elk Grove’s commuter-focused schedule provides a unique opportunity for a solar charging system, as a large portion of the fleet is in the yard during the midday period and thus does not need to rely solely on overnight charging.

Diesel prices can fluctuate with the market and per season, factors which transit agencies do not have control over. On the other hand, electricity prices tend to be more predictable for each season (e.g., winter vs. summer) but times of use (TOU) heavily dictated the final price per kWh. Meaning, charging buses during non-peak hours – which are determined by the utility company (usually morning hours) – can be significantly cheaper than charging buses at peak hours (e.g., 4 pm to 9 pm). The extra cost is determined by the price rate per kWh, as well as additional charges due to max power (kW) utilization, called demand charges.

Transit agencies can efficiently design their charging infrastructure to minimize such demand charges while ensuring enough charging time to have their fleet ready for operations. Therefore, for every bus depot considering a ZEB fleet, several facility issues need to be considered.

### 3.4.1 Depot Charging Infrastructure for Plug-In BEBs

Depot chargers can be either low power (<150 kW) or high power (>450 kW). Typical depot chargers that use plug-in dispensers include commercial products available from Siemens (Figure 7), ABB, and Chargepoint (Figure 8). Other BEB manufacturers, like Proterra, provide their own in-depot chargers ranging from 60 kW to 125 kW.
It is important to note that bus divisions will likely require multiple chargers and that depending on their use, this could significantly impact the facility power service. Furthermore, the charger capacity (e.g., 60 kW vs 125 kW) will dictate the charging time for each bus (10 hours vs 5 hours for a 450-kWh battery size), and the power peak of the charging cycle. For example, if one 60 kW charger per bus is installed for 100 buses and all are used/connected at once, this scenario will require a high-power demand capacity (~6 MW) and likely upgrades to the grid utility connection. On the other hand, if one 125 kW charger was to be used for up to three buses during overnight charging, then the power capacity would be reduced (~4.2 MW) but 33 buses would need to be moved around the division every four hours, twice during the night, charged. The second scenario has a lower power demand, likely a lower investment cost in equipment and grid upgrades, but requires a new operational system and additional staff to coordinate the charging schedule.

Depot-charging equipment includes the configuration of a modular charging system that provides charge power to multiple connectors. Such connectors can be plug-in dispensers, as showed in the figures above, or they can be pantographs. Most companies incorporate standard pantograph assemblies from companies like Schunk and Stemmann-Technik.
Although these are primarily intended for on-route opportunity charging, they can also be used in the depot where a fast-hands-off charge is required. This might be useful to coordinate preventative maintenance activities on a returning bus where maintenance needs to occur right away. Furthermore, pantographs are usually adopted where footprint restrictions justify the extra investment in charging equipment and supporting infrastructure.

### 3.4.1.1 Conductive On-Route Charging Infrastructure

The most common type of on-route charging is the overhead inverted pantograph, where a charging head is lowered on to a set of DC charging rails on the top of the bus (see Figure 3). Earlier iterations of this utilized a set of fixed overhead charge rails with a bus-mounted pantograph that raises to contact the overhead rails. This method evolved to the overhead inverted pantograph to reduce additional weight and cost required to accommodate a charging mechanism on each bus.

Many of the BEB providers have aligned with universal high-power opportunity chargers from companies such as Siemens (Figure 11) and ABB (Figure 12). Proterra offers their own high-power opportunity charger (Figure 13).
Many transit agencies and cities have expressed concerns over the impact these overhead chargers may have on the built urban environment. The foundations alone for the charge pedestal can be significant (Figure 14), not to mention the visual impact of the final unit.
There are also concerns over right-of-way easements and permitting constraints, as well as the "permanence" of such infrastructure should the chargers ever need to be relocated. For this reason, several companies have investigated the use of non-contact inductive charging for opportunity charging.

### 3.4.1.2 Inductive On-Route Charging

Inductive chargers, in principle, work the same as the cell phone charging pads that many consumer electronics utilize. A capacitive coupling plate is installed at the bottom of the bus which close-couples to an inductive charging pad embedded in the roadway.

Two companies, WAVE and Momentum Dynamics, have made significant headway with this technology and have successfully installed trials at several cities throughout the country. The WAVE installation shown in Figure 15, Figure 16, and Figure 17 are for the Antelope Valley Transit Authority (AVTA), which utilizes 250 kW inductive chargers. The company is currently working on a pilot for a 500-kW inductive charger in conjunction with Volvo.
There are many current and future advantages to this type of technology, including:

- Clean urban design integration
- Possible relocation of chargers
- No connector standards required
- Future integration with autonomous vehicles

The trade-offs to such benefits include slower charging rates, increase on price, traffic disruption during installation periods, and lower charging efficiencies.

### 3.4.2 Mitigating Charging Demand

For BEB fleets, the two most common methods for regulating charging are smart charging and charge buffering using energy storage, both described below.

#### 3.4.2.1 Smart Charging

Smart charging refers to software, artificial intelligence, and processes that control when and how much charging occurs. This requires chargers that are capable of being controlled as well as a software platform that can effectively aggregate and manage these chargers. A best practice is to select chargers where the manufacturers are participants in the Open Charge Point Protocol (OCPP), a consortium of over 50 members focused on bringing standardization to the communications of chargers with their network platform.

Well-planned and coordinated smart charging can significantly reduce the electric utility demand by timing when and how much charging each bus receives. Estimations on the ideal number of chargers is critical to the successful implementation of smart charging strategies.

#### 3.4.2.2 Energy Storage

The final mitigation measure which will most likely be required to electrify entire fleets is the use of stationary energy storage as "charge buffers". Energy storage, in the form of containers of lithium ion
batteries or other technologies, can be charged during periods of low facility electricity demand or even from renewable energy resources like solar or wind, and then discharged during periods of high electricity demand when the buses also need to receive a charge. Such storage systems deployed Behind the Meter (BTM) can react to charge events quickly so that the utility does not see the entire impact of the charging event. In this way, the electricity demand (and associated cost) can be reduced.

Many of the larger bus charging equipment companies like ABB and Siemens are exploring the pairing of such battery storage systems with their charging infrastructure. An Ontario (Canada) company named eCamion focuses exclusively on storage systems for electric vehicle charge buffering.

### 3.4.3 Site Assessment

On the outside of the facility, finding space to install a larger service transformer will be the first hurdle. Due to the additional charging, it is possible that a secondary utility service may also be required. In addition, since bus service during emergency situations must still be maintained, the backup power service will also need to be upgraded (see Figure 18).

![Electrical Servicing Conduits](image1.png) ![Upgraded Service Transformer](image2.png)

**Figure 18: Typical electrical servicing conduits and upgraded service transformer**

### 3.4.4 Facility Interior Infrastructure

Inside the facility, an electrical room must be designated for the ZEB equipment such as the A/C distribution panels, the “charger” room (the power inverters used to create the DC), DC distribution equipment, the actual charging equipment (charging cables and/or overhead inverted pantographs) and all associated Lock-Out-Tag-Out (LOTO) and Emergency Stop (E-Stop) stations.

If on-route charging is not feasible, due to range limitations from BEBs, accommodating extra buses (i.e., a larger fleet) might be required to maintain the same service level. Furthermore, with additional buses needed to serve the routes, additional charging equipment would be required. Also, daily cleaning routines would increase in tandem with a larger fleet to keep standards constant as well as vehicle incremental needs (licensing, parking spaces, etc.).
3.4.5 Infrastructure in Other Facility Areas

Other considerations within the facility include plug-in chargers required in the shop, harness system for mechanics to access batteries located in the bus roof, overhead cranes with increased capacity to handle battery modules and other heavy power electronics (likely 2-Ton or more), and specialized shop retooling to accommodate the new equipment and accessories. There will also need to be an area set aside for battery storage and testing with special fire prevention considerations. More personnel-related items (e.g., fall-arrest outfitting) will also be required.

Additionally, an assessment on the current configuration of Elk Grove's depot and how buses operate will be required. This type of assessment will provide options for future charging equipment and the recommended future depot charging infrastructure layouts at each division based on the charging and equipment requirements. The analysis will need to summarize the depot physical layout assessment, provide a review of existing policies and procedures, and identify the footprints available for future charging infrastructure.

From an IT standpoint, there will be additional wireless access points required throughout the facility and the associated control systems and SCADA supervision room.

3.4.6 AC versus DC Fast Charging

The BEB market is divided on the method of electricity delivery to charge the bus. One of the largest BEB and battery suppliers, BYD, primarily utilizes Alternating Current (AC) charging to the bus and then performs the conversion to Direct Current (DC) on-board to charge the battery. This is similar, in concept, to home Electric Vehicle (EV) chargers, which deliver 200-240 V AC to the car where an on-car converter changes this to DC so that it can charge the battery. The benefit of this method is that far less additional power infrastructure is required to facilitate charging (no charging cabinets). In addition, since the power delivered to the bus is AC, future migration to non-contact inductive charging is possible. The trade-off is that each bus must be equipped with enough on-board converters at additional cost and weight. Although
the standards are evolving, there are currently some restrictions as to how fast an AC-charged bus can charge.

Most of the other BEB suppliers accommodate fast DC charging whereby the conversion to DC occurs external to the bus (via a charger cabinet), and the DC is delivered to the bus and directly to the battery. Standards are evolving for this method of charging as well to facilitate future charging of transport as well as transit fleets.

### 3.4.7 Maintenance Considerations

For both BEBs and FCEBs, it has been observed that propulsion-related maintenance of the ZEB fleet may be reduced compared to non-ZEB fleets, as ZEB propulsion systems are more efficient and have fewer moving parts than conventional internal combustion engines. This also negates the need for oil changes as well as longer brake pad lifespans due to the use of regenerative braking. Beyond this, there are specific, technology-related differences between BEB and FCEB maintenance needs that are discussed below and in section 3.5.4.

Provided below is an overview of preventative maintenance considerations for BEB vehicles\(^\text{26}\). It should also be noted that there are many maintenance tasks related to engine, transmission, and alternator that are not applicable to BEBs. These include the following:

- Alternator bearings inspection and replacement
- Engine air filter restriction inspection
- Engine fluid drain and filter refill
- Engine primary and secondary fuel filter replacement
- Engine turbocharger inspection
- Engine vibration damper inspection
- Spark plug inspection and replacement
- Ignition coil inspection and test
- Engine valve adjustment
- Engine oil-water separator inspection
- Crankcase breather filter drain and inspection
- Muffler inspection

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\(^{26}\) [https://www.transittraining.net/images/uploads/full_documents/BEB_Session_1_Slides_and_Notes.pdf](https://www.transittraining.net/images/uploads/full_documents/BEB_Session_1_Slides_and_Notes.pdf)
Air intake piping inspection
Gas leak detectors inspection
Transmission fluid drain and refill
Transmission filter change

The following preventative maintenance schedule from the Transportation Learning Center is based on average vehicle use and typical operating conditions. The transit agency may determine that more or less frequent maintenance intervals are required based on the agency’s experience and local knowledge of environmental conditions. It is also important to note that battery degradation is a chief maintenance concern for BEBs, and that monitoring battery state of health in the transit agency’s own unique operating environment is of chief importance when related to preventative maintenance.

Table 15: Example BEB preventative maintenance schedule

<table>
<thead>
<tr>
<th>Preventative Maintenance item</th>
<th>Action</th>
<th>Schedule interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traction motor</td>
<td>Lube</td>
<td>Run-in</td>
</tr>
<tr>
<td>Electric HVAC</td>
<td>Cycle</td>
<td>Weekly</td>
</tr>
<tr>
<td>Battery pack cell voltage</td>
<td>Measure</td>
<td>Monthly</td>
</tr>
<tr>
<td>Battery charging and balance</td>
<td>Measure</td>
<td>Monthly</td>
</tr>
<tr>
<td>Traction motor</td>
<td>Inspection</td>
<td>Monthly</td>
</tr>
<tr>
<td>ESS battery chiller</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>High voltage cable</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>LV (25 VDC) electrical wiring</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Rear battery strings</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Rooftop battery strings</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>DC-DC converter</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Rooftop electronics enclosure</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Traction motor inverter</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>ESS battery cooler condenser</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>HV accessory cable</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Power steering</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
</tbody>
</table>
### Preventative Maintenance

<table>
<thead>
<tr>
<th>Preventative Maintenance item</th>
<th>Action</th>
<th>Schedule interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air compressor</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>Charging cable receptacle</td>
<td>Inspection</td>
<td>Quarterly</td>
</tr>
<tr>
<td>HVAC system</td>
<td>Inspection</td>
<td>Semi-annually</td>
</tr>
<tr>
<td>Coolant fluid</td>
<td>Inspection</td>
<td>Semi-annually</td>
</tr>
<tr>
<td>Low voltage distribution box</td>
<td>Inspection</td>
<td>Annually</td>
</tr>
<tr>
<td>High voltage distribution box</td>
<td>Inspection</td>
<td>Annually</td>
</tr>
<tr>
<td>Auxiliary power distribution box</td>
<td>Inspection</td>
<td>Annually</td>
</tr>
<tr>
<td>Insulation monitoring device</td>
<td>Inspection</td>
<td>Annually</td>
</tr>
<tr>
<td>Battery pack</td>
<td>Inspection</td>
<td>Annually</td>
</tr>
</tbody>
</table>

### 3.5 TRANSITION TO HYDROGEN CONSIDERATIONS

Planning for both the hydrogen fleet and fueling infrastructure must occur in tandem to develop a plan that right-sizes the fleet and the requirement for hydrogen fuel.

It is also important to keep in mind that optimal strategies for transition, implementation, and operation will be agency- and context-specific, dependent on a range of factors including anticipated hydrogen demand (based on fleet size, implementation schedule, expected fuel demand per vehicle), proximity to hydrogen sources, and current available space at facilities, among others.

Furthermore, it is recommended that safety be a cornerstone of the planning process when preparing for hydrogen operation and that the initial primary facility design considerations include completion of a risk assessment to determine specific equipment needed for safe operation and maintenance of the FCEBs and well as development of emergency preparedness procedures, employee training program, and engagement and potential training plan for emergency service providers (such as fire department personnel and other emergency response agencies).

Provided below is an overview of hydrogen refueling procedures, followed by a discussion on required refueling infrastructure. This section concludes with general considerations related to design and implementation of hydrogen fueling at maintenance facilities, touching on aspects such as safety and preliminary staff training considerations.

#### 3.5.1 Hydrogen Refueling Overview

Hydrogen refueling station (HRS) is a term used to refer to the equipment required to transfer hydrogen from static storage tanks to onboard vehicle storage. The refueling process of a FCEB is similar to that of
a CNG or diesel bus in that a hose is connected to the fuel gauge until the tank is full (the current standard for heavy-duty vehicles such as buses is 350 bar). This lower-pressure option of 350 bar is financially advantageous as the costs of the required storage vessels and HRSs is significantly lower for 350 bar fueling than for higher pressure fueling options (e.g., 700 bar used in light duty vehicles). Figure 20 below shows a generalized schematic of an HRS.

Figure 20: Generalized Schematic of a Hydrogen Infrastructure Facility\textsuperscript{27} [12]

HRSs can be classified into two main categories depending on whether the fuel is produced on- or off-site. Figure 21 below provides a succinct overview of the major differences between the two.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure20.png}
\caption{Generalized Schematic of a Hydrogen Infrastructure Facility\textsuperscript{27} [12]}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure21.png}
\caption{Schematic Illustrating the Differences Between On-Site and Off-Site Hydrogen Production}
\end{figure}

Figure 21: Schematic overview of on-site and offsite generation hydrogen refueling stations (HRSs)\textsuperscript{28}

The selection of the hydrogen production unit and delivery method will be based on a variety of factors and preferences from the transit agency. Table 16 presents a summary of common considerations and characteristics for each distribution and production method.

Table 16: Characteristics for different hydrogen production sources and distribution methods

<table>
<thead>
<tr>
<th></th>
<th>Compressed hydrogen gas</th>
<th>Liquid hydrogen</th>
<th>Local SMR</th>
<th>Local electrolysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Overall</strong></td>
<td>Good for smaller volumes</td>
<td>Suited for large volumes</td>
<td>Good for large volumes</td>
<td>Good for large volumes</td>
</tr>
<tr>
<td><strong>Distribution Costs</strong></td>
<td>High; price impacted by location from supply</td>
<td>Nominal; range flexibility</td>
<td>Nominal</td>
<td>Nominal</td>
</tr>
<tr>
<td><strong>Price volatility</strong></td>
<td>Dependent on fuel prices; available bulk discounts</td>
<td>Dependent on fuel prices; available bulk discounts</td>
<td>Dependent on maintenance and fuel costs</td>
<td>Dependent on maintenance and electricity</td>
</tr>
<tr>
<td><strong>Infrastructure costs</strong></td>
<td>Lower</td>
<td>Higher</td>
<td>Depends on production capacity</td>
<td>Depends on production capacity</td>
</tr>
</tbody>
</table>

The hydrogen dispenser is typically the only station component that agency staff (operators and maintenance personnel) will interact with, and typically includes a nozzle that connects to the bus and a user interface for initiating fueling that includes emergency shutdown controls. Details of the connection device (nozzle) are defined by international standards such as ISO 17268:2012 and SAE J2600. The hydrogen refueling process is also standardized with SAE J2601-2 19. This standardization is advantageous in that it acts to ensure a high degree of interoperability and vehicle compatibility, so that any FCEB designed to comply with the above international standards can refuel at any HRS designed according to these standards.29

Most transit projects to date in North America have used bulk delivery of liquid hydrogen. Table 17 presents a list of FCEB demonstrations in North America and their hydrogen source. In Europe, more small-scale deployments have used on-site electrolysis as a hydrogen source (with trailer delivery as backup). The “largest” is a 10-bus pilot in Aberdeen using Van Hool buses and 420 kg hydrogen storage tanks.

Table 17: FCEB demonstrations in North America and their hydrogen source

<table>
<thead>
<tr>
<th>City</th>
<th>Number of buses</th>
<th>Year started</th>
<th>Manufacturer</th>
<th>Hydrogen source</th>
<th>Hydrogen storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vancouver/Whistler; For 2010 Olympics</td>
<td>20</td>
<td>2010</td>
<td>New Flyer</td>
<td>Bulk delivery of liquid hydrogen</td>
<td>Unknown</td>
</tr>
<tr>
<td>San Francisco Bay Area, CA; AC Transit</td>
<td>13</td>
<td>2010</td>
<td>Van Hool</td>
<td>Bulk delivery of liquid hydrogen</td>
<td>Unknown</td>
</tr>
<tr>
<td>Thousand Palms, CA; SunLine</td>
<td>10</td>
<td>2011</td>
<td>AFCB; ENC/BAE</td>
<td>SMR; on-site electrolysis under construction</td>
<td>Unknown</td>
</tr>
<tr>
<td>Irvine, CA; UC Irvine</td>
<td>1</td>
<td>2015</td>
<td>AFCB</td>
<td>Bulk delivery of liquid hydrogen</td>
<td>250 kg</td>
</tr>
<tr>
<td>Santa Ana, CA; OCTA</td>
<td>10</td>
<td>2018</td>
<td>AFCB</td>
<td>Bulk delivery of liquid hydrogen</td>
<td>18,000 gal</td>
</tr>
<tr>
<td>Canton, OH; SARTA</td>
<td>6</td>
<td>2017</td>
<td>AFCB</td>
<td>Bulk delivery of liquid hydrogen</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

3.5.2 Hydrogen Refueling Infrastructure

While the above section provided an overview of how hydrogen vehicles are refueled, this section will dig deeper into the specific modifications and equipment required at maintenance facilities within the context of hydrogen refueling.

Hydrogen can be stored and transported as a liquid or as a compressed gas; however, hydrogen liquefaction is an energy-intensive process that can erode some of the cost benefits if used for low hydrogen demands. If more than ten hydrogen buses need daily refueling at a bus division, then investment for refueling equipment of liquid hydrogen is justified.

If liquefied hydrogen is selected as the delivery method, then the cold liquid (-430 °F) will be stored in liquid hydrogen tanks at between 50 and 150 PSI. Upon demand from the hydrogen dispensers, the liquid could then be pumped by triplex reciprocating pumps or compressors (3.94 kg/min. or 14.7 gal./min. at 5,000-6,000 PSI per pump) through vaporizers so that the hydrogen is warmed and becomes gaseous and near-atmospheric temperature. Finally, the gaseous hydrogen is routed through a chiller or other precooling system to increase its density, and then to the high-flow gas hydrogen dispensers, which will fill the buses to 350 bar (about 5,000 PSI). If no bus is connected to a dispenser or all buses are full, the gaseous hydrogen from the pumps and vaporizers are then directed to a buffer-storage array, as needed to allow the pumps to run during a typical 2.5-minute exchange time between sequential-bus fills. The buffer-accumulator both reduces the number of start-stop cycles of the pumps, and also improves fueling speed and efficiency, as the accumulated gaseous hydrogen is then utilized at the start of the next dispensing cycle. Figure 22 presents the layout of a liquid hydrogen fueling station.

The footprint of hydrogen stations can usually be accommodated by the space designated to CNG refueling stations. However, most diesel stations have underground tanks, reducing their footprint requirements. Given the need to accommodate a transitioning fleet of multiple fueling/propulsion types, one approach to consider is to use mobile tube trucks to temporarily store the hydrogen and installing the permanent storage units after diesel buses have been retired.

The use of pumps for the hydrogen refueling station will likely increase the power requirements at each division when transitioning away from diesel. As such, an important consideration is the power and energy requirements for the pumps and related equipment for on-site hydrogen dispensation.
Figure 22: Layout of liquid hydrogen refueling station

The images below show part of the hydrogen fueling yard at OCTA's Santa Ana Bus Base, recently completed and designed to serve 40-50 FCEBs.

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3.5.3 Infrastructure in Other Facility Areas

An assessment on the current configuration of the depots and how buses operate will be required since additional refueling time per bus may be necessary. The analysis will need to provide a review of existing policies/procedures and identify the operational modifications for the added refueling time.

A risk assessment should be conducted to clearly identify all risks with associated mitigation measures to ensure that sufficient measures are in place to allow for the safe maintenance of all vehicle parts.
Potential risks for FCEB maintenance in enclosed spaces differ from those associated with diesel vehicles and include potential leaks from gas elements that can lead to hydrogen rising and accumulating, resulting in a fire risk and risks associated with working with high-voltage systems. While appropriate mitigation measures will likely be site-specific, these can include installation of hydrogen sensors, improved ventilation, and installation of ATEX lighting (for use in explosive atmospheres). Other initial safety considerations include ensuring the mechanic has safe access to the roof (as hydrogen tanks are typically located on vehicle roofs) as well as the underside of the vehicles. In summary, the required modifications to maintenance facilities include:\(^\text{31}\):

- Removal of existing equipment
- Enhanced ventilation
- Ceiling/roof exhaust
- Upgraded alarm and added hydrogen sensors
- Upgraded electrical in control panel areas
- Upgraded lighting
- Updated signage for safety work around flammable gases
- Bridge crane for safe removal of rooftop components
- Scaffolding system to allow safe work at the roof level

Other implementation recommendations for agencies include\(^\text{32}\):

- Regular testing of hydrogen sensors and other important safety equipment
- Development and testing of an automated emergency response procedure (including shutting down of all standard equipment and activation of all emergency equipment such as sprinkler systems)
- Emergency procedure drills and evacuation plans should be developed and relevant staff should be fully trained on these procedures prior to hydrogen implementation

### 3.5.4 Maintenance Considerations\(^\text{33}\)

Battery degradation is not as significant for FCEBs as BEBs, as the typical allowed degrees of battery charge and discharge preserves battery health. However, the fuel cell-specific components and on-board hydrogen storage increase the number of components requiring maintenance as compared to a BEB. A 2018 NREL report states that most FCEB maintenance issues are related to the balance of the fuel cell powerplant, including air handling and cooling. Overall, the maintenance costs per mile for FCEBs are slightly higher than BEBs (with both being lower than diesel vehicles). The highest maintenance per mile costs for FCEBs include propulsion-related, cab, body, and accessories, and PMI. Other costs to consider


\(^{32}\) Ibid.

include brakes, frame steering, and suspension, HVAC, lighting, tires, general air system repairs, and axles, wheels, and drive shaft.

Concerning maintenance of the FCEB fueling infrastructure, it is important to conduct all maintenance activities according to a written and approved procedure/manual and that all maintenance activities be completed according to a schedule that includes safety system testing. A maintenance log should be maintained and include the following details for each maintenance activity performed:

- Maintenance activity performed and date completed
- Start and stop time of maintenance work
- If the maintenance was scheduled or unscheduled (if unscheduled, the reason why it was performed)
- Name of maintenance inspector
- A list of components replaced including serial number and/or certification number

### 3.6 OTHER CONSIDERATIONS TO IMPLEMENT ZEBS

As with the introduction of any new technology, the introduction and deployment of BEBs and FCEBs requires that relevant agency personnel become familiarized with hydrogen, batteries, and associated procedures. Best practices from the literature review reveal that the following components should be included in all training programs:

- Training programs should be tailored for the local context within which the agency operates, including accounting for regional safety requirements
- Training should include both theoretical and practical elements. Anecdotal evidence from agencies suggests that “on-the-bus” training results in more engaged personnel and increased efficiency
- Preparation and provision of written training manuals along with oral and hands-on instruction. These training manuals should be kept on-hand at all facilities to ensure employees remember important safety procedures
- An additional important component of training is expectation management. ZEBs do not have the same level of technical maturity as diesel or CNG buses and issues are likely to occur, especially during the early/initial stages of deployment.

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34 Ibid.
3.7 SUMMARY

The review of different technologies, their pros and cons, and their fundamentals demonstrates that there is no one-size-fits-all approach for any agency, and typically, one agency may need several types of ZEB technologies to deliver its service. The following sections examine the e-tran characteristics, that together with the preceding analysis, provide a good foundation for a ZEB rollout plan.

4.0 CURRENT OPERATIONS AND SERVICE ANALYSIS

This section provides an overview and analysis of Elk Grove’s bus operations, with the overall intent of laying the groundwork for the subsequent ZEB analysis, modeling, and ZEB rollout plan required by CARB outlined in the ICT. All information has been provided by Elk Grove unless stated otherwise.

4.1 FLEET COMPOSITION

The current e-tran fleet for fixed route services is comprised of 46 CNG-fueled 40-ft. buses with purchase years between 2000 and 2018.\(^{35}\)

Table 18: E-tran current fleet composition

<table>
<thead>
<tr>
<th>Year</th>
<th>Number of buses</th>
<th>Make</th>
<th>Length (ft)</th>
<th>Seating capacity</th>
<th>Fuel type</th>
<th>FTA useful life(^ {36})</th>
<th>Scheduled replacement year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>2</td>
<td>Orion V</td>
<td>40’</td>
<td>40</td>
<td>CNG</td>
<td>12</td>
<td>1 in 2022 1 in2023</td>
</tr>
<tr>
<td>2008</td>
<td>14</td>
<td>Orion VII</td>
<td>40’</td>
<td>39</td>
<td>CNG</td>
<td>12</td>
<td>3 in 2020 4 in 2021 4 in 2022 3 in 2023</td>
</tr>
<tr>
<td>2010</td>
<td>8</td>
<td>New Flyer C40 LFR</td>
<td>40’</td>
<td>40</td>
<td>CNG</td>
<td>12</td>
<td>2 in 2025 2 in 2026 2 in 2027 2 in 2028</td>
</tr>
<tr>
<td>2011</td>
<td>6</td>
<td>New Flyer C40 LFR</td>
<td>40’</td>
<td>40</td>
<td>CNG</td>
<td>12</td>
<td>2 in 2029 2 in 2030 2 in 2031</td>
</tr>
<tr>
<td>2014</td>
<td>3</td>
<td>New Flyer Xcelsior</td>
<td>40’</td>
<td>40</td>
<td>CNG</td>
<td>12</td>
<td>2032</td>
</tr>
<tr>
<td>2015</td>
<td>8</td>
<td>New Flyer XN40</td>
<td>40’</td>
<td>40</td>
<td>CNG</td>
<td>12</td>
<td>4 in 2033 4 in 2034</td>
</tr>
<tr>
<td>2018</td>
<td>5</td>
<td>New Flyer XN40</td>
<td>40’</td>
<td>40</td>
<td>CNG</td>
<td>12</td>
<td>2 in 2034 3 in 2035</td>
</tr>
</tbody>
</table>

\(^{35}\) Current fleet as of June 2019 as provided by the agency

The city’s current transit fleet is all entirely within the useful life benchmarks set by FTA (with the exception of the two Orion V vehicles, which underwent an 8-year refurbishment and are scheduled for replacement in 2022 and 2023) and thus are all expected to be in good working condition. Currently, Elk Grove has a fleet replacement schedule through 2035 to ensure vehicles are maintained in a state of good repair.

While some agencies utilize different vehicle types (such as motor coaches) for commuter services, Elk Grove maintains a homogenous fleet of standard 40-ft. buses (not including cutaway vehicles used for paratransit services). This likely reflects that commuter service demand does not warrant vehicles with a larger capacity; however, if demand for commuter services significantly increases in the future and the city decides to address this by acquiring larger or different vehicle types (such as over-the-road coaches), this will have an effect on the ZEB transition and implementation, as current ZEB options differ by vehicle type. One advantage of the current fleet composition is that vehicles can be assigned to blocks interchangeably, and there are no constraints on which vehicle can be assigned to a route.

Overall, Elk Grove maintains a fleet to sufficiently serve the needs of both commuters and those making local trips. In addition, all vehicles are in a state of good repair and within useful life benchmarks set by the FTA.

4.2 **KEY OPERATIONAL CHARACTERISTICS**

E-tran provides two major types of fixed route services: local services and commuter services. Local service provides mobility options for those traveling locally around Elk Grove, operating at frequencies between thirty and 90 minutes that connect local destinations and trip generators. Commuter routes operate during weekday peak AM and PM commute periods, providing access to major employment destinations in Sacramento and Rancho Cordova. Local routes operate on all days except Sunday.

Elk Grove commissioned a comprehensive operational analysis (COA) in 2017, which resulted in a network reworking and significant changes to e-tran routes. Despite these considerable changes, the city did not see a large change in the number of service miles or hours provided between 2017 and 2018 (see Table 19). Local routes saw minimal decreases to both revenue hours and miles, while commuter service saw more considerable decreases approaching a 10% decrease to both service hours and miles.

E-tran provided 762,784 unlinked passenger trips in 2018, a 9% decrease from 2017. It is interesting that local routes saw a more significant decrease in ridership despite a smaller decrease in service provision. Commuter services saw a smaller decrease in ridership of 6% with a larger decrease in service hours and miles, suggesting that commuter routes may be in higher demand for Elk Grove residents. This is reinforced by the almost 3% increase in commuter passengers per hour, suggesting that service changes cut unproductive trips, resulting in a higher service efficiency.
Table 19: Key operational characteristics by service type, 2017-2018 (NTD)

<table>
<thead>
<tr>
<th></th>
<th>Annual Revenue Miles</th>
<th>Annual Revenue Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>Local bus</td>
<td>522,675</td>
<td>515,320</td>
</tr>
<tr>
<td>Commuter bus</td>
<td>382,748</td>
<td>347,829</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Annual Unlinked Passenger Trips</th>
<th>Passenger per Hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2017</td>
<td>2018</td>
</tr>
<tr>
<td>Local bus</td>
<td>433,203</td>
<td>384,453</td>
</tr>
<tr>
<td>Commuter bus</td>
<td>403,636</td>
<td>378,332</td>
</tr>
</tbody>
</table>

When assessing service efficiency in terms of passengers per hour, Elk Grove overall saw a small net decrease between 2017 and 2018. When compared to similarly-sized bus transit agencies in the Sacramento area, no agencies saw significant increases or decreases in local and commuter bus passengers per hour between 2017 and 2018; however, YoloBus passengers per hour increased 6% and Placer County Transit increased 4%. Yuba-Sutter Transit Authority saw the largest decrease of 4%. Elk Grove is performing close to peer agencies in terms of number of passengers per hour as well as in percentage terms.

It is important to continue to monitor trends in service provision over time during ZEB implementation and transition to understand if changing service levels will result in more or fewer vehicles required to provide service, or if service changes result in scheduling differences and longer block lengths that could also require additional vehicles or an augmented charging strategy, depending on the zero-emission technology ultimately adopted.

As mentioned in the above section, Elk Grove operates a fleet of 46 revenue vehicles, all of which are conventional 40-ft. buses that can be assigned interchangeably regardless of route type (commuter or local). It is important to understand how the agency’s vehicles are used throughout the day and specifically when these vehicles are in and out of service to understand constraints and opportunities in regards to charging schedules, and also to inform the preliminary fleet mix and energy requirements.

Vehicle requirements for a typical weekday are shown in Figure 24. This figure shows hourly vehicle requirements for fixed-route services regardless of whether the vehicle is operating on a local or commuter route.
Figure 24: Weekday vehicle requirements by hour of day

As much of e-tran service is commuter-focused, the pattern of vehicles in use that spikes during standard AM and PM commute periods is typical and expected. The peak vehicle requirement of 38 vehicles occurs at 4 pm and translates to a spare ratio of 21%. As a spare ratio of 20% is recommended by the FTA, the city is doing a good job of adequately sizing their fleet to accommodate peak demand without too many or too few spare vehicles.

4.3 DAILY BLOCK MILEAGE

One of the largest challenges associated with transitioning to ZEBs are the range limitations associated with both BEBs and (to a lesser extent) FCEBs. Agency-specific circumstances (such as long routes and block lengths, challenging topography, etc.) can also exacerbate this issue by presenting additional constraints that must be accounted for to not interrupt service provision or negatively affect the rider experience. For e-tran, a key challenge is the commuter routes that travel long distances between Elk Grove and Sacramento or Rancho Cordova, resulting in long routes that translate to long block lengths.

Specifically, block lengths are displayed by frequency of blocks by total daily miles traveled (including revenue service and deadhead) for all service days in Figure 25. It should be noted that while e-tran provides some local Saturday service, the majority of service is provided on weekdays and thus the analysis focuses on weekday operations.
While daily block length averages 68 miles, block lengths vary between a minimum of ten miles and a maximum of 221 miles. The vast majority (84%) of blocks travel less than 100 miles in a day, which is encouraging as these blocks are safely within the daily range limitations of BEBs (the average current operational range of a BEB is 120-150 miles without on-route charging). However, it is still important to consider that seven (or 10%) blocks travel over 150 miles on an average weekday. There are multiple strategies that an agency can employ to mitigate this, such as reblocking to create shorter block lengths, installation of opportunity charging for BEBs, operating longer range FCEBs, or using two ZEBs to complete a block that was previously completed by one CNG vehicle.

Before assessing the best strategy to remedy these issues, it is important to consider how many vehicles are assigned to multiple blocks on a given day, as the sum of block lengths may exceed current ZEB ranges, as well as a detailed look at how much deadheading contributes to overall daily mileage.

When an agency operates long block lengths that might pose challenges for ZEB implementation, it is important to understand how much of the total block length is attributed to deadheading, and if blocking, run cutting, or scheduling changes can minimize the amount of deadhead to better fit daily total block lengths into the parameters of ZEB ranges. Figure 26 presents deadhead miles as a percentage of revenue miles for a typical weekday by block frequency.
Slightly less than half (49%) of blocks operate deadhead miles that are less than their daily revenue miles. However, this means that the majority of blocks are operating deadhead mileage that exceeds their daily revenue miles. Specifically, blocks average 21 miles of daily deadhead mileage and 47 miles of revenue service. While the highest frequency of blocks feature daily deadhead mileage between 100% and 120% of revenue miles, some blocks’ deadhead mileage significantly exceeds daily revenue mileage, as seen in the two blocks that exceed revenue mileage by 200% or more. However, these blocks are short compared to the overall system and together only account for 3% of total daily deadhead miles.

A major constraint in regards to minimizing deadhead for e-tran is that there is only one facility vehicles operate out of. In addition, vehicles operating on commuter routes return to the yard in Elk Grove during the day after morning revenue service, inherently adding considerably to the deadhead (while the average commuter block completes 23 miles of deadheading, which is only slightly higher than the overall average, commuter services make up 86% of the total daily deadhead miles). Often, agencies can minimize deadhead by scheduling vehicles and blocks to operate out of the facility that is closest to the starting location of the block. However, this is not an option for Elk Grove as all vehicles operate out of the Corporation Yard in the southeastern portion of the city. Because e-tran blocks exhibit considerable deadheading due to this operational constraint, a different approach will need to be taken to operate all current blocks with zero emission vehicles. For example, one potential solution is to operate the reverse commute service Route 18 (which travels from downtown Sacramento to Elk Grove in the AM and reverse in the PM) out of a SacRT yard in downtown Sacramento that may be closer to the route’s starting point, as SacRT is already responsible for e-tran operation and fleet maintenance.
As e-tran vehicles are assigned multiple blocks throughout the course of a day, it is important to examine operations from the perspective of how many miles each vehicle travels on an average weekday. Figure 27 shows the breakdown of vehicles in revenue service on a typical weekday based on their number of daily block assignments.

The majority (or 59%) of vehicles are assigned to complete two blocks on a typical weekday. Twenty-eight percent of vehicles are assigned to one block, and the remaining 13% are assigned to complete three blocks. While there are 69 blocks in operation on the sample weekday, some blocks are completed by more than one vehicle, so the total number of blocks shown above is 72. Because the majority of vehicles complete multiple blocks in a day, this may mean that the daily distances vehicles travel exceed the maximum ranges of current ZEB technologies. To understand if this is the case, a breakdown of total daily miles by vehicle frequency is presented in Figure 28 below.
While the most frequent mileage span for a block to complete in a day is between 25 and 50 miles, this number increases when looking at the distance a vehicle completes in a day, which peaks at 15 vehicles completing between 100 and 125 miles. While the average block length is 68 miles, the average distance a vehicle operates in a day is significantly higher and almost twice as much for vehicles, at 120 miles. This indicates that while most block lengths are in the range of current ZEB technologies, daily vehicle distances are more likely to fall outside this range. While only 10% of blocks travel over 150 miles on an average weekday, this jumps to 18% when looking at how many vehicles travel this distance. However, the maximum distance of 221 miles does not change, indicating that, in this instance, the vehicle that completes this block is not assigned to any other blocks.

As stated above, vehicles operating on commuter routes return to the facility in Elk Grove after completing their AM trips and layover during the day; afternoon service requires a deadhead trip to begin revenue service. While this contributes to both increased deadheading and long block lengths, it also presents an opportunity to charge or refuel vehicles during the midday period when these vehicles are in the yard.

### 4.4 MEAN DISTANCE BETWEEN FAILURES

Elk Grove maintains documentation on miles between road calls on a monthly basis. For FY 2019, the city reported an annual average of 7,622 miles between road calls, with these number fluctuating from a high of 14,176 miles between calls in February to a low of 5,010 miles in April. As the national average is 8,000 miles between road calls, Elk Grove is very close to this threshold. Elk Grove should strive to maintain an annual average of at least 8,000 miles between road calls especially in the context of ZEB.
transition and implementation, and especially because according to data provided by the agency, the majority of road calls are due to engine and transmission issues. The transition to a new vehicle technology (or technologies) may result in a higher number of road calls and breakdowns, so it is important to understand how Elk Grove is currently performing and whether the new technology may impact service provision or result in increased instances of monthly road calls.

However, it is also important to consider that anecdotal evidence suggests that there are fewer points of failure for ZEBs since there are fewer “moving parts” when compared with diesel/CNG vehicles, which can result in a reduced likelihood of breakdowns or failures. Thus, it is important for Elk Grove to understand the current mechanical failure rate to provide a baseline which can be used for comparison moving forward.

4.5 STAFFING CONSIDERATIONS

In March 2019, the city of Elk Grove entered into a contract with SacRT to operate and maintain the city’s fleet and transit services, which went into effect in July 2019 and is valid for five years, after which the city will have the option of annexing e-tran services into SacRT. If annexation occurs, all e-tran service and maintenance operations would be fully assumed by SacRT. Prior to this, e-tran operations and maintenance were carried out under contract with MV Transportation, Inc.

All employees working in operations or maintenance will be required to have some sort of training to become familiar with the new technologies. Scheduling sufficient time, allocating appropriate resources, and coordinating with SacRT should be planned in advance so as not to impact normal operations. It is also important to highlight that as e-tran is currently staffed with a small number of FTEs, should e-tran not be incorporated fully into SacRT, it is highly likely that e-tran will need to build capacity and expertise in ZEB operations, so growing the number of FTEs is likely needed in the future.

Elk Grove staff should work with SacRT to understand if SacRT is already planning ZEB technology training for its operations and maintenance staff. If this is the case, city staff can review planned training materials to understand if the content and scope is sufficient and consider participating in SacRT’s training to reduce duplication of work and enhance efficiency of time and resources.

If the ZEB strategy and chosen fleet mix requires a larger fleet size, this may require a greater number of FTEs both for operation and maintenance of vehicles. A corollary sometimes forgotten is parking requirements and space for additional FTEs, in addition to more revenue vehicles. It is more likely that operator and maintenance roles will change based on the differing fueling, operations and maintenance needs of ZEB vehicles as opposed to needing to hire a larger number of FTEs. Identification of operator and maintenance staff level of knowledge of ZEB technologies and skill gaps among these groups will be an important consideration and early step in formulating the training requirements to ensure e-tran staff are prepared to confidently operate and maintain a zero-emission fleet.
4.6 TRAINING CONSIDERATIONS

Regardless of the type(s) of zero-emission technologies that will be adopted and whether there are any training limitations or constraints due to Elk Grove’s contract with SacRT, it is important that operators and maintenance staff are trained on the different procedures related to the operation and maintenance of the new technologies. Similarly, the staff involved in bus planning, scheduling, and run cutting should be provided with ZEB training, as block scheduling and dispatching may be impacted by range limitations of certain ZEB technologies as well as other factors that influence bus scheduling and planning.

While a more robust discussion on training considerations for different technology types will be included in the forthcoming Needs and Opportunities Assessment, some high-level training considerations for ZEB operations include:

- New vehicle training for bus operators (for familiarization with any differences in layout, vehicle performance, or dimensions)
- Safety training for operators and maintenance staff (especially regarding the proper handling of high voltage equipment)
- Safety training should also include the consideration of providing training to local fire and emergency response personnel for emergency preparedness situations. This training should occur every few years
- With the introduction of zero-emission vehicles should also be an agencywide orientation to acquaint the staff with the new technology and also reinforce agencywide environmental/sustainability commitments
- All applicable legislation regarding workplace practices and standards will have to be understood and incorporated into facilities, personal protective equipment, and practices.

4.7 COLLECTIVE BARGAINING AGREEMENTS

Personnel who provide e-tran service are represented through the Amalgamated Transit Union Local Division 256, whose current labor agreement with SacRT is valid through 2022. These include operators, mechanics, technicians, dispatchers, customer service representatives, and utility workers.

The agreement gives considerable management rights to SacRT as laid out in Article 4, Section 4.1. These include the right to hire and fire, change or alter operations, and set standards for productivity and efficiency. Specifically of importance in the ZEB context is SacRT’s right to introduce new or improved technology, research, service, and maintenance methods. While all transit agencies in California are required to adopt ZEB technologies and it is unlikely that SacRT will adopt new technologies in the Elk Grove service area that are counterproductive to zero-emission operations, the city should be proactive in working with SacRT to ensure that the two ZEB plans and proposed changes to adopted technologies and maintenance procedures are not incongruous. As stated above, the city should also ensure that if
training procedures are under purview of SacRT, that these will be sufficient for operators and maintenance staff to perform their job duties under ZEB operations with confidence.

It should also be noted that, as an aspect of ZEB implementation, new maintenance and operations roles may emerge related to ZEB charging and vehicle maintenance that are not currently in place, or existing roles and routines may be required to be modified. In future MOUs, it will be important to consider outlining any new or changed roles and routines within maintenance classifications. Specifically, any applicable and new safety standards associated with ZEBs and unique operating characteristics and methods of operation should be included.

4.8 COMPREHENSIVE OPERATION ANALYSIS

In 2017, the city of Elk Grove commissioned a comprehensive operational analysis (COA) to assess and enhance the efficiency and productivity of transit services, identify new growth and development areas for future service expansion as the city and region grows, and to act as an implementation roadmap for service improvements over the short-term (five years). The COA was truly comprehensive, including a market analysis based on community demographics and land use analysis, public and stakeholder engagement, review of existing conditions, and a service and financial plan including performance measures to track progress over time.

Major service changes coming out of the COA were centered around the concepts of realigning local routes to fit the city’s grid street network, simplify and rationalize route alignments, reduce route duplication along commuter routes, and ensure alignments are scalable to accommodate future planned frequency improvements.

Moving forward, it is important to consider ZEBs when implementing these and future service changes. ZEB features such as range limitations and necessary charging infrastructure can impact service provision. For example, if some blocks become longer or result in increased deadheading, this can result in distances outside of current ZEB technologies and thus more vehicles may be needed to complete the block than non-ZEB vehicles, and increased frequencies that necessitate purchasing of additional vehicles may be a constraint as the purchase price of ZEBs can be higher than non-ZEBs. Just as it is prudent for e-tran to periodically complete COAs to ensure service matches demand and is as efficient and productive as possible, it is important for the agency to keep ZEBs in mind through every stage of future planning processes that result in service changes.

4.9 TRANSIT FLEET FACILITY ELECTRIC INFRASTRUCTURE PROJECT MILESTONE SCHEDULE

In November 2019, Elk Grove commissioned the preparation of a milestone schedule for transit fleet facility electric infrastructure upgrades and modifications to comply with ICT regulation. Specifically, the project outlines steps to be prepared for specifying, ordering, and delivery of ZEBs compliant with LCTOP (Low Carbon Transit Operations Program) funding requirements as well as outlining purchasing of charging equipment, site design and construction, and operational and maintenance changes.
The study was built on several assumptions, including the City accrual of $750,000 in LCTOP funding in FY19-20, required to be spent within four years. These funds are expected to be spent on site upgrades and infrastructure modifications required to support electric vehicle supply equipment. It is not expected that these funds will be used for purchasing chargers or ZEBs. It is also important to note that the milestone study was built on the assumption that the city is transitioning to BEBs, but will also include a high-level overview of FCEBs, which will be sufficient information for the city to decide whether zero-emission technology options outside of BEBs are feasible. Based on the final fleet mix chosen by the city at the end of this ZEB rollout plan process, the milestone schedule may need to be adjusted if FCEBs will be part of the final fleet mix to account for FCEB-specific facility modifications and infrastructure.

4.10 RIDERSHIP AND ROUTE ANALYSIS

The city of Elk Grove provides local and commuter fixed route bus transit service.

- Local routes: provides access to major destinations within the city of Elk Grove. Includes routes 110, 111, 112, 113, 114, 115, and 116.
- Commuter routes: offers connections to major employment destinations in Sacramento and Rancho Cordova. Includes routes 10, 11, 12, 13, 14, 15, 16, 17, 18, and 19.

Local routes operate on weekdays with some limited Saturday service, providing a lifeline service for Elk Grove’s transit-dependent populations, including car-free households and seniors. Local routes operate with headways between 30 and 90 minutes between the hours of 6 am and 10 pm. Routes 110, 113, 114, and 116 provide service on Saturdays. Saturday service spans are shorter, with service terminating before 7 pm. Local routes provide access to destinations such as local libraries, high schools, middle schools, Cosumnes River College, medical centers including Sutter Medical Center and Kaiser Permanente, shopping centers such as Walmart, and connections to other transit services including the SacRT Blue Line CRC station and SCT/Link services. E-tran local routes are highlighted in blue in Figure 29 below.
Figure 29: E-tran local routes

As previously mentioned, e-tran service underwent significant network changes as a result of the 2017 COA, resulting in the new network seen above. Weekly ridership data for a week in February 2020 was examined to understand route usage variation in the local network.

Table 20: E-tran local routes average weekday ridership

<table>
<thead>
<tr>
<th>Route</th>
<th>Average weekday ridership</th>
</tr>
</thead>
<tbody>
<tr>
<td>114</td>
<td>391</td>
</tr>
<tr>
<td>110</td>
<td>343</td>
</tr>
<tr>
<td>116</td>
<td>310</td>
</tr>
<tr>
<td>115</td>
<td>221</td>
</tr>
</tbody>
</table>
While ridership fluctuates day-to-day, ridership is slightly highest overall on Monday, and sees a slight overall decrease through the week, where Friday has lowest overall average ridership. Saturday ridership information was not provided.

Elk Grove’s commuter routes provide AM and PM weekday trips at 30-minute frequencies to and from major employment destinations within downtown Sacramento and Rancho Cordova. Most commuter routes provide access from Elk Grove to downtown Sacramento in the AM with reverse trips in the PM. This includes routes 10-17. Route 19 provides AM trips from Elk Grove to the Butterfield SacRT light rail station in Rancho Cordova. Route 18 provides reverse commute trips from Downtown Sacramento to Elk Grove in the AM with reverse trips in the PM. Commuter routes are shown in blue in Figure 31 below.
In terms of weekly ridership, it is interesting that commuter routes have roughly the same amount of weekly boardings as local routes despite providing fewer trips (see Table 21 and Figure 32), which is also reflected in the higher count of passengers per hour discussed in section 4.2.

Table 21: E-tran commuter routes average weekday ridership

<table>
<thead>
<tr>
<th>Route</th>
<th>Average weekday ridership</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>247</td>
</tr>
<tr>
<td>14</td>
<td>232</td>
</tr>
<tr>
<td>10</td>
<td>227</td>
</tr>
<tr>
<td>Route</td>
<td>Average weekday ridership</td>
</tr>
<tr>
<td>-------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>17</td>
<td>190</td>
</tr>
<tr>
<td>12</td>
<td>180</td>
</tr>
<tr>
<td>19</td>
<td>161</td>
</tr>
<tr>
<td>16</td>
<td>150</td>
</tr>
<tr>
<td>15</td>
<td>133</td>
</tr>
<tr>
<td>13</td>
<td>119</td>
</tr>
<tr>
<td>18</td>
<td>10</td>
</tr>
</tbody>
</table>

**Figure 32: Weekly commuter route ridership, February 24-28, 2020**

As seen with local routes, commuter route ridership varies widely depending on route. While it appears as though commuter routes are more highly-utilized than local routes in terms of service efficiency and passengers per trip and hour, daily ridership fluctuates from a high of 275 riders on Route 11 on February 25 to only five riders on Route 18 on February 28. In fact, Route 18 ridership is significantly lower than any other route. While a larger data sample can help to understand whether this trend is normal or if this is an abnormally low ridership week for Route 18, this may indicate that reverse commute trips from downtown Sacramento to Elk Grove are not in high demand, and providing this service for so few people may not be the agency’s best use of resources. Especially in terms of ZEB implementation, eliminating a commuter route that travels long distances and contributes to deadheading (as the vehicle needs to
deadhead from Elk Grove to downtown Sacramento every morning) may help to both use limited resources more efficiently as well as make the conversion to ZEBs easier.

4.11 DISADVANTAGED COMMUNITIES

CARB defines Section F of the rollout plan as “Providing Service in Disadvantaged Communities.” Specifically, this section requires agencies to first identify if they provide service to any disadvantaged communities, and if so, to describe how the transit agency is planning to deploy ZEBs in these communities. Section F also provides a table where transit agencies have the option to provide an estimate of the number of buses to be deployed in each disadvantaged community and during what year. CARB does not provide additional guidance on the level of detail required when denoting the location of the disadvantaged community. However, as CalEnviroScreen defines a disadvantaged community at the census tract level, it is assumed that listing by census tract is sufficient. An example of this table is provided in Table 22 below. This table is optional and not a required component of the rollout plan.

Table 22: Service in disadvantaged communities (example, optional)

<table>
<thead>
<tr>
<th>Timeline (Year)</th>
<th>Number of ZEBs</th>
<th>Location of Disadvantaged Community</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The ICT utilizes information provided by CalEnviroScreen to identify disadvantaged communities. ICT regulation defines CalEnviroScreen as a mapping tool that is developed by the Office of Environmental Health Hazard Assessment (OEHHA) at the request of the California Environmental Protection Agency (CalEPA) to identify California’s most pollution-burdened and vulnerable communities based on geographic, socioeconomic, public health, and environmental hazard criteria.

CalEnviroScreen evaluates the burden of pollution from multiple sources in communities while accounting for potential vulnerability to the adverse effects of pollution to identify disadvantaged communities from a wide variety of factors to comprehensively assess the overall health of communities, down to the census tract level. Specifically, CalEnviroScreen identifies disadvantaged communities as census tracts which scored in the top 25% based on the factors used by CalEnviroScreen to assess pollution burden and vulnerability.

Figure 33 reveals that disadvantaged communities within the e-tran service area are actually located entirely outside the city boundaries of Elk Grove, and instead lie in the commuter destinations within Sacramento and Rancho Cordova, as well as parts of unincorporated Sacramento County that e-tran commuter routes travel through. While the total amount of disadvantaged communities within the service area are concentrated in four pockets, these communities are in locations that are either popular terminus locations for e-tran commuter services or cover part of the Interstate 5 (I-5) and State Route 99 (SR 99).

37 ICT specifies that the most recent version of CalEnviroScreen should be used, which is currently version 3.0 (found here: https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-30)
corridors that are used by e-tran commuter routes. In fact, it is possible that the presence of busy highways within these communities contributes to their designation as disadvantaged. Consequently, all commuter routes touch at least one disadvantaged community. However, no local routes touch any disadvantaged communities. Specifically, routes that travel through at least one disadvantaged community are:

- Commuter routes 10, 11, 12, 13, 14, 15, 16, 17, 18 and 19

With this information, it can be determined that ZEB deployment should be prioritized along commuter routes first. This may pose challenges as commuter routes tend to be longer in length, contributing to longer overall block lengths that may be difficult to accommodate under current ZEB technology ranges.
A potential strategy to achieve compliance with this section of the ICT mandate may be to identify the commuter route with the shortest daily scheduled vehicle block lengths and prioritize ZEB deployment along this route.

**4.12 SUMMARY**

Presented above are some of the current service and operational characteristics of e-tran service that will need to be considered when transitioning to a ZEB fleet. The information provided above also serves as a brief overview of current Elk Grove bus transit operations to gain a better understanding of current operations before moving forward to the next steps of the ZEB planning and implementation process. Initial constraints, opportunities, and challenges identified that will affect e-tran ZEB transition and implementation moving forward include:

- Elk Grove operates a homogenous fleet of 40-ft. buses, which offers flexibility in dispatching
- Provision of commuter service, which is typically characterized by long routes, with service concentrated during weekday AM and PM peak commuting periods and long block lengths
- Some long block lengths with considerable deadheading due to the presence of only one facility where vehicles are housed and dispatched from
- While commuter vehicles return to the facility in Elk Grove during the day between AM and PM trips which contributes further to deadheading, this is a potential opportunity for midday vehicle charging or refueling
- The city has already completed a prior study focused on BEB charging infrastructure installation at their facility

**5.0 FACILITY EXISTING CONDITIONS**

**5.1 CORPORATION YARD FACILITY**

This section provides a high-level overview of the existing conditions of the infrastructure and facilities at the City's Corporation Yard that e-tran operates out of and also provides general guidance on what facilities and infrastructure may be required and/or considered as part of the agency's ZEB implementation plan. These preliminary considerations will be built upon in greater detail in the implementation plan to outline required upgrades and modifications to support ZEB operations.

**5.1.0 General Site Information**

E-tran occupies a portion of the City's Corporation Yard facility at 10250 Iron Rock Way in the City of Elk Grove. The transit agency occupies approximately 127,500 sq. ft. of the site for vehicle service and
parking, not including employee parking. The property currently has 59 full-size (44 ft. by 14 ft.) bus stalls, as well as various other areas available for vehicles adjacent to the maintenance bay entry doors. The transit agency also occupies approximately 18,000 sq. ft. of the 60,000 sq. ft. building on the property for maintenance and operation areas. The site and other portions of the building are occupied by the City’s public works department as well as the police department. Employee parking is also accommodated on site, generally along the east and west edges of the property.

5.1.1 Architectural & Maintenance Equipment

5.1.1.1 Summary

The building on the property was not specifically assessed as part of this report but appears to meet the needs for e-tran’s current operational and maintenance functions. The maintenance area is a large open space and is used to service as many as four vehicles at a time. Mobile vehicle lifts are utilized in lieu of in-ground lifts, which aids in the flexibility of the space (Figure 34 and Figure 35). Equipment is generally stored around the perimeter of the space. A mobile fall protection system is utilized in lieu of a fixed overhead cable trolley system typically used in maintenance bays for accessing the rooftop of vehicles. Vehicle exhaust reels and other typical vehicle maintenance equipment was generally observed at the facility.
5.1.1.2 Conditions

The facility and associated maintenance equipment appear to be in good working condition. The building’s exhaust system and connections to the existing gas detection system is also presumed to be in good condition.

Figure 34: Interior photo of the operations and maintenance facility
5.1.1.3 Preliminary Considerations

Limited improvements to the actual building would be required to accommodate either type of ZEB. Certainly, the necessary tools and specialty diagnostic equipment would be required for either type of vehicle and would be implemented at the time staff are trained to service the particular vehicle.

Fire Protection Considerations:

With the implementation of both FCEBs and BEBs, fire protection and life-safety concerns can be significant. However, due to the relatively new advent of these technologies, building and fire protection codes have not specifically addressed most of these concerns. NFPA 855 ‘Standard for the Installation of Stationary Energy Storage Systems’ is a standard that can potentially be applied to BEB storage, but this particular standard is excessive relative to the capacity of the batteries onboard. The need for enhanced fire protection systems has not been determined as a baseline requirement for BEB implementation and would be left up to the discretion of the local fire marshal and the local building officials.
5.1.2 Vehicle Service Cycle

5.1.2.1 Summary

The property has three access driveways, one each on Union Park Way to the north, Iron Rock Way to the east, and Elkmont Way to the south. Buses enter the property via the Elkmont Way driveway and continue through the site, generally in a clockwise circulation pattern. Buses are parked when they enter the property in any available bus stall and do not have assigned parking locations by bus (Figure 36 and Figure 37). Utility staff will pick-up bus from the yard, drop fares, and then fuel at the nearby offsite CNG station (see fueling section below). The service operator has designated staff for the fueling and cleaning activities. Vehicles are washed once a week with a mobile, walk-behind bus washer and are nightly broom cleaned and disinfected via fogging equipment per current COVID-19 health and safety guidelines.

Figure 36: Exterior photo of the Corporation Yard showing buses parked and the outside of the maintenance building
5.1.2.2 Conditions

The current service cycle facilities and functions appear to be in good, working condition and are suitable for e-tran’s current operations on the property (Figure 38). The ages of the existing equipment and facilities were not assessed, but should be assumed to need replacement during the normal life cycle of such equipment and could be considered for optimization during the course of ZEB implementation at the facility. In other words, e-tran could consider the phased replacement of vehicle washing or fare retrieval equipment if the implementation of ZEBs also triggered a reconfiguration of the bus yard.
5.1.2.3 Preliminary Considerations

The current site conditions and service cycle appear to be conducive for implementation of either BEBs or FCEBs. For BEBs, chargers and dispensers will need to be planned throughout the yard and may require modifications to the current parking layout on the property, thereby potentially impacting the flow of the service cycle. If FCEBs are utilized, no changes to the service cycle would be required if the hydrogen fueling station were similarly located offsite, comparable to the CNG fueling scheme currently in use.

5.1.3 Fueling Infrastructure

Though 100% of e-tran’ bus fleet is CNG fueled, the facility has no onsite fueling infrastructure. Instead, all buses are fueled at the nearby Clean Energy CNG facility located at 9050 Elkmont Way, which is about one mile from the yard. The facility allows up to two buses to fuel simultaneously, but performance is hindered if both are used, so only one bus fuels at a time. Each fill event takes about 20 minutes. With the round-trip travel to/from the yard accounted for, each bus-fill cycle takes about 30 minutes.
This arrangement works well for e-tran; the space required for CNG-fueling systems can be devoted to buses instead for e-tran’s facility. In addition, staff are not required to maintain the CNG facility. One potential drawback is the cost premium for fueling offsite, but the premium is modest and workable.

5.1.4 Gas-Leak Detection System

The bus maintenance building is equipped with a CNG-detection system. The system consists of a Sierra Monitor model 5000 controller (Figure 39), with 16 sensors located along the ceiling, which was installed in 2013, and the sensor units were updated/replaced in August 2020. The sensors are calibrated to detect methane / CNG.

![Gas leak detection controller](image)

Figure 39: Gas leak detection controller

If FCEBs are deployed, the existing detection system would need to be maintained for CNG buses, while an additional parallel system to detect hydrogen-gas leaks would be required. This system will need separate alarm lights that are distinct from the methane-leak alarms, as required by NFPA 72 (fire-alarm code).
5.1.5 Electrical

Electrical power is supplied to the Elk Grove Corporation Yard complex from a pad mounted transformer located near the southeast corner of the building outside of the yard wall along Iron Rock Way. The Sacramento Municipal Utility District (SMUD) is the electrical utility serving Sacramento County and the Corporation Yard. SMUD transformer, TX-01030487, provides 120/208 V, 3 phase power to the main switchboard located on the east wall of the building (Figure 40), inside the area operated by the Elk Grove Police Department.

Figure 40: Electrical switchgear

The main switchboard distributes power to the entire building, including the Elk Grove Transit facilities located in the northern third of the building. Subpanels in each of the areas provide power to the lights, HVAC equipment, and other equipment necessary for operations. The electrical loads in the building
include lights, HVAC, and some maintenance equipment including an air compressor and some portable bus lifts.

5.1.5.1 Conditions

The existing electrical distribution system appears to be in good condition and well maintained. Age of the equipment was not determined; but, based on the models of the electrical components it is anticipated that the system has a life expectancy of greater than 10 years before needing replacement. The system appears to be satisfactory for the current demands of the Corporation Yard operations.

5.1.5.2 Preliminary Considerations

The existing electrical system was designed to support a warehouse/light industrial operation, which is appropriate for the current requirements of the three entities, including e-tran, using the building. Primary electrical demands in the e-tran portion of the building are, as noted above, lighting, HVAC, and some periodic demands from the shop air compressor and the portable bus lifts.

The existing 120/208V system is not adequate to serve the loads that would result from BEB chargers. BEB charger demands vary depending on model, but demands often exceed 200 kW per charger and peak fleet charging demands greater than 2 MW are common. The chargers would require a new 480 V electrical service with a new service from SMUD. SMUD has 12 kV distribution lines surrounding the facility that could potentially feed a new 12 kV/480 V transformer that could provide service to the chargers.

In addition to the new feed from SMUD, a BEB charging system would require new 480 V switchgear and a new electrical distribution system to serve the chargers.

If FCEBs were adopted and a hydrogen fueling system was installed on-site, this would also require a new electrical service from SMUD to provide 480 V power to the hydrogen compressors and filling equipment.
6.0 FINANCIAL ANALYSIS

Financial analysis is a critical component of the ZEB rollout plan to ensure that the resulting plan is actionable and will result in tangible operational and financial benefits in addition to compliance with CARB’s mandate. Prior to evaluating the anticipated financial impacts of the ZEB and base case (CNG) scenarios, however, it is important to review the current state of the e-tran’s operating and capital expenses. Doing so will provide valuable insights for crafting the rollout plan while also acting as a basis upon which financial forecasts may be completed.

6.1 AGENCY OPERATIONS AND EXISTING COSTS

To consider the financial stability of Elk Grove, operating expense trending was examined for the data provided by the agency (NTD annual reports). A gradual increase in operating expenses over time is expected (to account for ongoing service expansions and inflation). As Elk Grove operating expenses increased 14% during this time, the city is doing a good job of controlling operating costs, especially considering changes in operating cost of similarly sized peer agencies (see Figure 41). As Elk Grove’s increases in operating costs are on the lower end when compared to other bus transit agencies in the Sacramento area, this is another indicator that controlling operating costs is an agency strength and significant or sharp year-over-year increases in operating expenses are not typical for e-trans.

![Graph: % change in operating expenses, 2014-2018](image)

**Figure 41: Percent change in operating expenses of peer agencies, 2014-2018**

Digging into this a little deeper, a breakdown of operating expenses for Elk Grove for 2018 as reported to the NTD for fixed route services (excluding demand response services) is illustrated in Figure 42 below.

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38 Data for all agencies was sourced from the NTD
Overall, the majority of operating costs are allocated to purchased transportation to operate service. Other significant expenditure categories include fuel and lubricants and service costs. In percentage terms, purchased transportation made up a similar amount of the overall fixed route operating budget in 2014, but fuel and lubricant costs decreased from approximately 15% of the operating budget in 2014 to slightly over 10% in 2018. The largest cost increases were seen in service costs and other materials and supplies, which increased 123% and 383% between 2014 and 2018, respectively. The relevance of each of the below categories to the ZEB rollout plan will be discussed in greater detail in the forthcoming financial analysis.

![City of Elk Grove e-tran fixed route operating expenses (FY17-18)](image)

**Figure 42: Breakdown of e-tran fixed route operating expenses, 2018**

It is also important to look at operating expenses in terms of miles and hours of service provided. For 2018, e-tran fixed route operating expenses per vehicle mile was $9.15 and $111.11 per vehicle hour (see Figure 43 and Figure 44). This is an increase compared with 2014, where Elk Grove spent $5.29 per vehicle mile and $101.57 per vehicle hour to operate its fixed route services. In fact, operating expenses increased over this time period as vehicle miles decreased and vehicle hours remained virtually the same (specifically, vehicle hours increased by 2% with vehicle miles decreasing by 35%). In addition, e-tran’s operating costs per hour and mile are slightly higher compared to peer agencies. Overall, operating

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39 2018 Operating Expenses, NTD
expenses per vehicle hour increased 9% and operating expenses per vehicle mile saw a 73% increase between 2014 and 2018.

E-tran fixed route operating expenses per vehicle mile

- Wages and salaries: $0.42
- Service costs: $0.24
- Utilities: $0.07
- Fringe benefits: $0.28
- Fuel and lubricants: $0.88
- Other paid absences: $0.98
- Casualty and liability costs: $0.31
- Other materials and supplies: $0.04
- Purchased transportation: $0.02
- Misc. expenses: $5.91
In addition to operating expenses, it is important to consider the trending of capital expenses and funding. Capital expenses are dependent on capital needs and funding availability. The funds received over the last few years have been reviewed to understand funding availability for small bus transit agencies in the Sacramento area. As seen in Figure 45, overall, changes in capital funding fluctuates widely, but has tended to increase over time (for the installation of new safety measures and mobile radios on buses, bus procurement, etc.), albeit with significant differences in how large the increase has been depending on the agency. For example, YoloBus saw an increase in capital funds of $330,268 in 2014 to $4,571,894 in 2018.
As it is best practice to typically ensure that capital spending is as consistent as possible year-over-year rather than subject to significant peaks and valleys in case funding availability changes in the future, it is important to examine agencywide capital funding sources and how they have trended over time. It appears that Elk Grove is performing well compared to its peers in regards to capital funding, as seen in the much higher changes in capital funding from YoloBus and Placer County Transit. Figure 46 shows that Elk Grove receives the bulk of its capital funding from state funds and federal assistance and a much lower proportion from local funds. Specifically, major sources of capital funding for 2018 include 5309 Capital Investment Grants, a discretionary grant program administered by the FTA, and SB 1, in which state funds are allocated to transit agencies for the construction of capital projects. It may be worthwhile to consider exploring additional opportunities for alternative funding sources in the future to ensure Elk Grove is maximizing the diversity of its funding portfolio and is not overly reliant on any one funding source that may not be stable or reliable in the future.
Together with the other tasks and analyses being undertaken in the context of the ZEB analysis and rollout plan, the existing state of Elk Grove’s transit operations and finances provides insight into current strengths, challenges, and opportunities as it relates to a full fleet conversion of ZEBs.

### 7.0 SUMMARY AND NEXT STEPS

Here, we presented a comprehensive review of e-tran’s existing conditions, encompassing operations, facilities, and finances with an emphasis on their relevance to ZEB transition and implementation and some initial observations and takeaways regarding current service that will have an impact on the city’s transition to ZEBs. Also included was an overview of the ICT regulation, required components of the ZEB rollout plan, and an overview of currently available ZEB technologies and their associated required charging infrastructure. Now that a thorough understanding of current fixed-route operations has been produced, next steps include:

- Modeling to forecast energy and/or fuel usage and to determine the feasibility of different technology types to meet Elk Grove’s operations
- Developing a preferred fleet composition based on minimizing operational and capital costs, while also considering qualitative trade-offs related to operations and other agency-wide impacts
- Detailing the needs of the preferred fleet composition

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**Figure 46: Breakdown of e-tran capital funding sources, 2014-2018**

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- Detailing the needs of the preferred fleet composition
ZERO-EMISSION BUS TECHNOLOGIES AND EXISTING CONDITIONS FOR E-TRAN

- Complete a GHG impact analysis detailing reduction in emission from conversion to ZEBs and energy storage opportunities and challenges
- Developing the rollout plan and implementation strategy
ZERO-EMISSION BUS TECHNOLOGIES AND EXISTING CONDITIONS FOR E-TRAN