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AIR RESOURCES BOARD

Comprehensive Review of California's Zero-Emission Bus Program Readiness: Phase II Summary Report

Third-Party Evaluation

Prepared for the California Air Resources Board

by the National Laboratory of the Rockies and University of California, Berkeley

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List of Acronyms

AC Transit	Alameda-Contra Costa Transit District
APCD	air pollution control district
APTA	American Public Transit Association
AQMD	air quality management district
ARCHES	Alliance for Renewable Clean Hydrogen Energy Systems
ATN	Anaheim Transportation Network
AVTA	Antelope Valley Transportation Authority
BABA	Build America, Buy America
BEB	battery-electric bus
BTM	behind the meter
CALACT	California Association for Coordinated Transportation
CalSTA	California State Transportation Agency
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CEC	California Energy Commission
CI	carbon intensity
CNG	compressed natural gas
CPUC	California Public Utilities Commission
CTA	California Transit Association
DGS	Department of General Services
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EV	electric vehicle
EVSE	electric vehicle supply equipment
FCEB	fuel cell electric bus
FTA	Federal Transit Administration
GHG	greenhouse gas
GO-Biz	Governor's Office of Business and Economic Development
HVIP	Clean Truck and Bus Voucher Incentive Project
ICT	Innovative Clean Transit
ICTRT	Innovative Clean Transit Reporting Tool
IOU	investor-owned utility
LADOT	Los Angeles Department of Transportation
LA Metro	Los Angeles County Metropolitan Transportation Authority
LCFS	Low Carbon Fuel Standard
LCTOP	Low Carbon Transit Operations Program
LH2	liquid hydrogen
Low-No	Low or No Emission Grant Program
MBRC	miles between road calls
MCI	Motor Coach Industries
MCS	Megawatt Charging System
mpdge	miles per diesel gallon equivalent
NLR	National Laboratory of the Rockies
OCTA	Orange County Transportation Authority
OEM	original equipment manufacturer

PG&E	Pacific Gas & Electric Company
ROP	rollout plan
SamTrans	San Mateo County Transit District
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
SDMTS	San Diego Metropolitan Transit System
SMRT	Santa Maria Regional Transit
SolTrans	Solano County Transit
TIRCP	Transit and Intercity Rail Capital Program
TTM	to the meter
VVTA	Victor Valley Transit Authority
ZEB	zero-emission bus
ZEV	zero-emission vehicle

Executive Summary

This Phase II comprehensive review report provides updates on the state of California's zero-emission bus (ZEB) transit industry and insights on key topical areas, including ZEB and infrastructure technologies, market status, incentive programs, and workforce development, with a focus on readiness to meet Phase II of the Innovative Clean Transit (ICT) regulation.

Drawn from a combination of literature review, data analysis, and surveys of the California transit industry, Phase II of the comprehensive review focuses on the readiness of transit agencies in the lead-up to the second round of ZEB purchase requirements commencing in 2026—50% ZEBs for large agencies and 25% ZEBs for small agencies, for new bus purchases. Thus, the Phase II review includes the scale-up of standard 40-foot ZEBs and adds other transit vehicle types, including articulated buses, over-the-road coaches, "cutaway" buses, and double-decker buses. Additional focus is placed on the unique needs and concerns of small transit agencies as the ICT regulation begins to apply to these bus fleets and ZEB types in 2026.

This stage in the program connects the initial pilot-oriented small deployments from Phase I to the full-scale deployment of transit ZEBs that will occur in 2029 per the ICT program schedule. The scale-up to larger ZEB fleets will rely heavily on the experience gained from previous ZEB deployments, but to be successful, it will involve several key elements in a broader environment supportive of ZEBs, such as clear policy and regulatory support, a stable manufacturing base and supply chains, maturation of advanced bus technology and infrastructure solutions, targeted funding support programs, and a skilled workforce. In addition, conditions in the adjacent market, including developments in zero-emission technologies and supply chains for commercial vehicles and energy systems, will influence the availability, cost, and performance of ZEB components and supporting infrastructure.

The overall approach for the Phase II comprehensive review focused on an updated review of ZEB literature, analysis of data collected from the ICT Reporting Tool and other available data sources, feedback from ZEB manufacturers and suppliers via an original equipment manufacturer (OEM) questionnaire, and an extensive survey of California transit agencies. The review covers the status of ZEB deployment, ZEB incentives and funding programs, ZEB market changes and outlook, ZEB cost and performance, charging and refueling infrastructure, and workforce development for ZEBs. It also summarizes recent progress and remaining barriers for ZEB deployment. Key findings of the comprehensive review are summarized below and covered in more detail in the body of the report.

Since the Phase I review in 2022, the U.S. transit bus industry and California transit agencies have had to adapt to a number of significant market dynamics, including bus manufacturer bankruptcies (e.g., Proterra, Lightning eMotors, and Vicinity Motor) and market exits (e.g., Nova Bus, REV Group), while some manufacturers (e.g., Gillig, New Flyer) are expanding through acquisitions and new engineering centers. Transitioning to ZEBs has also been challenged by supply chain issues, cost increases, and limited numbers of Buy America-compliant ZEB models, especially in niche segments like cutaway and articulated buses. Despite long delivery lead times, manufacturers like Gillig, New Flyer, and RIDE (formerly BYD) continue developing ZEBs, while initiatives like the American Public Transit Association ZEB Task Force aim to help stabilize the industry and support the zero-emission transition.

Despite these market fluctuations, ZEBs continue to offer significant energy efficiency and environmental benefits, making them a key focus for future transit solutions. California has made substantial initial progress toward its goal of transitioning to 100% ZEB transit fleets. Overall, California transit agencies and their partners in government and industry have demonstrated leadership in advancing ZEB deployment, exceeding initial ICT program targets, building necessary infrastructure, and securing funding to support future progress. Some notable highlights since 2018 are summarized below.

ZEB Deployment Progress and Milestones

- **Bus deployments ahead of initial schedule:** As of 2024, California transit agencies have deployed (in service and on order) a total of 1,671 ZEBs—1,241 battery-electric buses (BEBs) and 430 fuel cell electric buses (FCEBs)—getting ahead of the ICT target of 1,347 ZEBs for 2027 and gaining valuable operational experience. Compared to 2023 reporting data, total BEBs increased 17% from 1,065 to 1,241, and total FCEBs increased 90% from 226 to 430.
- **Achievements from both large and small transit agencies:**
    - Antelope Valley Transit Authority and Santa Maria Regional Transit completed the full transition to 100% ZEB fleets in 2022 and 2025, respectively.
    - Anaheim Transportation Network's (ATN's) fleet is more than 80% ZEBs and aims for full conversion in early 2026.
    - Long Beach Transit expressed at the 2025 California Transit Association Fall Conference that one-third of their fleet is zero emission and plans for full transition by 2030.
    - San Mateo County Transit District (SamTrans) purchased 108 FCEBs, marking the largest single order of hydrogen fuel cell buses in the United States.
    - Los Angeles County Metropolitan Transportation Authority (LA Metro) plans to add 500 more ZEBs to their fleet in time for the 2028 Olympics.
    - Los Angeles Department of Transportation (LADOT) has secured more than 200 BEBs and is building major ZEB infrastructure.
    - Victor Valley Transit Authority (VVTA) operates 12 BEBs with more than 1.4 million zero-emission miles logged to date.

Infrastructure Development and Technology Adoption

- **ZEB charging installations:** Charging infrastructure has expanded significantly, largely due to support from statewide transportation electrification programs (brought about by SB 350 and other legislation). Costs for "to-the-meter" and "behind-the-meter" installations have been closely evaluated to guide cost-effective deployment. Average electricity cost per kilowatt-hour decreases rapidly as the installed capacity increases beyond 50–100 kW. It is more cost-effective to install higher-kilowatt direct-current (DC) chargers. The expanded charging infrastructure in adjacent medium- and heavy-duty sectors (such as school buses and delivery trucks) greatly benefits BEB deployments in the transit industry.

- **Hydrogen fueling stations:** There are five operational hydrogen stations in the state for transit bus fleets: Emeryville and Oakland in the San Francisco Bay Area, both supporting Alameda-Contra Costa County Transit District; and Santa Ana, Thousand Palms, and Pomona in Southern California, serving Orange County Transportation Authority, SunLine Transit Agency, and Foothill Transit Agency, respectively. Numerous other agencies are building or expanding hydrogen stations to support new FCEB fleets.
- **Public access:** According to the survey of California transit agencies, 33% are planning to provide public access to their ZEB charging or fueling stations, advancing community benefits and supporting ZEB operations, especially at small and rural transit agencies.
- **Increasing interest in deploying FCEBs:** Around 45 transit agencies have identified in their ZEB rollout plan or demonstrated with recent vehicle purchases their plans to adopt fuel cell technology.

Funding, Incentives, and Other Supporting Programs

- **California financial support programs:** California has established programs like the Clean Truck and Bus Voucher Incentive Project (HVIP) and Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE) to accelerate ZEB deployments and fund related infrastructure. In addition, the Transit and Intercity Rail Capital Program (TIRCP) and Low Carbon Transit Operations Program (LCTOP) continue to provide significant funding for ZEB deployments.
- **Low Carbon Fuel Standard (LCFS) regulation:** This program continues to provide financial support for dispensing low-carbon fuels (hydrogen and electricity) throughout the state, along with providing additional "capacity credit" support for electric charging and hydrogen fueling stations that are initially underutilized. These capacity credits provide early financial support for stations that are not yet operating at full capacity but are critical for ZEB scale-up; a recent amendment extended the program through 2045.
- **Federal financial support programs:** Competitive and formula funding programs from the Federal Transit Administration such as the Low or No Emission Grant Program have provided historic levels of funding in recent years (especially in 2022–2024), helping transit agencies across the United States begin or expand pilot ZEB deployments.
- **Fleet planning tools:** New resources like the Funding Finder tool are available to help transit agencies in California identify funding programs available for ZEBs. Cal Fleet Advisor also provides no-cost expert assistance, peer-to-peer insights, and practical strategies to help transit agencies overcome real-world challenges to deploy ZEBs.

Phase II Implementation Challenges

Although the transit industry has seen continued advancements in ZEB technologies and infrastructure since the adoption of the ICT regulation, further cost reductions and performance improvements will support a complete transition to ZEB fleets, which requires substantial effort and investment. As reported by California transit industry stakeholders, the common challenges for transit agencies in deploying these technologies include:

- High costs for ZEBs and necessary infrastructure, as well as a lack of dedicated, long-term funding to support expanded ZEB deployments.
- Long lead times for large electrical infrastructure upgrades, impacting the deployment timelines for expanding BEB fleets.

- Lack of long-range ZEB models for some bus types (cutaway, over-the-road coach, and double-decker buses) and limited manufacturing/market support thus far from adjacent zero-emission vehicle markets, restricting some transit agencies' ability to purchase ZEB replacements.
- Insufficient supply of affordable low-carbon hydrogen, inhibiting cost-effective FCEB operations.
- Lack of a holistic approach to workforce development. Most funding programs and resources available to date support a bottom-up approach for transit agencies to improve their internal training programs and address specific agency workforce needs, rather than coordinated statewide programs.

The common challenges identified above are reflections of the ZEB market ecosystem. The transition to ZEBs under the ICT regulation presents multiple challenges across infrastructure, workforce, funding, and operational domains. Several key challenges from the Phase II comprehensive review are outlined below:

- **Bus market challenges:**
    - Small market size.
    - ZEB model availability.
    - Long lead times.
    - Different needs for small agencies.
- **Infrastructure challenges:**
    - High infrastructure costs.
    - Utility delays.
    - Reliability issues.
- **Workforce challenges:**
    - Shortage of technicians.
    - Lack of training availability.
- **Funding and cost challenges:**
    - Insufficient and inconsistent funding allocations.
    - High upfront costs.
- **Operational challenges:**
    - Range limitations.
    - Grid resilience.
- **Reliability and performance concerns:**
    - Infrastructure reliability.
    - Performance data gaps.

California transit agencies have taken advantage of available resources and achieved a great deal of progress in deploying ZEBs and developing necessary workforce training. Such accomplishments are reflected in the amount of early action to adopt ZEBs, especially by large transit agencies. It is crucial to note that the amount of early action may decline over time due to the ramping up of ZEB purchase requirements and other challenges facing California transit agencies. The federal government and California therefore continue to play an important role in providing policy drivers and support to keep the ZEB deployment momentum. Furthermore, developments in adjacent markets, such as progress in zero-emission commercial vehicle technologies and supply chains, will increasingly influence cost, availability, and technical maturity. Continued ZEB development is key for the entire industry to move forward and continuously improve the technologies, enhance reliability, and strengthen the bus market.

Based on the information collected and evaluated under this comprehensive review, it appears that:

- Standard and articulated bus technologies are more advanced than other technologies. They are suited for a one-for-one replacement ratio in the near future for many transit agencies. **As a result, the California transit industry is prepared to proceed with the 2026 purchase requirement of 50% ZEBs for large transit agencies and 25% for small transit agencies on standard low-floor and articulated transit buses.**

- **The other three bus types—cutaway, over-the-road coach, and double decker—will need more time and support from adjacent medium- and heavy-duty vehicle markets to provide sufficient volume for the market to take off.** It is crucial to examine the potential annual purchase volume in order to understand when (or whether) the market is able to respond to such demand based on a sensible investment strategy. It is unclear how long or what kind of investment it may take to bring these bus types to full market availability, but the market could benefit significantly from support from an adjacent market of other zero-emission medium- and heavy-duty vehicles. Therefore, individual compliance with the ICT regulation for these three bus types may be highly dependent on the specific circumstances of each transit agency.

To achieve ICT program goals of continuing successful deployment of ZEBs and expanding fleet transitions, the California transit industry reports needing more support in several areas.

- Long-range models are needed for cutaway, over-the-road coaches, and double-decker buses. Development of adjacent markets for medium- and heavy-duty zero-emission vehicles is crucial, especially for the current market size of these transit bus types.
- Though driving range may not be a primary issue for the standard and articulated buses in the near term, longer-range options and more robust infrastructure systems will be needed for sector-wide deployment, especially for the standard buses that could operate 350 to more than 500 miles per day. Reliability improvements will be needed as well.
- ZEB purchase cost will be a prohibitive factor when the incremental cost over conventional alternatives cannot be offset. Most of the existing ZEB grants are either competitive grants or dependent on annual budget allocations, which do not provide long-term certainty. Both a cost containment mechanism and dedicated funding are needed to provide policy incentives to stimulate the ZEB market, encourage competitive pricing, and enable long-term planning for successful ZEB fleet scale-up.
- Workforce development needs to utilize a top-down, holistic approach. Such an approach would focus on (1) identifying necessary workforce training for fleets to efficiently deploy ZEBs (including vehicle operation and maintenance, project management, procurement, planning, and other fields related to ZEB deployment); (2) developing coordinated training curriculum; and (3) identifying dedicated training funding.
- The expansion and training of the ZEB workforce is not limited to just transit agencies. While this is a transformation of the entire industry, it is also crucial to examine the sufficiency and adequacy of the manufacturing and supply chain workforce. It is equally

important to ensure the entire manufacturing and supply chain industry has sufficient and adequate workforce that can design products and build production lines to ensure product safety and performance. The manufacturing and supply chain workforce should also be able to identify gaps between vehicle design and existing charging/refueling standards and protocols for a smooth product rollout.

- Ensuring long-term fuel supply and cost stability is crucial to supporting increased ZEB deployments. Long lead times on electrical infrastructure build-out and lack of affordable low-carbon hydrogen supply must be addressed and factored into the sector-wide ZEB deployment schedule.

A coordinated holistic approach would address the above issues more effectively and efficiently. Currently, all state and federal supporting programs tend to address single issues without collaboratively looking at the entire market. While zero-emission vehicles play an important role for California to address air quality concerns and protect public health, a holistic plan with effective action items will be essential to achieving the desired outcomes.

The California transit industry articulated a number of recommendations and remaining questions to facilitate the transition to ZEBs under the ICT program, including:

- **Workforce development:**
    - Coordinate workforce development needs with transit agencies.
    - Increase funding for workforce development.
    - Expand internal training programs.
    - Focus on key training areas.
    - Collaborate with educational institutions.
    - Examine the sufficiency and adequacy of the manufacturing and supply chain workforce.
- **Funding mechanisms:**
    - Streamline incentive programs.
    - Increase funding allocations.
    - Provide innovative financing.
- **Infrastructure improvements:**
    - Prioritize utility coordination.
    - Focus on resilience.
    - Develop high-power charging standards.
    - Provide affordable, low-carbon hydrogen.
- **Policy enhancements:**
    - Create tax exemptions.
    - Promote adjacent market growth.
    - Educate on compliance.
- **OEM and technology support:**
    - Support R&D grants.
    - Encourage "second movers" in ZEB markets.

These recommendations aim to address workforce, policy, financial, and infrastructure challenges and ensure smooth transitions for transit agencies adopting ZEBs. In summary, the Phase II ICT comprehensive review captures the state of the ZEB industry, emphasizing opportunities for strategic collaboration, technological advancements, supportive policies, and sustained funding to expand zero-emission transit solutions and meet the 2026 ICT program goals.

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1 Introduction

The California Air Resources Board (CARB) has developed and implemented programs for decades designed to reduce mobile source emissions of particulate matter, oxides of nitrogen (NO_x), and other pollutants to help the state improve its air quality. Beginning with the Fleet Rule for Transit Agencies more than 20 years ago and continuing with the initiation of zero-emission bus (ZEB) demonstration projects in 2006 and subsequent technology developments that led to implementation of a ZEB purchase requirement, CARB has steadily encouraged the movement for decreased carbon intensity (CI) in the California transit fleet (Fleet Rule for Transit Agencies 2009; California Air Resources Board 2018b; 2022; 2015b; 2015a).

1.1 Summary of the Innovative Clean Transit Regulation

The Innovative Clean Transit (ICT) regulation, adopted in December 2018 to replace the Fleet Rule for Transit Agencies, is part of CARB's continuous effort to reduce emissions from the on-road transportation sector to help California meet its air quality goals (California Air Resources Board 2018c). The regulation established transit ZEB purchase requirements that defined a pathway to achieve 100% ZEB fleets in California by 2040. The ICT regulation is the first regulation in the United States that requires a statewide heavy-duty vehicle vocation or industry to fully transition to zero-emission vehicles (ZEVs). This regulation drives the transition to all-ZEB transit fleets by defining an increasing percentage of new bus purchases that must be ZEBs each year, phasing out conventionally fueled buses and ramping up the deployment of ZEBs over time. It applies to all public transit agencies in California that own and operate buses with a gross vehicle weight rating greater than 14,000 pounds and covers standard low-floor, articulated, double-decker, over-the-road coaches, and cutaway buses.

The ZEB purchase requirements began in 2023 for the 21 agencies in the state designated as large transit agencies, requiring 25% of new bus purchases to be ZEBs. Beginning in 2026, the purchase requirements increase to 50% for large agencies and extend to include small transit agencies, beginning at the 25% level (Table 1). Considering the 12-year expected lifetime of transit buses, the 100% ZEB purchase requirement that applies for all agencies in 2029 and beyond is designed to result in 100% ZEB fleets in California by 2040.

Table 1. ICT Regulation, ZEB Purchase Requirements (Percentage of New Buses Purchased Annually)

Date	Large Transit Agency [a]	Small Transit Agency [b]
2023–2025 (standard 40-ft buses only)	25%	—
2026–2028 (all bus types, if passed Altoona testing)	50%	25%
Jan. 1, 2029, and thereafter	100%	100%

[a] A transit agency that either (1) operates more than 65 buses in annual maximum service in either the South Coast Air Basin or the San Joaquin Valley Air Basin, or (2) operates in an urbanized area with a population of at least 200,000 and at least 100 buses in annual maximum service.

[b] All other transit agencies.

Public transit agencies in California have tested, deployed, and advanced low-emission vehicle technologies for more than 25 years, helping the state make measurable progress toward meeting its air quality and health goals. By aggressively expanding the deployment of ZEBs in the state, the ICT regulation is designed to achieve the following benefits (California Air Resources Board 2025b):

- Reduce NO_x and other harmful air pollutants for all Californians, especially transit-dependent communities. The majority of these benefits will be realized in the state's most populated areas where transit buses are most prevalent.
- Increase penetration of the first wave of zero-emission heavy-duty technologies into applications that are well suited to their use to further achieve emissions reduction benefits.
- Save energy and reduce dependency on petroleum and other fossil fuels.
- Expand the ZEV industry to bring high-quality jobs to local communities and a trained workforce to California.
- Provide other societal benefits by encouraging improved mobility and connectivity with low-carbon transportation modes and reduced growth in light-duty vehicle miles traveled.

The intent of the ICT regulation is to accelerate the transition to ZEBs and achieve these statewide goals without negatively impacting transit service. The regulation applies only to bus types that have market availability for Altoona-tested bus models (discussed in Section 5.1: ZEB Market Impacts and Bus Model Availability).

In addition, the regulation provides various compliance options and potential exemptions to provide safeguards and flexibility for transit agencies as they navigate the proposed emissions reduction schedule (California Air Resources Board 2025b). CARB is committed to working with transit agencies as needed to facilitate ZEB implementation and maintain ICT compliance without adversely affecting transit service. Exemptions may be granted, on an annual case-by-case basis, for transit agencies facing one of the following situations preventing the agency from meeting its annual compliance obligation:

1. Delays in ZEB delivery or operation due to delays in ZEB infrastructure completion.
2. Available ZEB models cannot meet the agency's daily mileage needs.
3. Available ZEB models do not have adequate gradeability performance to meet the agency's daily service needs.
4. Absence of a suitable ZEB replacement model (e.g., Altoona tested, Americans with Disabilities Act compliant) for the applicable weight class.
5. Financial hardship.

1.2 Purpose of ICT Comprehensive Review

When the ICT regulation was adopted by CARB, Resolution 18-60 directed CARB staff to conduct a comprehensive review of the program readiness to be completed before the onset of the first ZEB purchase requirements. The review would evaluate key metrics including costs, performance, and availability of ZEBs; associated charging/fueling infrastructure; funding support programs; and workforce development. To meet this objective, CARB contracted with the National Laboratory of the Rockies (NLR) and the University of California, Berkeley, to conduct the comprehensive, independent third-party review.

The comprehensive review was divided into two phases to match the timeline of the ICT implementation. Phase I focused on the "standard-length" (approximately 40-foot), low-floor-type transit buses and the initial 25% ZEB purchase requirements for large transit agencies beginning in 2023. The Phase I report from NLR and the University of California, Berkeley, was published in October 2022 and is available online (Jeffers et al. 2022).

Phase II of the comprehensive review focuses on the readiness of transit agencies in the lead-up to the second round of ZEB purchase requirements commencing in 2026—50% for large agencies and 25% for small agencies. Thus, the Phase II review includes the scale-up of standard 40-foot ZEBs and adds other transit vehicle types, including articulated buses, over-the-road coaches, "cutaway" shuttle buses, and double-decker buses. Additional focus is placed on the unique needs and concerns of small transit agencies as the ICT regulation begins to apply to these bus fleets and ZEB types in 2026.

The review also aims to identify the remaining needs for the full transition of the California transit bus fleets to ZEBs and determine what additional programs, resources, or support are needed by transit agencies. This review is intended to inform policies to advance heavy-duty zero-emission technologies and inform funding strategies related to ZEBs and infrastructure. This report represents the findings from Phase II of the comprehensive review.

1.3 Findings From Phase I Comprehensive Review

The objective of Phase I was to determine whether the currently available ZEB technologies in standard buses and industry experience from early ZEB pilots/deployments could be used by large transit agencies to meet the ZEB purchase requirement in 2023, while ensuring transit service or fares are not adversely impacted by the transition. Detailed findings from Phase I comprehensive review were summarized in the final report by NLR and the University of California, Berkeley, and presented to the board at the September 2022 meeting.

Based on the evaluation and information gathered at the time, it was determined that the California transit industry was well positioned to proceed with the 25% ZEB purchase requirement for large transit agencies in 2023. This assessment was informed and supported by:

- ZEB rollout plans (ROPs) developed and submitted by large transit agencies.
- Momentum developed from more than a decade of ZEB demonstrations and deployments.
- Continued ZEB product development and refinement led by the transit industry.
- A supportive funding and policy environment for ZEBs.
- Successful partnership and collaboration of California transit agencies, vehicle manufacturers, charging and fueling equipment suppliers, utility providers, and others.

However, it was also noted that to continue to meet the ICT requirements and achieve a successful transition to 100% ZEB transit fleets in the coming years, additional coordination, monitoring, technology advancement, and resources would be necessary, covering the following focus areas:

- Sustained progress from the vehicle, equipment, and infrastructure manufacturing base to continue driving down costs, improving reliability, and optimizing performance.
- Expansion of charging and fueling infrastructure via coordinated efforts and forward-looking planning by transit agencies, utilities, and developers.
- Comprehensive and standardized training programs to develop a highly skilled workforce to improve the efficiency and cost of maintaining ZEB equipment while creating new jobs and ensuring safety.
- Financial support for purchasing ZEBs and installing the related fueling/charging equipment, especially in the early years.

These topic areas will be further examined in the report summary.

1.4 Updates to ICT Approaching 2026

Starting in 2026, the purchase requirements for Phase II of the ICT regulation will be significantly expanded from the Phase I implementation. For large agencies, the ZEB purchase requirements double from 25% to 50% of new buses. For many of these agencies, the Phase I 25% purchase requirement was a reasonable and achievable start to gain experience with ZEB transition and provided an opportunity to gain experience beyond small ZEV pilot demonstrations. The 50% ZEB requirement is a significantly higher threshold which presents more implementation challenges, especially for charging/fueling infrastructure. For some agencies who may have delayed new bus purchases in the last few years in order to delay ZEB implementation, the 50% threshold may be a challenging place to begin transitioning to ZEBs.

Phase II is also the beginning of the ICT implementation for small transit agencies, with new bus purchase requirement starting at 25%. Small transit agencies benefit from the experience of the large transit agencies that have been operating ZEBs; however, their transit operations, service territories, and vehicle fleets can be substantially different than large agencies, creating unique considerations and challenges for transitioning to ZEBs.

In addition, the 2026 ICT purchase requirements will include nonstandard bus types that have market availability and have passed Altoona testing. One of the challenges with this aspect of the review is that limited operational experience and real-world data exist for nonstandard ZEBs—articulated, cutaway, over-the-road, and double-decker buses. The manufacturing of zero-emission powertrains for these buses is much less mature (or still in developmental stages), and transit agencies have less experience with ZEBs for these bus types. Once the vehicles are commercially developed and available for purchase, they must be built and delivered to the transit agencies to deploy in service. Only then can detailed evaluations of the new technologies in revenue service be conducted, which take additional time to complete in order to accumulate objective data on ZEB performance and costs. Thus, there is not yet a clear track record for many of these ZEB types with respect to performance, cost, reliability/longevity, and operational considerations on which agencies can base their future ZEB plans.

For these reasons, the Phase II review developed a methodology that utilizes a combination of quantitative and qualitative information to conduct the assessment of the ZEB transition in California. Information from industry surveys and questionnaires was used to supplement the detailed bus data where it was available.

1.5 Establishment of the ICT Task Force

Despite early commitments, substantial funding, and ongoing technological advancements, transit agencies continue to face significant challenges that may hinder their transition to ZEBs. These challenges include the high cost of procuring and operating ZEBs, extended lead times for infrastructure deployment, the need for standardized workforce training, and the complexity of navigating fragmented and administratively burdensome funding processes. To address these persistent barriers, effective collaboration between state and transit agencies is essential.

In response, CARB, in partnership with the California Transit Association, has initiated the formation of a multi-agency, executive-level task force. This task force is designed to identify and address the most pressing challenges faced by transit agencies in their transition to ZEBs. Launched in the first quarter of 2025, the 2-year initiative convenes quarterly meetings to facilitate interagency dialogue, prioritize key issues, and develop actionable strategies. The outcomes of these discussions will inform near-term recommendations for inclusion in the draft ICT Phase II Comprehensive Report. In parallel, long-term strategies will be shaped by insights from the Scale-Up Effect Study.

The task force is composed of principal-level representatives from state agencies and transit organizations. It is chaired by the Governor's Office of Business and Economic Development (GO-Biz), with the California State Transportation Agency (CalSTA) and CARB serving as co-chairs. Transit agency representation includes 10 members: the California Transit Association (CTA), the California Association for Coordinated Transportation (CALACT), and representatives from three large transit agencies (Alameda-Contra Costa Transit District [AC Transit], Orange County Transportation Authority [OCTA], and San Diego Metropolitan Transit System [SDMTS]) and five small transit agencies (Humboldt Transit Authority, Clovis Transit, Contra Costa County Transportation Authority, Monterey-Salinas Transit, and Victor Valley Transit Authority [VVTA]).

To support its objectives, the task force is organized into four working groups, each focused on a critical area of the ZEB transition. The ZEB Transition Funding group is tasked with identifying opportunities to extend and expand key sales and use tax exemptions, addressing funding gaps exacerbated by inflation, tariffs, and supply chain disruptions, and streamlining program requirements to improve the efficiency of state funding mechanisms. This group is also exploring the potential for bulk procurement strategies to reduce overall costs.

The Energy Issues group is focused on evaluating options to support microgrid and on-site energy deployment, clarifying the designation of transit as an emergency service across agencies, recommending strategies to reduce electricity costs for bus charging, and documenting hydrogen boil-off rates while proposing policy solutions to mitigate their impacts. As California's hydrogen hub, the Alliance for Renewable Clean Hydrogen Energy Systems (ARCHES), is on pause, the task force has recently agreed that this working group will explore group hydrogen procurement opportunities.

The Small and Rural Technical Assistance group is working to recommend new state formula funding tailored to small and rural transit agencies, identify infrastructure partnership opportunities, assess technical assistance needs, and develop program concepts to support rural ZEB deployment. This group is also exploring public-private pilot projects to address ZEB supply gaps and encouraging rural agency participation in the California Department of Transportation's (Caltrans') charging software integration efforts.

Lastly, the Infrastructure Models group is examining opportunities for shared infrastructure, assessing operational risks and liabilities associated with shared ZEB refueling systems, and developing strategies to mitigate long-term risks related to original equipment manufacturers (OEMs) and equipment suppliers.

Through this coordinated effort, the task force aims to deliver practical, scalable solutions that accelerate a broad and efficient transition to zero-emission transit across California.

2 Methodology for Phase II Review

The Phase II comprehensive review followed a slightly different methodology compared to what was conducted in Phase I, due to several factors regarding the ICT implementation and the ZEB industry. For instance, the ZEB purchase requirements beginning in 2026 are expanding to include small transit agencies and nonstandard bus types. The Phase I review benefited from years of detailed ZEB data collection and evaluation of the performance and costs of early ZEB demonstrations, mostly from large transit agency deployments of standard ZEBs. This type of detailed data is not available, or very limited, for the new bus types and for ZEB operation at small transit agencies. In addition, there have been numerous recent changes in the U.S. transit bus market that have important implications on the outlook for the ZEB industry but may not be captured or thoroughly evaluated yet in the available literature.

Thus, the methodology for the Phase II comprehensive review focused on the following elements as key information sources to conduct this review:

- Updated literature review.
- ICT data collection.
- OEM questionnaire.
- Survey of California transit agencies.

Literature Review

As with Phase I, the team conducted a literature review to collect relevant reports and other new documents covering the wide array of ZEB topics considered in the review. This included academic papers, news articles, reports from federal and state agencies, etc. The detailed literature review also led to the meta-analysis of bus performance and cost metrics outlined in Section 5. This analysis was generated from published "side-by-side" bus evaluations, ZEB case studies, and other reports which have published real-world results from their bus operating data, for one or more of the following metrics: bus availability (i.e., vehicle uptime), fuel price, fuel economy/efficiency, fuel cost per mile, maintenance cost per mile, and miles between road calls (MBRC). The meta-analysis of these published results was used to compare the cost and performance between buses of different powertrains, including battery-electric buses (BEBs), compressed natural gas (CNG), diesel, diesel hybrid, and hydrogen fuel cell electric buses (FCEBs).

ICT Data Collection

The comprehensive review analyzed transit agency data collected by CARB specifically for the ICT program. This data collection included updated ICT rollout plans, which is an ICT requirement that outlines each transit agency's plans for compliance with the ICT regulation, such as fleet composition and anticipated purchasing schedule for each fleet. Also included was data reported to CARB through the ICT Reporting Tool (ICTRT) for calendar years 2023 and 2024. The ICTRT data contains a detailed annual accounting of number of buses in service and on order by powertrain/fuel type for each agency. This data allows CARB to track ZEB compliance and overall progress of the ICT program.

Due to the inconsistency or lack of detailed ZEB data collection and technical evaluations of ZEB operations, CARB has also launched a long-term ZEB data collection effort since 2023. The purpose is to collect real-world performance data on all types of ZEBs (including nonstandard buses) to better understand their operational effectiveness under varying conditions. Participation is voluntary, and this effort is intended to minimize the reporting burden for transit agencies. ZEB availability is being requested and used as a surrogate measure to simplify data collection while still capturing meaningful insights about ZEB performance and reliability. The focus is on availability data during the first 6 years of vehicle operation. If average availability reaches 85% or higher, those bus models and years that are likely to achieve a full 12-year service life can be identified. This creates a unique opportunity to provide early input to guide the transition to zero-emission fleets. The data collection activity tracks both ZEBs and baseline sub-fleets of conventional fuel types, documenting the factors contributing to downtime. To date, only one transit agency has submitted consistent data, underscoring the need for continued outreach and process refinement to increase participation and improve coverage.

OEM Questionnaire
In fall 2024, a questionnaire was sent to transit industry OEMs and suppliers. The objective of the questionnaire was to obtain OEM and supplier perspectives on ZEB market forces including cost, parts supply, planning, maintenance support, and other factors that are critical to meeting ICT 2026 purchase requirements. This information is intended to supplement a broad array of data and literature the team is collecting for the ICT Phase II review, including the recently completed survey of California transit agencies.

Transit Agency Survey
Lastly, a major undertaking of Phase II was the development and administration of an extensive survey for California transit agencies regarding their ZEB experience and plans. The survey was divided into five sections and captured information on a wide variety of ZEB topics—from policy recommendations to bus and infrastructure cost and performance, to workforce development. This comprehensive review relies heavily on the responses received from the survey. These results are an especially important data source to learn about the unique perspectives, concerns, needs, and early ZEB experiences from small transit agencies and for nonstandard bus types, as little information has been published thus far evaluating ZEBs in these fleets. The survey is outlined in detail in Section 2.2.

2.1 OEM Questionnaire

The OEM questionnaire was designed with input from members of CARB, CALACT, and CTA. The questionnaire included approximately 35 questions organized into three general categories, including:

1. Product development.
2. Maintenance and warranty.
3. Government and market drivers for ZEBs.

Responses were received from two ZEB OEMs for standard buses, a fuel cell supplier and one OEM for cutaway buses. Key high-level takeaways from the questionnaire include:

- Bus market size limits the number of bus model options developed by transit bus OEMs relative to that of other heavy-duty vehicle manufacturers who have more annual sales and limits the bargaining power of the transit agencies purchasing new buses.

- Respondents claim to have sufficient manufacturing capability to meet the needs of ICT ZEB purchase requirements.
- A need to build deep, long-term partnerships with key suppliers to ensure a stable and resilient supply chain.
- Investments by OEMs and transit agencies in workforce development are critical to ensure long-term success.
- Policies that increase the use of ZEVs in adjacent markets with significantly higher annual production volumes (e.g., trucks) could drive the innovation of design, faster improvement of component reliability, and the scale necessary to reduce component costs.
- Consistency and predictability of incentive program funding availability is critical to ensure OEMs and transit agencies can rely on this funding for their longer-term planning.

More detailed responses from the three topical areas are summarized below and incorporated into the relevant sections of the broader report. The following is a sampling of key questions from each section followed by summarized bullets of the industry responses.

What are the most significant/impactful ZEB technology improvements (such as improved system integration, battery packaging improvements, etc.) achieved since 2020?

- New battery technology has significantly enhanced vehicle performance, safety, and operational efficiency.
- Improved energy density and space utilization have led to a 30% increase in driving range for our electric buses, also enhanced battery longevity.
- Fuel cell cost reduction (−70%), small module footprint, easier integration in vehicles, improved component reliability, and higher operating temperature to enable integration with heating, ventilating, and air conditioning.

What new technology development is needed?

- New technology transitions have historically been supported by extended R&D and validation cycles throughout the heavy-duty trucking industry, and once mature, the adoption of technology by the transit industry.
- For fuel cell modules, industry continues to invest in technology development to lower product cost and continues to improve component reliability—new stack development, sourcing of new-generation balance of plant components (air compressors, DC/DC converters).
- For fuel cells, a critical area is product industrialization and scaling up to reduce costs, further supported by predictable and steady demand—like that required by ICT.

What are key cost drivers for ZEBs?

- The key driver of ZEB costs and the premium over conventional buses is the cost of components such as batteries and fuel cells which require significantly more volumes than what is needed by the transit industry alone.
- Driving down the costs of ZEBs will require a multipronged approach which results in higher volumes of components utilized by multiple industries and supported by adequate supply of reliable, proven components and a trained and capable workforce at transit agencies who can reduce the burden of support currently on OEMs.

What are OEM viewpoints on "bus standardization" as a mechanism to drive down ZEB costs and increase reliability, uptime, and parts supply?

- From a manufacturing perspective, bus standardization is a valuable mechanism to shorten production timelines, reduce costs, and improve after-sales response time by simplifying parts supply and maintenance processes.
- However, each transit agency operates in a unique environment and serves a distinct ridership. OEMs understand agencies need to customize vehicles to meet specific operational, accessibility, and community needs.

What are key factors impacting bus lead times?

- Overseas supply chain for many subcomponents incorporated into electric motors and battery packs such as battery cells, many of which have experienced significant global demand which exceeds those suppliers' production capacity.
- Transit agencies have reported significant lead times for utilities to provide the additional electrical service needed to charge new electric buses.
- Additionally, electrical supply components such as switchgear have been challenging for customers to source timely.

What are some OEM strategies for sourcing part supplies & strategies to improve lead times?

- Build deep, long-term partnerships with key suppliers to ensure a stable and resilient supply chain.
- Proactively purchase and store critical spare parts in our warehouse to support timely after-sales service, maintain reliable part availability, and preserve competitive pricing.
- Provide forecasts to suppliers based on high-probability orders.

What are OEM plans for meeting long-range customer service requirements?

- Transit customers currently depend heavily on OEMs to support their ZEBs. Customers service their own buses but are supported by OEM Field Service Technicians located across the country that support our transit agency partners in troubleshooting and repair of OEM buses.
- For large deployments, OEMs often establish a multiyear local presence to ensure the vehicles are delivered to customer specifications and to ensure the customers' technicians are trained on maintenance and repair of the vehicles.

What are some challenges and strategies for providing transit maintenance support?

- To meet the ROPs, transit agency technicians will need to become proficient in the service and diagnosis of the ZEBs to the same extent they are with conventional buses.
- It is not feasible for OEMs to grow their service organizations to provide the level of support currently requested by customers.
- Investments by OEMs and transit agencies in workforce development are critical to ensure long-term success.

What are some policy recommendations that will support the ZEB transition, other than "more funding"?

- Policies that promote the growth of ZEV use in adjacent markets with significantly higher volumes (e.g., trucks) to drive the innovation of design, faster improvement of component reliability, and the scale necessary to reduce component costs.

- Transit agencies are concerned about the electric grid's resilience and how agencies would be able to charge buses in the event of an extended outage like might be seen during a natural disaster.
- Stronger policies are needed to require utilities to prioritize and streamline interconnection processes and infrastructure upgrades for transit fleet electrification.

What are some recommendations for improving California incentive funding programs?

- Consistency and predictability in the availability of incentive program funding are essential to support long-term planning by both transit agencies and OEMs. Unlike short-term, technology-specific programs such as the Clean Truck and Bus Voucher Incentive Project (HVIP), transit funding must be structured to provide sustained, long-term support. This ensures that agencies can make strategic investments in fleet transition, infrastructure, and workforce development with confidence in the continuity of financial resources.
- Changes to the programs where the incentive funding is applied for and received directly by the transit agencies to reduce the burden on OEMs and better match the costs of supporting the program with the entity receiving the benefits.
- Recommend that CARB enhance education and outreach to different types of transit agencies regarding their compliance status under the ICT regulation.
- Improved communication and guidance from CARB could help ensure agencies fully leverage available resources to support their ZEB transitions.

2.2 Survey of California Transit Agencies

In Phase II of the comprehensive review, the evaluation team conducted a survey of California transit agencies to gather information about ZEB deployment experiences and plans, remaining challenges, top priority needs, and other feedback about the ICT program. The survey was open to all transit agencies, whether or not they had begun deploying ZEBs. The survey asked about federal and state policies pertaining to ZEBs, current and future fleet compositions, ZEB cost and performance issues, infrastructure topics, and workforce development.

The survey was released in November 2023, and most responses were collected in the first quarter of 2024. Thus, the survey results generally reflect transit agencies' conditions and plans as of the end of calendar year 2023. Some agencies' plans may have evolved since the survey was conducted. The team compiled and analyzed the survey responses to evaluate each topic area relating to ZEBs. An initial summary of the anonymized findings was presented at the 2024 CALACT conference and reviewed with transit industry representatives in subsequent conference calls.

Results from this analysis are included throughout this report to help provide the transit agency perspective on each ZEB topic area. Feedback from transit agencies through this survey was critical to understanding their recent experiences with ZEBs and remaining plans, as well as major challenges faced by transit agencies transitioning to ZEBs, and suggestions for improvement. The evaluation team is grateful to California transit agencies for taking the time to share their valuable experiences, opinions, and fleet information.

Summary of Survey Responses

Responses to the survey were received from 62 California transit agencies, including 14 large agencies and 48 small agencies, representing all geographic regions of the state (Figure 1). Individual fleet sizes ranged from one bus to more than 760 buses per agency, with a total of approximately 6,100 buses represented by the survey respondents (Figure 2).

Statewide, there are approximately 200 transit agencies (21 large agencies, ~180 small agencies) which operate more than 13,000 buses. Thus, respondents to this survey represent two-thirds of the large agencies, about a quarter of the small agencies, and just under half of all transit buses in the state.

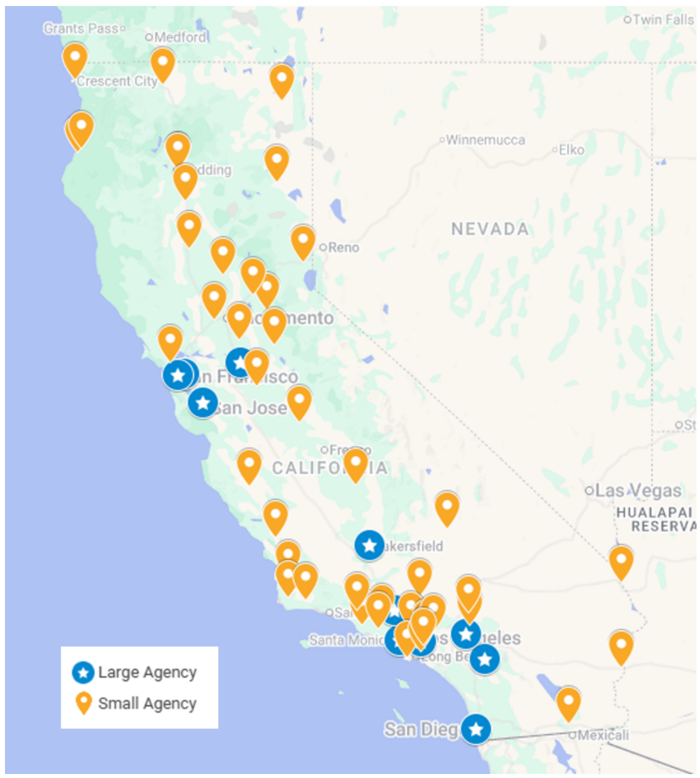

Figure 1. Map of transit agencies that responded to transit survey.

Blue markers (stars) indicate large agencies; orange markers (circles) indicate small agencies.

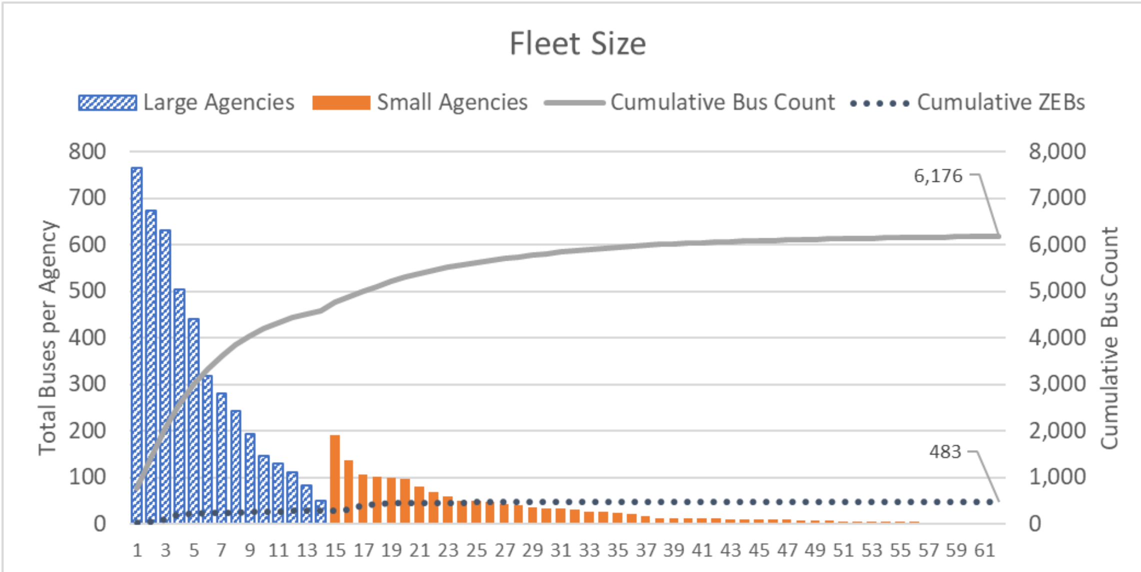

Figure 2. Distribution of fleet size and cumulative bus count for survey respondents.

Source: Survey of California transit agencies

Although the large agencies account for less than a quarter of all survey respondents, they represent nearly three-quarters of the buses reported in the survey due to the disproportionate sizes of these agencies' fleets (Figure 3). They also tend to have more complex transit service and fleet compositions, and these agencies are already subject to ICT purchase requirements. However, small agencies have unique needs and unique perspectives, especially as it relates to the ICT regulation. For these reasons, the results of the survey have been separated into these two groups to help highlight where there are commonalities and where there are differences.

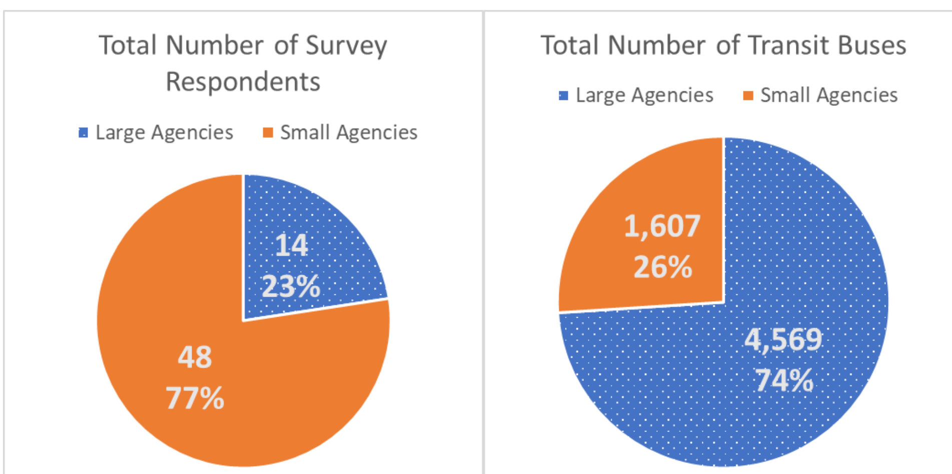

Figure 3. Number of survey respondents and number of reported transit buses.

Source: Survey of California transit agencies

Fleet compositions reported through the survey represented all five bus types—standard low-floor, articulated, over-the-road coaches, double-decker, and cutaways shuttles—with a mix of powertrain/fuel types, including BEB, FCEB, diesel, gasoline, compressed natural gas (CNG), liquefied natural gas (LNG), propane (liquefied petroleum gas, or LPG), and electric hybrids

(Figure 4, Figure 5). Large transit agencies primarily operate standard low-floor buses with approximately 30% of their fleet, on average, composed of cutaway, articulated, and over-the-road coaches (6%–15% for each type). Small agencies operate fleets with a much larger fraction of cutaway buses (over 37%, on average), while standard buses comprise just over half of the fleets, on average.

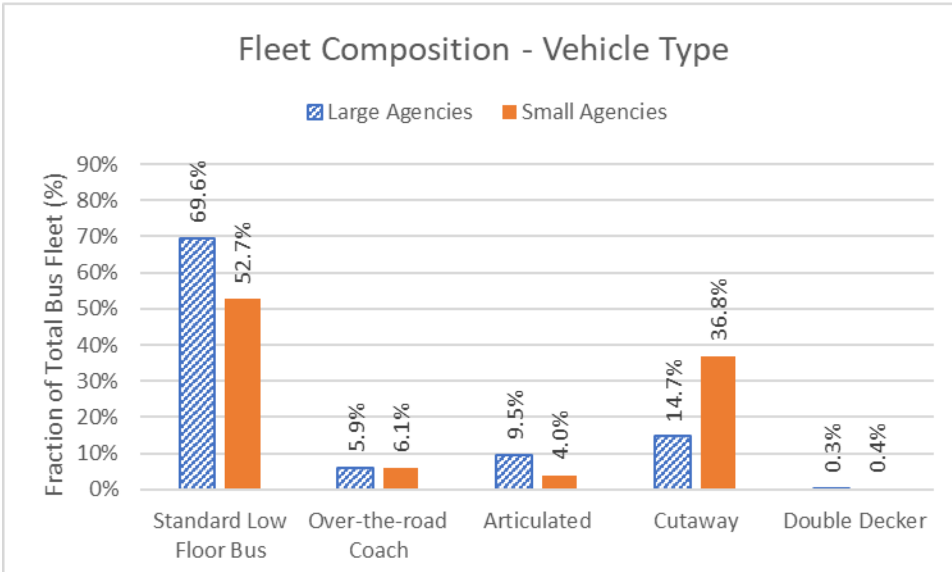

Figure 4. Fleet composition by vehicle type for survey respondents.

Source: Survey of California transit agencies

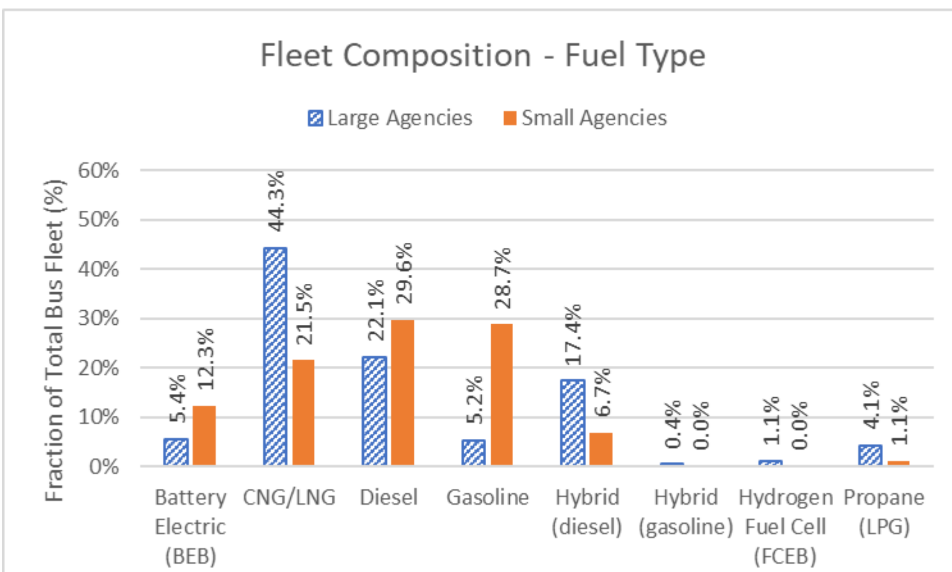

Figure 5. Fleet composition by fuel type for survey respondents.

Source: Survey of California transit agencies

Most respondents offer both fixed-route service and on-demand service. Large agencies tend to have a larger fraction of their bus fleets dedicated to fixed routes (>65%), whereas small agencies that offer both types of service have between 20%–85% of their fleets on fixed routes

(Figure 6). Some small agencies offer only fixed-route service, and some have only on-demand service. These different types of bus service may require very different approaches when planning for ZEB transition.

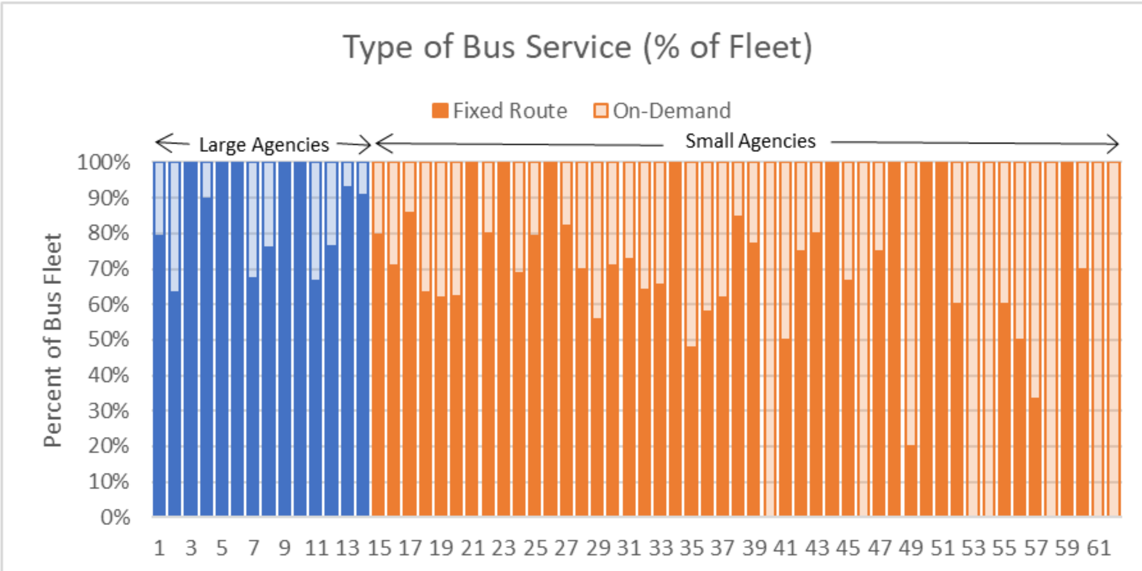

Figure 6. Type of bus service for survey respondents.

Note: Fleets 1–14 are large agencies; 15–62 are small agencies. Source: Survey of California transit agencies.

For the large agencies who responded to the survey, 10 out of 14 have already begun operating BEBs, with a combined total of 244 BEBs in their fleets. Three large agencies have begun operating a total of 49 FCEBs in their fleets. Of the 4,569 total buses reported by large agencies, 293 ZEBs represent a ZEB conversion of approximately 6.4% of the large agency bus fleet.

For the small agencies who responded, 13 reported operating a total of 190 BEBs and zero FCEBs. 190 ZEBs out of the total of 1,607 buses reported by small agencies represents a ZEB conversion of approximately 11.8% of the small agency bus fleet.

Thus, according to the survey responses, 7.8% of the combined transit bus fleet reported by survey respondents has been converted to ZEBs. These results reflect the fleet status of survey respondents as of the reporting in early 2024.

A detailed overview of the survey responses and summary of findings was presented to transit industry representatives and provided to CARB staff in 2024. Specific results from the survey are incorporated into the relevant sections throughout this report to provide important context directly from transit agencies' experiences and their valuable feedback.

3 Deployment Status of ZEBs

3.1 Current Status of ZEBs

3.1.1 National ZEB Deployment

With guidance and funding from the Federal Transit Administration (FTA), CALSTART performs an annual assessment to track ZEB deployments in the United States called *Zeroing in on Zero-Emission Buses* (CALSTART 2025b). This bus inventory includes all known ZEBs—buses on order and ZEBs already deployed in service—operating at public transit agencies as well as at universities, airports, and other private institutions. The assessment has been conducted for 6 years. In 2024, the number of full-size ZEBs (defined as Class 7–8 buses that are 30 feet or longer) in the United States grew by 14% to a total of more than 7,000 buses. This growth follows similar increases in previous years and demonstrates the continued interest in ZEBs and continued benefit of federal support for ZEBs, as many of these ZEB purchases were supported by FTA incentive and formula funding programs (Hynes et al. 2024; Hynes and Lemons 2025).

According to the CALSTART report, California continues to lead all other states, by a large margin, in number of ZEBs deployed, with 2,285 total ZEBs (1,850 BEBs and 435 FCEBs). The next closest state is New York with fewer than 800 total ZEBs. Figure 7 shows the latest count of ZEBs by state, and provides a summary of total ZEBs from 2021-2024 for the U.S. and for the state of California.

BEBs still dominate the share of ZEBs, but nationwide, there is a growing interest in FCEBs, which had a 55% increase in 2024 (Table 2). In California, FCEBs grew by a similar percentage (57.6%). This growth can be partially attributed to transit agencies' need for longer-range ZEBs and acknowledges continued commercial development and real-world experience with FCEB technology. In 2023 and 2024, California transit agencies consistently purchased nearly 29% of all BEBs and approximately 75% of all FCEBs in the United States.

Table 2. Summary of ZEBs for the United States and California, 2021–2024.

Source: *Zeroing in on Zero-Emission Buses* reports, 2021–2024 (CALSTART 2025b)

Year	Total U.S. ZEBs	Total U.S. BEBs	Total CA BEBs	CA % Increase	CA % of U.S. BEBs	Total U.S. FCEBs	Total CA FCEBs	CA % Increase	CA % of U.S. FCEBs
2021		3,364	1,244	--	37.0%	169	127	--	75.1%
2022	**5,480**	5,269	1,841	48.0%	34.9%	211	136	7.1%	64.5%
2023	**6,147**	5,775	1,670		28.9%	372	276	102.9%	74.2%
2024	**7,028**	6,453	1,850	10.8%	28.7%	575	435	57.6%	75.7%

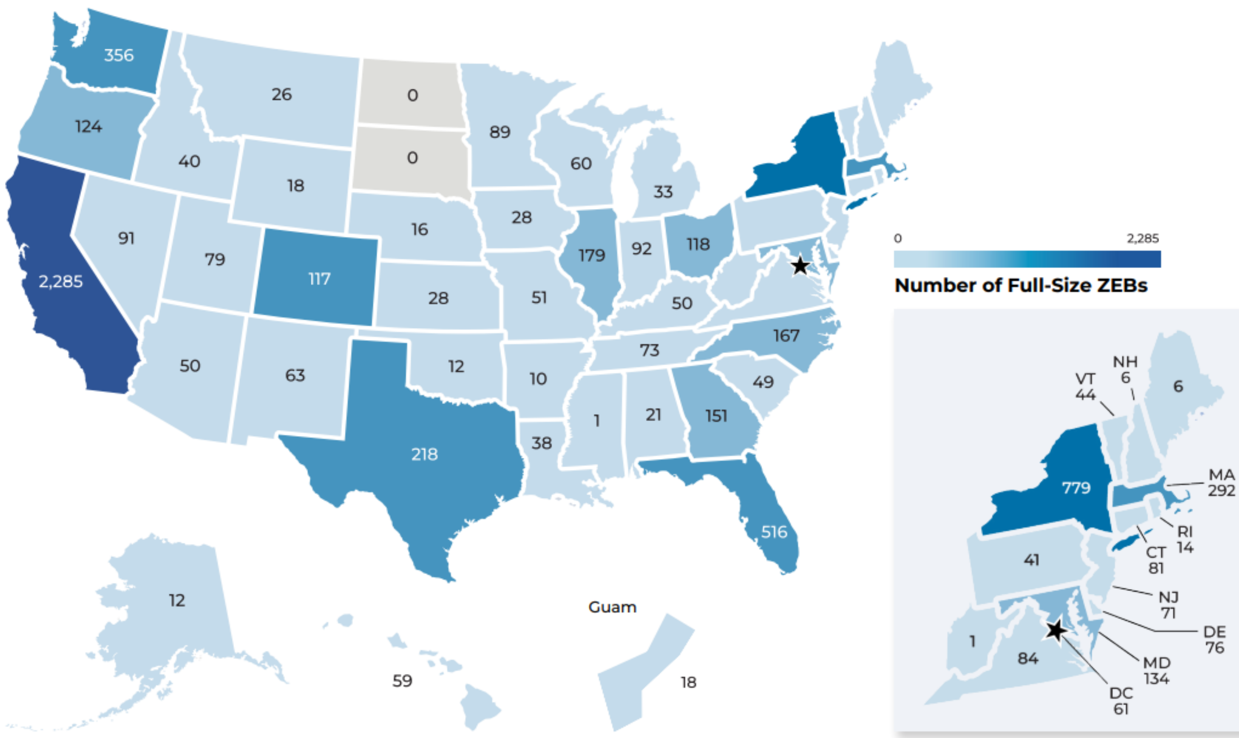

Figure 7. ZEBs by state for transit, airports, universities, and private fleets as of 2024.

Source: Hynes and Lemons (2025)

Nationwide, there has also been a steady increase of ZEBs in the small bus class (defined as less than 30 feet in length). The CALSTART report identifies 1,165 small ZEBs in 2024, up from 1,010 in 2023 (15% increase). The public transit sector accounted for 132 (85%) of the 155 new ZEBs in 2024, demonstrating a 25% increase in small ZEBs in transit. Once again, California had, by far, the largest statewide increase in small ZEBs, accounting for 674 of the 1,165 total (58%). All but nine of the total small ZEBs are BEBs; the report lists only four small FCEBs in California and five in Ohio.

3.1.2 California ZEB Deployment in Public Transit

In California, there are approximately 200 public transit agencies which operate a total of more than 13,000 transit buses. CARB has developed the ICTRT to allow transit agencies in the state who are subject to the ICT regulation to submit their annual fleet inventory, including number of ZEBs, so CARB can monitor ICT compliance and track progress toward the program goals (California Air Resources Board 2025c).[1] Based on ICTRT data reported to CARB through 2024, California transit agencies currently have a total deployment of 1,241 BEBs and 430 FCEBs (in service or on order). This represents about 13% of the state's total transit fleet and is a 29% ZEB increase from 2023. The current deployment of 1,671 ZEBs is significantly higher than the ICT target of 140 ZEBs for 2024 and is also above the 2027 target of 1,347 ZEBs. Figure 8 summarizes the annual ZEB deployments from 2020 through 2024 along with the annual ICT ZEB target through 2030. This target represents the expected trajectory of ZEBs replacing conventional transit buses according to the ICT regulation projections, beginning in

[1] CARB 2024 board memo.

2023 and assuming all large buses are replaced after 14 years and cutaway buses are replaced after 10 years.[2] Thus, the state is ahead of the ZEB target due to early adoption of ZEBs by numerous transit agencies prior to the start of the ICT regulation (for which they received ZEB bonus credits). Although the state is currently ahead of schedule, it is anticipated that this increasing target will become more difficult to meet after 2027 as the ZEB purchase requirements increase.

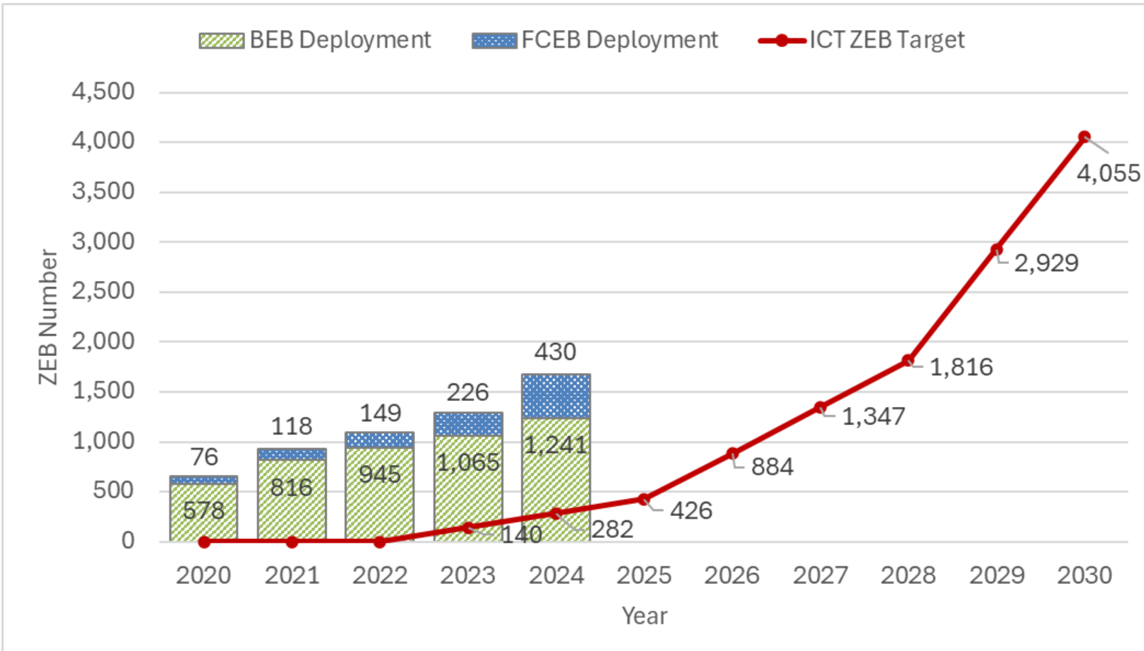

Figure 8. Cumulative California ZEB deployments and ICT ZEB target by year

About 70% of all transit buses in the state are operated by the 21 large transit agencies. The remaining 30% are dispersed across more than 160 small agencies. The majority of ZEBs deployed are also operated by large agencies, by a large proportion (~55% in 2023, ~60% in 2024). From the ICTRT data, large and small transit agencies in 2023 had a nearly identical ratio of BEBs versus FCEBs deployed (that is, in service and on order)—approximately 82% BEB and 18% FCEB for large and small agencies (Table 3). In 2024, small agencies reported a similar ratio while large agencies reported 68% BEBs and 32% FCEBs. This change in the ratio of ZEBs reflects a move by large transit agencies to opt for more FCEBs in their latest ZEB purchases (FCEBs account for 44% of new ZEB orders by large agencies in 2024).

[2] CARB 2023 board memo.

Table 3. BEB Versus FCEB as a Percentage of Total ZEBs Deployed, 2023 and 2024.

Source: ICTRT, 2023–2024 (California Air Resources Board 2025c)

Year	2023		2024	
ZEB Type	BEB	FCEB	BEB	FCEB
Large Agencies	82.8%	17.2%	68.2%	31.8%
Small Agencies	82.1%	17.9%	83.3%	16.7%
Combined	**82.5%**	**17.5%**	**74.3%**	**25.7%**

As of late 2024, a total of 418 ZEBs were operating at small transit agencies in California. This includes 28 articulated buses, 31 over-the-road coaches, and 13 cutaway buses —all battery-electric powertrains. The remaining 346 buses are standard low-floor buses, 37 of which are FCEBs. Antelope Valley Transportation Authority (AVTA), Anaheim Transportation Network (ATN), and Santa Maria Regional Transit are the top three small transit agencies reportedly operating the most ZEBs, with 104 BEBs, 46 BEBs, and 45 BEBs, respectively. SunLine Transit Agency operates 36 ZEBs and has extensive experience with FCEBs and workforce training.

Table 4 provides a summary of the ZEB bonus credits earned for early implementation of ZEBs, prior to the ICT regulation. Of the total 223 credits earned by all California transit agencies, 151 were earned by only 8 of the 21 large transit agencies—early adopters of ZEBs who piloted first- and second-generation ZEBs to test and demonstrate the new vehicles in their transit service. As of the end of the 2024 reporting period, 39 credits have been used so far to help agencies meet their annual compliance obligations, leaving 184 credits remaining to be applied toward ZEB compliance in the coming years.

Table 4. Bonus Credit Summary for All California Transit Agencies

Source: ICTRT, 2023–2024 (California Air Resources Board 2025c)

ZEB Type	Bonus Credits Earned	Bonus Credits Used	Bonus Credits Remaining
Battery Electric	89	14	75
Fuel Cell Electric	116	25	91
Electric Trolley	18	0	18
Total	**223**	**39**	**184**

3.1.3 Notable ZEB Purchases and Milestones in California

Since the completion of Phase I of the comprehensive review, transit agencies across California have made significant advancements in ZEB deployment. Supported by dedicated state and federal funding opportunities, these agencies have expanded their ZEB fleets, enhanced charging infrastructure, and accelerated the transition toward low-carbon transportation. Through these efforts, valuable lessons have been learned about the planning, implementation, and operation of ZEB technologies—insights that are helping refine strategies, improve performance, and guide future deployments. Collectively, these achievements continue to position California as a national leader in the ZEB industry and provide critical experience to support the state's ongoing transition to zero-emission transit. Notable ZEB deployment milestones from large and small agencies are highlighted below.

Large Agency ZEB Highlights

Los Angeles County Metropolitan Transportation Authority (LA Metro)
As we approach the 2028 Olympic and Paralympic Games, LA Metro will continue to showcase Los Angeles as a climate leader on the world stage, providing low-carbon transportation options to athletes and attendees. LA Metro plans to deploy approximately 500 ZEBs specifically for the 2028 Summer Olympics, with a broader goal of acquiring up to 2,000 ZEVs as part of its long-term fleet transition (Turner and Patel 2025). LA Metro plans to enhance service and infrastructure on the Metro G Line (formerly Orange Line) and Metro J Line (formerly Silver Line) to support high-capacity, zero-emission transit during the 2028 Olympics. These transit lines will play a key role in connecting Olympic venues and reducing car dependency (LA Metro, n.d.).

San Mateo County Transit District (SamTrans)
SamTrans recently marked the largest single fuel cell bus order in New Flyer's history, to date, by purchasing 108 zero-emission hydrogen fuel cell electric Xcelsior CHARGE FC 40-foot transit buses in Q2 2024 (New Flyer 2024). SamTrans is investing in both battery-electric and hydrogen fuel cell buses and is on track to complete the transition by 2034, 6 years ahead of the state deadline (SamTrans 2025).

Foothill Transit
Foothill Transit was an early adopter of zero-emission transit buses, operating a fleet of more than 30 all-electric buses, beginning with first- and second-generation fast-charge BEBs with on-route charging. In 2021, Foothill began operating two Alexander Dennis battery-electric double-decker buses and have since ordered 12 more electric double-deckers, to add to their fleet in 2026. Foothill continued the push toward an emission-free bus fleet with the purchase of 33 New Flyer Xcelsior CHARGE FC buses—one of the largest FCEB procurements in the United States. The FCEBs have been in operation since 2023 (Foothill Transit, n.d.).

Orange County Transportation Authority (OCTA)
OCTA has announced $77.5 million investment in replacing the existing CNG units to 40 FCEBs and 10 40-foot BEBs, with delivery expected by late 2026. OCTA selected New Flyer of America Inc. to purchase likely models from New Flyer's Xcelsior Charge NG and Xcelsior Charge FC lines (OCTA 2024; Munoz 2024).

Los Angeles Department of Transportation (LADOT)
LADOT provides public transit services to the city of Los Angeles and some areas in the surrounding neighborhoods. It operates the second-largest fleet in Los Angeles County with more than 350 vehicles serving nearly 21 million passengers per year. LADOT operates CNG and liquefied petroleum gas buses and is committed to transitioning their fleet to 100% ZEBs by 2030 or earlier. In 2020, LADOT placed an order of 155 ZEBs to be operated in their fleet—130 were purchased from BYD (now known as RIDE), and 25 were purchased from Proterra. So far, they have been able to secure grants for over 200 BEBs including standard, over-the-road coaches, and cutaway buses through a variety of local, state, and federal programs (LADOT 2020).In June 2025, with a STEP grant from CARB, LADOT launched a new service to serve

the residents of south Los Angeles. This LANow, on-demand ride share program will operate a fully electric fleet of shuttle vans. As LADOT works toward transforming its fleet to ZEBs, it is also working on the development of a ZEB maintenance and repair facility. In December of 2024, LADOT received a California Environmental Quality Act exemption for its Harbor City Zero-Emission Bus Maintenance Facility Project. The project would include a new office for operations staff, bus maintenance bays, and up to 70 charging stations to charge 140 BEBs. The estimated cost for this project is $90 million.

Alameda-Contra Costa Transit District (AC Transit)
In August 2024, AC Transit secured $144 million to improve their hydrogen fueling infrastructure, expand their ZEB fleet, and implement a comprehensive workforce development plan as part of the ARCHES partnership to establish a renewable hydrogen hub in California (AC Transit 2024a). AC Transit's ZEB Transition Plan aims to completely replace the current diesel fleet with 100% ZEBs by 2040, in alignment with ICT regulation. This vision anticipates a fleet composed of 70% FCEBs and 30% BEBs. They plan to acquire 259 ZEBs by 2028, provided the necessary funding is secured (AC Transit 2024b).

San Diego Metropolitan Transit System (SDMTS)
SDMTS began its ZEB transition in Dember 2019, piloting six BEBs to test their range under various driving conditions. In October 2023, SDMTS launched the region's first all-electric bus rapid transit route, Rapid 227, and operated 12 60-foot BEBs, the first articulated electric vehicles (EVs) in their fleet. By mid-2024, SDMTS had 25 electric buses in service, and their BEBs had reached the 1-million-mile mark (1,021,990 miles); this represents the prevention of 2,130 metric tons of carbon dioxide equivalent from being emitted into the air. SDMTS anticipated receiving 13 more electric buses in 2025 and beginning in 2029, 100% of new bus purchases will be ZEBs, with the goal for full transition by 2040 (San Diego Metropolitan Transit System 2024; n.d.).

Small Agency ZEB Highlights

Antelope Valley Transit Authority (AVTA)
In 2016, AVTA was the first U.S. transit agency to commit to a 100% electric bus fleet, electing to purchase 85 BEBs from BYD (now known as RIDE). They also adopted wireless inductive charging technology, installing wireless charging stations at transit centers throughout their service territory to enable on-route charging for their electric fleet. In May 2019, AVTA achieved the first 1 million miles driven by its all-electric buses and a year later achieved its goal of a 100% all-electric fleet after decommissioning the last diesel bus in the fleet. AVTA added eight GreenPower electric vans to their fleet in 2020 and launched a microtransit pilot program, serving rural Los Angeles County communities. AVTA currently operates a total fleet of approximately 121 battery-electric vehicles, including 102 buses and 19 paratransit vehicles (Royal 2022; Drake 2024).

Santa Maria Regional Transit (SMRT)
In October 2025, after the latest delivery of six Gillig electric buses, SMRT announced it had successfully completed the transition to a 100% battery-electric transit fleet—making it one of the first few transit agencies in the United States to accomplish this task. SMRT's now operates a

zero-emission fleet of 40 buses across its fixed-route, paratransit, and microtransit services (City of Santa Maria 2025).

Anaheim Transportation Network (ATN)

By 2022, ATN's fleet of 80 vehicles was 74% zero emission and 26% classified as "near-zero"-emission vehicles, and 90% of total revenue miles were driven with zero well-to-wheels emissions (including zero tailpipe emissions). In 2023, the Anaheim Transportation Network was awarded an FTA Low or No Emission Grant Program (Low-No) grant to expand the agency's electric bus fleet, charging capacity, and workforce development. The $3.6 million grant helped ATN purchase 10 40-ft BEBs and charging infrastructure. Anaheim is expecting to be the first city to operate a fully zero-emission transit system in Southern California by the 2028 Summer Olympic Games (Anaheim Transportation Network 2025; 2023; n.d.).

Santa Cruz Metropolitan Transit District (METRO)

In 2023, METRO announced the purchase of 57 FCEBs—a combination of 40-ft and 60-ft buses—which was the largest FCEB acquisition in North America at the time of the announcement, supporting an aggressive goal to achieve a 100% ZEB fleet by 2037. This order of FCEBs, manufactured by New Flyer, included 48 standard 40-foot buses and nine 60-foot articulated buses, which were planned primarily for routes servicing the University of California, Santa Cruz, area (Santa Cruz Metropolitan Transit District 2023a; 2023b).

Victor Valley Transit Authority (VVTA)

In 2018, VVTA established a goal to operate a 100% zero-emission fleet by 2035. VVTA is actively implementing a mixed-technology approach, purchasing both BEBs and FCEBs to meet its zero-emission goals. Their fleet consists of 12 BEBs in operation with more than 1.4 million zero-emission miles achieved. VVTA has 13 FCEBs on order, with expected delivery in late 2025, and is budgeted for an additional 10 FCEBs. A new hydrogen fueling station is in progress to include capacity for public fuel cell EV fueling. VVTA participated in Southern California Edison's (SCE's) Charge Ready Transport program to have charging infrastructure installed for the battery bus fleet (Victor Valley Transit Authority, n.d.; 2025).

SunLine Transit Agency

SunLine Transit plans to have their fixed-route bus fleet converted entirely to zero-emissions buses by 2035, 5 years ahead of state regulation requirements. The paratransit fleet will be entirely zero-emissions buses by 2032. As of December 2024, their fleet consisted of nine El Dorado National Axess 40-ft FCEBs and 23 New Flyer Xcelsior XHE40 40-ft FCEBs. Fuel cell buses are favored for the Coachella Valley's long routes and extreme high temperatures, as they can achieve a range of up to 350 miles on a full tank of hydrogen fuel, and the FCEB refueling time is comparable to conventional bus fueling times. In 2021, SunLine partnered with SoCalGas and STARS Technology Corporation to operate a commercial prototype STARS Clean Hydrogen Generator at SunLine's hydrogen fueling station—a first-of-its-kind demonstration for the technology. In 2024, SunLine continued its pattern of pioneering new hydrogen technology by commissioning a new liquid hydrogen (LH2) station with 15,000 gallons of LH2 storage and a public station that dispenses hydrogen at 700 bar (SunLine Transit 2025; n.d.).

Fresno County Rural Transit Agency
The Fresno County Rural Transit Agency has made significant progress in deploying ZEVs, with 33 EVs already in operation and a goal to fully transition its fleet by 2030. However, the agency has faced several challenges, including limited charging infrastructure, power grid constraints, long travel distances, high energy and equipment costs, lack of backup power, and supply chain issues. To overcome these barriers and ensure a reliable energy supply, the agency is implementing solar-powered microgrids and distributed energy resources across Fresno County. These systems will provide cost-effective EV charging, backup power during outages, and support for critical infrastructure. Serving as multimodal community resiliency hubs, they will also offer essential transportation and services to rural communities during emergencies—making Fresno County Rural Transit Agency a model for low-carbon, resilient, and comprehensive transportation in rural areas.

City of Porterville
The city of Porterville operates a fleet of 10 40-foot BEBs on fixed routes with 100% of the miles traveled within ZIP codes that contain communities at risk from significant air pollution. Porterville also operates 12 Lightning eMotors battery-electric vans for on-demand transit service (CARB, n.d.-a; "How Porterville Transit Is Using EVs to Improve Its Shuttle Services" 2021).

Solano County Transit (SolTrans)
SolTrans is a small transit agency with a mixed bus fleet of 76 diesel hybrid, CNG, and battery-electric buses. SolTrans set an agency goal to convert to a 100% zero-emission fleet by 2033, including electrifying shop trucks and other support vehicles in its fleet. It began its ZEB fleet conversion with two BEBs purchased from BYD (now known as RIDE) in 2017 and added two more BEBs to the fleet in 2020. In 2022, SolTrans installed wireless inductive charging to support its electric bus fleet. In 2023, it received its first all-electric commuter coach and secured a $12.5 million grant from the FTA to acquire 14 new electric buses and essential charging infrastructure. As of June 2025, SolTrans has 10 BEBs in service and another 14 BEBs on order. SolTrans initial goal was to achieve a 100% electric fleet in 2033 supported by future-ready scalable electric infrastructure that utilizes renewable electricity. As the operational range of currently available BEBs is not sufficient to meet their regional needs, SolTrans has modified its goal and plan. SolTrans adjusted its electrification goal to 2036 and considered using FCEBs for their commuter services starting 2029. SolTrans has also considered building hydrogen fueling infrastructure, using charge management system and energy storage for cost management and resiliency purposes. In addition, to solve the space restriction issue at their yard, SolTrans installed an overhead gantry system for automated charging (SolTrans, n.d.). Some lessons learned from SolTrans' experience include (1) preparation for budget increase and surprises when digging underground, (2) early and continued collaboration with utilities and funding partners, and (3) maintaining good relationships with internal and external stakeholders.

Humboldt Transit Authority (HTA)
HTA purchased its first BEB in 2018. In 2022, the Regional Transportation Plan, completed by the Humboldt County Association of Governments, set a target to have 100% of public transit buses be zero emission by 2030. Also in 2022, HTA won a Transit and Intercity Rail Capital Program (TIRCP) Cycle 5 grant to procure FCEBs and construct a hydrogen fueling station, which will provide both public (over-the-fence) and private (in-yard) fueling. HTA received the

pilot FCEB in early 2025 and will soon receive the remaining 10 New Flyer Xcelsior CHARGE FC FCEB. The FCEBs will operate on a new intercity route between Eureka and Ukiah. In 2023, HTA won a TIRCP Cycle 6 grant to work with New Flyer on the development of a new prototype fuel cell electric coach with more power and fuel capacity, resulting in a 370-mile range which allows this electric coach to successfully complete the challenging Redwood Express run (Humboldt Transit Authority, n.d.; Schatz Energy Research Center 2025).

3.2 ZEB Purchase Projections and Current ZEBs on Order

One of the initial requirements of the ICT regulation was for all transit agencies to develop and submit a ZEB rollout plan to CARB that outlines the agencies plans to deploy ZEBs in compliance with the regulation. ROPs were due in 2021 for large transit agencies, and in 2023 for small agencies. Several large agencies have revised and resubmitted their ROPs since the original plan submittal based on experience and learnings from their early ZEB deployments and other factors that impacted their ZEB transition plans.

The submitted ROPs have been reviewed to identify the timing of anticipated ZEB purchases for each agency. The majority of ROPs contained detailed information on anticipated bus purchases, by year, by bus type, and by fuel/powertrain type. This includes 51 ROPs—21 from large transit agencies and 30 from small agencies. The compiled ROP data were organized by fuel type (BEB or FCEB) and by bus type (standard, articulated, coach, cutaway, and double-decker buses). These individual purchase plans have been combined into the statewide ZEB purchase projections shown in Figure 9, for all bus types. Similar purchase projections for each of the five bus types are provided in the Appendix (A.1) to show the breakdown of anticipated purchases for standard, articulated, coach, cutaway, double-decker buses, separately.

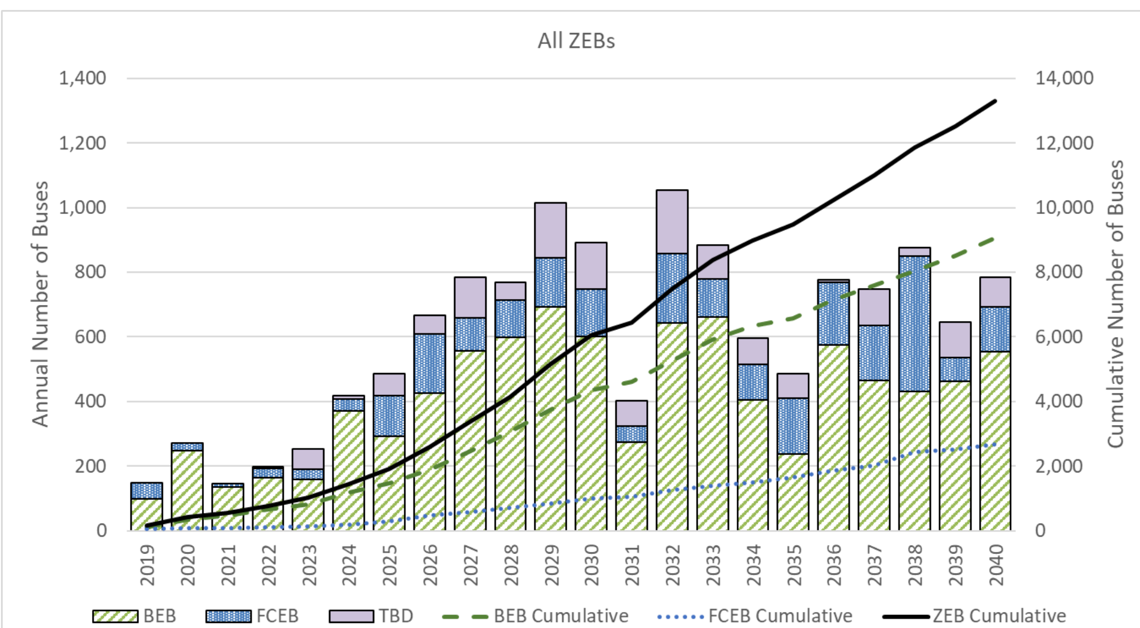

Figure 9. Projected annual ZEB purchases from transit agency ROPs, all bus types

According to the collective ROPs, a total of 13,300 ZEBs are expected to be deployed by 2040 to comply with the ICT regulation. Throughout the projected time period, BEBs account for 65%–

85% of the share of ZEBs. By 2040, approximately 68% of all ZEBs deployed are expected to be BEBs, while 20% are FCEBs, and 12% are as-yet undetermined (Figure 10). Figure 11 shows the cumulative ZEB purchases by bus type. By 2040, 78% of the ZEB purchases are expected to be for standard size buses, 15% for cutaway buses, 3%–4% for articulated buses and coaches, and less than 1% for double-decker buses.

These trends represent the agencies' best estimates at the time of their ROP development based on the age of their fleet and expected bus replacement schedules. Some agencies are unsure of the exact timing of ZEB deployments and of the future composition of their fleet with regard to fuel type and bus type, as these details can change based on ridership and other factors. Many agencies' ZEB purchases are also subject to available funding for ZEBs and the required charging/fueling infrastructure. However, these trends show the anticipated rollout of ZEBs in the state if all transit agencies stay on track with ICT compliance.

Table 5 provides the projected ZEB population for 2020–2040 based on the ICT program, which is included in the figures for reference.

Table 5. ICT Projected ZEB Population, 2020-2040

Calendar Year	Zero-Emission Transit Bus Population
2020	295
2021	406
2022	547
2023	544
2024	641
2025	803
2026	943
2027	1,210
2028	1,453
2029	1,954
2030	3,780
2031	4,869
2032	6,286
2033	7,788
2034	8,841
2035	9,736
2036	10,637
2037	11,582
2038	12,735
2039	13,450
2040	14,476

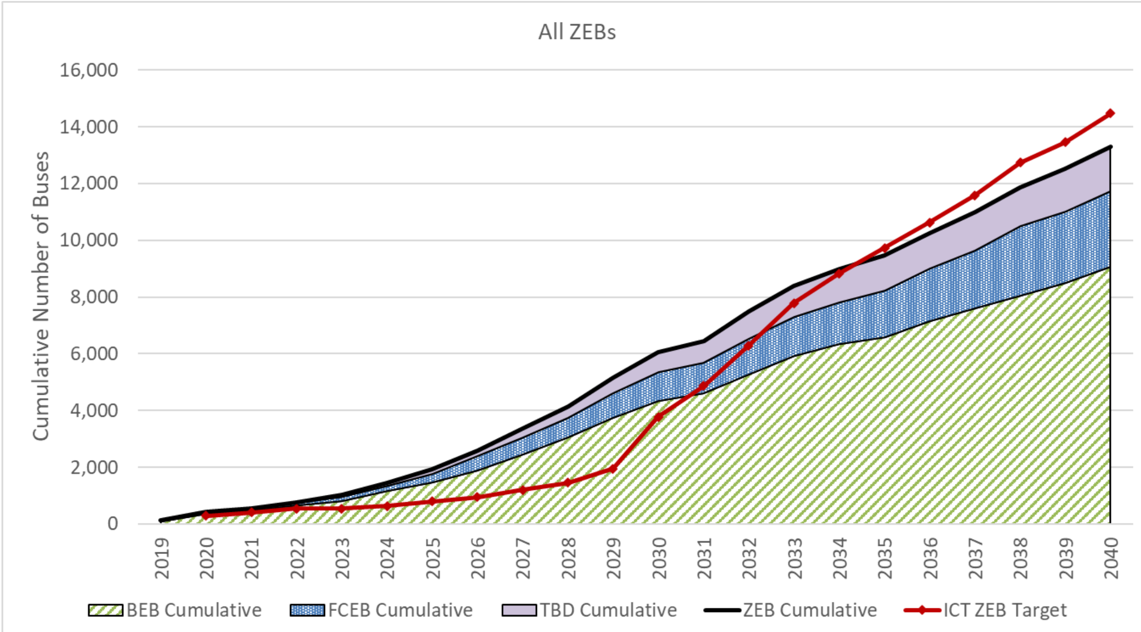

Figure 10. Projected cumulative ZEB purchases from transit agency ROPs, all bus types

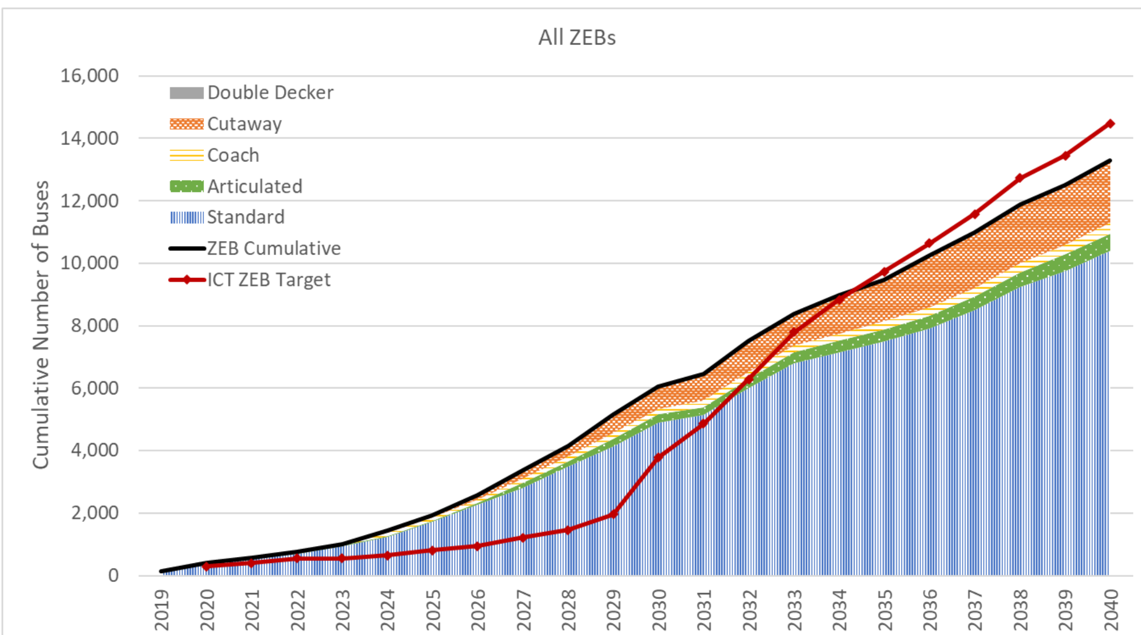

Figure 11. Projected cumulative ZEB purchases from transit agency ROPs by bus type

Whether these purchase projections are attained in the coming years depends on many important factors, such as funding availability, ZEB market availability for each vehicle type, completed Altoona tests for nonstandard bus types, infrastructure availability and installation timelines, etc.

Some agencies who have earned ICT credits for early adoption of ZEBs may choose to apply those credits rather than purchasing new buses initially, and still be able to maintain their compliance with ICT. They could choose to delay ZEB purchases in order to wait for necessary technology advancements, such as new ZEB models and/or performance improvements, infrastructure, advancements, or improved market competition which may stimulate cost reductions.

Agencies who are unable to purchase and/or operate their ZEBs due to one of the eligible reasons laid out in the ICT regulation may request a temporary exemption from their ICT compliance obligation. CARB is committed to working directly with transit agencies to find solutions that will enable the state to stay on track with ICT implementation without adversely impacting transit service (California Air Resources Board 2019).

4 ZEB Incentive, Funding, and Supporting Programs

Financial assistance and non-traditional funding support ZEB deployment in California. There are a variety of financial mechanisms available to California transit agencies to assist in the procurement and operation of ZEBs. These are made available through federal funding sources, especially the U.S. Department of Transportation (DOT) and the U.S. Department of Energy (DOE); statewide funding sources in California such as CARB, California Energy Commission (CEC), Caltrans, and CalSTA; and regional funding sources, such as those operated by air quality management districts (AQMDs) and air pollution control districts (APCDs). Particularly important programs for ZEB deployments include the federal Low-No program and California's HVIP. These incentive funding programs have been vital to the acceleration of ZEB deployments in California in recent years. Robust adjacent markets—including the zero-emission commercial vehicle and energy infrastructure sectors—play an essential role by reinforcing supply chains, advancing technology maturity, and contributing to long-term cost reductions for transit agencies.

In addition to funding programs aimed at offsetting ZEB capital costs, incentive rebate programs and other support programs were designed to, or have been expanded to, target the implementation of ZEB recharging/refueling infrastructure, ZEB operations and maintenance, and grants that support ZEB transition planning.

Considerable progress has been made over the past several years to establish and expand financial support to advance ZEB deployments and to make funding more accessible and understandable to transit agencies throughout the state, as well as to streamline their application and awarding processes. The major ZEB incentive programs and other informational resources available for California transit agencies are summarized in this section.

4.1 Advanced Vehicle Technology and Infrastructure Funding Finder Tool

The Funding Finder tool for advanced vehicle technology and infrastructure was developed as a web-based resource to help stakeholders identify funding opportunities in the state of California. It has been expanded to include all 50 states and the District of Columbia. The site allows users to easily search and filter for medium- and heavy-duty alternative fuel vehicle and infrastructure programs. This tool development was a collaborative effort among various agencies, with the work and the web site managed by CALSTART.

Funding Finder: fundingfindertool.org/

This resource lists four funding categories: Vehicles, Infrastructure, Tribal, and Federal Funding. It allows users to search by state or ZIP code and provides options to filter searches by technology type, vehicle type, vehicle class, and other details. As of 2025, there are 19 programs listed for transit vehicles and infrastructure in California. There are also numerous federal funding programs that apply to transit. Figure 12 shows a sample search result of the first few entries in the Funding Finder tool for California.

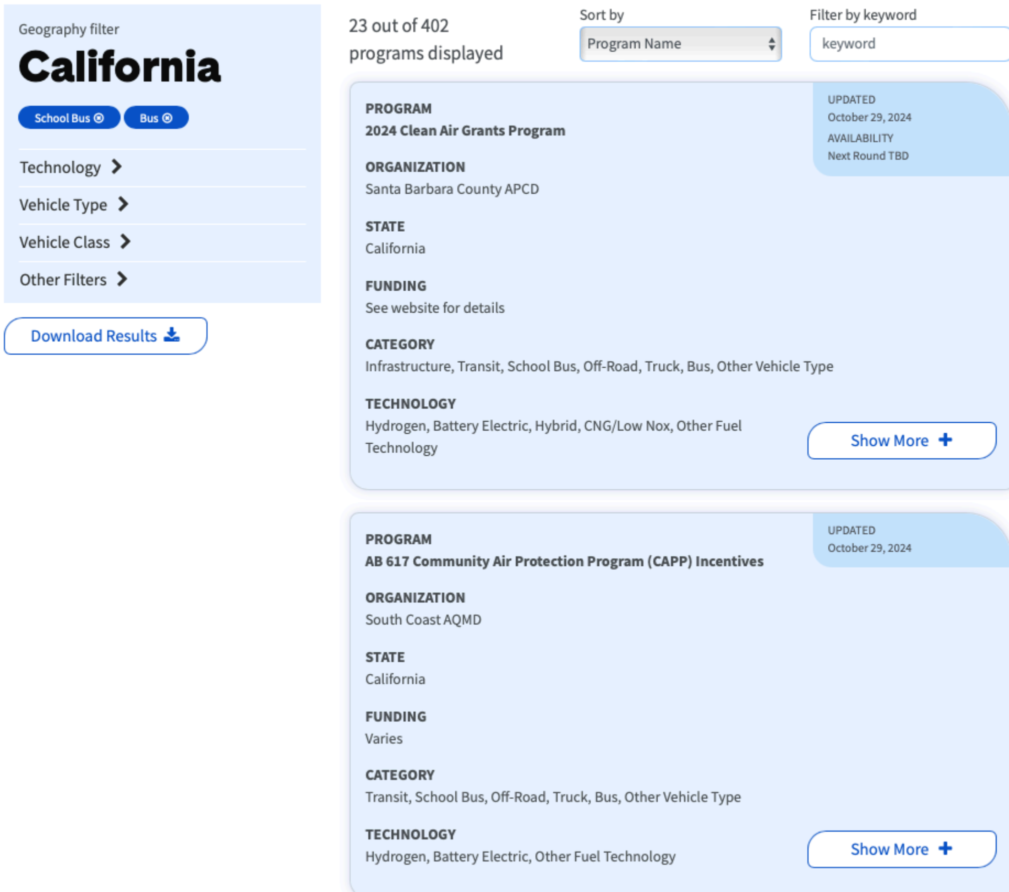

Figure 12. Advanced vehicle technology and infrastructure Funding Finder tool

The Funding Finder tool can be used to identify programs that are available in specific areas by filtering by ZIP codes. Other filter criteria that can be applied to narrow the scope of the search include requirements for vehicle scrappage, "stackability" (for example, combining HVIP grants with other programs), infrastructure support eligibility, and other eligibility requirements such as the need for a social benefit component.

4.2 U.S. Federal ZEB Incentive Programs

At the U.S. federal level, incentive programs for ZEBs are primarily available through DOT, and specifically the FTA. Programs are also available through DOE, especially for infrastructure funding. Specific information about the DOT and FTA incentive programs is discussed later in this section.

The Infrastructure Investment and Jobs Act (IIJA), enacted as the Bipartisan Infrastructure Law (BIL), passed Congress and was signed into law on Nov. 15, 2021, under House Resolution 3684. The historic law, with more than $1 trillion in total funding planned over 5 years, provides up to $108 billion in funding to support public transportation programs throughout the country ($91 billion of the funding guaranteed) (Federal Transit Administration 2025i). Key provisions of the legislation that are relevant for public transit buses include Section 30018 "Grants for Buses and Bus Facilities," Section 11130 "Public Transportation," and Section 30008 "Bus

Testing Facilities" (Federal Transit Administration 2021). An overview of these programs is provided in the following section.

Also, the Inflation Reduction Act of 2022 included Section 30C tax credits for development of alternative fuel vehicle refueling property that is located in low-income or nonurban census tracts. Tract eligibility (through 2024, 2029, or 2030) can be viewed in the 30C Tax Credit Eligibility Locator web tool: experience.arcgis.com/experience/3f67d5e82dc64d1589714d5499196d4f/page/Page. The credit can be captured by nonprofits such as transit agencies through an Internal Revenue Service (IRS) mechanism called "elective pay." The credit is for up to 30% of the depreciable costs of each item up to $100,000 if the project meets certain prevailing wage and apprenticeship requirements, or 6% otherwise (Alternative Fuels Data Center 2025). However, the passage of the One Big Beautiful Bill Act in 2025 has sunset this provision with such facilities needing to be placed into service by June 30, 2026, to capture the credit (Smithson 2025).

4.2.1 U.S. Department of Transportation Programs

The grant programs at DOT for transit agencies are largely administered by FTA. Primary programs of interest include the Buses and Bus Facilities Formula Program (5339(a)), Grants for Buses and Bus Facilities Competitive Program (5339 (b)) (Federal Transit Administration 2025g), the Low or No Emission Grant Program (Low-No) (5339(c)) (Federal Transit Administration 2025h), and Capital Investment Grants Program (5309) (Federal Transit Administration 2025c).

Low-No is a competitively awarded program that provides funding for purchase or lease of zero- and low-emission transit buses along with supporting infrastructure. Eligible projects include (1) purchasing or leasing low or no-emission buses, (2) acquiring low- or no-emission buses with a leased power source, (3) constructing or leasing support facilities and related equipment including intelligent technology and software, and (4) constructing, rehabilitating, or improving new public transportation facilities for low- or no-emission buses. Low-No program funds can be spent in the award year and for 3 additional years. Applications for funding must include a Zero-Emission Transition Plan and allocate 5% of the award for workforce development and training under the plan. The cost of developing the transition plans cannot be covered with Low-No program funds but can be eligible for funding under formula funds and other planning grants.

Program website: www.transit.dot.gov/lowno

The Low-No program had its most recent award announcements on July 9, 2024 (see below for details of California awards). Historical funding for the program has ranged from $55 million in FY 2016, increasing each year up to $182 million in FY 2021. Figure 13 shows the authorized funding for this program increased dramatically under the Infrastructure Investment and Jobs Act, up to about $1.1 billion per year for FY 2022–2026, which represented a major shift in program priorities toward funding the lowest-emission bus technologies for transit in the United States. According to FTA, Low-No apportionments for FY 2022, FY 2023, and FY 2024 were approximately $1.1 million, $1.2 million, and $1.1 million, respectively (Table 6). The Infrastructure Investment and Jobs Act has authorized funding at this level through FY 2026, but future funding under Low-No and other discretionary programs to support ZEB deployment is uncertain. Also included in the table are annual apportionments for Capital Investment Grants (Section 5309) and Technical Assistance, Standards, and Training (Section 5314).

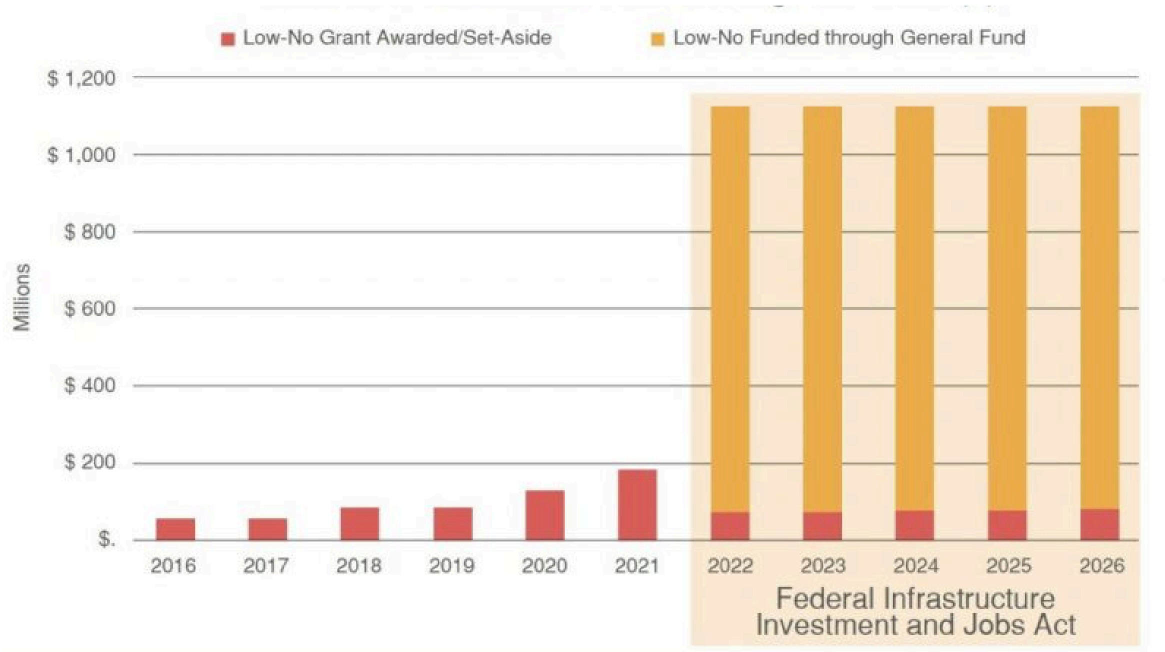

Figure 13. FTA Low-No program, past and future funding allocations

Table 6. 2016–2025 FTA Apportionments for 5339 (a-c), 5309, and 5314 (Federal Transit Administration 2025e)

Total	Buses and Bus Facilities Formula, § 5339 (a)	Grants for Buses and Bus Facilities Competitive, § 5339 (b)	Bus Low/No Competitive Program, § 5339 (c)	Capital Investment Grants, § 5309	Technical Assistance, Standards & Training, § 5314
2016	$427,800,000	$210,990,000	$55,000,000		
2017	$436,356,000	$264,446,775	$54,992,016		
2018	$654,623,476	$366,162,441	$84,448,990		
2019	$614,964,489		$84,951,386		
2020	$632,282,994	$887,178,768	$129,956,625		$7,000,000
2021	$597,238,328		$182,156,692		$12,375,000
2022	$605,752,480	$949,183,784	$1,105,329,750	$3,325,364,359	$25,000,000
2023	$617,803,934	$472,922,707	$1,216,941,397	$4,351,678,354	$13,615,456
2024	$635,022,174	$393,712,298	$1,107,355,187	$3,573,538,565	$650,000
2025	$648,766,670	$0	$0	$0	$0

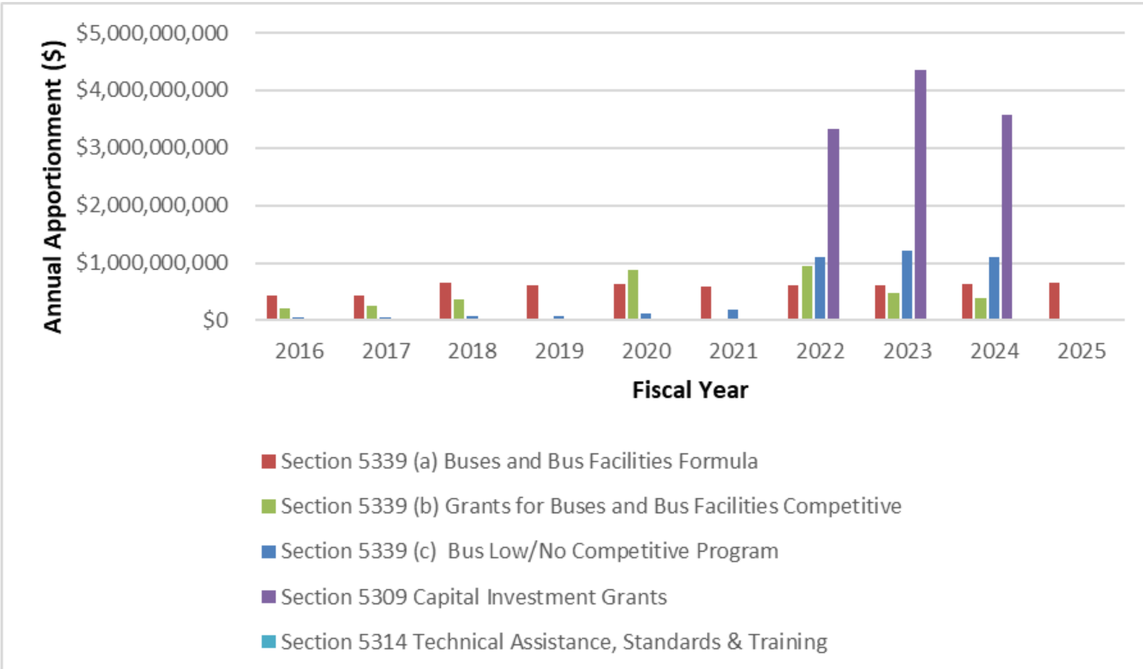

Figure 14. 2016–2025 FTA apportionments for 5339 (a-c), 5309, and 5314

In Fiscal Year (FY) 2024, FTA announced $1.5 billion in funding for 117 projects to improve public transportation in 47 states under the Infrastructure Investment and Jobs Act. Overall, of the 117 funded projects, almost 80% of the buses funded will run on zero or low-emission fuels (Federal Transit Administration 2025g).

In California, 15 projects were awarded in FY 2024, totaling $226 million (Table 7). This represents approximately 13% of the awarded projects and 15% of the awarded funding. The largest awards were $77.5 million for Los Angeles Metro to purchase dozens of new BEBs and to improve charging facilities, and $76.8 million for the Sacramento Regional Transportation District to purchase up to 29 hydrogen fuel cell buses, improve a maintenance facility, and initiate a workforce development program. A summary table of the programs awarded to California is provided below.

Table 7. Bipartisan Infrastructure Law – FY 2024 Funding for California Transit Bus Projects

Awardee	Program	Summary	Amount ($)
Los Angeles County Metropolitan Transportation Authority (LA Metro)	Low-No [a]	Dozens of new BEBs and charging equipment for West Hollywood bus yard	$77,536,675
Sacramento Regional Transit District	Low-No	New hydrogen fuel cell buses to replace older buses, modernize a maintenance facility and initiate a workforce development program	$76,847,678
Western Contra Costa Transit Authority	Low-No	New hydrogen fuel cell buses to replace older diesel buses and expand existing hydrogen fueling station and maintenance facilities	$20,646,189
Alameda-Contra Costa Transit District (AC Transit)	Low-No	New hydrogen fuel cell buses to replace older diesel buses and expand existing hydrogen fueling facilities	$15,000,000
City of Commerce Transit	Low-No	New BEBs and charging equipment to replace older diesel and CNG buses	$14,229,180
Omnitrans	Low-No	New BEBs and charging equipment for Omnitrans	$8,447,217
Twenty-Nine Palms Band of Mission Indians	BBF [b]	BEBs and chargers to replace older buses	$3,226,457
Santa Barbara Metropolitan Transit District	BBF	BEBs and chargers to replace older diesel buses	$2,894,131
San Luis Obispo Regional Transit Authority	BBF	BEBs and chargers to replace older buses	$2,572,888
Kings County Area Public Transit Agency	Low-No	Upgrades to renewable natural gas fueling station	$1,610,875
City of Davis	BBF	Charging equipment for BEB fleet	$1,600,000
CA Dept. of Transportation	BBF	New low-emission buses for Humboldt Transit Authority	$639,000
CA Dept. of Transportation	BBF	New low-emission buses for Redwood Coast Transit Authority	$474,478
CA Dept. of Transportation	BBF	A new BEB for Lassen Transit Service Agency	$154,367
CA Dept. of Transportation	BBF	A new BEB for Morongo Basin Transit Authority	$131,168

[a] Low or No Emission Vehicle Program.

[b] Bus and Bus Facilities Competitive Program.

Despite the historic increase in funding in the last three fiscal years, the funding has not been able to meet the increase in demand for these resources. In FY 2024, the Low-No program received applications for 214 eligible projects requesting a total of $4.7 billion and awarded 62 projects with a total of $1.1 billion. That represents less than 29% of requested projects and less than 24% of requested funding. Similarly, the Bus and Bus Facilities Competitive Program received applications for 263 eligible projects requesting a total of $4.4 billion and awarded 55 projects totaling $390 million—less than 21% of requested projects and less than 9% of requested funding (Federal Transit Administration 2025f).

4.2.2 U.S. Department of Energy Programs

DOE does not provide funding for transit bus agencies to install BEB charging or hydrogen fuel infrastructure for FCEBs as those programs are administered by FTA. However, under the Bipartisan Infrastructure Law, DOE solicited a network of regional "hydrogen hubs" for a total of $7 billion in available funding. A California statewide public-private partnership known as ARCHES was formally awarded in 2024, a total of $1.2 billion in federal hydrogen hubs funding over several years, matched by approximately $10 billion in state, local, and private sector funds.

ARCHES is led by a collaboration including the University of California Office of the President, GO-Biz, the State Building and Construction Trades Council of California, and Renewables 100, a nonprofit focusing on the transition to renewable energy sources. The ARCHES consortium consists of more than 100 additional firms and organizations (ARCHES 2025).

The ARCHES plan includes expanded production and use of renewable hydrogen primarily for transportation, marine ports, and power sector uses. In transportation, the focus is on reducing the use of diesel fuel for heavy-duty trucks and buses. A total of 13 transit agencies has been involved in developing the ARCHES deployment plans with anticipated purchases of approximately 1,000 FCEBs over 6 years (ARCHES 2024a). However, in October 2025, DOE subsequently canceled its contractual commitment to provide funding to ARCHES. ARCHES has since paused hydrogen hub activities. GO-Biz is maintaining the momentum established by ARCHES and working with public and private project partners to help the planned projects continue. The loss of DOE funding, which accounted for about 10% of the overall ARCHES project budget, will impact the scale and timing of deploying key aspects of the hydrogen ecosystem. It is now up to state, local, and private funding partners carry out scaled-down elements of the hydrogen hubs proposal.

4.2.3 U.S. Joint Office of Energy and Transportation

The U.S. Joint Office of Energy and Transportation established the Clean Bus Planning Awards to provide free technical assistance to fleets looking to develop ZEV transition plans. This technical assistance program is managed by NLR and available to transit and school bus fleets (designated as eligible under the U.S. Environmental Protection Agency Clean School Bus program (U.S. Environmental Protection Agency 2025) and the FTA Low-No program (Federal Transit Administration 2025h), respectively). Applications are reviewed on a rolling basis since the program opened in February 2024. The goal of the program is to help participants prepare for all aspects of fleet electrification. Creating a clear, comprehensive, and attainable plan for integrating EVs can help school and transit fleet managers be more competitive in applications for other incentive funding programs which can support the capital costs for EVs and charging infrastructure.

Program website: driveelectric.gov/clean-bus-planning-awards

4.3 California ZEB Incentive Programs

There are several state of California agency incentive programs that are available to transit agencies for potential procurement of ZEBs and associated infrastructure. These are primarily offered by CARB and CEC. Additional agencies such as Caltrans and CalSTA provide funding to help modernize the state's transit systems. Caltrans administers Low Carbon Transit Operations Program (LCTOP) funds and CalSTA administers Transit and Intercity Rail Capital Program (TIRCP) funds. Collectively, these funds can support the state's transportation improvement programs.

In the 2024–2025 state budget, where the state is contending with a major budget deficit, only the Air Quality Improvement Program received additional funding in the Clean Transportation Incentives area. A total of $34.9 million will be available to support small fleets and their adoption of zero-emission technologies. Additional funding from other programs is still available based on past year budgets, as described below.

4.3.1 CARB HVIP Program

One of the most important incentive programs for California transit agencies is CARB's **HVIP**. HVIP provides point-of-sale price reduction vouchers to approved applicants to help make zero-emission transit buses more affordable. This long-standing program funded the first transit agency fuel cell bus at SunLine Transit in 2009 and has funded many other transit bus and other zero-emission medium- and heavy-duty vehicles. Overall, HVIP has provided funding for the purchase of over 14,000 advanced vehicles since 2010, with over $1.5 billion in funding. Because HVIP also supports technologies across adjacent markets, including zero-emission commercial trucks and related infrastructure, the program helps strengthen supply chains and accelerate technology developments that ultimately benefit transit bus deployment. Also part of HVIP is Cal Fleet Advisor, a resource that provides no-cost expert assistance and tailored solutions to help transit agencies and other fleets deploy zero-emissions vehicles, offering peer-to-peer insights, shared experiences, and practical solutions to help overcome real-world challenges (Cal Fleet Advisor, n.d.).

In the 2024 Clean Transportation Incentives Plan, CARB proposed to examine the HVIP voucher amounts and to consider options to simplify and streamline the application process (California Air Resources Board 2025a). At this time, it is important to note that HVIP funding cannot be used for ICT compliance for transit agencies, only pre-compliance or excess compliance. As the ICT rule becomes more binding over time, this will further limit the ability of transit agencies to benefit from HVIP funding. Ongoing activity in the adjacent markets will therefore remain an important factor in maintaining technology availability and cost stability as ZEB purchase requirements increase.

Funding available in HVIP at any point in time can vary depending on budget allocations, legislative priorities, funding demand, and canceled vouchers. Recent funding cycles have included set-aside funding for transit, drayage trucks and the Innovative Small E-Fleets program. The uncertainty of funding availability at any given time makes it difficult for transit agencies to count on this funding source, although the set-aside funding for transit at a minimum ensures that agencies are not competing with other sectors for this funding.

Voucher amounts of $120,000 per vehicle are available for full-sized (40–60-foot) BEBs, and $240,000 for full-sized FCEBs. Medium-duty bus voucher amounts range from $60,000 to $85,000 per vehicle for battery-electric models (there are no commercially available FCEBs in this segment). Public transit agencies and small fleets with 20 or fewer vehicles can qualify for increased HVIP voucher amounts. Details of the vehicle models that are available for voucher requests are found in the HVIP vehicle catalog (California HVIP 2025b).

The HVIP has specific guidelines for "stacking" (or, combining) voucher funds with other sources. For example, transit agencies may combine HVIP support with funds from the Volkswagen Environmental Mitigation Trust and with other state incentive programs. Small fleets with 20 or fewer vehicles can stack HVIP funds with the Carl Moyer Memorial Air Quality Standards Attainment Program. Further details are available in the program Implementation Manual (California HVIP 2025a).

Program website: californiahvip.org/funding/

HVIP is currently open with approximately $72 million remaining in HVIP standard and $10 million in the transit set aside as of Dec. 29, 2025. Transit agencies can apply for both funding categories. Voucher amounts are provided in Table 8. Significant program changes include:

- Funding capped at 90% of vehicle cost without taxes and fees, 100% for public (unchanged).
- All fleet size caps are removed (previously limited to 50 vehicles). Bulk purchasing removed. Large fleets are now eligible.
- Simplified voucher table, updated voucher levels – no more plus ups, just one value.
- Limits the small fleet double voucher to 5 vehicles per fleet as a lifetime total.
- Increased truck conversion incentive.
- Streamlined compliance requirements.

Table 8. HVIP Zero-Emission Vehicle Public School or Public Transit Bus Vouchers

Bus Class	School Bus Voucher	Small Public School Bus Voucher	Public Transit Voucher	Small Public Transit Agency Voucher
Class 2b (8,501–10,000 lb)	N/A	N/A	$9,750	$19,500
Class 3 (10,001–14,000 lb)	$81,000	$103,500	$58,500	$117,000
Class 4 (14,001–16,000 lb)	$108,000	$138,000	$78,000	$156,000
Class 5 (16,001–19,500 lb)	$108,000	$138,000	$78,000	$156,000
Class 6 (19,501–26,000 lb)	$153,000	$195,000	$110,500	$221,000
Class 7 (26,001–33,000 lb)	$153,000	$195,000	$110,500	$221,000
Class 8 (33,001+ lb)	$216,000	$276,000	$156,000	$312,000
Class 8 Fuel Cell (33,001+ lb)	N/A	N/A	$312,000	$552,000

4.3.2 CEC Programs

The CEC awards grant funding especially for infrastructure projects to support low-emission heavy-duty vehicle deployments. These grants complement other funds to help support procurements for the vehicles themselves that typically come from CARB and local air districts, along with federal programs. The CEC has awarded hundreds of millions of dollars in recent years for battery-electric vehicle infrastructure and hydrogen fueling infrastructure in support of light-duty and heavier-duty vehicle applications of ZEV deployments.

The CEC released its 2024-2025 Investment Plan Update for the **Clean Transportation Program** in November 2024 (Tuggy 2024). This program has provided more than $2.3 billion in funding for ZEVs, infrastructure, alternative fuels, and workforce development projects since 2008. For FY 2024-2025, the Investment Plan calls for spending of $95.2 million in base funding plus proposed funding of $1.3 billion through FY 2027–2028 (but none in 2024-2025) through the Greenhouse Gas Reduction Fund (GGRF) and state General Fund. The base funds are allocated with $40.0 million for light-duty electric charging infrastructure, $38.2 million in medium and heavy-duty electric and hydrogen charging/fueling infrastructure, $15.0 million for additional hydrogen fueling infrastructure (open to all vehicle classes), $2.0 million for workforce training and development.

CEC released its 2025-2026 Investment Plan Update for the Clean Transportation Program in November 2025 (Tuggy 2025). The plan mentions two open solicitations from prior year funding totaling $60 million for medium- and heavy-duty ZEV infrastructure available to transit agencies and other on-road applicants. CEC's latest budget for FY 2025-2026 totals $136.5 million, which does not include $38 million in FY 2025-26 GGRF funding appropriated for medium- and heavy-duty infrastructure. The 2025-2026 budget includes $98.5 million for light-duty electric charging infrastructure, $22 million in medium- and heavy-duty electric and hydrogen charging/fueling infrastructure, $15 million for additional hydrogen fueling infrastructure (open to all vehicle classes), and $1 million for workforce training and development. The Investment Plan is not the last step in determining how funds will be spent. The CEC gathers public feedback, such as through workshops, and considers several funding mechanisms when developing the funding implementation strategy for each allocation. Each funding opportunity will include unique requirements and selection criteria.

The 2025-2026 Investment Plan Update estimates annual program funding of $95.2 million each in fiscal years 2026–2027 and 2027–2028, not including GGRF funds. Within that, the plan proposes allocating $44 million annually to medium- and heavy-duty ZEV infrastructure, which includes charging and hydrogen infrastructure for both transit and trucking applications. However, these allocations may change in future Investment Plan Updates, including the possible addition of GGRF funding based on future state budgets.

> Program website: www.energy.ca.gov/programs-and-topics/programs/clean-transportation-program

CEC also provides funding for the **Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE Commercial Vehicles)** program. The program administration is led by CALSTART, along with TetraTech for administrative support and Grid Alternatives for helping to manage the equity component. The program is targeted at supporting the development of recharging and refueling infrastructure for medium- and heavy-duty ZEVs, including transit buses. Because the build-out of this infrastructure is closely linked to developments in the broader adjacent market—such as zero-emission commercial vehicle deployment and the growth of supporting energy and charging sectors—the program also helps strengthen supply chains and improve technology readiness across multiple transportation applications.

The program has four standard funding lanes: (1) EV Fast Track (first-come, first-served); (2) Hydrogen (competitive); (3) EV Jump Start (competitive, targeted at low-income communities); and (4) EV Public (competitive). Further details are available on the program website, including a published list of program awards (California Energy Commission 2025) and an interactive program impact map (CALSTART 2025a). According to the site, more than 260 applications have been awarded with $142 million in funding conditionally awarded. The Drayage and Transit set-asides have thus far provided a conditionally awarded total of $26.5 million to 17 awardees, though it is not clear how much of this funding has gone specifically to transit infrastructure projects.

As of December 2025, there was $15 million available in Transit set-aside funding. The latest program contains set-aside funding lanes for drayage trucks and transit that were open through October 2, 2025. For transit, maximum award sizes are $5 million with BEB charger incentives from $31,250 to $375,000 depending on power level, and hydrogen dispensers up to $2.5 million each. Up to 100% of eligible costs are covered, with prioritization of projects that are ready for deployment and that include public charging/fueling aspects.

Program website: www.energiize.org/

4.3.3 CalSTA and Caltrans Programs

Caltrans operates **LCTOP**, one of several funding programs that are part of the Transit, Affordable Housing, and Sustainable Communities Program established by the California Legislature in 2014 by Senate Bill 862. The LCTOP is designed to reduce greenhouse gas (GHG) emissions and improve mobility with a priority focus on low-income communities. Caltrans is responsible for ensuring that LCTOP meets statutory requirements in terms of project eligibility, GHG reduction, community benefits, and other requirements of the law (California Air Resources Board 2020).

Eligible transit agencies must quantify GHG reductions in their projects and prioritize low-income communities. If an agency has a service area that includes qualifying communities, at least 50% of the total money received must be spent on projects to benefit these communities. Past LCTOP recipients received funding to replace diesel electric buses with ZEBs as well as to construct a hydrogen fueling station. In addition, the program funds new or expanded bus or rail services, intermodal transit facilities, and implementation of facility and operational supports (such as free or reduced fares). As of November 30, 2023, the program had allocated $1.2 billion in funding across more than 1,000 projects and implemented a total of $932 million with $875 million benefiting priority populations (California Climate Investments 2025).

Caltrans has released a draft of its FY 2024–2025 LCTOP Guidelines. Key requirements for the program include identification of priority populations, documentation of addressing important community/household needs, estimates of GHG emissions reductions using the CARB approved Benefits Calculator Tool, and an estimate of jobs creation using the CARB Job Co-Benefit Assessment Methodology. Program compliance and reporting requirements can be found in the guidelines document, along with a 2024–2025 program schedule calendar that indicates an expected next call for projects in March 2025 (California Department of Transportation, n.d.).

The FY 2024–2025 list of awardees has been posted on the LCTOP website. A total of 143 projects totaling $202.3 million have been selected for funding.

Program website: dot.ca.gov/programs/rail/low-carbon-transit-operations-program-lctop

CalSTA administers **TIRCP**, also established under SB 862. TIRCP was developed to "provide grants from the Greenhouse Gas Reduction Fund to fund transformative capital improvements that will modernize California's intercity, commuter, and urban rail systems, and bus and ferry transit systems, to significantly reduce GHG emissions, vehicle miles traveled, and congestion." TIRCP funding comes from Senate Bill 1 and a continuous (through 2030) appropriation of 10% from the quarterly Cap-and-Trade auction proceeds deposited in the GGRF. TIRCP funds capital projects, including feeder buses to intercity rail services, as well as vanpool services that are eligible to report as public transit to FTA. Also included are ferry and rail transit system projects.

Through six cycles of TIRCP thus far, more than $10 billion has been awarded to 132 projects. SB 125, passed in 2023, guides the distribution of General Funds in the amount of $4 billion in TIRCP funds through a population-based formula to regional transportation planning agencies. The funds can be used for either transit operations or capital improvements. An additional $1.1

billion for a Zero-Emission Transit Capital Program was also established and distributed through a population and revenue-based formula. SB 125 also calls for a Transit Transformation Task Force to make recommendations to improve transit ridership and address long-term operational needs (California State Transportation Agency 2025).

A seventh TIRCP cycle will start in FY 2024–2025 and continue through 2028–2029. This will include funding for ongoing projects that have not been fully allocated and for new projects. The 2024 awards include 27 projects for a total of $1.3 billion in funding. Twelve of the projects include funding for new ZEB purchases (California State Transportation Agency 2024).

Program website: calsta.ca.gov/subject-areas/transit-intercity-rail-capital-prog

4.3.4 Volkswagen Mitigation Trust

The **Volkswagen Mitigation Trust** was established from a legal settlement in response to Volkswagen's use of illegal emissions testing defeat devices in certain Volkswagen diesel vehicles. A fund of $2.9 billion in total was established for the mitigation trust, of which $423 million was designated for California specifically.

The California mitigation trust program is divided into five program areas: (1) zero-emission transit, school, and shuttle buses; (2) zero-emission Class 8 trucks; (3) combustion trucks and freight and marine equipment; (4) zero-emission freight and marine equipment; and (5) light-duty zero-emission infrastructure. The ZEB program had a total of $150 million allocated to help replace older buses with new battery or fuel cell electric buses, with funds available to applicants statewide and administered by the San Joaquin Valley Air Pollution Control District. The program requires replaced buses to be scrapped within 60 days of receipt of the new buses (Valley Air District 2025).

Thus far, the trust has awarded total funding amounts of $58.3 million for transit buses, $8.4 million for shuttle buses, and $63.6 million for school buses. Funding requests for transit and school buses quickly exceed available funding, with the school bus category significantly oversubscribed. New applications are still being accepted for the waitlist for transit and shuttle buses on a first-come, first-served basis.

Program information: ww2.arb.ca.gov/vwmitigationtrust

4.4 California State Regulations and Support Programs

4.4.1 Low Carbon Fuel Standard Regulation

This report outlines the primary funding programs that provide direct support to California transit agencies for ZEBs and infrastructure deployment. In addition to these programs, California also has a market-based system for stimulating investments into the development and end use of low-carbon fuels for vehicles, called the **Low Carbon Fuel Standard (LCFS)** program. The LCFS regulation was designed to reduce GHG emissions and to provide California's transportation sector with an increasing range of low-carbon and renewable alternative fuels such as hydrogen and electricity, which support the deployment of ZEVs in all transportation sectors. This regulation provides strong support for the implementation of advanced fuels based on recent credit prices, providing a market-based policy designed to reduce the carbon intensity of transportation fuels in the state.

Under the LCFS, low-carbon fuels like electricity and hydrogen are rewarded with credits, while producers and importers of high-carbon fossil fuels must purchase credits to cancel out the deficits they generate. The owners of equipment used to dispense electricity and hydrogen used as transportation fuels, or their designees, are eligible to generate credits and sell them to other LCFS program participants. Transit agencies can earn credits in two main ways: dispensed fuel, which refers to the electricity or hydrogen used to power ZEVs, and infrastructure operation, which refers to the unused capacity of EV chargers and hydrogen refueling stations—essentially, the capacity[3] of the ZEV infrastructure minus the amount of fuel it dispenses. These infrastructure credits are available for light- and medium-duty infrastructure and for heavy-duty infrastructure. In order to take advantage of either of these credit generation opportunities, entities must register in the online LCFS Reporting Tool as an "opt-in" entity, register their fuel supply equipment in the tool, and report dispensed fuel each quarter in the tool. CARB will then review the report and issue credits for the fuel and the infrastructure at the end of each quarter. At recent credit prices, credits would be worth around $0.11/kWh electricity used by vehicles and $1.05 per kilogram of hydrogen dispensed. Transit agencies may also benefit from holdback equity spending, which refers to the investments that utilities are required to make in electrification projects in low-income communities using proceeds from the sale of LCFS credits. Some form of financial support for electrification of transit buses is included in each investor-owned utility's (IOU's) LCFS holdback program.

The California LCFS was first adopted in 2009 as a part of the state's overarching Global Warming Solutions Act (AB 32) with the original goal of achieving a 10% reduction in CI from 2010 values by 2020. The LCFS was amended several times, including an important amendment in 2018, which increased the target to a 20% CI reduction level from the 2010 baseline by 2030, among other program changes. The 2018 amendment also provided support for the deployment of zero-emission infrastructure for light-duty ZEVs, where the LCFS provides credits for installed ZEV infrastructure based on the unused fueling capacity of the hydrogen station or EV fast charging site to provide a revenue stream for fuel supply equipment until ZEVs become more commonplace (California Air Resources Board 2025e). Amendments to the LCFS regulation effective on July 1, 2025, added capacity crediting provisions to public, private, and shared charging and hydrogen infrastructure serving heavy-duty zero-emission trucks and buses (California Air Resources Board 2025e).

LCFS establishes a market mechanism to incentivize the production of low-carbon fuels and renewable alternative fuels by assigning emissions credits or deficits based on the CI of the fuel pathway relative to the CI compliance target. Since its inception, the program has continually generated more credits than deficits, as shown in Figure 15, leading the excess credit bank to reach its highest level to date. As of early 2024, there were about 30 million metric tons of CO_2-

[3] Public heavy-duty hydrogen stations can earn capacity credits for up to 6000 kg/day of unused capacity. A crediting factor of 31.5% is used for private stations and 61.5 for shared stations. Public heavy-duty charging infrastructure sites can earn capacity credits for locations with up to 40MW. A crediting factor of 10% is used for private sites and 20% for shared sites.

equivalent emissions credits in total that have been banked over the previous years, primarily since mid-2021 (California Air Resources Board 2025d).

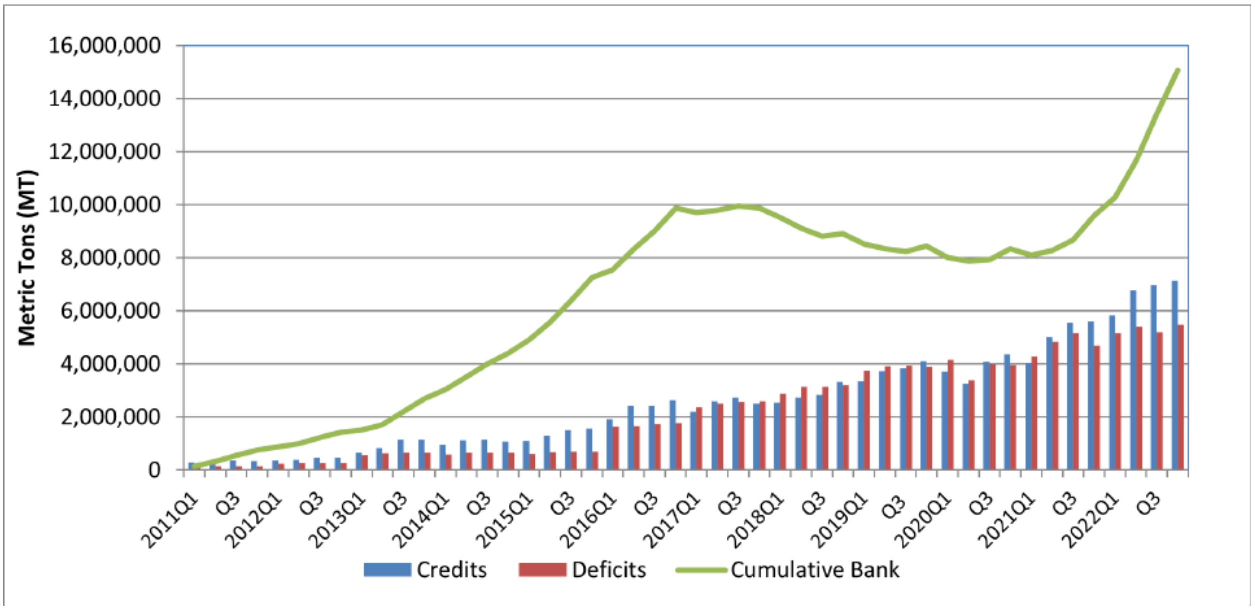

Figure 15. LCFS quarterly credits and deficits and cumulative credit bank.

Source CARB (2023)

This stimulation of the low-CI fuel market has led to significant over-compliance with the LCFS regulation since 2020, which can be seen by the green performance trend line in Figure 16.

Since CARB's previous LCFS rulemaking in 2018, the production capacity and end use of renewable diesel, electricity, and hydrogen as transportation fuels have all increased substantially and far exceed the projections used by CARB staff to establish the CI benchmarks. CARB expects this trend to continue as California proceeds to implement numerous programs aimed at reducing transportation GHG emissions in the state—regulations affecting truck and bus fleets, transport refrigeration units, cargo handling equipment, ocean going vessels, and locomotives.

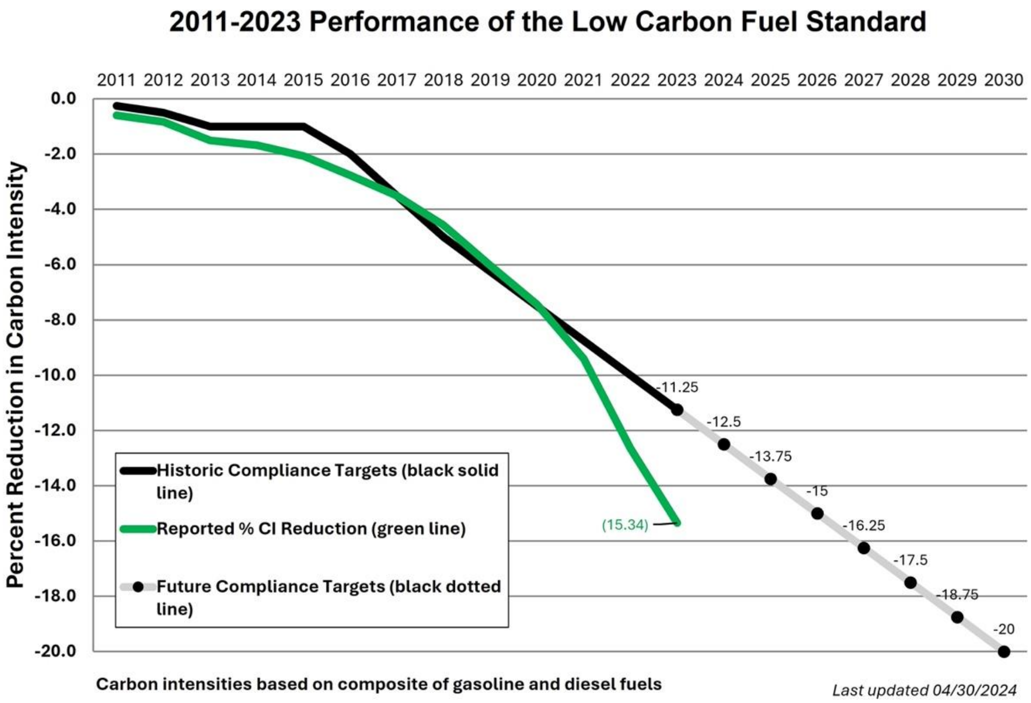

Figure 16. 2011–2023 performance of the LCFS.

Source: CARB (2025d)

Recognizing the early successes of the LCFS program in reducing GHG emissions in the transportation sector, along with the need to continue pursuing ambitious climate goals as outlined in several executive orders and statutes recently enacted in California, CARB proposed additional amendments to update and strengthen the LCFS regulation. The most recent set of LCFS amendments were approved in November 2024 and include, most notably, an increase of the compliance target to 30% CI reduction by 2030 and 90% CI reduction by 2045 from the 2010 baseline (displayed in Figure 17). As stated by CARB in the Staff Report: Initial Statement of Reasons, “a primary objective of this rulemaking is to strengthen the CI benchmarks of the LCFS regulation both pre- and post-2030 so that the LCFS continues to serve as a key policy to reduce GHG emissions from the transportation sector.” CARB explained, “to accommodate documented rapid advances in transportation fuel decarbonization that have already occurred, and which could occur again due to these rapid changes, the proposed amendments include both a near-term step-down in CI benchmark stringency in 2025, and an Automatic Acceleration Mechanism. A step-down in stringency was strongly supported by feedback provided by stakeholders, particularly in response to February and May 2023 technical workshops. The step-down reflects the current effectiveness of the program, which suggests that the pace of CI reductions can be increased through the benchmarks” (California Air Resources Board 2023).

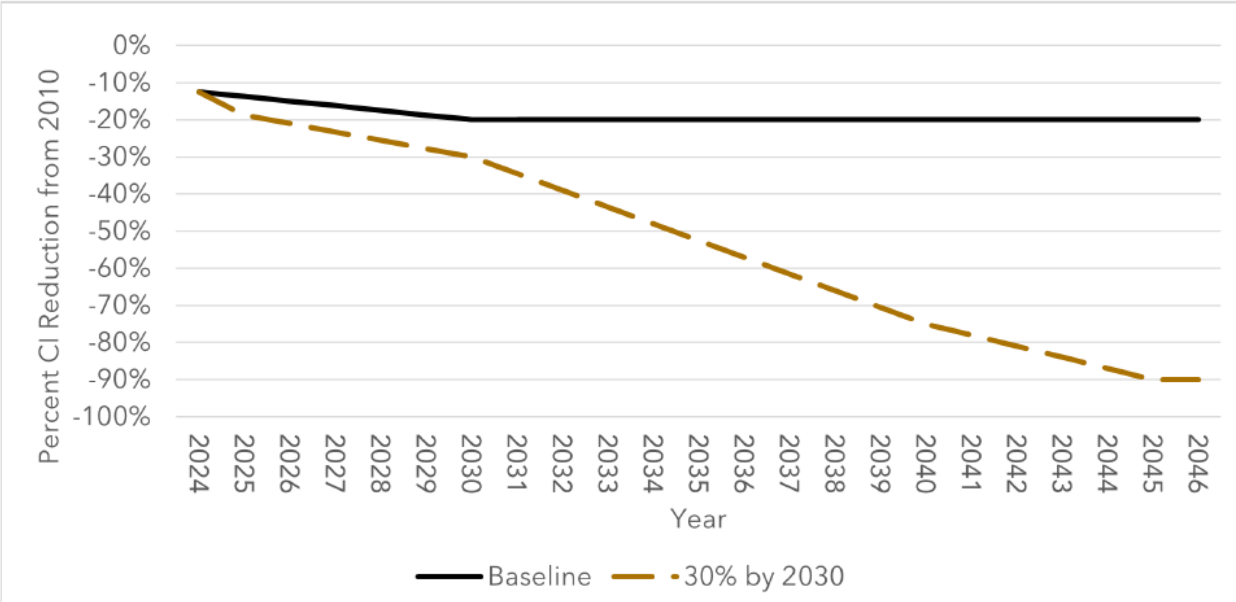

Figure 17. LCFS new CI benchmarks.

Source: CARB (2023)

The impact of fuel prices for low-CI fuels (such as electricity and hydrogen) can be a significant factor for transit agencies deploying or considering purchasing ZEBs. At its peak, from 2019 through 2021, LCFS credits were trading in the band of about $180–$200 per credit (see Figure 18). Credit prices at this level can help make electricity and hydrogen cost-competitive with conventional transportation fuels. However, in 2022 credit prices declined and have been in the $50-$75 range for the past 2 years (Figure 18). These fluctuating prices complicate the value of the LCFS program for transit agencies as they plan to deploy ZEBs which utilize lower CI fuels. The lower credit prices for renewable fuels can result in higher fuel costs relative to conventional alternatives, increasing the operating expenses. The value of LCFS credits is further eroded by brokerage fees that typically must be paid to capture the credits.

Thus, the new amendments are intended to provide clear, long-term market signals and strengthen the competitiveness and value of credit generation to ensure LCFS continues to be a market-driving policy incentivizing fuel providers to invest in low-CI alternative fuels and supporting end users with competitive prices for those fuels.

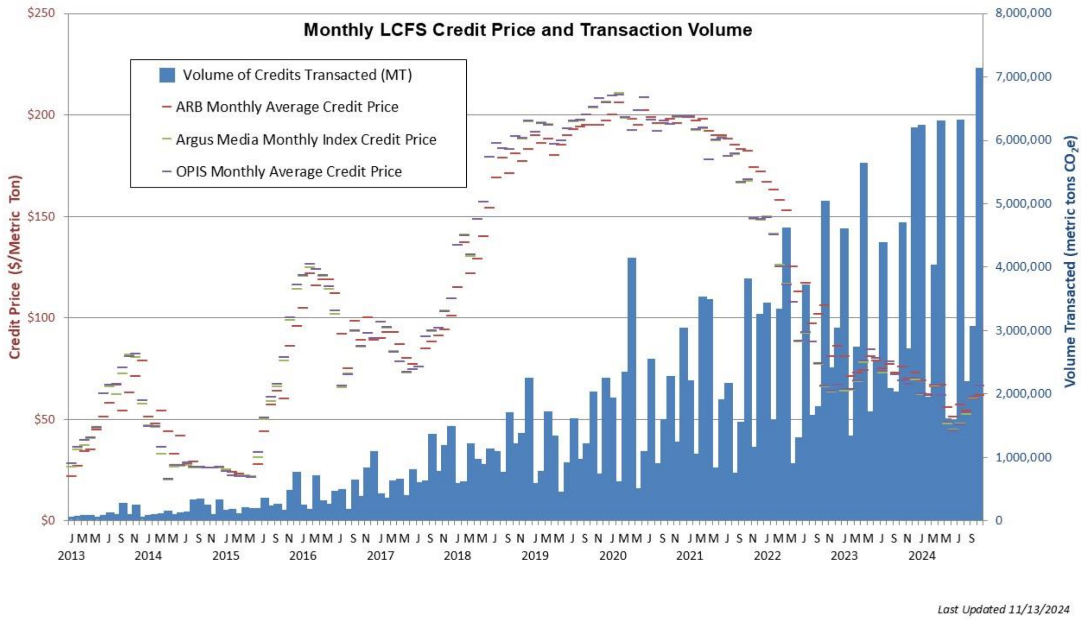

Figure 18. Monthly LCFS credit price and transaction volume.

Source: CARB (2025d)

4.4.2 Group Bus Procurement

Another strategy to reduce ZEB purchase costs and improve purchasing efficiency is to utilize group bus procurements. California's Department of General Services (DGS) has previously secured statewide contracts for ZEB procurements that cover multiple manufacturers, fuel types, and models (DGS 2025). These contracts have also met FTA's bus procurement criteria. For zero-emission transit buses, a previous contract was established for RIDE bus purchases (40- and 45-foot models) offering discounted pricing and a range of different options for battery capacities and warranty periods, but this contract expired on August 17, 2025. A similar contract with New Flyer expired on December 15, 2024. In mid-2025, California DGS released a new solicitation for statewide contracts for ZEBs and awarded contracts with New Flyer of America Inc., Phoenix Motorcars LLC, and RIDE Mobility LLC, covering a variety of BEB and FCEB options for buses ranging from 35 feet to 60 feet. ZEB model details and contract prices are provided in Section 5.2.1.

Besides California, similar ZEB statewide contracts have been released or are underway by other states such as Washington state's Department of Enterprise Service, Georgia's Department of Administrative Services, and Virginia's Department of General Services (Schnader and Hamilton 2020). In addition, transit agencies have also been putting out joint procurement solicitation for transit buses, to relieve the procurement burden for many of the participating agencies. For example, in October 2020, Morongo Basin Transit Authority, on behalf of the CALACT member agencies, issued a request for proposal (RFP-20-01) for joint procurement for the manufacturer and delivery of accessible transit/paratransit vehicles, that also included BEBs. The request has been extended to 2025 (Basin Transit 2025).

4.4.3 State Sales Tax Exemption for Bus Purchases

California has had an exemption from state sales tax for transit bus purchases since AB 2622 was signed into law in September of 2022. However, the exemption is in place only until January 1, 2026, at which time it is set to expire (California Legislative Information 2022b). Unless this exemption is extended in 2025, transit bus purchases will be subject to the appropriate state sales and use tax rate after that date.

4.4.4 Electric Charging Infrastructure Reporting Requirements

With regard to accessing state funds for installing charging infrastructure for BEBs, California has implemented a law under AB 2061 that institutes new reporting requirements for electrical charging infrastructure operations. Entities receiving state funds are now required to report on charging station uptime for a minimum of 6 years for incentive funds received after Jan. 1, 2024. The CEC will then issue reports documenting station uptime every 2 years, with potential additional metrics designed to indicate charger reliability including in low, medium, and high-income areas. These requirements impose an additional cost burden on entities receiving incentive funds for infrastructure but are designed to ultimately improve the performance of electrical charging infrastructure in the state (California Legislative Information 2022a).

4.5 California Regional ZEB Incentive Programs

At the regional level, ZEB incentive funding programs are primarily provided through the AQMDs/APCDs, although these programs are variable and typically focus more on light-duty vehicles and heavy-duty vehicles for ports than public transit buses. Also at a regional level, the major electric utilities in California are offering incentives for installing BEB charging infrastructure. These programs are listed and described below.

4.5.1 AQMD and APCD Programs

California includes 35 regional AQMDs and APCDs, including some large districts like the South Coast (SCAQMD), Bay Area (BAAQMD), Sacramento, and San Joaquin Unified AQMDs. These AQMD programs typically focus on stationary sources of pollution such as oil refineries, large food processing centers, cement manufacturing, and other industrial sources, with a particular focus on particulate matter (PM) emissions and precursors to ozone production such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs). They historically have provided some funds for vehicle retrofit technologies such as PM filters, especially for trucks, but also have been supportive of low-carbon transit programs through various coordinated efforts with local transit agencies.

Highlights of the major air district programs addressing low-carbon transportation are provided below. Additional details can be found through the included links:

- Bay Area AQMD – Carl Moyer Program
    - Details: (www.baaqmd.gov/?sc_itemid=7A9A5ACC-1CD1-41E9-B429-7BFDAE17FEF3)
        - For 2024–2025 application cycle, over $75 million is available.
        - Transit bus funding is available in West Oakland, East Oakland, Richmond-San Pablo, and Bayview-Hunters Point/Southeast San

Francisco, and other designated low-income communities and low-income communities located within the Air District's jurisdiction.
    - Funding is available for ZEBs that are domiciled in or have at least one stop in these areas.
- Bay Area AQMD – Community Health Protection Grant Program
  - Details: www.baaqmd.gov/community-health/community-health-protection-program/grant-program
    - Priority for communities most impacted by pollution.
    - Various mobile sources and infrastructure are eligible including heavy-duty transit buses.
- Sacramento Metropolitan AQMD
  - Details: www.airquality.org/Businesses/Incentive-Programs
  - Provides transit bus funds through Carl Moyer and Community Air Protection Incentives programs.
- San Joaquin Valley APCD – VW Trust Zero-Emission Transit and School Bus
  - Details: vwbusmoney.valleyair.org/
  - Funding available to all California transit agency applicants statewide
  - See VW Mitigation Trust fund details above
- South Coast AQMD – Investment Incentive programs
  - Details: www.aqmd.gov/home/programs
  - Vehicle and Engine Upgrades programs available: www.aqmd.gov/home/programs/business/business-detail?title=vehicle-engine-upgrades

4.6 Electric Utility Programs

Programs sponsored by major electric utilities in California include "make-ready" programs to develop electrical charging infrastructure, as well as vehicle rebate programs, charger installation rebate programs, and interim rate designs for electricity charging costs.

Historically, the utility rate structures for medium and large commercial and industrial facilities have included "demand charges" that require payments for peak power usage per month, as well as "energy charges" for actual kWh of electricity delivered. To help transit agencies adjust to increased use of electricity for bus charging, some utilities have waived demand charges on a temporary basis for these EV rate structures. However, there are plans to reintroduce these utility demand charges, and transit agencies should carefully review and understand these changes to plan for fuel costs when shifting from diesel and CNG to electricity and hydrogen.

Pursuant to SB 350, the California Public Utilities Commission (CPUC) Decision D.18-05-040 authorized California's IOUs to offer ratepayer funded programs to support charging infrastructure for zero-emission medium- and heavy-duty vehicles. It allows funding to install make-ready infrastructure for medium- and heavy-duty fleets including design, engineering, and build-out from both the utility side of the meter, referred to as "to the meter" (TTM), and the customer side of the meter, or behind the meter (BTM). Rule 29 in both SCE and Pacific Gas & Electric Company (PG&E) territory and Rule 45 in San Diego Gas & Electric (SDG&E) territory requires the utilities to pay for TTM make-ready work for EV charging infrastructure. SCE's Charge Ready Transport program, PG&E's EV Fleet program, and SDG&E's Power Your Drive

Fleet program are authorized by D.18-05-040 with subsequent refinements through individual IOU advice letters, allowing for some BTM infrastructure to be funded for critical areas, including dedicated funding for BTM make-ready work for transit agencies adopting BEBs. Each of these programs has different commitments depending on the utility operating service in the customer's area.

Another opportunity available for funding transportation electrification infrastructure projects is the use of credits earned by an IOU under the LCFS program. These projects do require CPUC approval. The near-term priority investment decision (D.21-07-028) approved IOUs to fast-track ratepayer funded projects in several critical areas such as medium- and heavy-duty vehicle electrification, which is explicitly highlighted as one of the near-term priority sectors.

The CPUC also has rules (or tariffs) that could be applicable to facilities that support medium- and heavy-duty charging infrastructures. Rule 15 is for distribution line extension for multiple customers supported through ratepayer funding. New developments are required to have underground distribution lines as a default but can be requested above ground at customer cost. Rule 16 is for individual service line extensions that would be installed underground in certain cases where it is legally required or technically needed. Most of the cost is covered by an incentive/allowance. If the customer chooses to have the service line installed underground, the customer will have to bear the additional cost of it.

In addition to these Rules, AB841 directs the CPUC, in consultation with CARB and CEC, to approve or modify transportation electrification infrastructure programs including TTM distribution infrastructure for EV charging, with at least 35% of the investments to be directed toward underserved communities and ensures that a portion of the workforce involved in EV charging infrastructure installations is certified through the Electric Vehicle Infrastructure Training Program (EVITP). It also established a new tariff or rule (Rule 29 for PG&E and SCE, and Rule 45 for SDG&E) that authorizes each IOU to design and deploy all electrical distribution infrastructure on the TTM side for customers installing separately metered EV charging infrastructure to be paid by ratepayer funds.

The CPUC is aware that the traditional distribution planning process tends to be relatively reactive and conservative, as it depends heavily on customer interest, application submission, and subsequent assessment and approval for energization. This leads to energization delays and long lead times for customers, preventing them from receiving service within a reasonable timeframe and further hindering the pace of EV adoption. For EV charging depots, demand can require the installation of very large amounts of power within just a few months—or in some cases, only a few weeks. Such rapid and concentrated demand growth poses significant challenges for utility distribution planning process as it requires them to jump from a relatively uncertain time frame (6–10 years) to an immediate near-term (1–3-year) certainty of known load.

To address this, the CPUC is developing a Pending Loads category aimed at improving mid-term (approximately 3–6-year) planning. The stated goal of the pending loads category is to increase visibility in where significant new loads are likely to appear within that timeframe. CPUC's decision D.24-10-030 directs utilities to present their ideas at a CPUC hosted workshop that could address the void created in this mid-term forecast. This will enable the utilities to leverage available data and engage with transit agencies on future fleet electrification plans to create a reliable projection of transportation electrification loads before customer applications are received. Utilities are still determining what classifies a pending load and how to avoid stranded assets, formulating reporting requirements, and how to align them with the existing transmission planning. This process can significantly alleviate the infrastructure challenges for transit agencies trying to expand their zero-emission electric bus fleet and should encourage more proactive transit agency-utility engagement.

Another approach that is currently being considered by some IOUs is the Flex Connect Pilot. In the case of PG&E, under this pilot a customer can connect their EV charger and energy management system to PG&E's grid management system. The EV chargers can then automatically adjust the local energy consumption resulting in the customer being able to receive a full 2 MW of service immediately for most of the time.

These programs, whether participated collectively or individually, can support transit agencies in planning for the purchase of zero-emission electric buses and the necessary charging infrastructure. With thoughtful coordination, agencies operating within the same utility service territory have significant opportunities to collaborate—reducing upfront installation costs and timelines, streamlining processes and enhancing their ability to deliver reliable zero emission transit service to their communities. Such coordinated growth can accelerate the broader deployment of charging infrastructure benefiting not only transit buses but a wide range of medium- and heavy-duty vehicles and equipment.

The major California utilities offering make-ready infrastructure programs are Southern California Edison (SCE), Pacific Gas and Electric Company (PG&E), San Diego Gas and Electric Company (SDG&E) and Sacramento Municipal Utility District (SMUD). Each utility's program is briefly summarized below:

- SCE – Charge Ready Transport Program
  - Details: crt.sce.com/overview
  - Offers low- to no-cost electrical system upgrades to support the installation of EV charging equipment for qualifying vehicles
  - Under the CRT, SCE will:
    - Perform on-site visits to evaluate the site's electrical infrastructure needs.
    - Develop cost estimates for utility side and customer side of the meter.
    - Design, secure permit, project manage and install the necessary infrastructure—participants will have the option to instead perform the necessary work on their side of the meter and receive a make-ready rebate.
    - Install a separate meter dedicated to the EV charging infrastructure and waive customer demand charges through 2025 for EV rates TOU-EV-8 and TOU-EV-9.
    - Make final inspections once the charging equipment is installed.
  - In return, the customer must lease or purchase at least two medium or heavy-duty EVs, keep chargers active for 10 years, and provide charging data for 5 years.
- PG&E – EV Fleet Program
  - Details: www.pge.com/en/clean-energy/electric-vehicles/ev-fleet-program/transit-fleets.html.

    - Incentives for medium- and heavy-duty vehicle electrification including transit fleets.
    - Provides incentives and rebates for vehicles and chargers:
        - Up to $15,000 per charger for up to 50-kW units.
        - Up to $25,000 per charger for 50.1–100-kW units.
        - Up to $42,000 per charger for >150-kW units.
        - Vehicle rebates of $9,000 per vehicle for full-sized transit bus and $4,000 per vehicle for smaller buses.
    - Requires 10-year commitment and sharing of data with PG&E.
- SDG&E – Power Your Drive for Fleets Program
    - Details: www.sdge.com/business/electric-vehicles/power-your-drive-for-fleets.
    - Assists with the installation of electrification infrastructure with two options:
        - Option 1: SDG&E owns all infrastructure up to charger units with no cost to the host site other than chargers.
        - Option 2: SDG&E owns infrastructure up to meter and host site can qualify for up to 80% rebate of infrastructure cost from meter to chargers.
    - Rebates are available for different tiers of chargers:
        - Up to 19.2 kW: $3,000 per charger unit.
        - 19.3–50 kW: $15,000 per charger unit.
        - 50.1–150 kW: $45,000 per charger unit.
        - >150 kW: $75,000 per charger unit.
- SMUD – Commercial EV Fleet Program
    - Details: www.smud.org/en/Going-Green/Electric-Vehicles/Business.
    - Program provides incentives for purchase of EV chargers, including these incentives for non-public DC fast chargers:
        - Less than 50 kW: $7,500 per charger unit "handle."
        - 50–149.9 kW: $15,000 per charger unit "handle."
        - Up to 50.1–150 kW: $30,000 per charger unit "handle."

These make-ready infrastructure programs administered by California's major IOUs have been funded through a series of state legislation including SB 350, AB 1082, and AB 1083 to spur adoption of EVs in the state. Approximately 90% of the funding from these programs target medium- and heavy-duty vehicles. These programs require data sharing from participants, which enables a detailed analysis of EV charging behavior and an annual assessment of the infrastructure deployment. The annual assessment report for these "Standard Review Projects" details the findings, lessons learned, and overall status of the funding programs (Cadmus Group et al. 2024; 2025).

Pursuant to SB 350, the CPUC has approved several decisions, resolutions, and advice letters authorizing $765 million ratepayer funding toward the expansion of EV charging infrastructure for light-, medium-, and heavy-duty ZEVs and off-road equipment. In compliance with AB841 the utility-side electrical distribution infrastructure costs would be covered by ratepayers and included in the general rate case for each IOU (Rule 29 for PG&E and SCE, Rule 45 for SDG&E). CPUC's recent actions aim to make grid planning more proactive, with focus on better forecasting, coordination, faster connections, and transparency. The IOUs are also required to integrate pending electrification loads into their distribution planning focusing on flexibility and near-term solutions (Refs: R.21-06-17, D.24-10-030).

4.7 Transit Agency Experience and Use of Incentive and Other Programs

Many of the transit agencies responding to the ICT survey who have begun deploying ZEBs reported that they utilized one or more incentive funding programs to either purchase the new buses, install fueling/charging infrastructure, or assist with workforce development needs. The programs most widely cited include FTA Low-No, CARB HVIP, VW Mitigation Trust, and the Carl Moyer program. Some have also made great use of the make-ready infrastructure funding through the CEC to prepare their sites for BEBs.

In some cases, the awards from these programs were sufficient to fully offset the additional capital cost of ZEBs compared to purchasing equivalent size conventional buses. However, in most cases, multiple awards needed to be combined to enable ZEB purchases. This challenge grows as the size of the ZEB fleet grows. Particularly for large transit agencies who operate multiple bus depots, the facility upgrades that are often needed to accommodate large fleets of ZEBs can significantly increase the capital funding that is necessary. Even when approached strategically and incrementally, this represents a significant near-term need for support funding to enable the expanding ZEB transition.

Increasingly, smaller transit agencies throughout the state are also now beginning to deploy ZEBs. Although their bus fleets are much smaller than large agencies, they tend to be even more dependent on additional award programs and financial support to begin piloting ZEBs in their service. These agencies also expressed a need for the award processes to be as simple and as streamlined as possible, as they typically do not have excess staff time/resources and grant expertise to navigate complicated or time-consuming processes. This becomes a major barrier to applying for available funding.

OEM questionnaire responses:

What are some recommendations for improving California incentive funding programs?

- Consistency and predictability of incentive program funding availability is critical to ensure OEMs and transit agencies can rely on this funding for their longer-term planning.
- Changes to the programs where the incentive funding is applied for and received directly by the transit agencies to reduce the burden on OEMs and better match the costs of supporting the program with the entity receiving the benefits.
- Recommend that CARB enhance education and outreach to different types of transit agencies regarding their compliance status under the ICT regulation.
- Improved communication and guidance from CARB could help ensure agencies fully leverage available resources to support their ZEB transitions.
- Processes for applying for incentives can be slow and burdensome on OEMs who are not typically staffed to process ongoing reporting for our customer fleets.

4.8 Summary of ZEB Incentive, Funding, and Supporting Programs

The available incentive funding and supporting programs described above have had a dramatic impact on the implementation of ZEBs in California in recent years. These programs can significantly offset the upfront cost of the buses at this early stage of deployment, bringing them closer to cost parity with traditional buses. The LCFS program can provide continued monetary returns without a sunset date to help lower operating costs. With improved technologies, installed infrastructure, and a trained workforce, it is reasonable to anticipate declining capital costs and operational costs for ZEBs that can then lead to a substantially beneficial cost of ownership.

Despite the increased availability of funds in recent years, particularly through the FTA Low-No program and California state programs, the need for additional funding is one of the largest concerns for transit agencies looking ahead at their ZEB transition plans. Many cite this as a critical need in order to meet their ICT compliance obligations. The additional funds are needed to help purchase new vehicles, to install charging/fueling infrastructure along with necessary facility upgrades, and to upskill their workforce for operating and maintaining ZEBs.

OEM questionnaire responses:

Q. Bus OEM recommendations for funding mechanisms that would help OEMs/suppliers develop new technologies and/or address technology barriers:

1. Support for research and development grants is essential to design and validate new technologies and prepare for their adoption.
2. Support OEMs that conduct extensive testing and validation before product launch to improve product safety and reliability (i.e., encourage industry ‘first movers’ and help them to take risks with product development that can later benefit the overall market)

4.9 Key Questions Moving Forward for Funding Sector-Based ZEB Deployment

Despite a significant amount of funding, incentives, and supporting programs provided to support the ZEB transition, many transit agencies continue to feel overwhelmed by the cost. In addition to external factors such as supply chain, tariffs, inflation, and lack of support from adjacent markets, it is also important to review and reevaluate current programs’ effectiveness and identify gaps. Each funding support program, as it is developed, evaluated, and revised, should consider some of the following questions to determine the purpose and effectiveness at achieving the end goal(s).

1. What is the purpose of this funding program? Is it simply to supplement the unfunded mandate of the ICT regulation? To provide interim support to cover incremental costs of ZEBs? To increase volumetric sales/production to reduce manufacturing costs? To push the technology readiness level (TRL) of new bus technologies forward?
2. Has this funding program achieved its goal, and if not, why?
3. Can this funding program accommodate the procurement strategies and approaches used by different types of fleets (i.e., public vs. private)?
4. What are the deficiencies in each funding program and how are they impacting participation by different types of fleets? For example, HVIP is designed to increase volumetric sales in early commercialization years, but its budget appropriation faces a lot of uncertainties. Are there any remedial approaches to provide more certainty? Are the transit set-aside funds improving transit agency participation in HVIP? How can the set-aside program improve?

5. Has each funding program seen its desired outcome? For example, are we seeing volumetric related cost reductions or are we seeing incentive-induced price inflation?
6. Are there opportunities to introduce greater transparency into the funding programs without divulging OEM confidential information? What types of cost and pricing information could be made public support or justify incentive amounts?
7. Is incentive-induced price inflation occurring? What information is needed to verify that it is not?
8. How should the market be designed in a way that can reduce incentive-induced inflation? Expand the market to encourage more competition? Provide more long-term market certainty? Provide cost share on R&D?
9. Should R&D or demonstration grants be made available for fueling infrastructure efficiency improvements and loss prevention, both of which affect return on investment? For example, grants to integrate boil-off prevention equipment into LH2 station equipment?
10. What else needs to be funded? Or, what type of ZEB deployments have we not seen that need support to get off the ground (e.g., large-scale BEB projects, cutaway FCEBs, and over-the road FCEBs)?

Additionally, exploring and attempting to answer these related questions can help evaluate or improve the implementation of the programs:

1. What is the funding gap for bus procurement that needs to be addressed through purchase incentives? And how are the funding gaps defined?
2. Could there be expanded and/or new funding sources?
3. How could funding be further streamlined or aligned to support large projects?
4. Should we revisit funding for pilot projects that encompass bus procurements and refueling and maintenance infrastructure?
5. How could the state design its funding programs in a way that is easier for transit agencies to use as matching funds to apply for federal competitive funding?
6. How could the state design funding programs to provide cost containment mechanisms and incentivize a steady production supply?

5 ZEB Market and Outlook

The U.S. transit bus industry has had to adapt to a number of significant market dynamics in recent years, including company bankruptcies (e.g., Proterra, Lightning eMotors, and Vicinity Motor), market exits (e.g., Nova Bus, REV Group) while some, like Gillig and New Flyer, are expanding through acquisitions and new engineering centers. Transitioning to ZEBs has also been challenged by supply chain issues, cost increases, and limited numbers of Buy America-compliant bus models, especially in niche segments like cutaway and articulated buses. Despite long delivery lead times (often longer than the typical 12–18 months for a U.S. transit bus), manufacturers like Gillig, New Flyer, El Dorado National-California (ENC), and RIDE (formerly BYD) continue developing ZEBs, while initiatives like the American Public Transit Association (APTA) Task Force aim to help stabilize the industry and support technology deployment.

The U.S. transit industry is navigating challenges in adopting ZEBs and associated infrastructure, including high upfront costs, supply chain issues, and limited domestic manufacturing options. Installing charging infrastructure for BEBs often involves major site work for conduit trenching and pouring concrete, in addition to the actual equipment installation process, disrupting operations for a period of time. Hydrogen fueling stations for FCEBs are fairly well established after about 20 years of experience from the initial installations, but with technology that continues to evolve and with high implementation costs and maintenance requirements with present-day technology. Charging and fueling infrastructure is discussed in more detail in Section 6.

BEBs and FCEBs also face operational and reliability concerns, such as range limitations, long infrastructure installation lead times, and some reliability issues with recharging/refueling systems and the buses themselves. Recommendations to support the transition to ZEBs include stable funding, tax exemptions, group procurements, sufficient supply of affordable low-carbon hydrogen, and streamlined utility and permitting processes to reduce costs and improve market confidence. Despite these barriers, ZEBs offer significant energy efficiency and environmental benefits, making them a key focus for future transit solutions. This section underscores the importance of consistent policies, support funding and purchase incentive programs, and collaborative strategies to address the high upfront costs and operational challenges of ZEB deployment. Agencies aim to expand ZEB adoption to achieve long-term environmental goals while mitigating barriers in cost, performance, and supply chain readiness.

5.1 ZEB Market Impacts and Bus Model Availability

The following subsections describe status of four major ZEB market influencing factors, including:

1. Build America, Buy America.
2. Notable Changes to ZEB Market.
3. Available ZEB Models.
4. Bus Manufacturing Challenges.

5.1.1 Build America, Buy America

The Infrastructure Investment and Jobs Act, signed into law in 2021, included the Build America, Buy America (BABA) Act that was intended to "bolster America's industrial base, protect national security, and support high-paying jobs" by using federal financial assistance awards to promote the use of goods, products, and materials that are produced and sold in the United States (Young 2022; 2023). This policy builds on and expands the existing Buy America policy FTA had in place previously for transit agencies. While FTA's original Buy America policy was focused narrowly on transit projects funded by FTA grants, BABA represents an expansion of domestic sourcing requirements across all federally funded infrastructure projects, extending those requirements to all construction materials and manufactured products. It also implements stricter requirements for the domestic content of transit buses (up to 70%) and final assembly of buses in the U.S.

The effect of the current BABA requirements is that any public transit agency that applies federal funding toward the procurement of new transit buses must select a BABA-compliant bus OEM that produces buses in the U.S. This policy was designed to support American manufacturing and labor in the long-term, due to the wide number of transit agencies that use federal funds for bus purchases. In the short term, however, this can create challenges within the U.S. bus market as it effectively reduces the number of OEMs that are able to offer ZEBs to U.S. transit agencies. This reduced competition in the U.S. bus market, as a result, can have a negative impact on transit bus prices.

In response to a question in the OEM questionnaire regarding the impact of the BABA policy, the bus OEMs commented that:

1. The BABA policies support domestic production, enhance national security, certify quality and safety standards, and support environmental interests.
2. Without these protections, it is possible that the influx of vehicles produced using cheap offshore labor could shutter existing domestic manufacturing capacity. This would leave the market dependent on foreign suppliers, which would ultimately drive costs higher.

One supplier commented that BABA probably adds about 10% to the cost of a transit bus fuel cell module, because bus drivetrain components have to largely be produced domestically to meet requirements so that the bus chassis can be produced internationally and imported (Johnston 2025).

It is important for a federal policy like BABA to be evaluated to determine what effect it is having on the bus market (e.g., bus prices and availability) and whether it is meeting its intended goal of strengthening the U.S. manufacturing and supplier base. Is it leading to a larger or smaller commercial market and supply chains? What is the impact on bus costs, and on the U.S. manufacturing workforce?

5.1.2 Notable Changes to ZEB Market

Since the initial phase of the ICT ZEB purchase requirements went into effect in 2023, there have been a number of notable changes to the ZEB market in the United States, including changes related to domestic manufacturing of transit buses and changes to ZEB models available to the market. The early 2010s saw a strong level of entry of new bus OEMs in response to local air quality concerns and promotion by regional AQMDs with a focus on near-zero and zero-emission technologies. This built momentum and created greater competition. However, the COVID-19 pandemic starting in 2020 changed this picture considerably, with decreased ridership and corresponding lower farebox recovery creating unforeseen financial pressure on transit agencies. It also brought about significant manufacturing and supply chain challenges. Bus procurement plans were delayed, orders were reduced, and some OEMs filed for bankruptcy, withdrew from the California market or exited the U.S. bus market completely. ENC left the market shortly in 2024 but has now returned. In addition, the National Defense Authorization Act enacted in 2019 prohibits transit agencies from using FTA funding to purchase the Chinese-owned, California-made BYD (now known as RIDE) buses, unless they were already in a previously executed contract.

Today, there are fewer ZEB OEMs in the U.S. market compared to 2018, when the ICT regulation was adopted. New Flyer continues to be the only bus OEM that manufactures all types of large transit buses, as well as an electric trolley. Major updates from other OEMs in recent years are highlighted below.

- **Proterra files for bankruptcy:** In August 2023, Proterra filed for Chapter 11 bankruptcy (Wanek-Libman 2023b). Proterra had three business segments:
    - Proterra Transit, which manufactured and sold electric buses, was sold to Phoenix Motorcars for $10 million via bidding process (St. John 2023),
    - Proterra Powered, which produced batteries for EVs, was sold to Volvo Group for $210 million via bidding process (Adler 2023), and
    - Proterra Energy, which produced bus charging equipment and related enterprise-level software solutions, was retained by the reorganized Proterra under its chapter 11 restructuring plan (Paul, Weiss 2024).
- **Lightning eMotors files for bankruptcy:** In December 2023, the Securities and Exchange Commission (SEC) approved the bankruptcy filing, dissolving Lightning eMotors, which had delivered 600 zero-emission commercial vehicles while in operation (Metro Mag. 2024; Lewis 2024). In February 2024, Gillig announced that its subsidiary GERCO LLC acquired select assets of Lightning eMotors and Lightning Systems, as well as some of its former engineering workforce; it plans to launch a new Colorado Technology Center, which Gillig says is to become “an engineering hub for the manufacturing of heavy-duty transit buses” (Hampel 2024; GILLIG 2024b).
- **Nova Bus exits U.S. transit bus market:** In June 2023, Nova Bus (owned by Volvo Group) announced plans to close its manufacturing facility in Plattsburgh, New York, by 2025, “effectively exiting the U.S. transit bus market.” The company says it will continue to support U.S. customers with parts and service needs for existing Nova buses still in service (Wanek-Libman 2023a). Its manufacturing plant in New York state was acquired by Micro Bird Inc., which will produce school buses and cutaway buses in the United States.
- **ENC closes and restarts:** In January 2024, REV Group Inc. announced it would wind down and close its ENC business by the end of 2024. No buyer had been identified at the time of announcement, but the company said that all existing warranties, aftermarket

services, and parts would be fulfilled (Wanek-Libman 2024). In October 2024, the sale was finalized to Rivas Inc. for a purchase price of approximately $52 million (REV Group 2024). In April 2025, ENC announced they would restart the bus production and customer deliveries in June 2025, under the new ownership. ENC offers buses in lengths of 30, 32, 35, and 40 feet that are fully Buy America and FTA compliant (ElDorado National California 2025).

- **BYD North America rebrands as RIDE Mobility:** In 2023, BYD announced the spinoff of its transit bus division as RIDE Mobility, headquartered in Pasadena, California. Initially branded as BYD|RIDE during a transition period, the division is now known as RIDE Mobility.
- **Vicinity Motor Corp files for bankruptcy:** Back in July 2021, Vicinity Motor announced a new Buy America-compliant vehicle assembly facility in Ferndale Washington—its first U.S.-based assembly plant (Vicinity Motor Corp. 2021). Just a few years later, by November 2024, the company was filing for bankruptcy and declared insolvent (Randall 2024).
- **Gillig announces FCEB model:** In April 2024, Gillig announced the development of a hydrogen fuel cell powertrain option for its low-floor bus platform, in partnership with Ballard Power Systems for the fuel cell powerplant and BAE Systems for the electrical system integration, with production scheduled to begin in 2026 (GILLIG 2024a; n.d.). However, in mid-2025, Gillig quietly canceled its FCEB development program.
- **Alexander Dennis announces U.S. builder for electric double-decker bus:** In September 2023, Alexander Dennis announced that it selected Big Rig Manufacturing in Las Vegas, NV as a North America manufacturing partner to assemble its buses, achieving Buy America compliance for its electric Enviro500EV CHARGE double-decker buses (Alexander Dennis 2023a). So far, contracts for the electric double-decker buses from the North American production facility total 82 buses, including the first order of 7 buses for Spokane Transit (which began receiving buses in 2025), an order of 33 buses for Sound Transit (largest single order to date), and an order of 12 more buses for Foothill Transit (first order for California transit agency, scheduled for delivery in 2026) to add to Foothill's two electric double-decker BEBs already in operation (Alexander Dennis 2025; 2023b; 2024b; 2024a).

The ZEB market had been expanding rapidly in recent years; however, this growth has amplified stress on the battery supply chain. As legacy or foreign-linked battery suppliers exit or prove unreliable, OEMs must shift to more reliable domestic battery pack producers to improve the domestic supply chain resilience, but this triggers some short-term disruptions. In late 2025, NFI Group announced a major battery recall affecting about 700 BEBs made by New Flyer, due to defective battery modules supplied by XALT Energy LLC. Additionally, XALT announced its decision to exit battery manufacturing, advising that it will wind down its U.S. battery operations (NFI Group 2025a).

5.1.3 Available ZEB Models

Bus OEMs offering one or more transit bus types in the U.S. market as of 2025 are listed in Table 9 below, organized by bus type and fuel/powertrain type (BEB, FCEB, and conventional). This includes OEMs that offer at least one type of ZEB which pertains to the ICT rule. The list also includes companies that offer repower/remanufacture of buses with zero emission powertrains, provided all other requirements are satisfied.

For each of the five identified bus types (standard, articulated, double-decker, coach, and cutaway), the table indicates whether the OEM listed offers battery electric (green "B" symbol), hydrogen fuel cell (blue "F" symbol), and/or conventional (black "C" symbol) powertrains. The conventional category includes all fuel types with nonzero tailpipe emissions (CNG, diesel, gasoline, propane, and all hybrid electric options).

Table 9. OEMs Offering Zero-Emission Transit Buses in U.S. Market[4]

OEM	Standard	Articulated	Double-Decker	Coach	Cutaway
Alexander Dennis			C B		
Complete Coach Works*	B				
ENC	C				
Endera					C B
Forest River LLC					C B
Gillig	C B				
Karma Automotive*					B
MCI				C B	
Micro Bird					C B
Motive					B
New Flyer	C B F	C B F			
Optimal*					B
Phoenix	B				B
RIDE (BYD)	B	B	B	B	
* bus repower/remanufacture	C = conventional B = battery electric F = fuel cell electric				

There is currently only one U.S. OEM for hydrogen-fuel-cell-powered transit buses, offering standard size and articulated buses. There are currently no fuel cell powertrain options in the double-decker, coach, or cutaway bus market segments.

For battery-electric powertrains, there are currently five OEM options for standard buses, two options for articulated buses, two for double-decker buses, two for coaches, and seven for cutaways. It is important to note that New Flyer, Alexander Dennis, and Motor Coach Industries (MCI) companies are all part of the New Flyer Group, collectively offering ZEB options in four of the five types of transit buses (NFI Group 2025b). RIDE is the only other manufacturer to offer as many ZEB options, also in the four large bus categories.

[4] Most of the bus types listed, but perhaps not all, may be fully Buy America-compliant and/or have fully completed Altoona testing at the time of this reporting.

For the OEMs offering standard size and articulated ZEBs, Table 10 outlines the model, length, type, energy storage capacity, and nominal driving range between refueling/recharging events (if reported by the OEM). The range specified is the driving range advertised by the OEM for each available energy storage option (battery capacity or hydrogen tank size).

Table 10. Available Standard Size and Articulated ZEB Models in the U.S. Market

OEM	Model	Nominal Length (ft)	BEB	FCEB	Max./Nominal Range (miles)	Energy Storage (kWh, kg)
ENC [a]	AXESS EVO-BE	33	✓		—	Up to 738
	AXESS EVO-BE	35	✓		—	Up to 738
	AXESS EVO-BE	40	✓		—	Up to 738
Gillig [b]	Low Floor	35	✓		—	490, 588, 686
	Low Floor	40	✓		—	490, 588, 686
New Flyer [c]	Xcelsior CHARGE NG	35	✓		182, 220	345, 435
	Xcelsior CHARGE NG	40	✓		176, 216	345, 435
	Xcelsior CHARGE FC	40		✓	370	37.5 (kg)
	Xcelsior CHARGE NG	60	✓		143, 165, 186	530, 605, 690
	Xcelsior CHARGE FC	60		✓	—	56 (kg)
Phoenix [d]	ZX5+	35, 40	✓		240	492
	ZX5 Max	35, 40	✓		340	738
RIDE [e]	K7M, K7M-ER	30	✓		158, 196	213, 313
	K8M	35	✓		196	391
	K9MD	40	✓		208	455
	K11M	60	✓		193	576

[a] eldorado-ca.com/axess/
[b] www.gillig.com/
[c] www.newflyer.com/
[d] phoenixev.ai/
[e] ride.co/

Table 11 lists manufacturers providing zero-emission options for cutaways and other small bus models (length of approximately 30 feet or less). Currently, all ZEB models of the cutaway segment (Class 4–7) are battery electric; there are no commercial fuel cell options for this bus type yet. Nominal battery sizes for the BEBs range from 94 kWh to 237 kWh. Class 5 and 6 cutaways do not yet have commercial models available for zero-emission technologies and have either not passed the FTA Altoona bus testing procedure or obtained a bus testing report. The zero-emission technologies for standard and articulated buses are more mature compared to other bus types. Both cutaway and over-the-road bus types, in particular, need long-range ZEB models due to the nature of their operations in many transit fleets.

As industry continues to develop viable technologies, transit agencies are facing a gap between regulatory expectations and what manufacturers can currently deliver. This disconnect highlights the need for flexibility in the early years of the ZEB transition, particularly for specialized vehicle types that have fewer commercial options. With this context in mind, the following considerations describe why temporary exemptions remain necessary.

The ZEB market and technologies for cutaway, over-the-road coaches, and double-decker buses are not adequately available and mature enough to be ready for implementation in the near term. Therefore, providing exemption from the ZEB purchase requirements for these bus types will ensure transit service will not be adversely impacted by the transition.

Transit agencies that are planning to purchase zero-emission cutaway Class 4, over-the-road coaches, and double-decker buses for the calendar years 2026 through 2028 but cannot find suitable models with suitable driving range could request an ICT exemption. An exemption request must be submitted with complete information by November 30 of each calendar year. A transit agency may purchase conventional internal combustion engine buses instead of ZEBs once the exemption request is granted.

Table 11. Cutaway ZEB Models in the U.S. Market

OEM	Model	Class	ZEB Type	Battery Size (kWh)	BABA	Altoona Tested	FTA Funding Eligible	HVIP Eligible
Endera	B Series	4	BEB	150	Yes	Yes	Yes	Yes
Forest River LLC	E450	4	BEB	122.4	Yes	Yes	Yes	No
Karma	E450	4	BEB conversion	120	Yes	No	Yes	Yes
Micro Bird G5	G5	4	BEB	140 / 175	Yes	No	Yes	Yes
Motive	EPIC	4, 6	BEB	127 / 158 / 237	Yes	No	Yes	Yes
Optimal	S1	4	BEB	113	Yes	Yes	Yes	Yes
Phoenix Motorcars	E450	4, 5	BEB	94 / 105 / 125 / 156	Yes	No	Yes	Yes

There are several online resources to assist with finding commercially available ZEVs, which include transit buses as well as other medium- and heavy-duty vehicle types:

- Zero-Emission Technology Inventory (ZETI): globaldrivetozero.org/tools/zeti/
- HVIP Eligible Vehicles: californiahvip.org/vehiclecatalog/
- Alternative Fuels Data Center (AFDC) vehicle search: afdc.energy.gov/vehicles/search

The overall composition of transit bus fleets by bus type from the ICT survey of California transit agencies is summarized in Figure 19. Large agencies primarily operate standard low-floor buses, with less than 30% of their fleets, on average, containing cutaway, articulated, and over-the-road coaches. Small transit agencies tend to operate a much larger fraction of cutaway shuttles (nearly 40%), with less than half of their fleets comprised of standard buses.

In addition, based on the transit survey, small transit agencies have a wide range of fleet sizes (1–190 buses per agency), and composition of bus types can vary significantly between agencies. Each transit agency will be impacted differently by the market availability of ZEBs depending on their specific fleet composition and unique service conditions. Large agencies will be primarily procuring standard size ZEBs in the coming years, with a smaller mix of coaches, articulated, and cutaway buses. Some large agencies may introduce more double-decker buses in place of articulated buses to maintain high passenger capacities with a smaller footprint to help navigate congested urban streets. Small agencies will be in much larger need of cutaway ZEBs. Some small agencies may opt to increase their number of transit vans (which are not subject to ICT regulation, but may be subject to California's Advanced Clean Fleets regulation) in place of cutaway shuttles to provide flexibility with their bus fleet, particularly for on-demand and paratransit service.

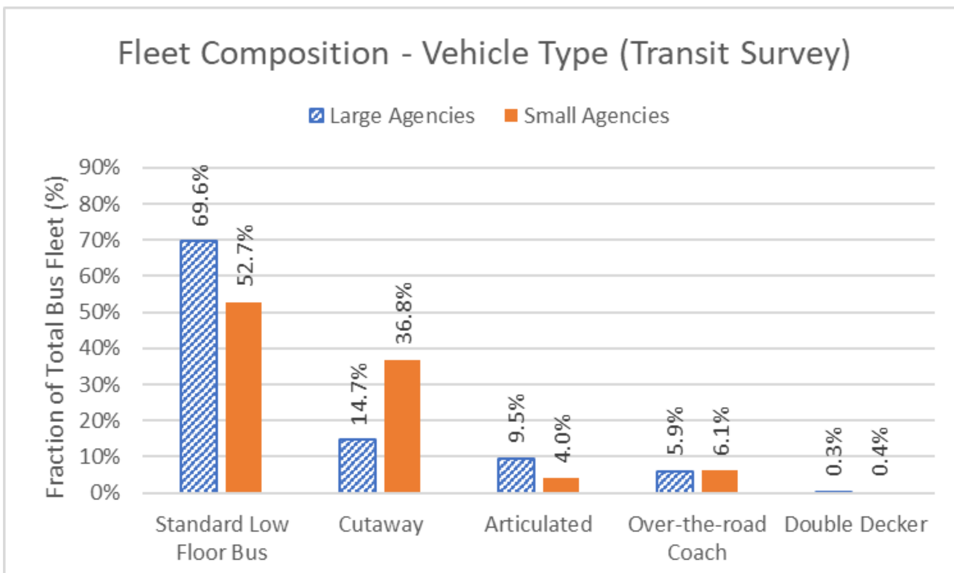

Figure 19. Fleet composition by vehicle type for large and small agencies, from ICT transit survey.

Source: Survey of California transit agencies

The fleet composition ratios calculated from the transit survey data match very well with the ICTRT data collected in 2024, as seen in Figure 20. The corresponding vehicle counts from the ICTRT data are provided in Table 12, with a total of 12,838 active buses reported.

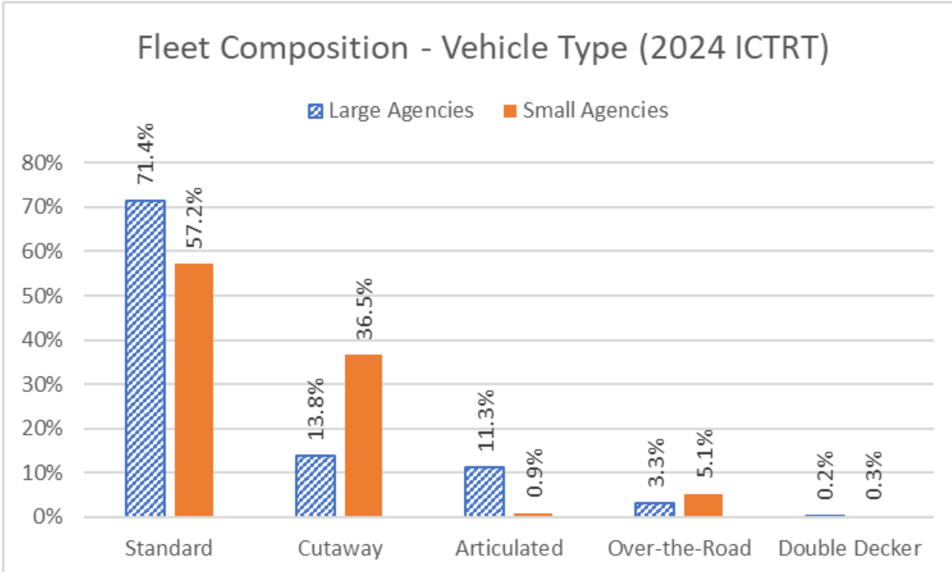

Figure 20. Fleet composition by vehicle type for large and small agencies.

Source: ICTRT, 2024

Table 12. Total Bus Count for Large and Small Agencies, by Vehicle Type.

Source: ICTRT, 2024

	Standard	Cutaway	Articulated	Over-the-Road	Double-Decker	Total
Large agencies	6,389	1,237	1,009	295	17	8,947
Small agencies	2,225	1,422	35	199	10	3,891
Total	**8,614**	**2,659**	**1,044**	**494**	**27**	**12,838**

5.1.4 Bus Manufacturing Challenges

Recent challenges such as increased component prices, supply chain issues, and long delivery times have affected the financial health and stability of the transit bus manufacturing industry. The market has contracted some in recent years, partly due to the global COVID-19 pandemic and subsequent market changes, as noted above. The transit bus market was already relatively small compared to other medium- and heavy-duty vehicle markets. Larger vehicle markets tend to be more stable, with healthy supply chains, and provide more vehicle models/options to consumers. This also allows risk to be shared among a greater number of manufacturers, making the market less susceptible to major disruptions. Expanding the transit bus market moving forward, potentially through measures to encourage transit use and decrease vehicle miles traveled from light-duty vehicles, can be expected to lead to greater stability, greater competition, and more robust supply chains, all of which would be welcomed developments for the ICT program.

Furthermore, the costs of financing bus production from contract award through delivery have become more challenging for manufacturers. Some of the strategies recommended by the FTA to help address this issue include modifying contracts or seeking additional federal funds to account for price increases, as well as providing advance payments and/or progress payments to the contractor during the production phase. This may be especially important for large bus procurements.

The FTA has developed a new webpage devoted to bus procurement resources and guidance for agencies to help streamline the bus procurement process, decrease costs, and accelerate bus delivery timelines.

FTA Bus Procurement: www.transit.dot.gov/funding/procurement/bus-procurement

In early 2025, NLR distributed a list of questions to transit bus OEMs to learn about the current status of the industry and the challenges facing the domestic manufacturing base for ZEBs. In response to questions about ZEB markets, OEM responses to the questionnaire stressed that the U.S. transit bus market is relatively small, with only about 4,500 heavy-duty transit buses purchased annually. This size limits economies of scale, as individual OEMs often produce fewer than 100 buses per configuration each year. This is a challenge for reducing costs and supports the need for leveraging adjacent markets such as heavy-duty trucks to achieve the component production volumes necessary for scaling and innovation.

When asked about the current lead time for delivering a standard BEB, three bus OEMs reported 8-12 months, 12-18 months, and 15-18 months as the expected lead times, depending on the level of customization for the bus order. These estimates are similar to typical historical lead times for transit buses; however, many transit agencies have reported experiencing longer lead times in recent years, following pandemic-related disruptions. It was also reported that the lead time for installing a hydrogen fueling station or for electric utilities to complete necessary service upgrades for charging stations both frequently exceeds the bus delivery times.

OEM strategies to address bus manufacturing lead times include a focus on maintaining supply chain stability through long-term agreements and proactive stock management. OEMs noted that they proactively purchase and store critical spare parts to support timely after-sales service, maintain reliable part availability, and preserve competitive pricing. One strategy for improving critical part supply lead times involves providing forecasts to suppliers based on high-probability orders. Respondents also noted that ICT ZEB purchase requirements help grow the size of the market in California, and that the U.S. bus manufacturing industry is capable of meeting future demand driven by the ICT requirements.

The OEMs were asked what specific policies are needed to improve the health of the ZEB bus industry, and they provided the following responses:

1. To ensure transit agencies are able to continue growing the use of ZEBs in California, additional incentive funding availability will likely be necessary.
2. "Adjacent market" (e.g. medium- and heavy-duty truck markets) adoption of zero-emission technologies will also be critical for the long-term viability of the ZEB market.
3. Significant volumes from heavy-duty trucking will be required to ensure component and system supplier viability, especially for the expensive components like batteries and fuel cell stacks.

4. Stable, multiyear funding commitments: multiyear funding programs with clear and consistent guidelines will allow transit agencies and OEMs to plan ahead, scale-up operations, and invest in workforce and infrastructure with confidence.
5. Certainty, prioritization, and resource support are keys to the development of any emerging technology—policies must consistently prioritize the development of the sector as a strategic state priority.
6. Stronger policies are needed to require utilities to prioritize and streamline interconnection processes and infrastructure upgrades for fleet electrification.

A fuel cell supplier added that they recommend no change to the ICT regulation, as long-term stability and visibility are critical for the industry to continue investment in ZEB technology and plan production and support scaling up. The OEMs also commented on key factors affecting ZEB parts supply and ZEB charging equipment, including:

- BEB parts supply:
  - There is an overseas supply chain for many subcomponents incorporated into battery packs and motors such as battery cells, many of which have experienced significant global demand which exceeds those suppliers' production capacity.
  - While historical supply constraints on battery packs were the largest contributor to parts unavailability, this has eased considerably over the last 6-12 months.
- BEB charging equipment supply
  - The most significant impact is utility infrastructure readiness.
  - Transit agencies have reported significant lead times for utilities to provide the additional service needed to charge electric buses.
  - Components such as switchgear have been challenging for customers to obtain in a timely manner.

5.2 ZEB Costs

There are numerous vehicle-related costs associated with deploying ZEBs, which are largely separated into two categories: (1) upfront capital costs to purchase the buses, and (2) operation and maintenance costs throughout the bus lifetime. There are additional costs for purchasing and installing the infrastructure required for charging or fueling ZEBs, and there may be costs associated with modifying or upgrading facilities such as parking areas and maintenance bays at a bus depot. Infrastructure topics are discussed in the next Section (6: ZEB Charging and Refueling Infrastructure).

5.2.1 ZEB Capital Costs

One significant barrier for transit agencies trying to deploy ZEBs is the higher cost to purchase ZEBs compared to the conventional buses they stand to replace. New and advanced technologies typically carry a cost premium over the incumbent technology, especially when production volumes are low, the supply chain for critical parts is not well established, and learning-by-doing is still occurring, and this remains true for transit buses. With increases in R&D and higher sales volumes as the technologies mature, the upfront capital costs are expected to decrease; however, ZEBs have not yet reached cost parity with conventional transit buses. Higher market competition will help drive down the prices as seen in many other industries and businesses such as telecommunications, electronics, groceries, etc. Market competition enables innovative pricing strategies. Competitive pricing strategies also have an advantage in advancing technologies and improving vehicle reliability.

Purchase incentives, which are designed to offset the higher purchase price of zero-emission technology and increase initial production volumes, may also affect a manufacturer's pricing strategy, potentially causing incentive-induced price inflation. Incentive programs are designed so that per-vehicle incentive amounts decrease as economies of scale and cost reductions are achieved, making incentives no longer necessary to spur broad market adoption. An example of this was the phase out of California's Clean Vehicle Rebate Program vouchers for light-duty ZEVs for all but low-income buyers. In the transit bus space, it is critical for OEMs, fleets, parts suppliers, and technology providers to work together to identify a long-term price containment mechanism for a healthy market, and for the incentive programs to align with these strategies (CARB, n.d.-b).

Prior to the global COVID-19 pandemic (circa 2015–2020), BEB and FCEB costs generally had been decreasing steadily. But then due to supply chain disruptions and other factors affecting the ZEB market, the declining upfront purchase costs leveled out briefly and then began to increase for ZEBs.

Some of the elements of the cost that make up the total capital cost of a bus include the base price, spare parts, OEM support, extended warranties (for energy storage system and/or other vehicle systems), and markup for additional bus options or upgraded features/components, if selected. Costs of customized parts (not heating, ventilating, air conditioning, or propulsion) can significantly affect the overall bus cost. One OEM quoted a price difference of $100,000 per bus between two customers purely based on customization. This is an example of how bus standardization can reduce ZEB costs (Caltrans 2024). Similarly, some bus purchases may be given a volume discount for large orders. The California DGS required the individual cost components be listed separately by bidders in a recent request for proposals for statewide Zero-Emission Transit Bus procurement in order to produce a more transparent comparison between costs from each ZEB manufacturer (State of California Department of General Services 2024). The 2025 DGS solicitation process resulted in statewide purchase contracts with three transit bus manufacturers for ZEBs of various size, type, and battery capacity combinations (details provided in the Appendix).

Many of the transit agencies that submitted ROPs to CARB projected the capital costs for the ZEBs they anticipated purchasing for compliance with the ICT regulation in the coming years. Some of these estimates are based on actual purchase quotes that agencies solicited from one or more bus OEMs, and some reported costs are simply a best estimate by the agency based on the available public information. Some of the estimates also include a cost escalation for later years to account for inflation and other factors increasing the bus costs over time. These cost ranges indicate what California transit agencies were expecting to pay for ZEBs at the time of their ROP developments.

The boxplots in Figure 21 show the distributions of bus cost estimates provided in the ROPs for BEBs (left) and for FCEBs (right), separated by vehicle type. The average of the estimated costs for standard BEBs was more than $900,000. The FCEB average from the estimated costs reported by transit agencies was approximately $1.2 million per bus. For both plots, the triangles and diamond markers indicate average costs for conventional fuel buses (CNG, diesel, and gasoline) as provided in some of the ROPs for baseline comparison to the ZEBs. Standard size CNG and diesel buses were expected to be near or below $600,000 per bus.

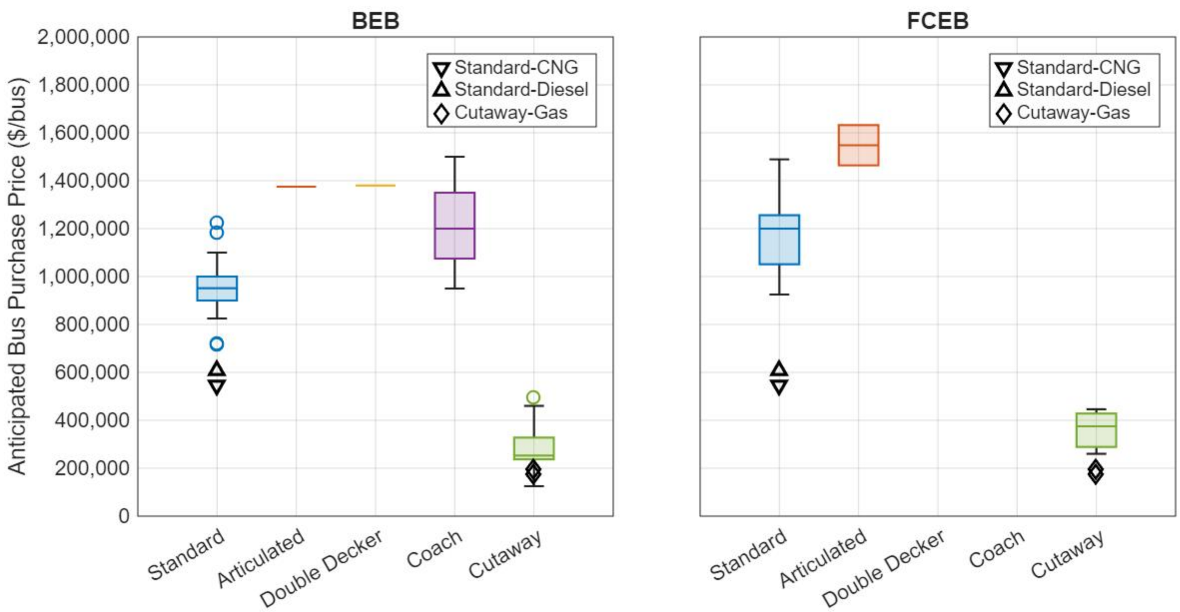

Figure 21. Anticipated purchase prices for ZEBs from transit agency ROPs.

Source: ICT rollout plans submitted to CARB

To begin evaluating the actual cost trends of standard size ZEBs that have previously been deployed in service, NLR performed a meta-analysis of published bus evaluations from the literature review, comparing standard size ZEBs to conventional buses (see Appendix for publication list). One of the metrics evaluated was the capital cost of the BEBs or FCEBs in each study compared to the cost for the baseline conventional buses (CNG, diesel, and/or diesel hybrid). The published studies reported the average bus capital costs shown in Figure 22. Each column in the figure represents the average cost of all buses for that model year (labeled along the top of the columns), and the columns are grouped by fuel/powertrain type. The number in the middle of each column indicates the number of buses included in the average for each model year. The weighted average capital cost for each powertrain group is shown as a horizontal black line and labeled to the right of each line.

For FCEBs, the 2018-2022 model years were substantially less expensive (approximately $1.2 million per bus) compared to the earlier generation FCEBs (averaging between $1.9 and $2.4 million per bus). Many of the early-generation FCEBs were early demonstration buses that were part of an FCEB deployment program to begin testing the new technology in revenue service. The later generation FCEBs (2018-2022) demonstrate a significant decrease in costs but were still approximately twice as expensive as the reported prices of the baseline CNG, diesel, and diesel hybrid buses in the studies, although it is important to note that some of these baseline buses represent older model years than the new FCEBs that were compared. For the BEBs in the published studies, the weighted average of the reported capital costs was approximately $1 million per bus, with slightly higher costs for model years 2018, 2019, and 2020. Diesel, CNG, and diesel hybrid buses in these studies had average costs of approximately $245,000, $567,000, and $612,000, respectively, with each conventional bus group showing a steady, incremental cost increase over the years.

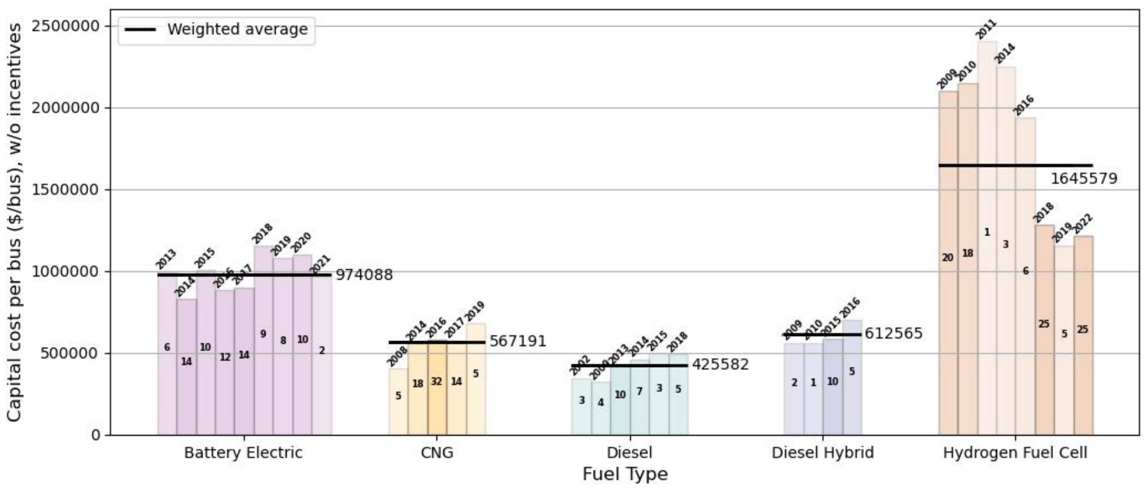

Figure 22. Comparison of bus capital costs by fuel type.

Source: NLR meta-analysis of published ZEB evaluations

One of the primary cost drivers for ZEBs is the high cost of advanced, lithium-based batteries. ZEB battery costs cannot be directly comparable to passenger car battery costs because the vehicles and their duty cycles impose different technical and commercial requirements. ZEB batteries must deliver much higher usable energy (often several hundred kilowatt-hours) compared to a typical passenger car battery capacity of 50–100 kWh. Besides higher power demand, ZEB batteries also need to withstand deep discharge and recharge cycles and meet more rugged thermal management, safety, and packaging requirements (CARB 2020). The heavy-duty EV market is smaller and more fragmented than the passenger car market, so battery manufacturers are unable to lower per-unit manufacturing, overhead, and warranty costs. As a result, even if individual battery-cell prices fall, the heavy-duty vehicle battery pack's cost per kilowatt-hour of useful energy is higher than that for light-duty vehicles. Unlike light-duty vehicles, integrating depot and/or opportunity charging (en route) is an additional expense for ZEBs.

While the Buy America requirement does create and potentially retain domestic manufacturing jobs by directing public procurement toward U.S. suppliers, strengthening resilience and accelerating investments in the domestic market, it does have some unforeseen consequences like increasing the production timelines, raising procurement costs and risks involved in supply chain bottlenecks, and trade disputes complicating market participation by allied countries (Federal Transit Administration 2025b).

Complementary policies such as incentives, workforce training and recycling could potentially alleviate these costs to some extent. However, if Buy America is implemented as a stand-alone policy it may not create cost-competitive domestic industries and ultimately result in necessitating increased cost to transit riders. One approach would be to implement some or all of the following actions: establishing ZEB demand guarantees, offering domestic production investment tax credits, providing targeted waivers, and introducing phased domestic content in the Buy America requirement. Together these measures could help reduce short-term disruption while still supporting long-term domestic industrial goals.

The rising BEB costs are coupled with the fluctuating battery manufacturing market. For example, Gillig's ZEB batteries are manufactured by AKASOL AG—a German manufacturer of EV batteries that was bought in 2022 by BorgWarner Inc., a supplier of automotive components and technologies. New Flyer's ZEB batteries are manufactured by another German company, Freudenberg e-Power Systems' XALT. They have recently announced that they are closing down the Michigan location due to the decreasing demand for heavy-duty electric and hybrid electric vehicles in North America. Such instabilities in the market are adversely impacting ZEB vehicle manufacturing, sales, and operations.

As bus manufacturers increased the onboard storage capacity of BEBs to achieve longer driving ranges, the upfront cost of BEBs increased. This is a trend that was seen as the BEB technology matured over the past 10–15 years, and it is one of the main reasons the BEB costs increased slightly for the later BEB model years shown in Figure 22. To evaluate this relationship more closely, Figure 23 shows examples of total BEB capital costs compared to nominal battery capacity, from the meta-analysis of published BEB evaluations. Buses identified in the figure as fast-charge BEBs were model year 2014 and 2016 first-generation electric buses which used on-route charging for short-range, circulator routes. The other BEBs in this data set, which had model years between 2015-2021, had larger battery capacities (greater than 250 kWh) and were primarily marketed as extended range buses that utilized depot charging. The majority of extended range BEBs had between 400-500 kWh of energy storage, and the average BEB costs were between $800,000 and $900,000 per bus. Costs increased to nearly $1.2 million per bus for 525 kWh and up to $1.4 million per bus for 660-kWh battery capacities.

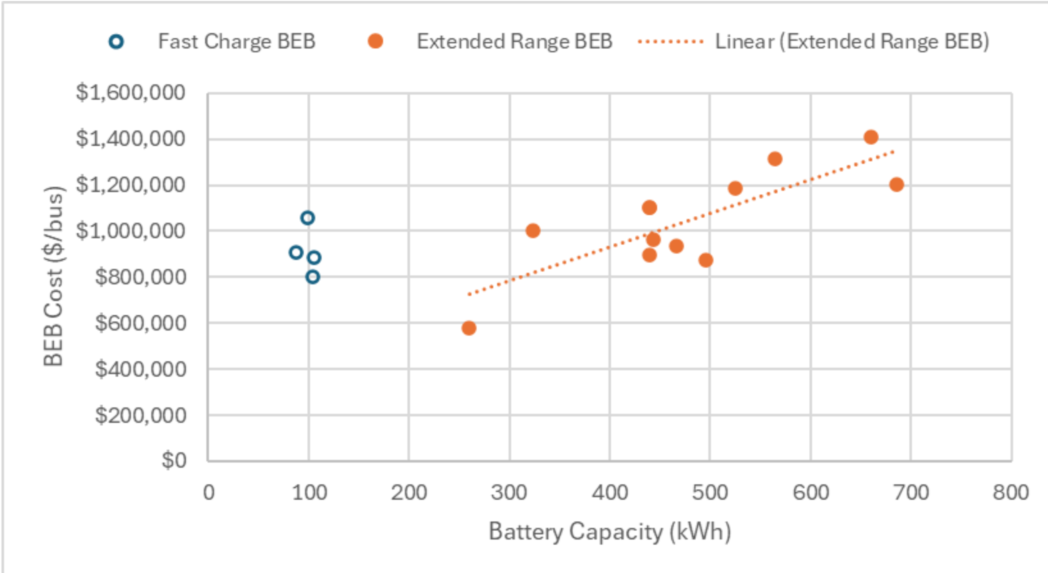

Figure 23. BEB capital cost ($/bus) compared to nominal battery capacity (kWh).

Source: NLR meta-analysis of published ZEB evaluations

To provide an updated view of this relationship, Figure 24 shows a similar comparison of BEB capital costs versus nominal battery capacity with the most recent price information from the 2025 California DGS contracts awarded to multiple BEB manufacturers. The standard low-floor buses in the dataset were grouped by size and linear trend lines were added for 30-foot, 35-foot, and 40-foot bus groups, which show very close alignment. Thus, it currently costs approximately $1,000,000 per bus for a BEB with 400 kWh, between $1,100,000 and $1,200,000 for 500 kWh, and $1,300,000 for around 700 kWh of energy storage. Within each bus platform (i.e., consistent make & model of BEB), the incremental cost per kilowatt-hour to purchase a BEB with a larger battery size than the minimum size offered is $567/kWh, on average. For reference, BloombergNEF reported at the end of 2024 that the global average commodity price for lithium-based battery packs from a variety of end-use applications had dropped to $115/kWh (BloombergNEF 2024).

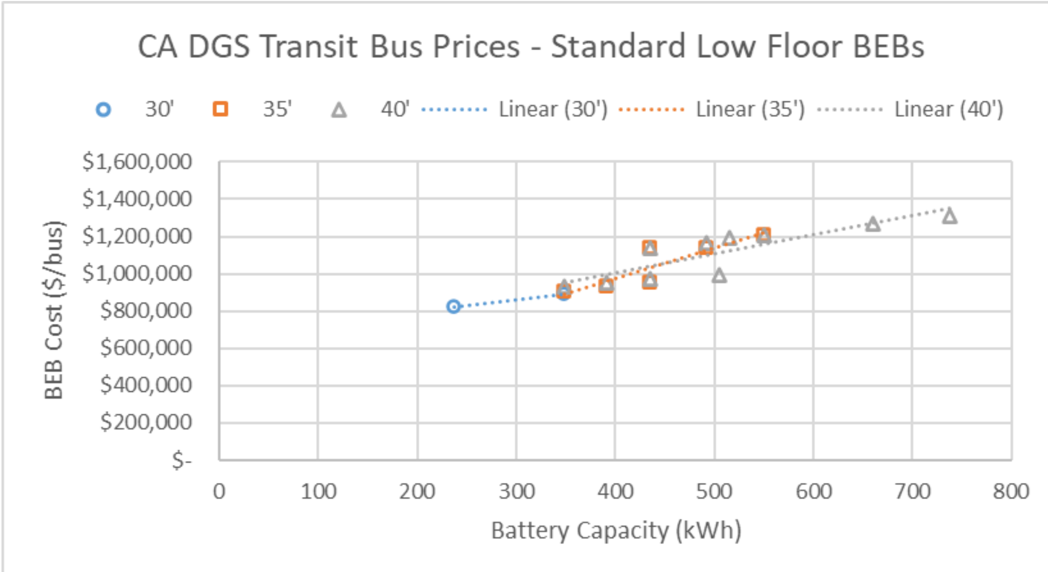

Figure 24. California DGS 2025 BEB capital cost ($/bus) compared to nominal battery capacity (kWh).

Source: California DGS statewide purchase contracts, 2025

Another important source of historical capital cost data for transit buses is the annual APTA Public Transportation Vehicle Database (American Public Transportation Association 2025b). This annual inventory of transit vehicles catalogs buses in operation and new buses on order at agencies throughout the U.S., detailing the OEM, model, size, powertrain type, year, location, and number of vehicles in each bus purchase. In many cases, transit agencies also provided the purchase cost of the buses which enables a direct comparison of buses with different powertrains/fuel types for each model year. Thus, Figure 25 provides the historical trends of the purchase costs for standard size transit buses (35–45 feet) separated by powertrain/fuel type. The individual purchases reported by transit agencies to APTA were computed into a weighted average bus cost for each model year and powertrain type. Data points for years after 2025 indicate purchases for buses on order that have not yet been built and delivered.

Over the past 15 years, conventional buses have all steadily increased in capital costs. By 2020, average costs were approximately $500,000 per bus for diesel, similar or slightly higher for CNG, and $750,000-$800,000 for diesel hybrid. BEBs show a decreasing average cost from 2012 to 2017, leveling out for a few years as decreasing battery technology costs were generally offset by increasing battery sizes, and then increasing in 2021 and beyond due to post-pandemic market conditions.

For FCEBs, there are very few datapoints prior to 2020 in this dataset, and the reported prices in these early years were highly variable because the early demonstration vehicles with nascent yet evolving fuel cell technology were still expensive but sometimes offset with grant funding for the FCEB demonstration program. From 2021 to 2025, the FCEB average shows a very sharp increase, from approximately $1.0 million per bus to $1.4 million per bus—a 40% increase in only 4 years following the start of the COVID-19 pandemic.

Also included in Figure 25 for reference are the latest California DGS statewide contract prices for standard low-floor ZEBs, averaged across all manufacturers and bus options within each fuel type group. The average FCEB cost is $1.538 million per bus, and the average cost for a standard size BEB is $1.062 million per bus.

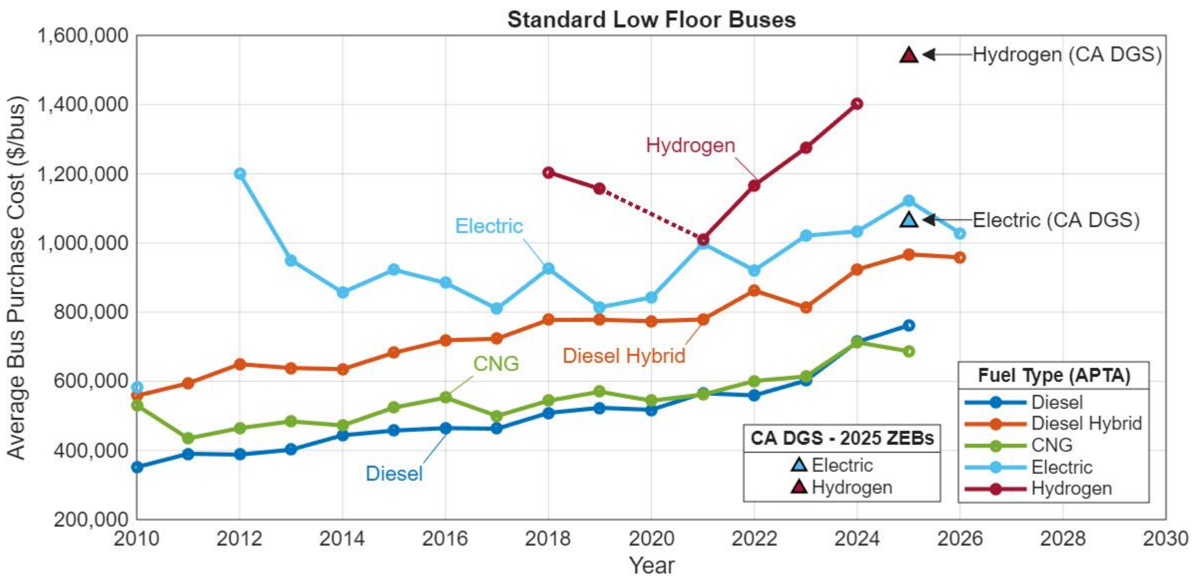

Figure 25. Purchase cost trends for standard buses by fuel type, 2010–2030.

Source: APTA (2025b)

Additional examples of costs reported by California transit agencies purchasing ZEBs in recent years include:

- Foothill Transit reported a cost of $1.41 million for new standard 40-ft FCEBs in 2023/2024.
- OCTA reported $1.3 million for a standard FCEB, and $1.1 million for a standard BEB.
- Santa Cruz Metro reported that standard 40-ft FCEBs cost $1.44 million as of December 2023, and articulated FCEBs cost $2.13 million.

Similar to standard size buses, articulated buses have been steadily increasing in capital costs over the past 15 years for CNG, diesel, and diesel hybrid powertrains (Figure 26). The 2025 average cost for diesel was $1,107,000 per bus. Hydrogen fuel cell and battery-electric models in this data set show very steep increases in the past 3–5 years. From the APTA data, 2025 average costs for fuel cell and battery-electric articulated buses were $2,000,000 and $1,845,000 per bus, respectively. The equivalent purchase costs from the 2025 California DGS contracts were $2,107,000 per bus for hydrogen fuel cell and $1,739,000 per BEB.

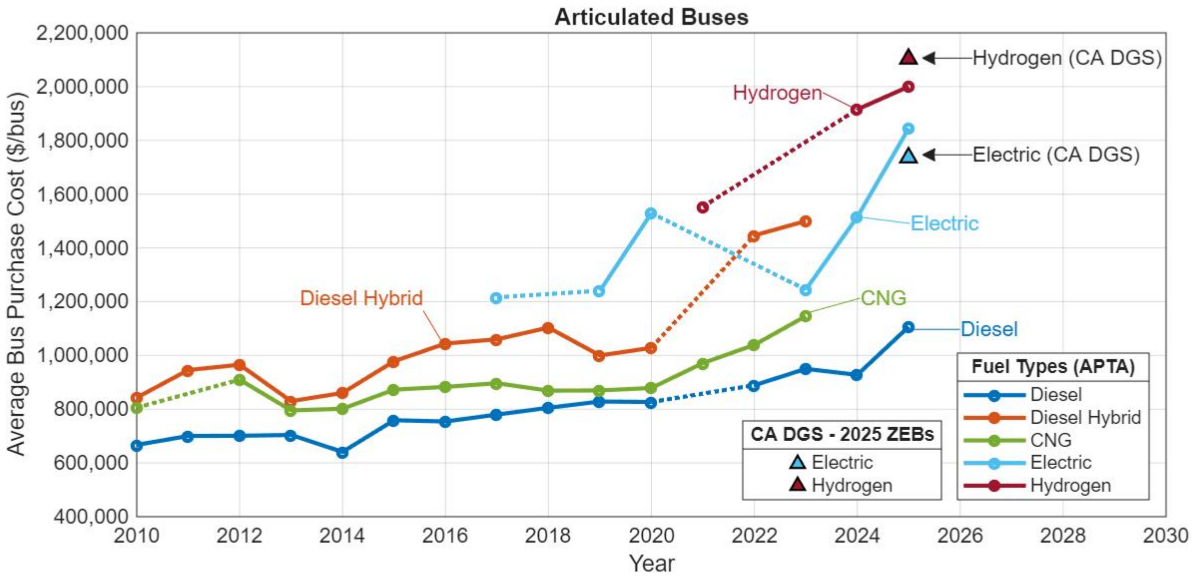

Figure 26. Purchase cost trends for articulated buses by fuel type, 2010–2030.

Source: APTA (2025b)

The 2025 APTA database reports recent purchases of diesel over-the-road coaches averaged $850,000 per bus in 2025 (Figure 27). New models of battery-electric coaches sold for an average of $1,264,000 per bus in 2023 and $1,133,000 per bus in 2024. California DGS statewide contract pricing in 2025 for an electric coach is $1,285,000 per bus, revealing the steep cost premium that exists for zero-emission coach buses.

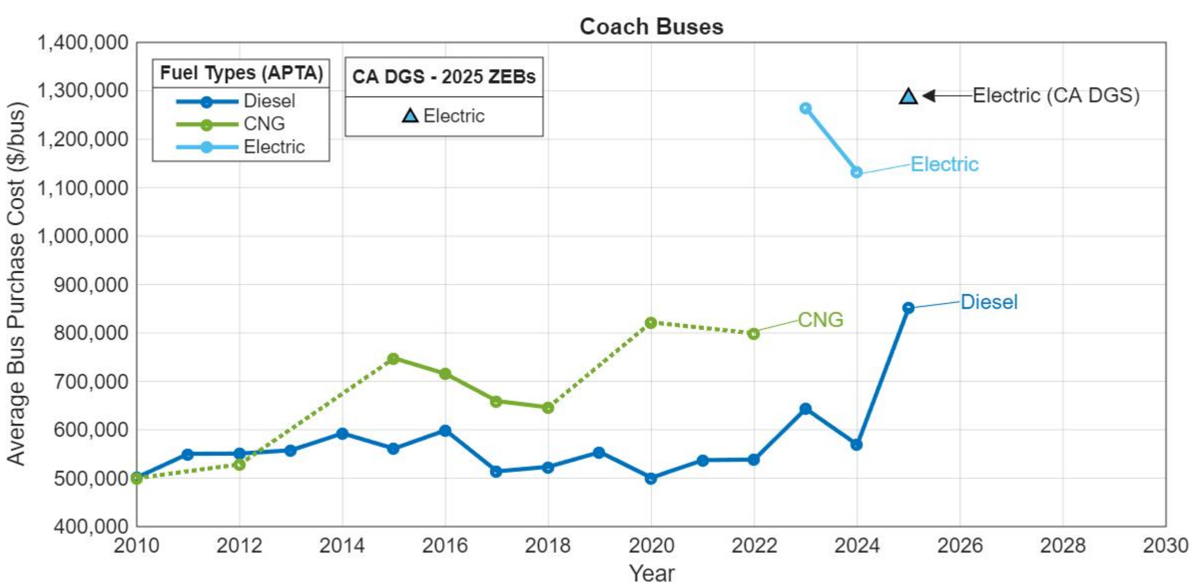

Figure 27. Purchase cost trends for coach buses by fuel type, 2010–2030.

Source: APTA (2025b)

Double-decker buses are much less common in the United States than standard and articulated transit buses. They are typically only used in highly congested urban areas with high passenger volumes. Prices reported in the 2025 APTA database show diesel double-decker buses have typically cost between $600,000 and $900,000 in recent years (Figure 28). There are even fewer electric double-decker buses in operation in the United States currently. Foothill Transit, as one prime example, made an initial purchase of two electric double-decker buses in 2018 and reported a capital cost of nearly $1.7 million per bus. The agency made a subsequent order of 12 more electric double-deckers, with delivery expected in 2026. Foothill reported an increase of approximately 40% in the Producer Price Index commodity index for truck and bus bodies between their first and second purchases. The 2025 APTA database shows purchases for electric double-decker buses between 2020 and 2022 averaging between $840,000 and $1,200,000 per bus.

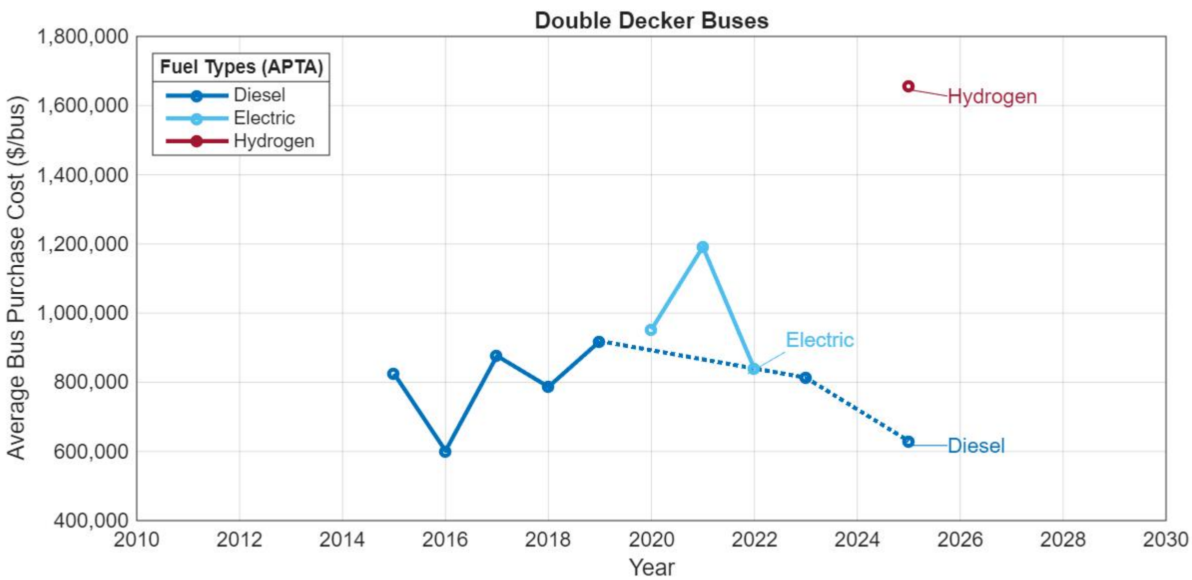

Figure 28. Purchase cost trends for double-decker buses by fuel type, 2010–2030.

Source: APTA (2025b)

For cutaway buses, the APTA database has insufficient data to show average trends for BEBs (only 2 reported purchases) and no data for FCEBs, as fuel-cell-powered cutaway buses are not yet available in the market. Cutaways using conventional fuel show average costs in 2024 of approximately $150,000 per bus for gasoline and $250,000 per bus for CNG (Figure 29). 2023 model year electric cutaways were reported at approximately $300,000 per bus, which is nearly twice as expensive as a new gasoline cutaway, and the electric cutaway is not yet considered to be a one-to-one replacement with the gasoline models. Although the ICT regulation is expanding to cover cutaway buses in 2026, the market for ZEB cutaways is less mature than other bus types.

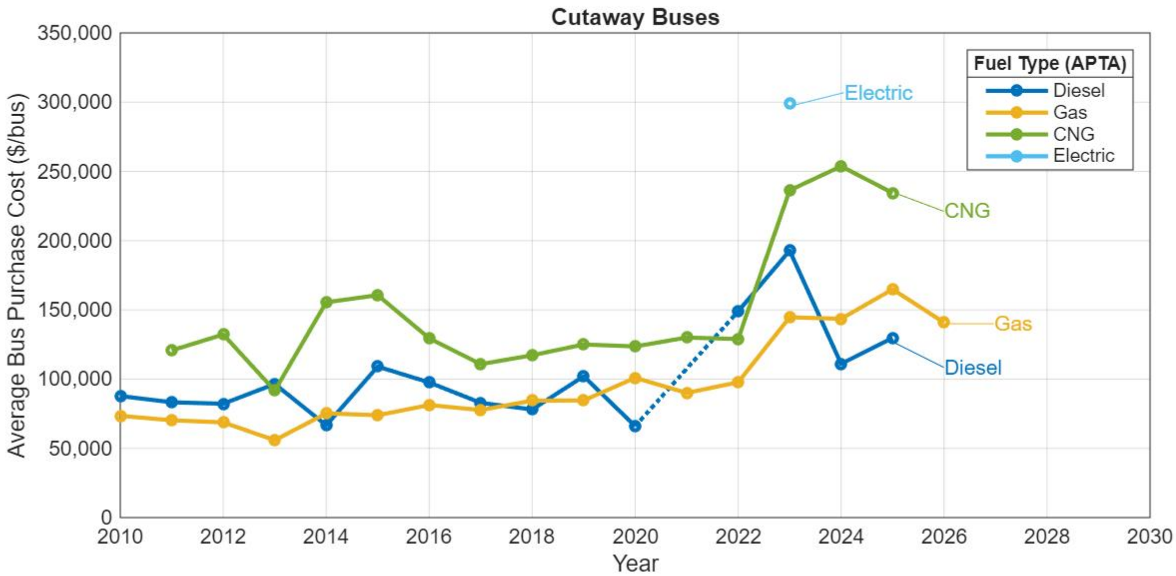

Figure 29. Purchase cost trends for cutaway buses by fuel type, 2010–2030.

Source: APTA (2025b)

It has been reported that the cost of a Ford E-Transit van was $100,000 without HVIP incentives in recent years.[5] The 2026 base model van is advertised to be closer to $50,000 (89 kWh) (Ford, n.d.). For agencies looking to replace cutaway buses with EVs, an electric passenger van may be the more economic choice in the near term. Utilizing smaller vehicles (for short routes and/or on-demand service) may have additional benefits such as not requiring special training and/or endorsements for driver's licenses, helping transit agencies attract vehicles operators.

In its latest needs assessment report, the California Transportation Commission provided an estimate of the cost to transition all transit agencies in the state to all-ZEB fleets. Using data from the ROPs submitted by all 21 large transit agencies and 28 small transit agencies, the California Transportation Commission estimated the cost will be approximately $8.4 billion for all large transit agencies ($400 million per agency) and approximately $1.06 billion for all small transit agencies ($38 million per agency) (California Transportation Commission 2024).

Strategies for Decreasing Bus Capital Costs

In the survey of California transit agencies, respondents provided a variety of suggestions on strategies that would help make ZEBs more affordable (i.e., by decreasing the cost of ZEBs directly and/or supporting transit agencies' ability to purchase ZEBs). Some of the top suggestions are detailed below.

- **Standard design buses and group procurements:** Numerous agencies reported they would be willing to buy more standardized ZEBs and participate in large, collaborative purchasing (such as statewide procurement contracts) in order to reduce the average cost per bus for ZEBs. This was the view 33 of 48 small transit agencies. This approach was

[5] San Diego Metropolitan Transit System, per correspondence with CARB.

less favorable to large transit agencies (only 5 of 14 agreed), as many of these agencies already have the purchasing power of large procurement contracts that small transit agencies do not benefit from. In addition, large transit agencies tend to have stronger preferences for specific vehicle configurations that fit their service requirements and a desire to maintain consistent and compelling branding for their agency.

- **Exempting state taxes:** Nearly every transit agency responding to the survey is in favor of extending California Assembly Bill 2622 to exempt state taxes for ZEBs. All 12 large agencies who responded to the question agreed with exempting taxes, and 43 of 47 small agencies agreed. A follow-up question asked the agencies about their desired timeframe for exempting taxes. Large agencies were evenly split between the option for "extend through 2040" (when the entire California bus fleet is expected to be converted to ZEB, per the ICT program), and the option "the state should never tax transit". Small transit agencies were roughly divided between three options, "extend though 2040", "extend until ZEB costs are equivalent to conventional bus costs", and "the state should never tax transit". There is broad consensus among transit agencies that exempting state taxes would help them afford ZEB purchases.

In addition, some recommendations will help strengthen the financial position of transit bus OEMs, which will enable the continued operation and increase competition in the market, thereby reducing bus costs, including the implementation of milestone payments (e.g., progress payments made as portions of a large bus order are completed/delivered by the OEM to the transit agency).

5.2.2 Fuel/Energy Costs

In addition to capital costs, the major factors driving the cost of ownership for transit buses are the operating costs. The cost of fuel/electricity for the bus, as one of the primary elements of bus operating costs, bears major influence on the overall cost of ownership, especially for a vehicle which logs many miles per day with an expected lifetime of at least 12 years.

Respondents to the transit survey reported the average unit price that was paid for various fuels used by their bus fleets. The provided results, summarized in Figure 30, were converted to dollars per diesel gallon equivalent for direct comparison. All conventional/fossil fuels—including natural gas (CNG/LNG), diesel, gasoline, and propane (liquefied petroleum gas, or LPG)—have average unit prices between $2.60 and $5.00 per diesel gallon equivalent. Hydrogen fuel averages $10 per diesel gallon equivalent, based on prices provided by three large agencies currently operating FCEBs, which is 2–3 times the unit price of conventional fuels.

The electricity prices provided in the survey vary substantially. This is partially due to the nature of electricity rates, where the overall costs for the energy can depend a lot on *when* the energy was used (for time-of-use pricing) and *how fast* the energy was used (total demand for electricity). Thus, higher-powered DC fast charging and/or charging that occurs during peak electricity times can significantly drive up the electric bills from the dollars-per-kilowatt-hour base rate. The actual costs for electricity to charge BEBs can far exceed estimates based only on the simple/flat base rates for electricity, depending on the utility rate structure.

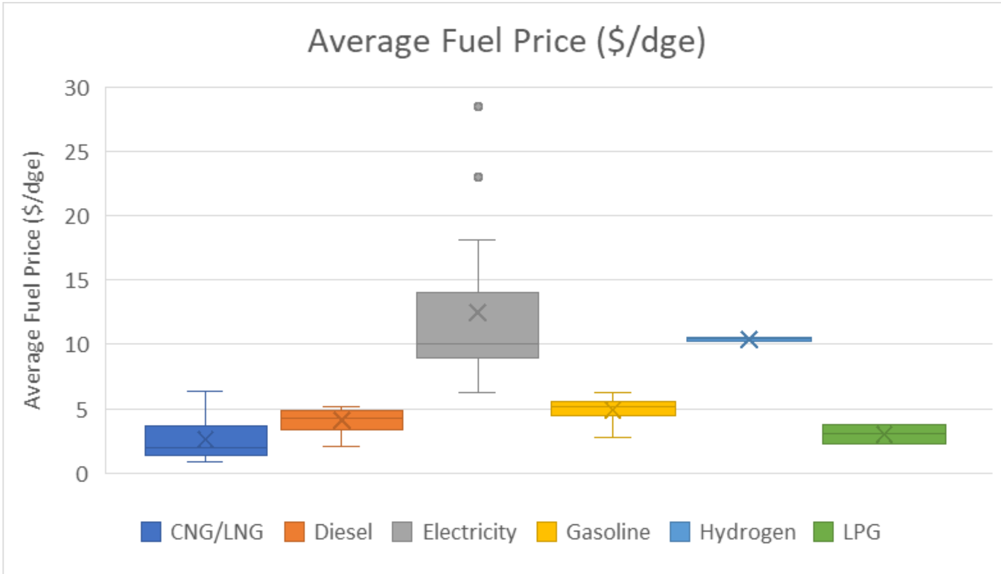

Figure 30. Average unit prices for fuel, from transit survey.

Source: Survey of California transit agencies

It is clear from the survey results that transit agencies operating BEBs in California are currently paying a premium for electricity as a transportation fuel compared to conventional fuels, on a per-unit-energy basis. (This does not account for the difference in energy efficiency between the different powertrains, in terms of cost per mile, which is discussed below.) The actual energy costs often do not match the expectations of the transit agencies when they initially plan for BEBs. In the evaluation of the Standard Review Projects, it was reported that "expected fuel cost savings was one of the primary motivators for fleet operators to begin electrifying their fleet" (Cadmus Group et al. 2024; 2025). Some of the fleets experienced lower fuel costs for their EVs, but this was not the case for all fleet operators.

With the exception of LPG, small agencies tend to pay more per unit than large agencies for conventional bus fuels, and for electricity (Figure 31). This is primarily due to transportation or transmission distances, which increases the cost.

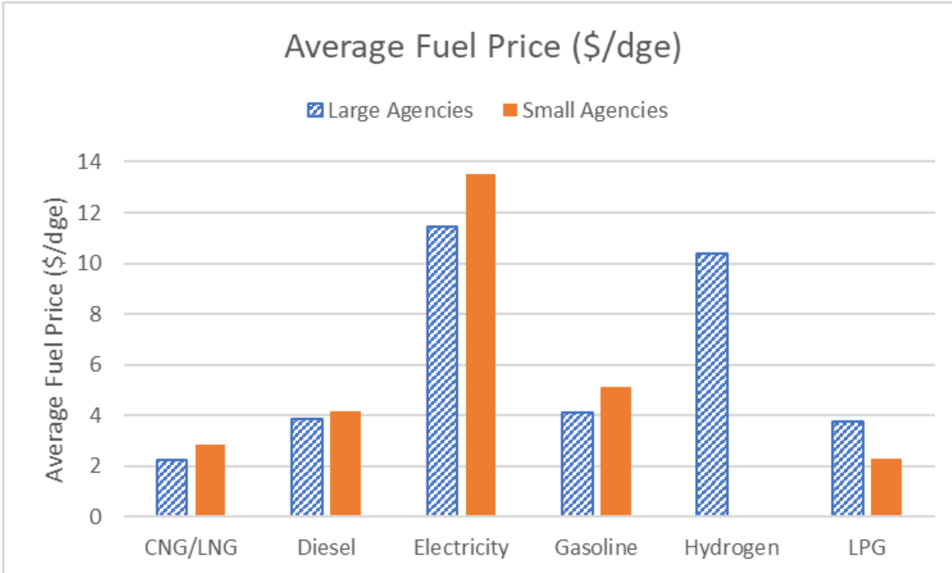

Figure 31. Average unit prices for fuel, large versus small agencies.

Source: Survey of California transit agencies

The latest fuel price forecasts from the CEC's Transportation Energy Forecasting Unit were updated in August 2024 (Figure 32). The forecasts utilize historical data from 2019 up to 2024, and project future costs out to 2050. The projected costs are based on the Energy Information Administration's Annual Energy Outlook for the underlying data, adjusted using a statistical approach to represent California prices.

Prices for conventional fuels (diesel, gasoline, CNG/LNG, and LPG) are shown to be relatively stable for the next 25 years, averaging between $3.00 and $5.00 per unit. Commercial electricity is also shown to be stable at about $8.00 per gasoline gallon equivalent. The most notable trend in the figure is the sharp peak for hydrogen in 2024, followed by an equally sharp decline until 2028 when it levels off at $15.00 per gasoline gallon equivalent.

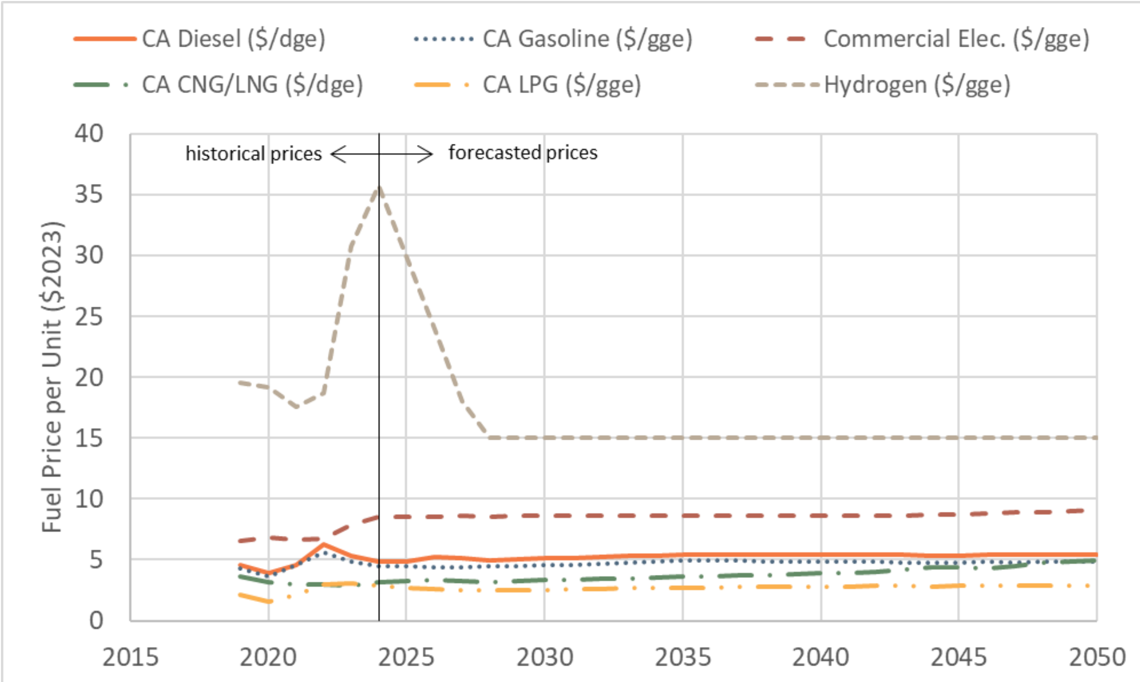

Figure 32. Price forecasts for California transportation fuels, 2025–2050.

Source: CEC transportation fuel price forecasts, 2024

Although the price is expected to quickly drop below the plotted historical level, this hydrogen fuel price is still significantly higher than what agencies recently reported paying in the transit survey ($10/kg), and far exceeds the price projections that CARB estimated during the initial rulemaking for the ICT regulation (California Air Resources Board 2018a). At that time, based on the available data, it was expected that the unit price for hydrogen would decrease steadily from $8.00/kg in 2016 and reach the DOE target of $4.00/kg in 2020 and beyond.

Evaluations of transit agencies participating in the IOU SB 350 Standard Review Projects have provided some insights into these costs, from the fourth year of the evaluation (Figure 33). The comparison shows the variation in monthly average electricity cost per kilowatt-hour versus the proportion of energy consumed during the peak time-of-use (TOU) rate period (4–9 p.m.), for sites in California separated into four vehicle segments—heavy-duty vehicles, medium-duty vehicles, school buses, and transit buses. The report indicated that 45% of transit bus charging sessions overlap with peak periods, and 20% of energy consumed could be shifted to lower-cost periods. The charging flexibility analysis from the SB 350 program evaluation report also suggests that many of the transit fleets could significantly reduce the average cost of electricity by shifting some charging sessions to lower-cost time periods with managed, or scheduled, charging (California Public Utilities Commission, n.d.).

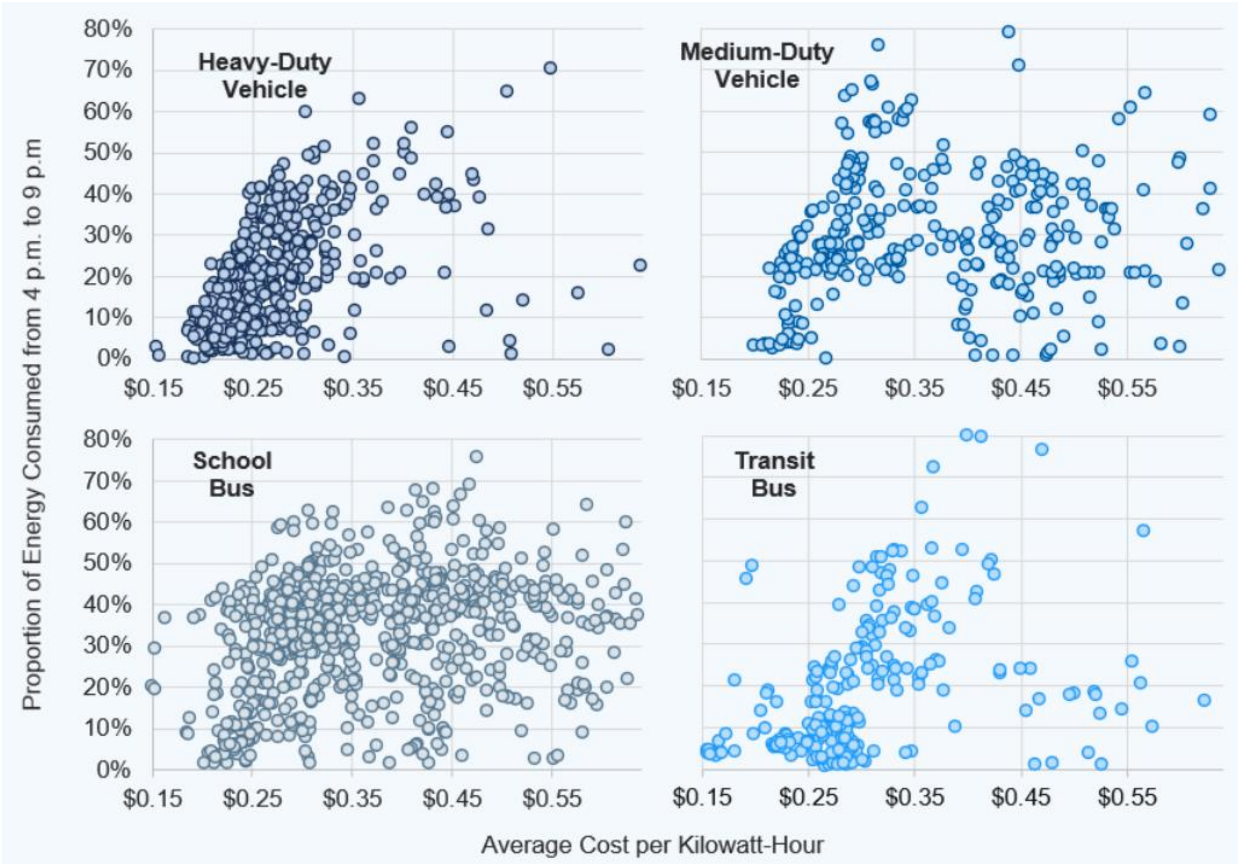

Figure 33. Average cost per kilowatt-hour for 23 transit bus sites in California.

Source: Cadmus Group et al. (2025)

For transit operations, fuel costs are ultimately measured on a per-mile basis, which accounts for the differences in unit prices of fuel as well as the different energy efficiency of each powertrain type. This allows for a direct comparison of fuel costs—one of the primary operating costs for transit buses.

Figure 34 compares reported fuel costs per mile by bus type for non-ZEBs (all conventional fuel types combined) to BEBs and FCEBs. This chart reflects data collected from the ICT transit survey. Compared to non-ZEBs, standard BEBs have lower fuel costs, electric coaches have higher fuel costs, and electric articulated buses have essentially equal fuel costs (on a per-mile basis). For FCEBs, only standard size buses have fuel costs reported in the survey, which were approximately 70% higher than the per-mile fuel costs for non-ZEBs. This is a result of the high cost per kilogram for hydrogen fuel.

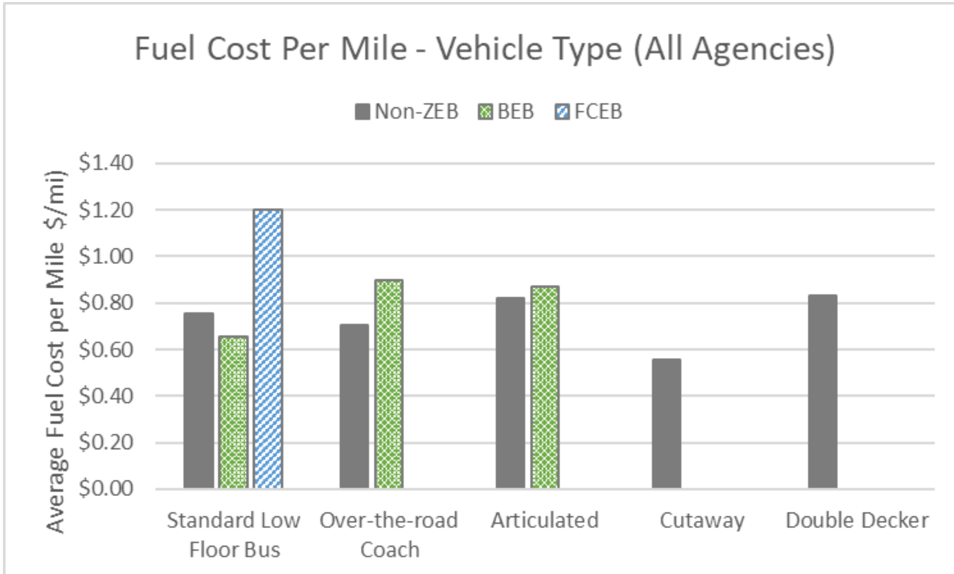

Figure 34. Average fuel cost per mile by bus type.

Source: Survey of California transit agencies

The more recent per-mile costs provided via the transit survey are higher than what was calculated in the meta-analysis of published ZEB evaluations (for standard size buses). Figure 35 shows the fuel costs for conventional buses (CNG, diesel, and diesel hybrid) were between $0.40 and $0.60 per mile. The BEBs in the published studies, with model years 2014-2021, had a weighted average of $0.50 per mile. The weighted average of the FCEBs in the figure is influenced slightly by high fuel costs for the earliest generation of FCEBs, which had lower fuel efficiencies than later models. In more recent years, the costs were below $1.30 per mile for FCEBs, which is significantly higher than the per-mile costs for other fuel types.

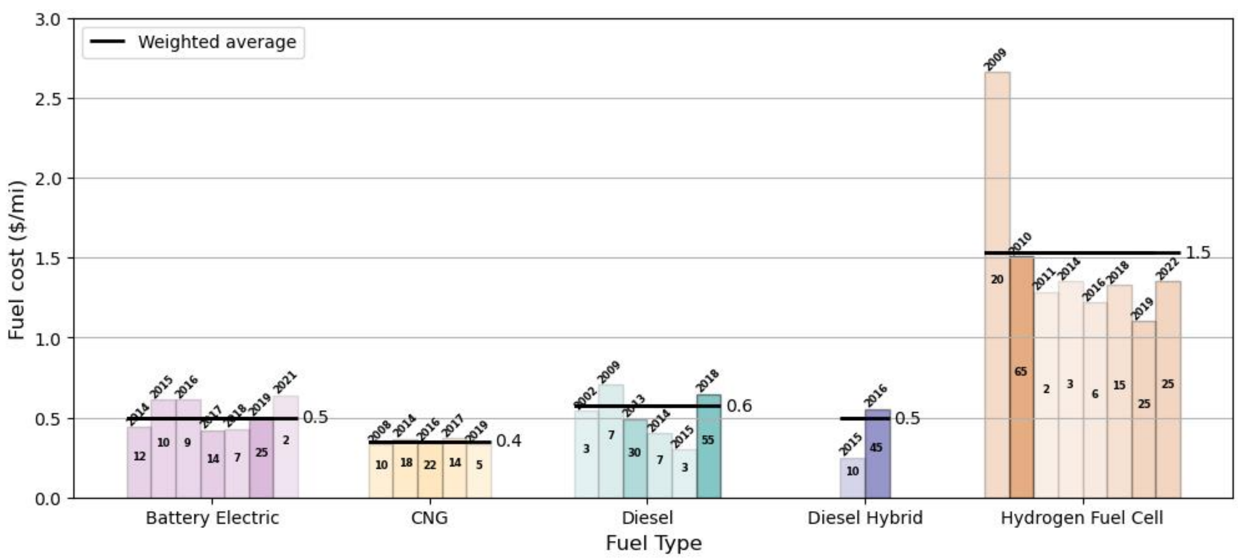

Figure 35. Comparison of fuel costs, from meta-analysis of published transit bus studies.

Source: NLR meta-analysis of published ZEB evaluations

Respondents to the transit survey overwhelmingly agreed that the state should promote an electricity rate specific to public transit to help stabilize and offset operating costs for BEBs. This was the response of 87% of small agencies and 100% of large agencies. It was suggested that a flat rate be created for all automotive EV fleet customers to reduce the cost distortions caused by rate structures designed to reduce peak demand. Transit agencies could largely utilize off-peak overnight charging, yet their priority is ensuring the bus fleet is ready to meet daily service and, therefore, may have difficulty completely avoiding on-peak charging, especially as the size of the electric fleet grows.

A large majority of survey respondents—9 of 12 large agencies (75%) and 29 of 46 small agencies (63%)—also agreed that federal agencies should utilize funding from the Infrastructure Investment and Jobs Act or the Inflation Reduction Act to subsidize transit agencies' hydrogen fuel costs.

Transit agencies operating ZEBs can qualify for LCFS credits to lower the cost of low-carbon transportation fuels (electricity for BEBs, hydrogen for FCEBs). However, as described in Section 3 on Incentive Funding Programs, the credit price has decreased substantially in recent months/years, reducing the effectiveness of the LCFS market for reducing fuel costs. Availability of low-carbon hydrogen is crucial to FCEB deployment, so transit agencies are not subject to a compliance obligation in LCFS regulation by using the FCEB technology.

A large majority of respondents to the transit survey agreed that CARB's LCFS regulations should provide a plus-up for transit agencies' hydrogen stations, regardless of fleet size and station size, because public transit helps reduce personal vehicle miles traveled and provides affordable transportation to all Californians, including low-income communities. There was agreement by 9 of 12 large agencies (75%) and 31 of 46 small agencies (67%). When asked if rural transit agencies' hydrogen stations, specifically, should be given a plus-up for CARB LCFS credit due to higher transportation costs, agreement from small transit agencies increased to 74% (34 of 46). Responses from large transit agencies remained the same.

Reliable and consistent supply of affordable hydrogen is necessary for the successful deployment of FCEBs. Transit agencies need price certainty for their fuel supply, with budgets limited on how much price increases they can absorb. In addition, transit agencies that are not in close proximity to hydrogen supply pay higher fuel transport costs.

The supply of low-carbon energy takes time to ramp up due to its capital investment and limited initial market off takers. For electricity, RPS requirements started in 2000 with a gradual ramp-up schedule in California and many other states. Due to the need for lower-carbon transportation, public policy tends to push hydrogen to be on par with electricity within a very short period of time. More financial and policy support would be needed if such expedited rate is desired.

Additional comments from transit survey respondents:

- With the significant cost difference between hydrogen and CNG, additional fuel incentives for transit agencies utilizing hydrogen need to be considered. It will cost an estimated 2–3 times more per mile for transit agencies to operate hydrogen over CNG in fuel costs alone.

- Although hydrogen used in FCEBs is about twice as efficient as diesel, it is over two times the cost of diesel and over three times the cost of CNG on a per-mile basis. A strategy of subsidizing a third of the hydrogen fueling cost would help lead to a more cost neutral transition.

ARCHES, described earlier, prepared a "Transportation White Paper," published in October 2024 and written in collaboration with the ARCHES Transportation Working Group. The paper identified the opportunities and challenges to achieving a mature market for heavy-duty fuel cell trucks and buses (ARCHES 2024b). Findings in the white paper recognized that reaching total cost of ownership parity requires reaching hydrogen cost targets and expanding FCEB and fuel cell electric truck (FCET) production to volumes that achieve economies of scale. Reduced hydrogen price is critical to achieving total cost of ownership parity, and vehicle subsidies will be needed to accelerate FCET and FCEB production and adoption. ARCHES determined that a retail hydrogen price of \$5–\$6/kg would be needed to achieve operational costs for this technology to be comparable to diesel. For FCEBs, the industry in general believes that a net hydrogen cost of \$9/kg would be sufficient to achieve cost parity with diesel buses, with a lower net price for cost parity with CNG buses. Regardless, increasing hydrogen demand and offtake by both FCETs and FCEBs will be critical to achieving the lower hydrogen price targets. In addition, when a refueling station's capacity is fully utilized, it also helps reduce the station operation and maintenance costs per kilogram of hydrogen.

One potential opportunity to increase station utilization is to allow refueling by other fleets, specifically public fleets, that are subject to the state and local government provisions of the Advanced Clean Fleets regulation. There is precedent for this. Today, there are transit agencies that share their natural gas fueling infrastructure with other public fleets using natural gas-powered vehicles, including refuse trucks. Manufacturers of refuse and recycling trucks agree that these vehicles are a natural fit for fuel cell technology given their duty cycles and demonstrated ability to pivot in recent years to natural gas (Fuel Cell Works 2025). Sharing hydrogen infrastructure with public fleets operating fuel cell refuse trucks would both lessen the cost of the demonstration and increase hydrogen demand at the transit hydrogen station. As fuel cell refuse truck technology advances enough to encourage greater adoption, there would be sound argument for the refuse fleet to develop their own on-site renewable hydrogen production from landfill gas or other biogas resources.

Without DOE funding, GO-Biz is sharing learnings from materials submitted by project partners in response to requests for information and qualifications. GO-Biz is using this information to develop strategies that rely on the existing support and commitments from state and local agencies and other project partners.

Beyond the need to achieve economies of scale in FCEB production and renewable hydrogen production, distribution and offtake, the Transportation White Paper identified the need to reduce boil-off losses from LH2 storage. Most transit agencies adopting FCEBs are using or intend to use delivered LH2 for their fuel supply. Reducing boil-off from hydrogen storage systems ensures that more of the hydrogen delivered to the transit agency makes it into the buses. Today's boil-off reduction technology shows a lot of promise, but it must be integrated into the tank system and cannot be added after the fact.

5.2.3 Maintenance Costs

Maintenance costs are the other significant operating cost for transit buses. The total maintenance costs include scheduled, or routine, maintenance (such as inspections, tire rotations, fluid flushes, and filter changes), as well as unscheduled maintenance to repair components when they break or wear out from normal usage.

The meta-analysis from published vehicle studies produced the average maintenance costs shown in Figure 36. A primary challenge with understanding maintenance costs for new technology buses (BEB and FCEB) is having to look at historical data to predict future maintenance costs for rapidly advancing technologies. The more data that accumulates for reliable trends, the more the data represents a slightly outdated version/generation of the technology.

The conventionally fueled buses in the reports show weighted average maintenance costs of $0.60 per mile, $0.80 per mile, and $1.30 per mile for CNG, diesel, and diesel hybrid, respectively. The early-generation BEBs show average maintenance costs below $0.50 per mile. Model years 2018 and newer, however, had significantly higher costs, between $1.30 and $2.00 per mile, which increased the weighted average to $1.00 per mile. For FCEBs, the later model years in the published studies (2018, 2019, and 2022) all show maintenance costs similar to the weighted average of $1.30 per mile.

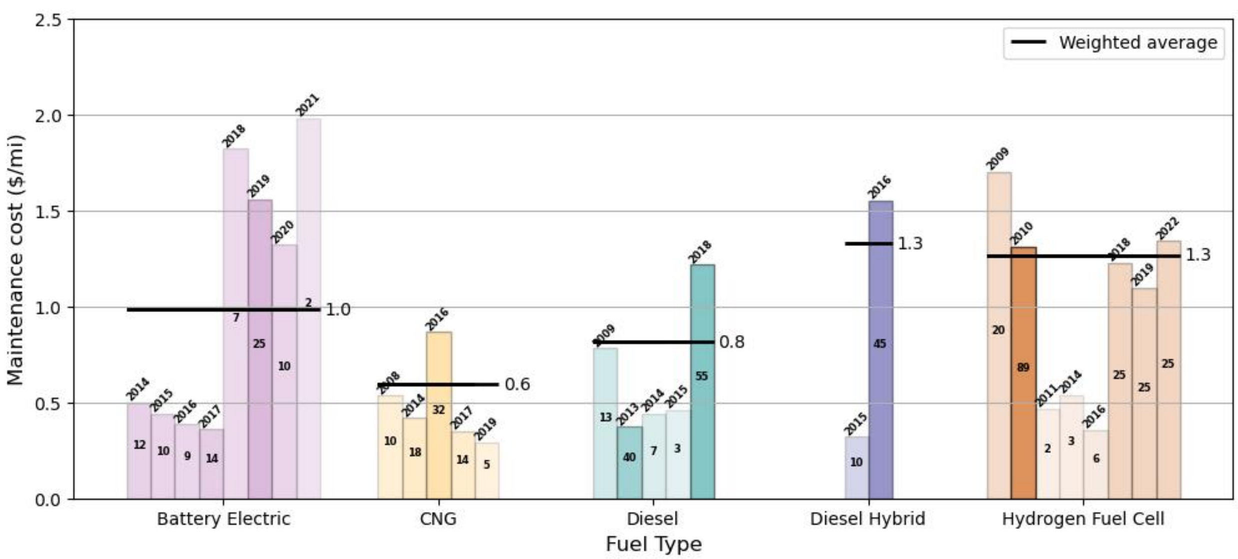

Figure 36. Comparison of bus maintenance costs, from meta-analysis of published transit bus studies.

Source: NLR meta-analysis of published ZEB evaluations

As part of the OEM questionnaire, OEMs were asked about long-term strategies for securing parts supply and price stability. OEMs commented that one strategy they use is negotiating long-term supply agreements with the suppliers. They also choose proven, reliable suppliers that are assessed by OEM due-diligence teams and have a proven ability to deliver on the negotiated commitments. Despite the uncertainties in global markets, they are working to minimize the impact on our customers through strategic sourcing and risk mitigation efforts.

5.3 ZEB Performance

5.3.1 Energy Efficiency/Fuel Economy

It is well established that vehicles with electrified powertrains are more energy efficient on a per-mile basis than equivalent conventional vehicles that have internal combustion engines. This is primarily due to the efficiency of electric motors and the recuperation of kinetic energy through regenerative braking. This can be seen in the initial analysis of data collected for a performance evaluation for Anaheim Transportation Network. Preliminary results from the 2025 study show energy efficiency averaged 0.73 miles/kWh and 0.29 miles/kWh for 30-foot and 60-foot BEBs, respectively. The extent of the vehicle energy efficiency benefit varies by powertrain type and vehicle duty cycle, but the high kinetic intensity of most transit operations (marked by frequent stops in urban and suburban environments) make transit buses well suited for electrification.

However, EVs are also more sensitive to several external factors, such as weather conditions (temperature, humidity, precipitation), driving conditions (traffic, road grade, speed, stop frequency), vehicle weight (passenger loading), and operator behavior (acceleration/deceleration rates). Some of these factors may be amenable to improvement over time (e.g., improved heating and cooling systems, better operator training, etc.) but others are harder to address.

The energy efficiency of a bus directly affects the operational costs and the achievable driving range. For BEBs, efficiency also impacts the required recharging time, which can dictate the operational downtime and potentially impact bus operations.

From NLR's transit survey, it was reported that standard size BEBs, with an average fuel economy of 17.3 miles per diesel gallon equivalent (mpdge) are approximately four times as efficient per unit energy as standard non-ZEBs (4.4 mpdge). Standard FCEBs are twice as efficient, averaging 8.6 mpdge. For coaches and articulated buses, electric models are approximately three times as efficient. Similar efficiency benefits are likely for cutaway and double-decker buses, although no real-world data were reported for these bus types (Figure 37).

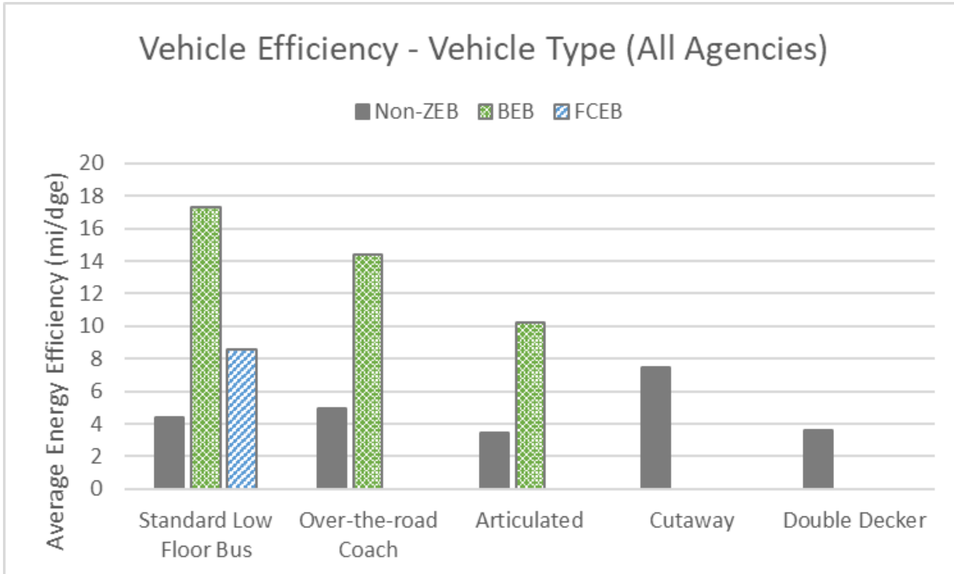

Figure 37. Comparison of vehicle energy efficiency by bus type and fuel type.

Source: Survey of California transit agencies

These responses are similar to the energy efficiency results from the meta-analysis shown in Figure 38. Non-ZEBs—CNG, diesel, and diesel hybrid—have average energy efficiencies between 3.9 and 5.4 mpdge, with CNG being the least efficient and diesel hybrid being the most efficient. FCEBs have a weighted average efficiency of 7.0 mpdge, although the later model years in this data set show notably higher values around 8–9 mpdge, which is approximately twice as energy efficient as the non-ZEBs. BEBs are approximately four times as efficient as the non-ZEBs at 17.4 mpdge.

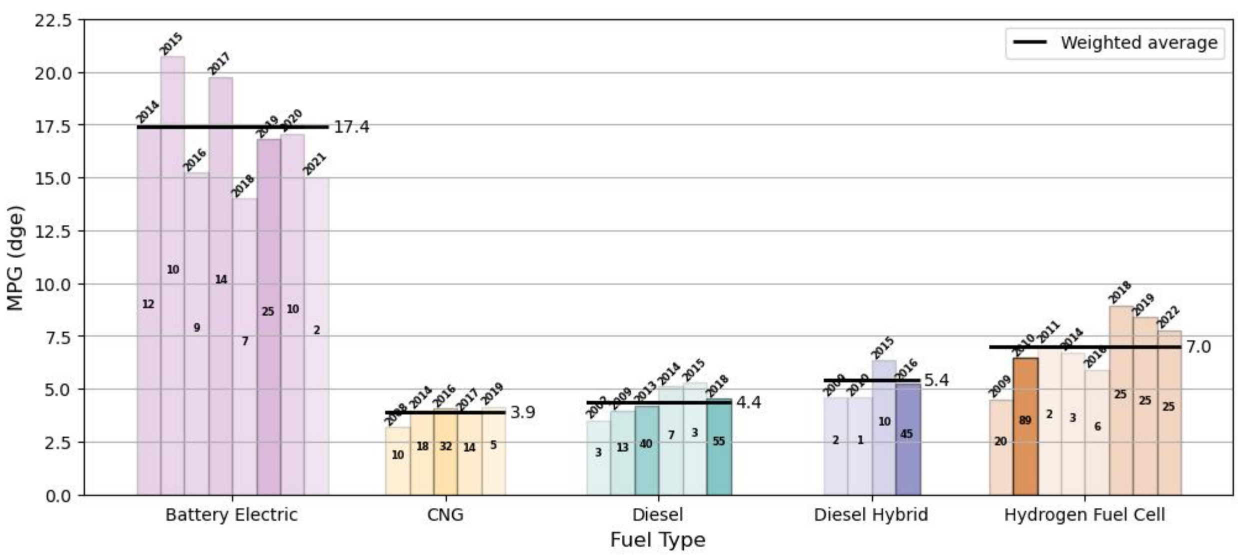

Figure 38. Comparison of vehicle energy efficiency by fuel type for standard buses.

Source: NLR meta-analysis of published ZEB evaluations

5.3.2 BEB Driving Range

In the transit survey, agencies were asked about the daily distance traveled by all the buses in their fleets—both on fixed routes and those operating on-demand service. The results are shown in Figure 39 and Figure 40. For fixed routes, respondents reported a fairly even distribution of service across the four mileage bins specified—less than 100 miles, between 100 and 150 miles, between 150 and 200 miles, and more than 200 miles. For on-demand service, small transit agencies report a much larger share of shorter daily distances, with 89% of their bus fleet traveling less than 150 miles per day, and 65% traveling less than 100 miles per day, on average. For large agencies, 73% of on-demand buses travel less than 150 miles per day, and 25% travel less than 100 miles per day.

There is wide variability in route lengths between transit agencies, but these distributions highlight the challenges agencies face trying to scale up ZEB fleets to cover their entire passenger service. Large and small agencies alike reported that 25% of their fixed-route buses must cover 200 miles or more per day. And for on-demand routes, which are often serviced by smaller cutaway shuttles, a smaller but significant fraction of the fleet must travel more than 150 miles per day. It is inherently difficult to predict daily service levels for on-demand service.

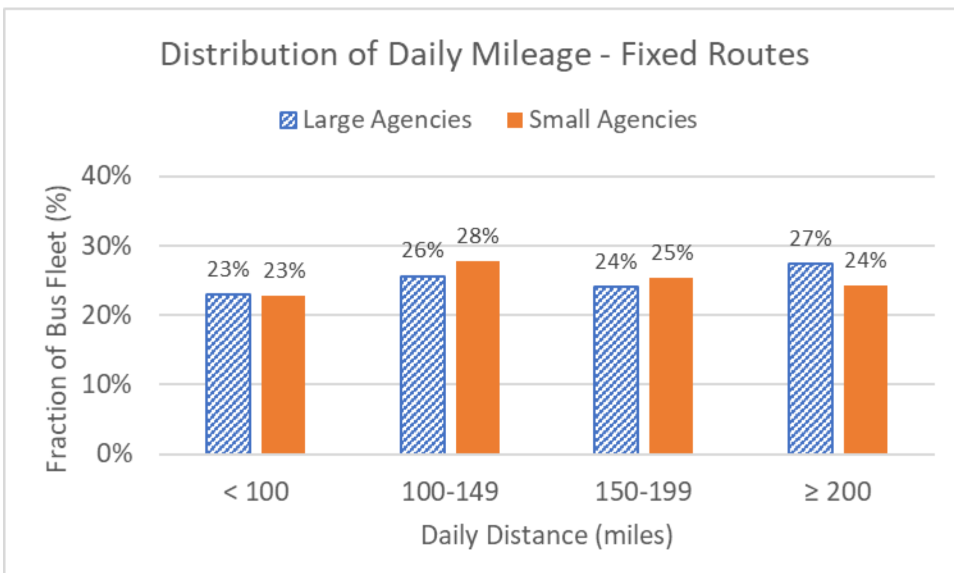

Figure 39. Distribution of daily distance traveled per bus, fixed-route service.

Source: Survey of California transit agencies

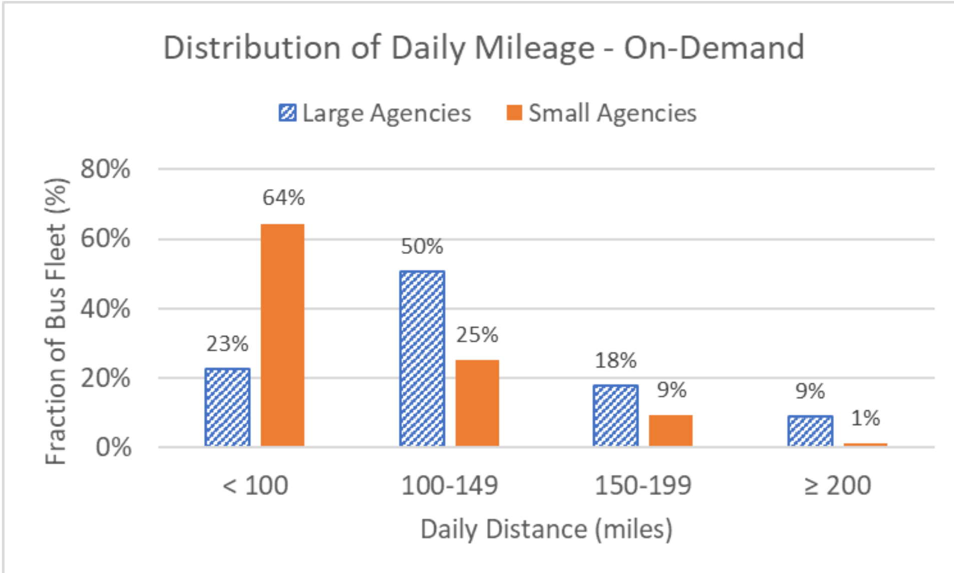

Figure 40. Distribution of daily distance traveled per bus, on-demand service.

Source: Survey of California transit agencies

In the survey of California transit agencies, ZEB range (primarily, BEB range) was one of the most significant concerns for agencies looking ahead at integrating ZEBs into their service, described by one respondent in this way:

> "Fleets with high share of cutaways… will have limited options for 1:1 vehicle [replacement] and transitions that require increase of fleet size and bus operators might be unfeasible for jurisdictions with limited budgets and workforce pool. In small rural communities, transit fleets also have a mandate to support emergency response and evacuation. ZEBs will need to meet extended ranges to meet the emergency response and evacuation mandates."

5.4 ZEB Reliability

5.4.1 ZEB Availability for Service

Bus availability is a measure of the bus's readiness for revenue service, and is an indication of bus reliability. Bus availability is impacted by numerous factors, including frequency of breakdowns/issues, ease of troubleshooting and maintenance, warranty support and OEM responsiveness, lead times for parts, and other factors such as a maintenance crew's familiarity with a particular make or model of bus.

The calculation of bus availability can vary between transit agencies, but generally it is a percentage of the time a bus is available for use in revenue service compared to when it is scheduled for service. This is often determined by whether the bus meets the scheduled "pull-out" and does account for planned downtime for routine maintenance and inspections. Thus, 100% availability is not the expectation of bus operators because all transit buses require routine maintenance. The expected bus availability also varies by agency, but 85% is often considered the industry standard or benchmark, although that does not necessarily reflect the average of transit fleets.

Figure 41 shows the bus availability results from the meta-analysis of ZEB studies. The weighted average for all conventional buses was 80% or higher—84% for CNG, 87% for diesel, and 80% for diesel hybrid. BEBs had a weighted average of 73%, and FCEBs had a weighted average of 68%.

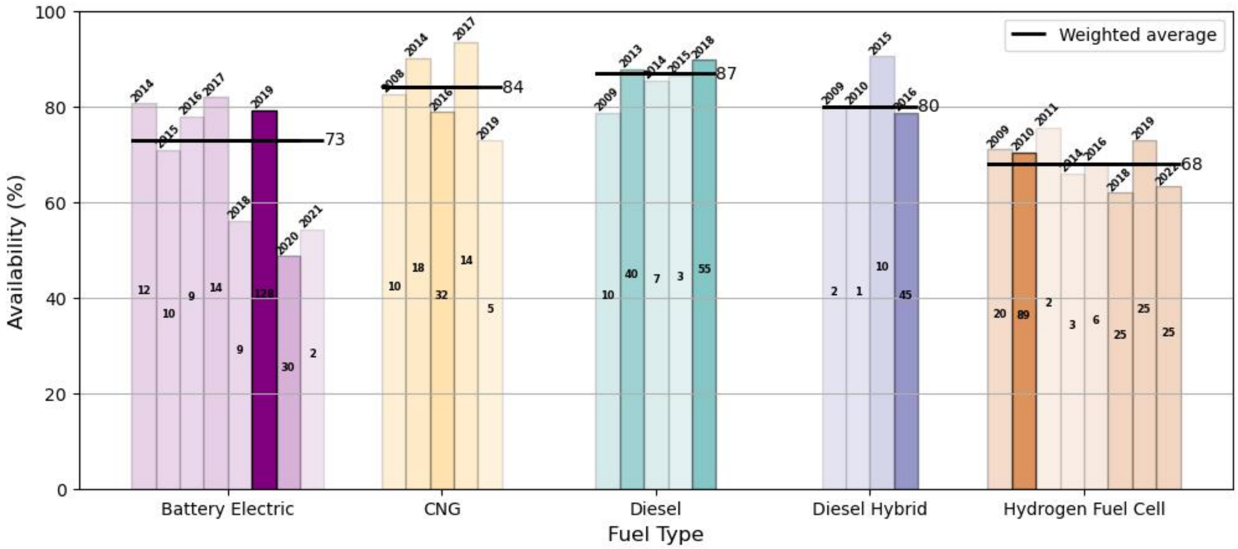

Figure 41. Average bus availability by fuel type.

Source: NLR meta-analysis of published ZEB evaluations

Similar trends were reported from California transit agencies in the survey. For standard size buses, Figure 42 shows an average availability of 85% for non-ZEBs, and approximately 70% for BEBs and FCEBs.

There is limited real-world data available for ZEBs of different vehicle types, but survey respondents reported average availability of close to 100% for BEB coaches (from two agencies) compared to approximately 77% average availability for conventional coaches. Articulated buses were very similar between BEBs and conventional, both around 78%.

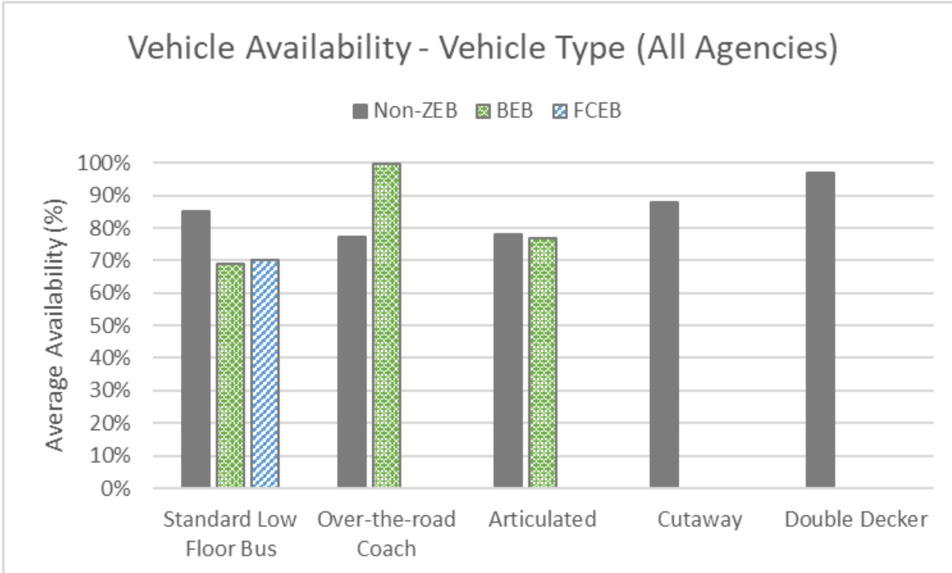

Figure 42. Average bus availability by bus type for ZEBs and non-ZEBs.

Source: Survey of California transit agencies

One reason for lower availability for the ZEBs could be that when unexpected issues arise, the newer technology buses sometimes take longer to diagnose and repair than the conventional buses because maintenance technicians are less familiar with them. This leads to longer downtime for these buses. In addition, parts supply for ZEBs has been limited and slower compared to conventional buses. There is still some room for improvement in ZEB availability and in ZEB troubleshooting and repair times to gain parity with conventional transit buses, but the industry has seen measured improvement with the technologies.

5.4.2 Miles Between Road Calls

The mean distance between failure—otherwise known as miles between road calls, or MBRC—is a direct measure of a vehicle's reliability and is a critical performance metric for transit buses. When a bus experiences a road call event, it causes a delay and disruption to service, and in many cases requires the bus to be replaced on route. Thus, the frequency of road call events impacts an agency's operational efficiency. Average MBRC is a cumulative measure that typically increases early in a bus's operating lifetime but is expected to decrease as a bus ages and approaches the end of its useful life.

Average MBRC can vary considerably between agencies, depots, and even individual buses based on a variety of factors, such as route and weather conditions, agency maintenance practices, and the underlying bus technologies in use. Issues resulting in road calls can originate in any vehicle system, including those that are very similar (or potentially the same, depending on vehicle manufacturer) between buses of different powertrains, such as steering or suspension systems. Road calls can also originate from safety-related systems, because even a minor or easily resolved issue with a safety-related system requires the bus to be removed from service and inspected. Of particular interest to transit agencies looking to deploy ZEBs is whether the propulsion systems of the ZEBs are responsible for more road calls than the propulsion systems of their conventional buses.

From the available published ZEB studies, NLR's meta-analysis found the following MBRC values reported for various fuel types and model years of transit buses. These represent buses with different operating environments, different vehicle ages and data reporting periods, and perhaps different maintenance practices between transit agencies. These published ZEB studies also do not reflect the latest bus models, as maintenance and reliability data require years of operation to collect and begin to analyze trends.

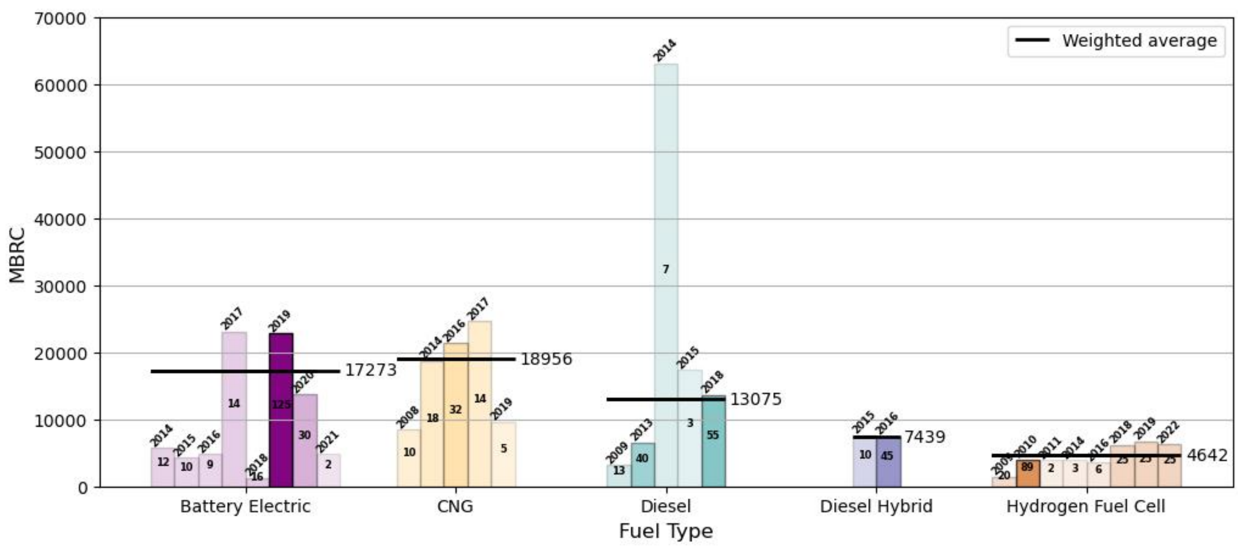

Figure 43. Average MBRC by fuel type.

Source: NLR meta-analysis of published ZEB evaluations

MBRC data reported in the transit survey was insufficient for a comparison between buses of different sizes and fuel types. A broad, comprehensive, and continuous data collection effort could properly evaluate the reliability of new ZEB technologies in transit service, including improvements for each new generation within a vehicle platform, and to identify root causes to be addressed.

Zero-emission technologies for both standard and articulated buses have reached a level of maturity where their performance and availability are comparable to conventional diesel and CNG buses. Major OEMs now offer both BEBs and FCEBs across standard and articulated platforms, giving transit agencies flexibility in selecting technologies that match their operational needs. While continued reductions in ZEB total cost of ownership remain a long-term objective, agencies must still evaluate near-term impacts on dispatching flexibility to ensure reliable service without significant operational adjustments.

Today's BEBs and FCEBs, including articulated models, provide ranges, availability, and durability that meet the daily service demands traditionally handled by diesel and CNG buses. Their improved reliability and parts availability also allow them to satisfy standard fleet spare-ratio requirements, supporting consistent service delivery. Although upfront capital costs remain higher, lower lifecycle fuel and maintenance costs, combined with available incentives, are making ZEBs increasingly cost-competitive.

With these technology and economic improvements, both standard and articulated ZEBs are now capable of achieving a 1:1 replacement ratio with their conventional counterparts for most transit cases, particularly when supported by well-planned charging or fueling infrastructure and thoughtful route and depot optimization. Though range may not be an issue for the standard and articulated buses in the near term, longer-range and more robust infrastructure systems will be needed for the sector-wide deployment, especially for the standard buses that could operate 350 to more than 500 miles per day.

5.5 ZEB Safety

The transit industry has experienced a number of transit bus thermal events with ZEBs in recent years that have brought safety concerns to the forefront. This Review has compiled and reviewed a list of ZEB thermal event incidents from public reporting, which includes more than 35 documented cases across North America (White 2023), Europe (Sustainable Bus 2024), Asia (China Observer 2024), and Australia (9News Sydney 2024) involving both BEBs and FCEBs. In the United States, multiple incidents occurred in California—including San Jose, San Diego, Bakersfield, and Lancaster—as well as in other states like North Carolina, Connecticut, New Jersey, Massachusetts, and Oregon. Several of these involved school buses or occurred during charging or battery testing. Canada reported fires in Quebec and Huntsville, with one case initially misattributed to a diesel heater before being linked to battery failure. Europe saw significant events in France (Paris and Territoire de Belfort), the United Kingdom (London, York, and Gloucestershire), Germany (Stuttgart, Hanover, and Düsseldorf), Italy (Venice), and Slovakia, with some cities suspending entire fleets after repeated thermal events. In Asia, India experienced a surge in incidents in 2024 across cities like Delhi, Pune, and Ahmedabad. China had at least three separate incidents, including a ship thermal event caused by EVs. Taiwan and Australia also reported ZEB-related thermal events. Additional high-profile cases include a thermal event involving 40 decommissioned SEPTA buses in Philadelphia and a maritime incident off Alaska. Common themes across these events include thermal runaway in lithium-ion batteries, thermal events during charging or storage, and the involvement of both transit and school buses, highlighting ongoing safety challenges in the deployment of ZEB technologies.

Unlike fires with traditional transportation fuels, thermal events originating with an EV's lithium-based batteries and are extremely difficult to extinguish. Especially for transit agencies which park buses in very close proximity to each other, and sometimes indoors, there is a risk of one battery thermal event extending to each neighboring vehicle and to nearby structures causing enormous damage. The current needs for the transit industry with regard to ZEB thermal safety were described very succinctly in a report by the San Francisco Municipal Transportation Agency (SFMTA):

> "The industry needs to focus its efforts on bus fire safety, specifically on early detection, fire suppression, and fire prevention systems. Additionally, bus storage facilities need robust design guidelines and standard operating procedures for safely storing large numbers of zero-emission buses" (SFMTA 2024).

Battery health and thermal event prevention, detection, and control has become an urgent need for the transit industry and for other EV applications. Many transit agencies would like to see more standardization in battery health on-board diagnostics requirements as well as additional battery testing in the Altoona bus testing program.

6 ZEB Charging and Refueling Infrastructure

The following section of the ICT review provides an overview of the charging and fueling infrastructure necessary to support the deployment of ZEBs, with a focus on electric charging systems for BEBs and hydrogen fueling systems for FCEBs. It highlights the technologies, costs, timelines, challenges, and opportunities associated with deploying and maintaining these systems. A number of recommendations from the transit industry for improving infrastructure planning, funding program structures, and resiliency measures are highlighted.

6.1 Charging Infrastructure for BEBs

Deploying a fleet of BEBs in transit service requires the implementation of charging equipment with sufficient capacity to replenish the energy stored in the bus batteries during downtimes between bus operations. This can involve dedicated chargers for each BEB, or alternately, the need to relocate buses or charging cables between shared chargers during the charging periods to access the needed electrical power for each bus.

Charging infrastructure for BEBs includes to-the-meter (TTM) electrical supply equipment that carries electricity onto the site from the utility (substation/transformer), and behind-the-meter (BTM) equipment that delivers electricity to the vehicle chargers, also called electric vehicle supply equipment (EVSE). Necessary equipment varies depending on the size of the charging installation and typically includes electrical cabinets/switchgear as well as the charging dispensers.

6.1.1 Charging Technology Review

The most common charging methods used for transit applications are both conductive charging approaches—either manual plug-in charging (cord and plug), or automatic overhead charging (pantograph). Plug-in charging is the preferred option for lower-power charging and works well for buses that have long dwell periods at the depot between service. Numerous organizations are actively collaborating to develop a new high-power charging standard called the Megawatt Charging System (MCS) that could be employed to help improve plug-in charging options for medium- and heavy-duty vehicles including transit buses. Because the development of MCS is also being driven by the adjacent market—particularly heavy-duty zero-emission trucking—advancements in this area are expected to accelerate technology refinement, increase equipment availability, and reduce costs for transit applications. This new system will enable charging capacity up to 3.7 megawatts, greatly reducing required charging times for high-energy-consumption applications (CharIN 2025; SAE International 2025). MCS technology is gaining traction, especially in heavy-duty, battery-electric trucks and buses, but it is a relatively new technology that is still being evaluated. Researchers are currently studying high-power charge profiles from commercially available EVs and EVSE under differing operating conditions to fully quantify charging loads seen by the grid, optimizing station design requirements and site energy management systems, evaluating potential impacts on battery life, and evaluating MCS EVSE reliability. There are still important questions to be answered about what types of batteries can best sustain high-power charging from MCS and how this will impact battery longevity and costs, as well as how MCS will impact infrastructure installation costs and timelines. Continued progress in the adjacent market, especially commercial vehicle segments adopting MCS, will likely inform these evaluations and contribute to faster maturation of the technology for transit fleets.

Pantograph charging is better suited for situations where high-power charging is needed for quick recharging of buses. This method can be utilized at a bus depot or on-route where there are brief dwell periods, such as at transfer stations or end-of-line layovers. Pantograph charging is a good option for space-constrained bus parking facilities and to minimize obstacles to driving through the yard. The automated or semi-automated nature of the pantographs also require fewer actions from transit workers responsible for parking and charging BEBs.

In addition to the conductive charging options, some transit agencies are implementing wireless inductive charging for their BEBs. This method uses a transmitting coil embedded in the pavement to transfer power wirelessly to a receiving coil mounted under the bus chassis when the bus is parked over the charging pad and the components are properly aligned. Wireless charging is typically used for on-route charging applications but can also be installed at depots where there is a need for higher charging power and/or space-saving charging solutions (similar to pantograph charging applications). Wireless charging systems for transit buses can achieve power levels of 125–500 kW from one manufacturer and 50–450 kW from another (WAVE Wireless 2025; InductEV 2025). A new industry standard for static wireless power transfer for heavy-duty EVs (J2954-2) is under development by SAE International and is expected to be released in late 2025 or early 2026 (Federal Transit Administration 2024; SAE International 2022). The emergence of wireless charging in adjacent commercial vehicle markets is also helping drive the technical requirements, encouraging greater interoperability and lowering long-term equipment costs.

ZEBs operate for long service hours and on extended routes, which demands both higher charging rates and high levels of system availability and reliability. As agencies scale up deployment, challenges related to vehicle supply, charging station performance, interoperability, and overall cost must be addressed proactively. Establishing robust charging codes and standards for BEBs is foundational to resolving these challenges. Charging standards play a central role in ensuring ZEB systems function safely, efficiently, and consistently across diverse operating environments. They help optimize product performance, protect equipment and personnel, and create common technical expectations across the industry. In addition, well-defined codes and standards ensure interoperability between equipment from different manufacturers—reducing vendor lock-in, increasing competition, and streamlining maintenance and operations. They also provide market certainty and reduce long-term risks such as data-management uncertainties and the potential for stranded assets as technology evolves.

Because of these benefits, the timely development and adoption of consistent charging codes and standards is critical for enabling scalable, cost-effective, and reliable medium- and heavy-duty ZEV deployment across the transit sector (University of California, Irvine 2024).

6.1.2 Charging Infrastructure Capital Costs

About 70% of all transit buses are operated by the 21 large transit agencies. All large transit agencies receive formula funding from FTA for capital projects, workforce training, planning, etc. (Federal Transit Administration 2025e). Some small transit agencies are not direct FTA formula funding recipients and rely instead on various local and state resources for capital projects.

California's state legislature has enacted several bills (including SB 350, AB 1082, and AB 1083) aimed at expanding the EV charging infrastructure in the state. The combined legislation has led to the development of "make-ready" charging infrastructure programs at each of the major IOUs in the state, which applies to public light-duty charging as well as depot charging for medium- and heavy-duty fleets, including transit agencies. For California, these programs have enabled many fleets to begin deploying battery-electric vehicles by covering the capital expense of the TTM charging infrastructure. In some cases, the programs help cover costs for BTM equipment as well. These programs are discussed in more detail in section 4.6. The continued growth of adjacent markets – particularly zero-emission trucking, logistics, and energy storage – also enhances the value of these make-ready investments by driving higher utilization, stimulating equipment innovation, and helping reduce infrastructure costs over time.

The enacted legislation also enabled the third-party evaluation of the progress and effectiveness of those make-ready infrastructure programs administered by the utilities. The evaluation, led by CADMUS and supported by numerous organizations, including NLR, produces an annual summary report of the findings. The most recent analysis is found in the evaluation year 2024 report (Cadmus Group et al. 2025). The projects contain 23 transit bus sites that were activated and financially closed out as of evaluation year 2023, and the evaluation summarized the costs for TTM and BTM infrastructure. Median TTM cost (per kilowatt of installed capacity) was approximately $500/kW and the median BTM cost was approximately $300/kW. These correspond to median costs per EV of approximately $25,000/EV and $10,000/EV for TTM and BTM, respectively (Figure 44). It is important to understand the variation in cost for installing charging infrastructure at various sites. These values can vary considerably depending on the number of ports installed, as well as the time required for the installation and energization.

Figure 44. Charging infrastructure costs for 23 transit bus sites in California.

Source: Cadmus Group et al. (2025)

To gain a better picture of how the charging infrastructure costs scale up for larger vehicle fleets, the evaluation combined data from all medium- and heavy-duty market sectors (including school buses; transit buses; and medium-/heavy-duty trucks, buses and cargo handling equipment) to assess the TTM and BTM cost versus installed capacity curves, shown in Figure 45. For TTM and BTM, the cost per kilowatt decreases rapidly as the installed capacity increases beyond 50-100 kW. Level 2 chargers tend to cost more, on a per-kilowatt basis, than the DCFC systems, in part because the installed capacity for Level 2 rarely exceeds 400-500 kW. For DCFC systems, there are minimal additional savings (on a per-kilowatt basis) beyond approximately 1,000 kW of installed capacity.

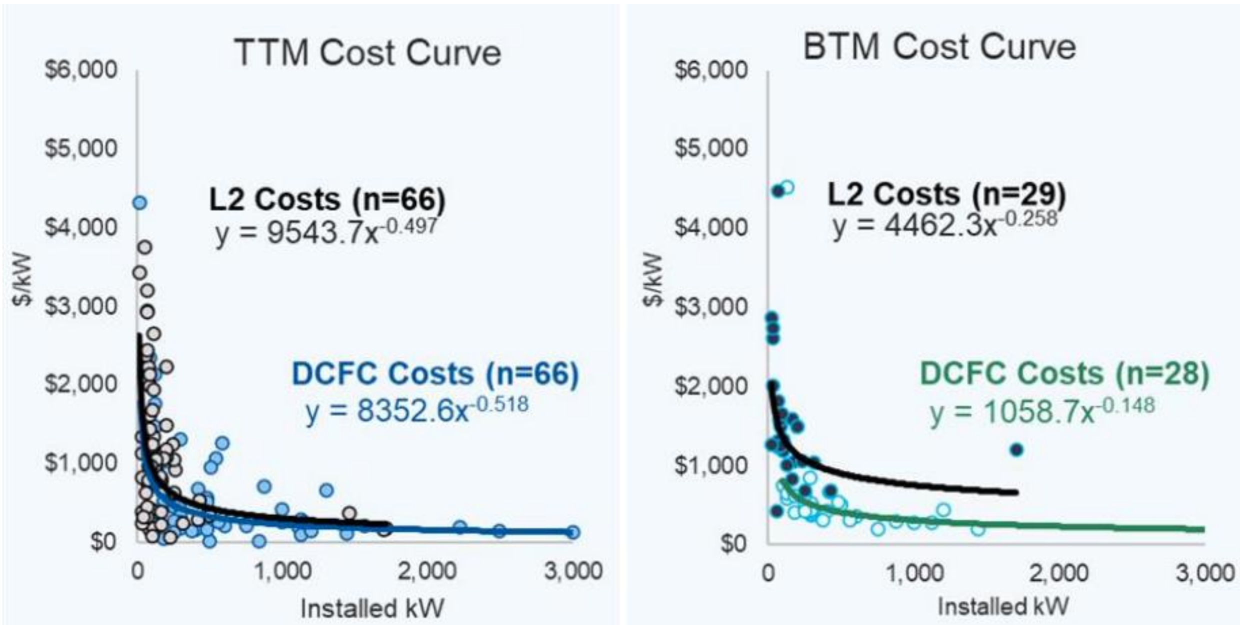

Figure 45. TTM and BTM cost curves for medium- and heavy-duty charging infrastructure.

Source: Cadmus Group et al. (2025)

The transit agency survey conducted by NLR included detailed insights into the challenges, experiences, and recommendations of transit agencies concerning funding for BEB charging infrastructure. For instance, 75% of large transit agencies (9 of 12) and 78% of small agencies (36 of 46) agreed that the state should mandate that electric utilities pay for substation costs to enable or support transit agencies' charging infrastructure upgrades and installation (specifically, through an amendment to AB 841). A summary of additional responses from the transit industry on the topic of funding for charging infrastructure include:

- *Funding Availability*: Many agencies highlighted insufficient funding for infrastructure compared to the high costs of transitioning fleets to ZEBs. Specific funding challenges included overly competitive environments, restrictive deadlines, and cumbersome administrative and reporting requirements.
- *Recommendations*: Increased funding allocations, long-term multiyear commitments, formula-based funding, and reduced competitiveness in awarding funds were the top recommendations. Agencies also recommended innovative financing mechanisms (e.g., public-private partnerships and infrastructure bonds), as well as a focus on sustainability and resiliency in funding priorities.
- *Funding Programs Used*: Agencies reported having utilized state, federal, and other local grant programs such as FTA's 5339a (Bus/Bus Facilities), 5339c (Low-No), and 5337

(SGR) programs, as well as other funding sources like TIRCP, Carl Moyer, and local government programs.

The survey also highlighted unique infrastructure challenges of small and rural transit agencies, including the following notes and recommendations:

- Small agencies, in particular, need help with electrical infrastructure upgrades and want to be able to use grants to help pay for those upgrades to enable BEB charging equipment.
- CARB should look at smaller agencies who may have a hard time affording infrastructure changes.
- Rural areas will have the biggest lift to establish ZEB infrastructure and operations.
- Small rural communities need more support on infrastructure or a more relaxed mandate on ZEB purchasing requirements.
- Infrastructure technology and reliability are still behind the bus technology; the market is not yet mature.

6.1.3 Charging Infrastructure Timelines and Cost Containment

Timelines required for getting BEB charging infrastructure purchased, installed, and activated is a critical consideration for transitioning to ZEBs. Delays are common, and are often related to permitting, sitework, and equipment delivery or supply chain issues.

By all accounts, it is important for transit agencies planning to deploy BEBs to engage with their electric utility as early as possible to begin coordinating about their plans for charging infrastructure. Large capital projects for electricity supply take many years for utilities to develop and complete, so the sooner they are made aware of future plans for increased electrical demand—especially at the scale of a bus depot transitioning to electric buses—the sooner they can start work to meet that need. Furthermore, cost overruns are also common and can be a source of contention between the agencies and their infrastructure supply contractors.

The Standard Review Projects evaluation for make-ready infrastructure programs in California contained 23 activated sites in the Transit Bus market sector as of the 2024 evaluation year. The evaluation tracked the timeline for all phases of the infrastructure build-out leading up to site activation (Figure 46). The Design and Permitting phase and the Construction phase were the two longest phases, with median number of days to complete greater than 800 days for Design and Permitting and approximately 100 days for Construction (Cadmus Group et al. 2025).

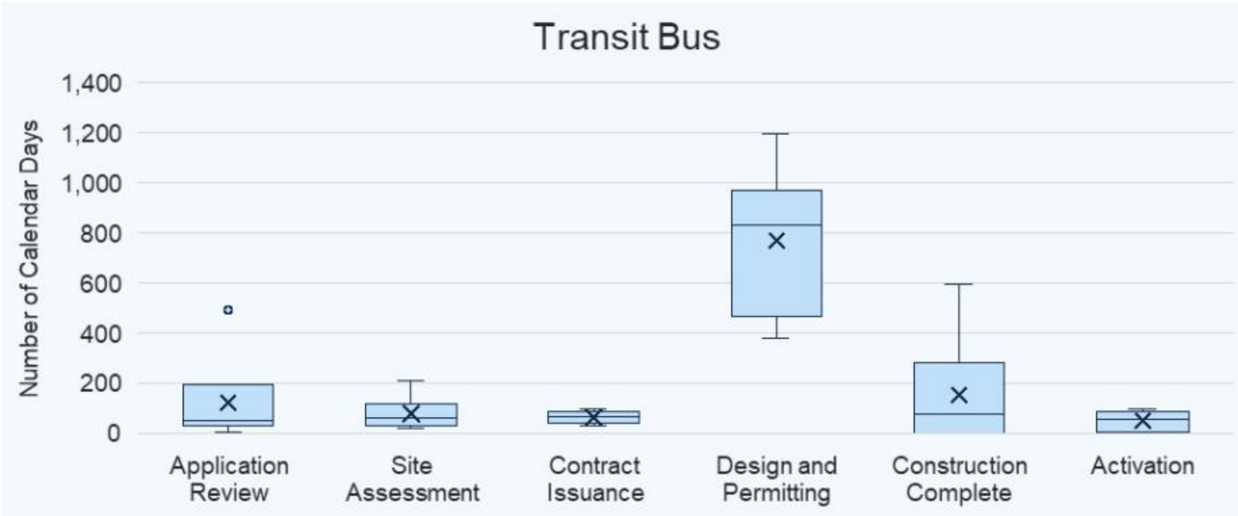

Figure 46. Timelines for installation phases of charging infrastructure.

Source: Cadmus Group et al. (2025)

From the transit agency survey, respondents overwhelmingly supported the idea that the state should mandate that utilities prioritize transit agencies' electrical infrastructure upgrades over other sites to help facilitate the transition to ZEBs, which is required of them by the ICT. (83% of large agencies and 78% of small agencies agreed).

Pursuant to SB 350, the CPUC has approved several decisions, resolutions, and advice letters authorizing $765 million ratepayer funding toward the expansion of EV charging infrastructure for light-, medium-, and heavy-duty ZEVs and off-road equipment. In compliance with AB841 the utility-side electrical distribution infrastructure costs would be covered by ratepayers and included in the general rate case for each IOU (Rule 29 for PG&E and SCE, Rule 45 for SDG&E). CPUC's recent actions aim to make grid planning more proactive, with focus on better forecasting, coordination, faster connections, and transparency. The IOUs are also required to integrate pending electrification loads into their distribution planning focusing on flexibility and near-term solutions (Refs: R.21-06-17, D.24-10-030).

6.2 FCEB Hydrogen Fueling Infrastructure

A hydrogen refueling station is essential for a transit agency planning to operate FCEBs to ensure a reliable and efficient fuel supply to support daily operations. This includes supplying hydrogen at the right pressure and purity in adequate quantity to refuel an agency's entire operating FCEB fleet. Proper refueling infrastructure is critical to maximizing the performance, range, and environmental benefits of FCEBs while aligning with the agency's goals for low-emission transportation.

6.2.1 Hydrogen Fueling Technology Review

The infrastructure needed to refuel FCEBs ultimately requires gaseous hydrogen to be dispensed to the buses in a similar fashion as with the more conventional CNG bus refueling. Many CNG stations store LNG that is then evaporated to compressed gas for vehicle fueling. Similarly, hydrogen stations can store cryogenic LH2 and dispense the evaporated gas at typically 350 bar

(5,000 psi) of pressure; buses also can be designed for higher pressure storage of 700 bar (10,000 psi) to enable extended driving range.

A recent example of a hydrogen station is provided in Figure 47, which shows a 25,000-gallon LH2 storage tank, cryogenic pumps, evaporator towers and gaseous storage tubes, plus other components which help supply hydrogen to the dispensers for vehicle fueling.

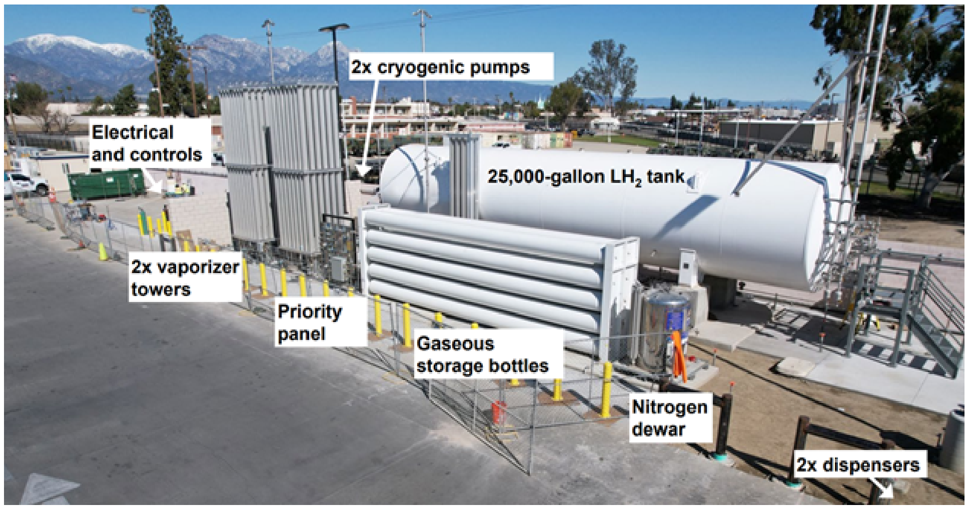

Figure 47. Example hydrogen fueling station at Foothill Transit.

Source: Foothill Transit

Hydrogen fueling stations are developed by industrial gas suppliers, major oil companies, and companies specializing in hydrogen refueling infrastructure. Stations developed by industrial gas suppliers will then include a multiyear hydrogen supply contract, typically at a fixed price but with allowable annual price escalations within limits, while other types of stations will require multiple parties to be involved.

The primary benefits offered by a hydrogen station for ZEB operations are a similar refueling process and similar refueling duration as conventionally fueled buses (diesel and CNG), as well as similar driving range between refueling events. Hydrogen stations also offer more cost-effective scale-up to larger ZEB fleets than is expected for electric charging stations. In addition, the ability to continue hydrogen refueling and operation of FCEBs during an outage of the electric grid provides resiliency to transit agency operations.

6.2.2 Hydrogen Fueling Infrastructure Costs

As with electric bus charging infrastructure, the cost to install a hydrogen fueling station is one of the most significant barriers to transit agencies deploying FCEBs. In early 2025, industry experts reported that the latest costs for a 25,000-gallon LH2 station were estimated to be in excess of $10 million.[6] A station of this size could support a fleet of approximately 250 FCEBs, filling with an average of 20 kilograms a day and reserving about 30% of fuel storage in the liquid system.

[6] Discussion with Jamie Levin and CARB, May 28, 2025.

In July 2025, SamTrans approved a $20.3 million contract with Trillium for a fueling station at its South San Francisco facility to support 118 FCEBs initially, with expansion potential for additional buses, that is scheduled to be operational by early 2027. The contract includes $17.4 million for design, construction, and commissioning, plus $2.9 million for a 5-year maintenance agreement (Fuel Cells Works 2025). Capital costs are escalating to address challenges with the boil-off of stored LH2 and the need to reduce venting losses from transferring hydrogen between delivery trailers and storage tanks, as well as losses associated with station operations. Recently awarded station projects are featuring boil-off gas compressors and added gaseous storage to capture vaporized hydrogen in the headspace of a liquid storage tank. Newer, more efficient and effective cryogenic pumping technologies are being developed to reduce boil-off and losses and are expected to be commercially available in 2026.

In the transit survey, agencies were asked if the LCFS should provide a funding increase for transit agencies' hydrogen fueling station, for all agencies, regardless of fleet size and station size (Figure 48). Large majorities agreed, including 11 of 14 large agencies (79%) and 33 of 48 small agencies (69%). When asked if LCFS should provide an increase only for rural transit agencies' hydrogen stations, 10 of 14 large agencies (71%) and 36 of 48 (75%) small agencies agreed (Figure 49). These results highlight transit agencies' broad agreement and strong desire for policies to support hydrogen infrastructure development.

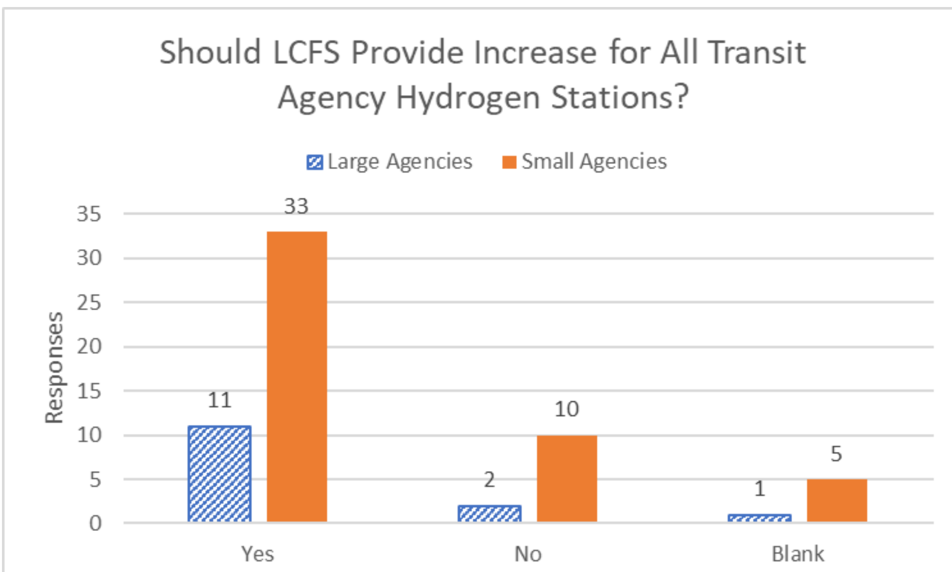

Figure 48. Transit survey responses for LCFS to support all hydrogen stations.

Source: Survey of California transit agencies

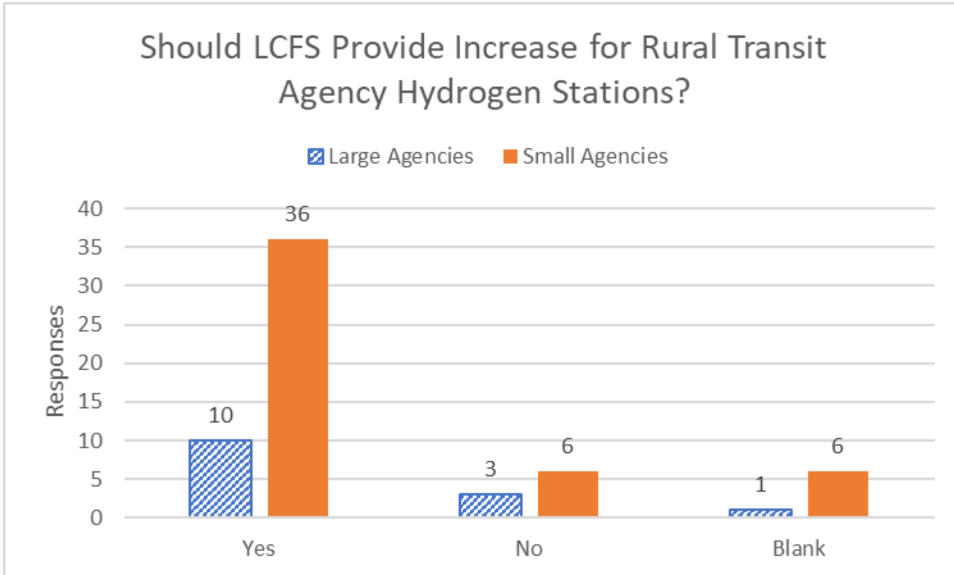

Figure 49. Transit survey responses for LCFS to support rural hydrogen stations.

Source: Survey of California transit agencies

Some respondents to the transit survey who are operating FCEBs also provided a few data points regarding the maintenance costs for hydrogen stations. One respondent reported $12,500 per month to maintain their station with 15,000 gallons LH2 storage. Another respondent operating an 18,000-gallon LH2 station reported maintenance costs of $25,000 per month. In both cases, the average costs were approximately one-third for scheduled maintenance and inspections while two-thirds of the costs were the result of unscheduled repairs. Another respondent, operating two stations (9,000-gallon and 13,000-gallon LH2 storage), reported a combined maintenance cost of $30,000 per month. A fourth respondent initially reported approximately $29,000 per month to maintain their 25,000-gallon LH2 station, which increased to $50,000 per month ($600,000 per year) due to the addition of boil-off gas compressors.

Below are some additional comments and recommendations provided by transit agencies in the survey:

- It would be ideal if the state purchased temporary portable fueling stations for transit agencies with a lease-to-buy option while agencies design and build permanent stations.
- The state could supplement the start-up of private hydrogen fueling stations, for shared use, so public transit agencies do not each have to build their own stations.
- It would be helpful to have bulk hydrogen procurement and development of standardized hydrogen infrastructure to help stabilize and minimize costs.

6.2.3 Hydrogen Fueling Infrastructure Timelines

Transit agencies are increasingly adopting FCEB technology compared to 2023. Of the 45 agencies that currently have FCEBs in service or on order, 14 are large transit operators. In California, several hydrogen stations dedicated to transit fleets are already operational or under construction. Pioneer agencies such as SunLine Transit and AC Transit have accumulated many years of experience operating hydrogen infrastructure, generating valuable lessons learned and reducing barriers for future adopters.

Permanent hydrogen fueling stations are currently operating or under development at Santa Ana, the Pasadena, Santa Clarita, Eureka, Pomona, Acadia, Thousand Palms, Emeryville, Oakland, Hayward, and Riverside. In addition, four temporary hydrogen stations remain in use to support ongoing fleet operations and near-term deployments.

6.2.4 Hydrogen Fuel Cost Considerations

Further support for hydrogen fueling for buses is expected through the ARCHES effort, under a $1.2 billion award from DOE combined with over $10 billion dollars in matching funds from California and private sector partners. DOE paused funding for ARCHES and other selected state's hydrogen hubs programs in early 2025; however, California is contesting this pause, which was not placed on all DOE hydrogen hub awards. Much of the ARCHES effort is designed to increase the production scale and decrease the cost of low-carbon hydrogen and to produce more of it near demand centers including urban areas where transit buses mostly operate. There is currently a production tax credit known as Section 45V that was implemented in the Inflation Reduction Act and that applies to new hydrogen production systems that are under construction by the end of 2027. The tax credit varies by the CI of the hydrogen produced and can reach up to $3.00 per kilogram for the lowest CI level (U.S. Department of Energy 2025). This program could thus help to reduce both the cost of hydrogen fuel for transit agencies as well as to reduce the carbon emissions from their operations.

6.3 Infrastructure Performance and Reliability

Reliability of hydrogen stations is a general concern based on the now extensive (over 15-year) light-duty fueling station operational experience. For example, in September 2025, the Hydrogen and Fuel Cell Partnership (H2FCP) reported that, of the 58 light-duty stations in California, 51 were currently open and operational, while 7 were on a temporary non-operational status. The average availability of the stations was 87% during a recent 30-day period, suggesting that on average an individual station may be non-operational for about 4 days per month.[7] As the broader hydrogen and zero-emission vehicle market expands, lessons learned from adjacent sectors are increasingly informing best practices that can help improve long-term reliability for transit-focused refueling infrastructure.

A detailed study of light-duty stations in California in 2019 found that the most recently installed stations at that time had the highest failure rates for the dispenser and compressor sections, with chillers and mechanical controls also demonstrating relatively high failure rates. Dispensers were failing and requiring unscheduled maintenance after approximately 250 fills, with the other three types requiring this after about every 500 fills (Kurtz et al. 2019). It is important to note, however, that public hydrogen stations designed to serve light-duty vehicles at 700 bar are more complex, requiring compressors and cooling systems that are not needed for transit bus refueling systems.

Larger hydrogen stations to support transit bus fleets are designed differently, in a more robust fashion that only requires 350 bar pressure dispensing and are not experiencing the same challenges highlighted with light-duty stations. That said, all hydrogen stations are fairly

[7] According to a H2FCP member update on Sept. 10, 2025.

complex with a variety of sub-systems, have many potential points of failure, and also require periodic scheduled maintenance as well as unscheduled repairs.

In the survey, California transit agencies were asked whether the state of California should mandate the reliability, or equipment uptime, of ZEB charging/fueling infrastructure. This was asked generally, with no indication or suggestion of how a reliability mandate would be developed or implemented. Survey respondents from small agencies were evenly split—21 of 48 agreed and 22 of 48 disagreed. Large agencies had a slight preference for a reliability mandate, with 9 of 14 agencies agreeing and 5 of 14 disagreeing (Figure 50).

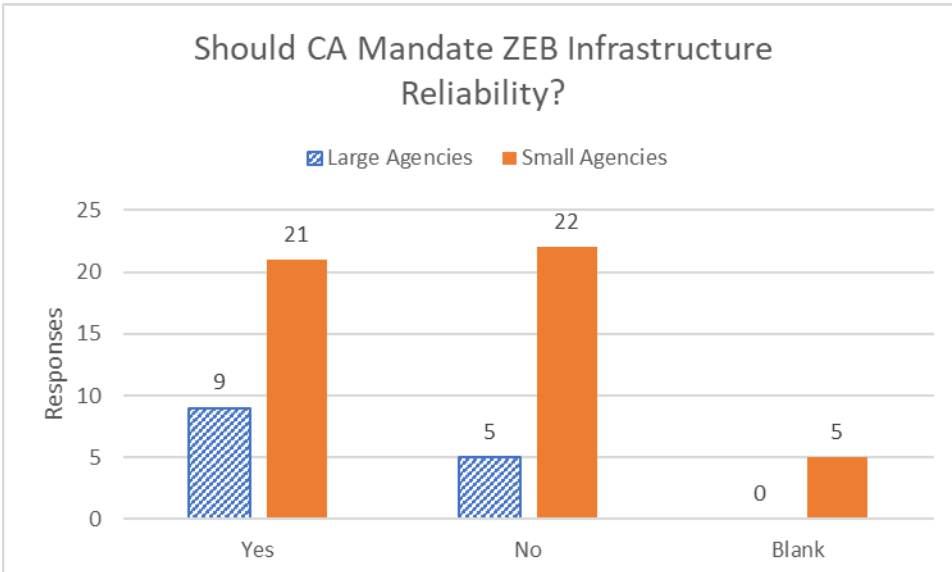

Figure 50. Transit survey responses for California mandates to ZEB infrastructure reliability.

Source: Survey of California transit agencies

When asked what their desired level of infrastructure reliability would be, in terms of equipment/station uptime, transit agencies who preferred a reliability mandate responded with the results shown in Figure 51. All large agencies desired reliability/uptime of 95% or higher while most small agencies suggested a reliability/uptime of at least 75%. The highest and lowest responses are summarized in Table 13. The average level for large agencies is significantly higher than the 87% recent observation in light-duty hydrogen stations in California, but the average level for small agencies is similar.

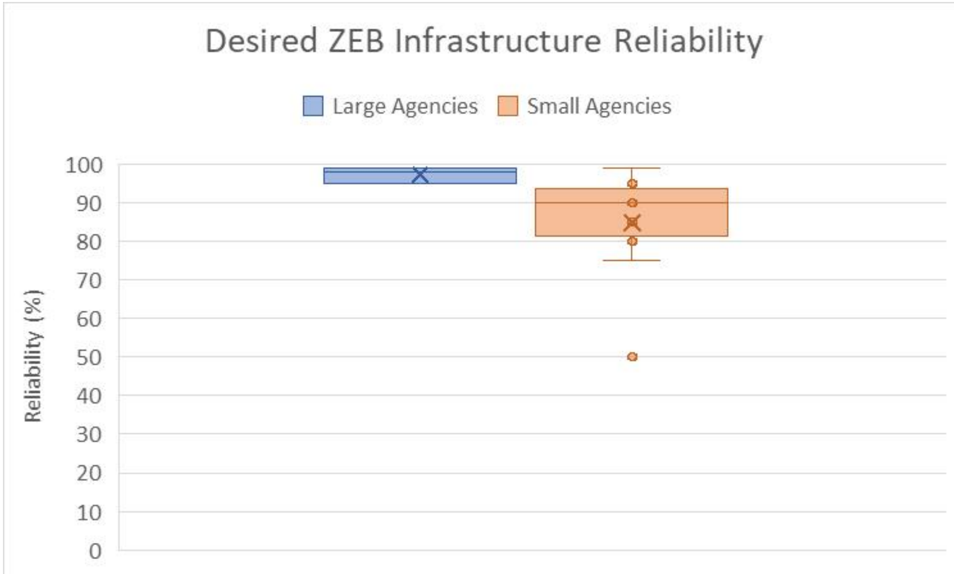

Figure 51. Transit survey responses for desired level of ZEB infrastructure reliability.

Source: Survey of California transit agencies

Table 13. Range of Survey Responses for Desired Infrastructure Reliability

Reliability (%)	Large Agencies	Small Agencies
Maximum reliability (%)	99	99
Minimum reliability (%)	95	50
Average reliability (%)	**97.3**	**84.8**

Source: Survey of California transit agencies

The three large transit agencies operating FCEBs who responded to questions in the transit survey regarding their hydrogen fueling station reported infrastructure reliability/uptime of 95%, 99%, and 99%. The uptime of hydrogen fueling stations will need to be near 100% during the refueling windows in order to ensure consistent operations for transit agencies, especially as FCEB fleet sizes expand.

One significant challenge specific to hydrogen fueling stations related to performance and reliability is minimizing the boil-off from LH2 storage. If not used effectively, excess boil-off requires venting, and this loss of hydrogen fuel directly impacts the total fuel cost to operate FCEBs, increasing per-mile costs. There are systems being developed to minimize these boil-off losses, including through R&D programs from DOE, but they remain a concern at present especially when liquid fuel is being delivered.

Related to station reliability and fuel boil-off issues, safety is a critical concern for hydrogen fueling stations that support transit bus fueling. There are extensive hydrogen safety materials and resources available through the Hydrogen Tools Portal, an effort managed by Pacific Northwest National Laboratory for DOE. The information includes information on codes, standards, and permitting, frequently asked questions, best practices for safety, web-based toolkits such as H2First (technology validation and system design) and HyRAM (hydrogen risk assessment), and a workforce development module called H2Skills. There is also information about the Center for Hydrogen Safety, a global nonprofit that promotes best practices for safety and investigates safety incidents (h2tools.org). These extensive resources should be useful for transit agencies seeking to develop hydrogen fueling stations with their development partners.

The survey also asked transit agencies whether they plan to provide public access to their ZEB charging or fueling infrastructure, as this can generate additional revenue to help cover operating costs and increase the amount of LCFS capacity credits they can earn for unused station capacity, among other benefits. Of the transit agencies responding to this question in the survey, less than one-third are planning to provide public access (Figure 52). Transit agencies should explore sharing fueling infrastructure with other public and private fleets as a way to increase station utilization and drive down operating costs.

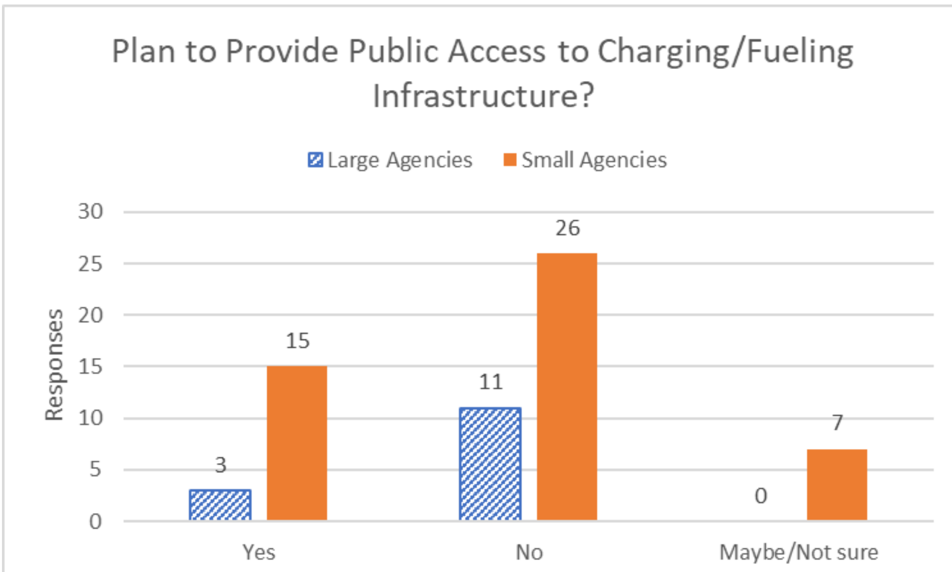

Figure 52. Transit agencies planning to provide public access to charging infrastructure.

Source: Survey of California transit agencies

6.4 Remaining Infrastructure Challenges

The primary challenges with ZEB charging and fueling infrastructure are related to costs. The upfront capital costs can be the most significant barrier to deploying ZEBs, especially if major upgrades to existing facilities are needed to accommodate the new infrastructure.

Transit agency experience so far indicates that the installation of ZEB infrastructure is often delayed and can vastly exceed initial expectations for completion timelines. When construction deadlines are delayed, the costs nearly always increase—again, exceeding initial expectations and planned budgets. Industry stakeholders need to determine if there are effective ways to avoid the costly delays and/or remediate the added costs.

Low station reliability and incidents leading to unscheduled maintenance can also increase the cost burden on transit agencies. Improved components, standardized systems and maintenance practices, and additional experience operating stations will all help transit agencies better predict and manage the costs in the long term, but high operating costs are still a real concern for transit agencies currently deploying new station technology to expand their ZEB fleets. Growing experience and proven technologies emerging from adjacent zero-emission markets may help enhance component durability, strengthen supply chains, and lower operational costs as similar systems become more widespread.

The transit agency survey included detailed insights into the challenges, experiences, and recommendations of transit agencies concerning BEB charging infrastructure. A summary of responses from the transit industry on the topic of charging infrastructure, include:

- Downtime challenges:
    - Agencies reported frequent and varied causes of downtime, such as power module failures, software and programming issues, grid outages, vandalism, and weather-induced shutoffs. The duration of downtime ranges from hours (in some cases) to months (for major component replacements). Agencies reported issues such as failure of charging control software, slow replacement of circuit boards, and delays due to limited manufacturer support or parts availability.
- Utility coordination and infrastructure upgrades:
    - Many agencies noted that installing chargers required utility upgrades, with half of smaller agencies and a majority of larger agencies reporting infrastructure work beyond basic equipment installation and facility construction.
    - Agencies experienced long delays with utility coordination and infrastructure upgrades. In some cases, utility providers capped energy supply to charging stations or were unwilling to plan for future fleet expansions beyond 5 years. There were also significant delays in grid upgrades and low prioritization by utilities, which hindered progress.
- Warranty coverage:
    - Charging equipment warranties typically range from 1 to 5 years, covering parts and labor. Standard warranties may include options for purchased extensions, with coverage varying by manufacturer (e.g., ABB, Heliox, and others).
- Charging infrastructure management:
    - Charging infrastructure management highlighted complexities like inadequate redundancy for failures, costlier transitions relative to CNG fleets, compatibility issues, and complications in managing large-scale charging systems. Utility energy availability and grid constraints were identified as significant bottlenecks.
- Infrastructure recommendations from transit agencies:
    - Agencies responding to the survey suggested several strategies to address challenges, including:
        - Prioritizing land acquisition or reducing land-related barriers through local political support.
        - Streamlining utility processes to align with project timelines.
        - Incorporating resilience features into BEB infrastructure, like backup diesel/natural gas generators, microgrids, and solar power to counteract grid constraints.
        - Promoting community and stakeholder engagement to ensure local needs are addressed in infrastructure programs.

The development of hydrogen fueling infrastructure for FCEBs also entails considerable challenges for transit agencies. While hydrogen fueling stations have been used by transit agencies for many years now—dating back to the early 2000s for AC Transit and SunLine Transit (two early hydrogen bus pioneers)—there can still be issues with station reliability given the complexity of the equipment. As noted above, some hydrogen fueling stations for transit applications are reported to be operating at 99% uptime, but one reported 95% uptime meaning a handful of days per year that the station was not operational and able to fill buses. This could be addressed in the future with improved station designs and more robust technologies (especially the critical hydrogen compressor section), including greater redundancy with key components. In turn, these improvements could allow continuous station operation, perhaps with reduced throughput, rather than a station being completely compromised with the sudden downtime of one critical station component.

The questionnaire to transit industry OEMs also included reference to infrastructure challenges. Infrastructure readiness is noted as a significant challenge for ZEB deployment. Key infrastructure issues noted in OEM responses include utility delays in providing necessary upgrades for charging, long lead times for equipment like switchgear and hydrogen station components, and the complexity and cost of deploying large-scale charging/fueling infrastructure. Policies to encourage utilities to prioritize and streamline interconnection processes are recommended, along with stronger public-private collaboration to facilitate infrastructure deployment.

7 Workforce Development

The U.S. transit industry has been facing a severe and growing issue with its workforce—a shortage of operators and mechanics that has impacted 96% of agencies and caused difficulty to 84% of agencies in meeting their transit service (according to a survey by APTA). The crisis is largely caused by the aging of the transit workforce, leading to many ongoing and impending retirements (43% of transit workers are over 55), but it is also influenced by persistent hiring barriers and concerns about worker compensation and schedules in the current job market. The industry has found it increasingly difficult to attract and retain talented young professionals looking to make a career in the transit sector (American Public Transportation Association 2022; 2023a; 2023b; TransitCenter 2023a; 2023b).

As ZEBs become more prominent in nationwide transit service, a critical need has emerged for a workforce capable of operating and maintaining advanced, electrified bus fleets. This need has been echoed by early adopters of ZEBs and is reflected in the evolution/expansion of ZEB funding programs that increasingly allow funds to be invested in workforce development programs. This compounds the existing need for new competent and motivated workers in transit positions at large and highlights the great challenge agencies currently face to develop the next-generation workforce.

Therefore, transit agencies nationwide—and especially in California, where the ZEB transition is paramount—are in serious need of resources to help recruit, retain, and train workers to support the ZEB transition without compromising transit service.

Some of those workforce needs include training for:

- **Fleet planning, procurement, project management, and bus scheduling/dispatching:** When agencies are short-staffed, there is often little or no bandwidth to adequately learn and plan for a ZEB transition (e.g., applying for grants, coordinating infrastructure) and managing the ZEB projects, which leads to less successful ZEB deployments, delayed deployments, or no deployments at all.
- **ZEB operation:** Fleets with ZEBs in service highlight the need for bus operators to be aware of important differences such as regenerative braking; the impact of heating, ventilating, and air-conditioning usage; and, for BEBs, monitoring the bus's remaining state of charge. Additional training to provide familiarity with proper ZEB procedures can prevent problematic and/or costly situations, from minor electronic faults to road calls and extended bus downtime (Los Angeles County Metropolitan Transportation Authority 2024).
- **ZEB maintenance, troubleshooting, and repair:** ZEBs contain new technology and advanced powertrain components which can take longer to troubleshoot and repair until technicians become more familiar with them.

However, the expansion and training of the ZEB workforce is not limited to just transit agencies. While this is a transformation of the entire industry, it is also crucial to examine the sufficiency and adequacy of the manufacturing and supply chain workforce. It is equally important to ensure the entire manufacturing and supply chain industry has sufficient and adequate workforce that can design products and build production lines to ensure product safety and performance. The manufacturing and supply chain workforce should also be able to identify gaps between vehicle design and existing charging/refueling standards and protocols for a smooth product rollout.

In recent years, many new initiatives have emerged, and existing training programs have grown to help meet the workforce development needs of the zero-emission transit industry. These initiatives appear at the national, state, regional, and local levels; have been developed by a mix of government agencies, transit industry associations and private companies, as well as transit agencies themselves; and were created to both address specific needs and to provide a broad swath of resources.

7.1 National Training Programs and Resources

At the federal level, the DOT's FTA has recently created the Transit Workforce Center, a technical assistance center aimed at helping all public transit agencies meet their workforce training needs. The Transit Workforce Center provides an abundance of resources, including training curricula, a recruitment toolkit, apprenticeship and mentorship information, a workforce data dashboard, transit case studies, and train-the-trainer programs. The center also has training materials designed specifically for maintenance of low- and no-emission bus technologies to help prepare technicians to support fleet transition to ZEBs (Federal Transit Administration 2025j; Transit Workforce Center 2025a).

The Transit Workforce Center is operated under a cooperative agreement by the International Transportation Learning Center, a nonprofit organization dedicated to assisting critical sectors of our economy—including public transit—with recruitment, hiring, retention, training, and career advancement (International Transportation Learning Center 2025).

Recognizing the urgent and growing need for transit workforce development, FTA has provided support funding through the Technical Assistance and Workforce Development Program—nearly $60 million since 2020. Eligible projects for this funding program include: (1) technical assistance, (2) human resources/training, and (3) innovative public transportation frontline workforce development. Approximately $20 million has been used to fund more than 45 grants for transit agencies implementing innovative workforce development projects for hiring, upskilling, and retaining workers (Federal Transit Administration 2025j). FTA publishes a variety of research reports, including the findings from these grant-funded projects, to share all lessons learned and best practices with stakeholders throughout the transit industry.

FTA plans to provide more than $60 million in funding ($12–$13 million per year, 2022–2026) through the Bipartisan Infrastructure Law for Technical Assistance and Workforce Development programs, as outlined in Table 14 (Federal Transit Administration 2025d). Since 2020, CA has only received apportionments from this program for one calendar year (2022), representing 20% of that year's funding and only 8% of the total funding from the reported period (Federal Transit Administration 2025a).

Table 14. FTA, Bipartisan Infrastructure Law Funding for Technical Assistance and Workforce Development (Federal Transit Administration 2025d)

Fiscal Year ($ in millions)	2022	2023	2024	2025	2026
Technical Assistance and Workforce Development	$12	$12	$12	$13	$13

Also at a national level, the American Public Transportation Association (APTA), which is a membership organization for the U.S. transit industry, has collected and organized a variety of workforce development resources in their APTAU Workforce Clearinghouse. Notable resources in the clearinghouse range from a Transit Workforce Readiness Guide and six Workforce Miniguides on relevant training topics to webinars, case studies, research reports, and other industry materials. The content is designed around attracting, training, and retaining transit workers of all types, including and extending beyond ZEB-related careers/topics (American Public Transportation Association 2025a).

For EV charging-related vocational training, the Electric Vehicle Infrastructure Training Program (EVITP) is a well-established program to train and certify electricians in the U.S. and Canada on the proper installation of EVSE. The curriculum is developed collaboratively by the industry partner organizations involved in the program, which is a long and diverse list of stakeholders that includes vehicle and component manufacturers, charging equipment manufacturers, electrical professional associations, utilities, educational institutions, and other EV technology providers. These stakeholders are committed to setting and upholding the highest safety and quality standards to help meet the growing needs for residential, public, and commercial fleet charging. This type of training program is especially important to help keep professionals up to date on the latest charging technology, safety requirements, and installation best practices as the EV markets expand rapidly (EVITP 2025).

For resources related specifically to hydrogen, the Hydrogen Education for a Decarbonized Economy (H2EDGE) initiative is a program run by the Electric Power Research Institute (EPRI) and supported by DOE's Hydrogen and Fuel Cell Technologies Office and the Low-Carbon Resources Initiative to provide professional development opportunities for the hydrogen industry. The initiative provides courses, hosts/promotes professional events, and supports collaboration and networking between industry organizations to address a wide array of research, training, and educational needs related to hydrogen. The program is organized around the four primary pillars of the hydrogen industry: production, delivery, storage, and end use of hydrogen. H2EDGE lists a network of 27 university partners, over 400 university students, and 19 industry partners on the advisory board for the program. Hydrogen is expected to continue growing as an increasingly important component of low-carbon transportation systems. Providing training tools and curricula related to hydrogen technology through H2EDGE will help ensure there are qualified professionals to fill the emerging employment opportunities and continue to advance the technology (Electric Power Research Institute 2025a; 2025b).

Additionally, some workforce training programs have been developed by vehicle manufacturers, such as the New Flyer Vehicle Innovation Center and the MCI Academy. The Vehicle Innovation Center is intended to be a state-of-the-art learning laboratory to showcase and advance the latest R&D in transit bus and coach technology. At the center's headquarters location in Alabama, the center hosts visits and tours for industry professionals and provides both in-person and virtual training programs on topics related to ZEBs, infrastructure, as well as connected and automated vehicle technology. Similarly, MCI Academy is a learning system focused on the maintenance, diagnosis/troubleshooting, and repairs of MCI vehicles. The program caters to all levels of technicians and offers multiple corresponding certifications. MCI also offers to bring their training programs on-site to transit agencies' locations for a convenient and efficient option for upskilling an agency's entire maintenance staff (New Flyer 2025; MCI Academy 2025).

7.2 California Training Programs and Resources

As many California transit agencies were on the leading edge of early adoption of ZEBs, so too are several agencies at the forefront of training their staff to operate and maintain ZEBs. Some of the initial training programs that were initially developed in-house were subsequently refined and expanded into larger programs that were able to help other transit agencies beginning their ZEB transition.

One example is AC Transit, which has been building and refining its in-house maintenance training for more than 20 years into an effective, industry-leading technical training program. This program has been expanded into what AC Transit calls the Zero Emission Bus University (ZEB U) that includes technical training, career development, and apprenticeships, as well as a vision to rebuild its old training and education center into a "21st-century learning lab" with advanced software and hardware tools for an immersive and comprehensive training on ZEB technology. These efforts were made possible by sizeable grants from FTA's Low-No program and other sources to invest in the necessary workforce development for ZEBs. AC Transit has also partnered with local community colleges and trade associations to expand the reach of the program and bolster the impact of vocational and academic institutions helping to build the future transit workforce (AC Transit 2023; 2025).

Another notable case is SunLine Transit's West Coast Center of Excellence in Zero Emission Technology and Renewable Energy, which stands out as an early accomplishment in establishing a dedicated training and education center focused on new ZEB technologies. This center and state-of-the-art maintenance facility, built on the expertise SunLine had gained from operating ZEBs, was funded by a grant from the FTA and hosted by SunLine Transit, with collaborative input invited from other stakeholders. The initial plans and courses were developed in coordination with other transit agencies and transit bus OEMs through a series of workshops to identify the most important topic areas. Initial courses combine classroom instruction and hands-on demonstrations, covering everything from ZEB overviews to ZEB procurement and planning to ZEB operations, maintenance, and safety topics. The center began hosting its first workshops in early 2023 (Transit Workforce Center 2025b; SunLine Transit 2021; 2025).

The California Transit Training Consortium (CTTC) recently celebrated its 20th anniversary as a leading nonprofit organization providing technical training for the public transit industry. CTTC was originally founded by regional transit leaders as the Southern California Regional Transit Training Consortium, with the aim to develop and deliver cost-effective training for the transit workforce on emerging alternative fuel technologies. The consortium is managed by the Center for Transportation and the Environment and now consists of numerous public transit agencies, educational institutions, and private industry partners collaborating on effective and up-to-date transit workforce training to help achieve the state's ambitious transit goals. Some areas of focus include safety, maintenance, and operations for advanced bus technologies and alternative fuels. Partnering associations include APTA and CTA. CTTC supported transit agencies in Southern

California as they transitioned their bus fleets from diesel to CNG technology and is now prepared to support the transition to ZEBs by all transit agencies (CTTC 2023; 2024; 2025).[8]

7.3 Workforce Topics From Transit Survey

Despite this list of programs providing a growing list of resources and training curricula, workforce training is still cited by many California transit agencies as a concern and major remaining need to enable the statewide fleet transition to ZEBs. The transit survey conducted by NLR asked transit agencies about their current experience and expected training needs to support ZEB transition. For transit agencies responding to the survey, 12 of 14 large agencies (86%) and 16 of 48 (33%) small agencies said they have begun training staff for ZEBs. This disparity reflects the fact that only large agencies have been subject to the ICT regulation so far, and they represent the majority of agencies deploying ZEBs. For those who have begun ZEB training of any kind, the staff/roles that have been the focus of training efforts so far are shown in Figure 53. These primarily include maintenance staff and bus operators, and to a lesser extent dispatchers and first responders.

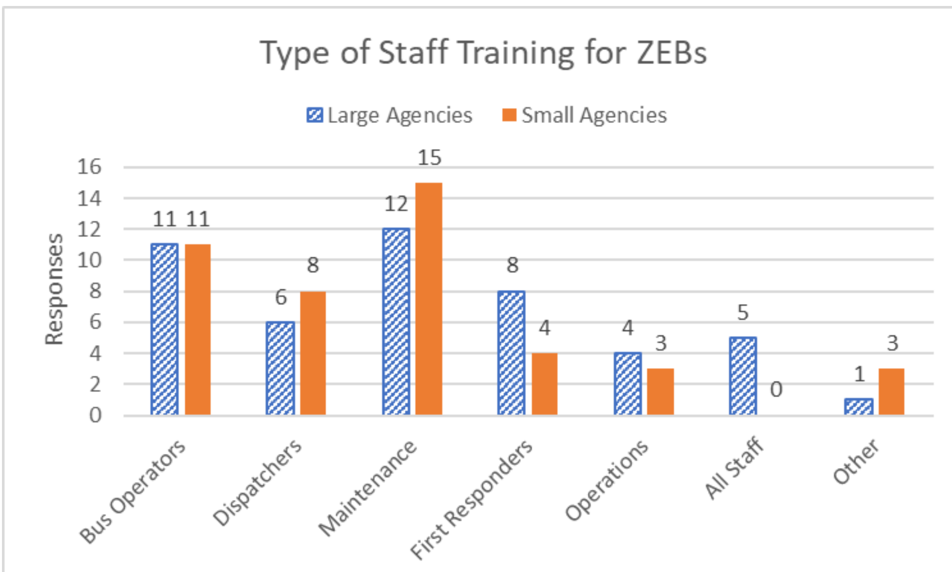

Figure 53. Staff training conducted for ZEBs, from transit survey.

Source: Survey of California transit agencies

For the ZEB training conducted so far, there is a mix of sources selected for the provided training—including the transit agency (i.e., training programs developed in-house), the bus OEM providing the ZEBs, and training from a third-party contractor or specialized training organization (Figure 54). Some agencies utilized more than one source of training for different topic areas. Many agencies reported that they utilized ZEB training from OEMs that was included in the bus purchase. This often covered ZEB familiarity training or orientation of the new vehicles for all staff, plus initial operator training, and sometimes also included first responder training. Some agencies purchased additional training from the bus OEM, beyond what was included in the bus purchase. Large agencies reported additional training costs between $50,000-$200,000. Small agencies reported additional training costs between $5,000-$30,000.

[8] CARB 2024 board memo.

Some agencies responding to the survey only provided the rate they paid for training, as approximately $250 per hour or $4,500 per bus for the OEM-provided training, but did not specify how much training was received.

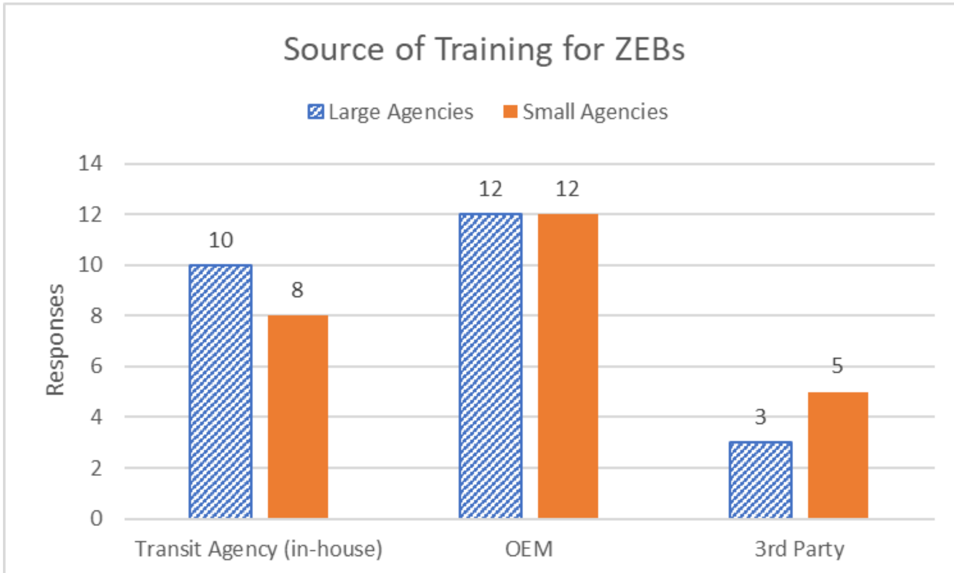

Figure 54. Source of training for ZEBs, from transit survey.

Source: Survey of California transit agencies

In addition to OEM-provided training, several agencies cited the California Transit Training Consortium as the source for ZEB-specific training such as BEB maintenance and high-voltage safety awareness training. The West Coast Center of Excellence was cited as providing courses covering Introduction to ZEBs, ZEB Operation, ZEB Planning and Deployment, and ZEB Leadership and Acquisition. These training courses were free or included in the cost of membership (not including travel costs).

Regardless of the source of ZEB training, more than 80% of transit agencies reported that the training met or exceeded their expectations and that it was effective and sufficient. However, a couple of agencies said the training effectiveness was yet to be determined, and one respondent said the training was very basic and did not include enough diagnostics/troubleshooting.

Only half of the large agency respondents reported having received grants or other funding to help specifically with training needs. For small agencies, only four (less than 10% of respondents) have received grants for training-specific funding. For those who received training grants, the programs mentioned by name primarily include FTA's Low-No and Bus and Bus Facilities programs (Section 5339), and TIRCP funding. Some small agencies reported having applied for competitive Low-No funding but have not been successful yet.

More than half of the large agencies reported that the required transition to ZEBs is requiring additional staff at their agencies. Some of the new or additional roles that are needed at different agencies include:

- ZEB planning and procurement staff,

- Engineering and project management for large infrastructure projects (charging/fueling stations and maintenance facilities),
- ZEB training curriculum developers and instructors,
- Maintenance technicians, and
- A ZEB transition manager to coordinate all aspects of ZEB procurement and deployment.

Many small agencies voiced the need for some of the same positions as the large transit agencies, although they reported a greater need for staff to help with ZEB transition planning, grant writing, and maintenance technicians for ZEBs.

Similarly, large and small agencies alike report that the ZEB transition has already created significant additional workload on existing staff at their agencies. In some cases, the agency was able to hire more staff to assist, but in most cases thus far, the increased workload has had to be absorbed by existing staff.

Going forward, nearly all large agencies said they plan to grow their in-house training programs to address ZEB needs, and many said they would use external programs as needed to build their capabilities. Most intend to follow a "train-the-trainer" approach where they will send select staff to receive specialized training via external professional training programs and educational institutions, which will equip them with the necessary skills and knowledge to effectively teach other staff within their organization. The in-house trainers would then be responsible for developing and delivering comprehensive training programs tailored to the specific ZEB training needs of the agency, whether that is focused on planning, operations, maintenance, or multiple categories. This is one area of the ZEB transition where state agencies and the funding support they provide could be effectively utilized to help transit agencies (especially small agencies) gain new technical expertise to jump-start their in-house ZEB training capabilities.

The survey asked California transit agencies to describe their priority training needs. Figure 55 shows the transit agencies' responses for priority training needs, in ranked order, with the corresponding topic areas listed in Table 15. The open-ended responses provided by transit agencies often described various aspects of the same training topics—some very specific, and some very broad. The responses were reviewed and organized with the intent to identify the key need(s) of each response. Thus, some of the categories below are similar and may even overlap with one another to some extent.

The most common topic area was (1) General Maintenance, with 13 total responses. Closely connected to general maintenance were the next two categories: (2) PPE/safety procedures with 11 responses, and (3) ZEB diagnostics/troubleshooting with 7 responses. Also closely related, but a bit more specific, were categories (7) ZEB repairs, advanced components/systems, and (8) ZEB preventive maintenance. These results highlight the overwhelming concern that transit agencies have regarding ZEB maintenance topics.

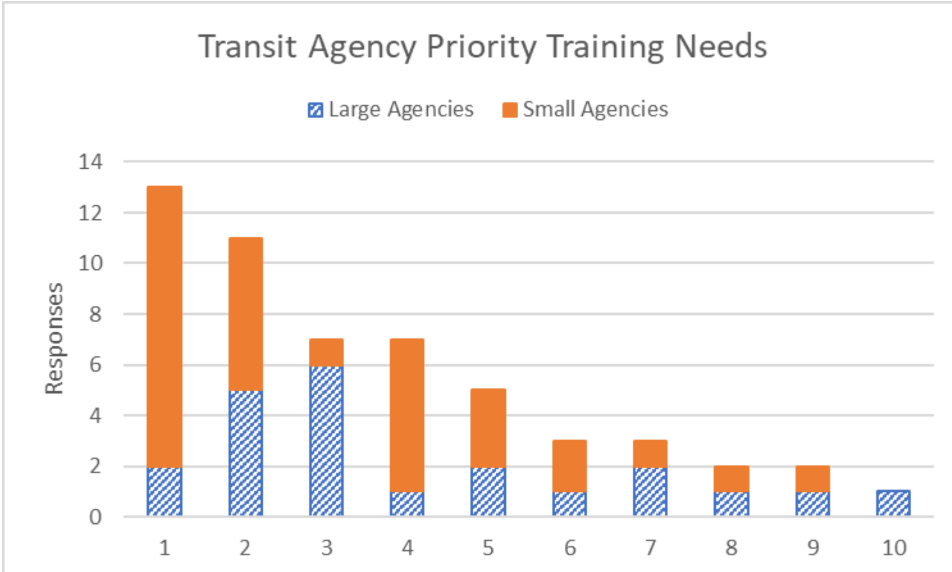

Figure 55. Priority training needs, from transit survey.

Source: Survey of California transit agencies

Table 15. Priority Training Needs, From Transit Survey

Rank	ZEB Topic Area
1	Maintenance (general)
2	PPE/safety procedures (high voltage, high-pressure gas), emergency response
3	ZEB diagnostics/troubleshooting
4	Driver training, operations/BEB fleet management
5	Infrastructure operation and maintenance
6	All areas
7	ZEB repairs, advanced components/systems
8	ZEB preventive maintenance
9	Battery monitoring, maintenance, replacement/disposal
10	Regulatory compliance and best practices

In the transit survey, agencies were asked if they thought some ZEB training should be included as part of FTA's safety training. Of those who responded, 71% of large agencies agreed and 69% of small agencies agreed (Figure 56). Detailed explanations from follow-up questions about the agencies' desired safety training were grouped into similar topic areas. These areas highlight the agencies' most significant training needs. The desired or recommended topic areas that were suggested by respondents are shown in ranked order in Figure 57, with the corresponding list provided in Table 16. Although there is significant overlap/intersection between many of the provided survey responses, and therefore, the resulting topic areas, the top three categories of responses are (1) batteries and high-voltage electrical systems, (2) accident/emergency response and fire suppression, and (3) maintenance/preventive maintenance inspections (PMI) procedures and mechanics training.

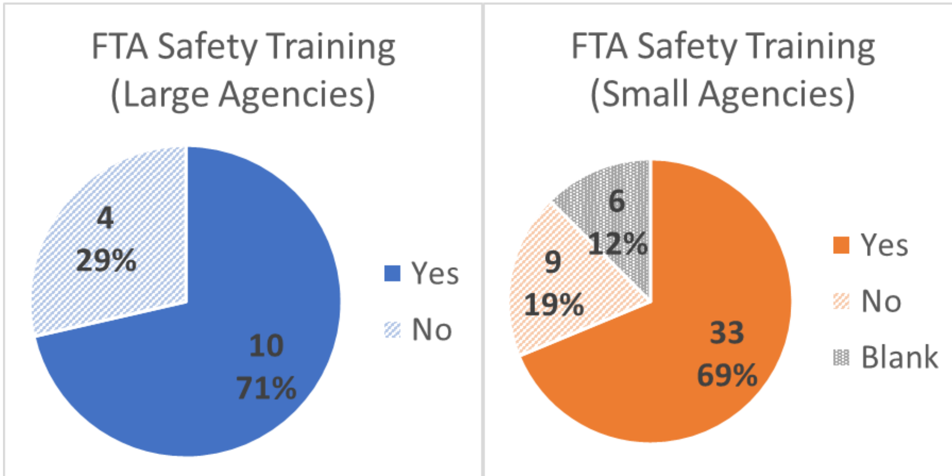

Figure 56. Transit agency support for FTA safety training for ZEBs.

Source: Survey of California transit agencies

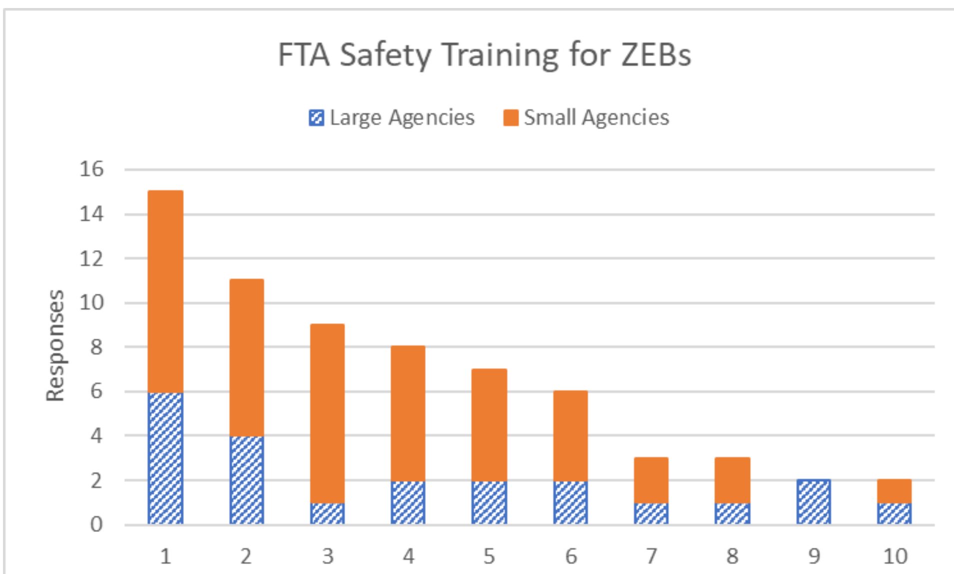

Figure 57. ZEB topics to include in FTA safety training, from transit survey.

Source: Survey of California transit agencies

Table 16. ZEB Topics To Include in FTA Safety Training, From Transit Survey

Rank	ZEB Topic Area
1	Battery/high-voltage electrical systems
2	Accident/emergency response, fire suppression
3	Maintenance/PMI procedures, mechanics training
4	ZEB operations, driver training, passenger safety/awareness training
5	Safe work practices, LO/TO
6	Charging/fueling
7	ZEB basics (battery and fuel cell)
8	Environment and health considerations, hazardous materials
9	Hydrogen/high pressure systems
10	Regulatory compliance and best practices

7.4 Workforce Topics From OEM Questionnaire

OEMs and suppliers responding to the questionnaire indicated they provide various training programs tailored to transit agencies, suppliers and personnel. They described customizable training programs for transit agencies and first responders based on specific needs and preferences. Training can be delivered online, in person, or as a hybrid format, and refresher courses are available upon request. Training and knowledge transfer to transit maintenance teams were emphasized to improve fleet reliability.

One OEM described a training process that starts with operator and technician familiarization during the initial delivery of ZEBs. Additional sessions offered by the OEM cover theory, operation, safety, troubleshooting, and diagnostics related to ZEBs.

OEMs typically collaborate with suppliers for key training needs but indicated that certain supplier components are not serviceable by end users, so detailed service training may be limited. Plans to expand training programs include using technology and media to improve accessibility for its transit agency customers. One supplier commented that they provide extensive training on operating, maintaining, troubleshooting, and repairing fuel cell modules, supported by virtual learning tools. This approach helps to reduce costs and make the training more widely available to transit agency staff than in-person, hands-on training.

7.5 Remaining Challenges and Industry Recommendations

Although numerous training programs are emerging and expanding to meet the workforce development needs of the transit industry, a primary challenge is that agencies do not always have sufficient resources available to adequately train their existing workers and hire additional help that is needed.

Based on feedback from transit agencies, key remaining challenges related to workforce development for ZEBs include:

1. **Training needs:** Agencies require extensive training in new areas like ZEB maintenance, diagnostics and repairs, and safety for high-voltage systems that are often in addition to their existing training programs.
2. **Workforce shortages:** Aging transit staff nearing retirement (43% over age 55) and difficulties in attracting younger workers lead to recruitment and retention issues, which amplify the additional training needs caused by the ZEB transition.
3. **Funding gaps:** Many small agencies, in particular, struggle to secure adequate funds for training-specific initiatives or to offset high costs for additional training.
4. **Workload burden:** ZEB transitions increase the workload on existing staff, often without additional hires to support new planning and operations tasks.
5. **Training accessibility:** Agencies feel that the existing programs are not always affordable or accessible, and effectiveness can vary depending on training sources.

Based on feedback from transit agencies, key recommendations to address workforce development challenges for ZEBs include:

1. **Expand training programs:** Begin utilizing external training programs and resources like the FTA’s Transit Workforce Center, AC Transit’s ZEB University, and SunLine Transit’s West Coast Center of Excellence and apply a “train-the-trainer” approach to build in-house training expertise for each agency.
2. **Increase funding:** Expand and streamline financial support, such as grants or vouchers, to make training programs more accessible and affordable for small and large agencies.
3. **Focus on key training areas:** Identify and target critical training gaps such as ZEB maintenance and system diagnostics, certifications for work with high-voltage electrical systems, hydrogen fueling safety, and emergency response procedures to prepare staff for work with advanced technologies.
4. **Collaborate with stakeholders:** Partner with local community colleges, industry organizations, trade unions, and technology providers to refine best practices, standardize curricula, and increase access to advanced learning tools.
5. **Improve recruitment efforts:** Address persistent hiring barriers, invest in the workforce by offering competitive compensation, and attract young professionals to build the next generation of transit workers.

As mentioned, the ZEB market relies on the strength of a broader, thoroughly developed zero-emission transportation industry before a successful sector-specific vehicle transition can occur. Expanding manufacturing capacity, supply chains, and infrastructure—combined with comprehensive workforce developments across the entire market—is critical to ensuring high-quality product design and production, proper vehicle operation and maintenance, reliable performance, minimal downtime, and the protection of both workforce and passenger safety. These industrywide advancements help reduce costs, enhance technical expertise, and improve overall system dependability for transit agencies adopting ZEBs. Collectively, workforce development is a leading factor for an effective progression to zero-emission technologies.

8 Summary and Conclusions

Based on the review presented here, this section provides a summary of key points and overall conclusions from the assessment. Summaries of recent industry progress and key remaining challenges, as well as an overall assessment of industry readiness to meet the ICT requirements, are also provided.

8.1 Phase I Review: Four "Key Needs"

In Phase I, the ICT comprehensive review concluded that the California transit industry was well positioned to proceed with the 2023 requirement of 25% of new bus purchases being ZEBs for large transit agencies. This was supported by large transit agencies' ZEB rollout plans; momentum developed from more than a decade of ZEB demonstrations and deployments; continued product development and refinement led by the transit industry; a supportive environment for ZEBs as described above; and successful partnership and collaboration of California transit agencies, vehicle manufacturers, charging and fuel equipment suppliers, utility providers, and others.

The Phase I review stressed that additional coordination, focus, and resources would be necessary to achieve a successful transition to 100% ZEB transit fleets in the coming years. Specifically, the following areas were identified to be addressed:

- Sustained progress from the vehicle, equipment, and infrastructure manufacturing base is needed to continue driving down costs, improving reliability, and optimizing performance.
- Expanded charging and fueling infrastructure is a fundamental need that will require coordinated efforts and forward-looking planning by transit agencies, utilities, and developers.
- Comprehensive and standardized training programs are needed to develop a highly skilled workforce that can improve the efficiency and cost of maintaining ZEB equipment while creating new jobs and ensuring safety.
- Financial support for purchasing, installing, and operating ZEBs and the related fueling/charging equipment is necessary.

8.2 Summary of Recent Progress

Despite a number of market and technology barriers, ZEBs continue to offer significant energy efficiency and air quality improvements, making them a key focus for future transit solutions. California has made substantial initial progress toward its goal of transitioning to ZEB transit fleets. Overall, California transit agencies and their partners in government and industry have demonstrated leadership in advancing ZEB deployment, exceeding initial targets, building critical infrastructure, and securing funding to ensure future progress. Some notable progress since 2018 is summarized below.

Deployment Progress

- **Ahead of schedule:** As of 2024, California transit agencies have collectively deployed (in service and on order) a total of 1,671 ZEBs (1,241 BEBs and 430 FCEBs), getting ahead of the ICT target of 1,347 ZEBs for 2027 and gaining valuable operational experience. Compared to 2023 reporting data, BEB numbers increased 17% (from 1,065 to 1,241), and FCEB numbers increased 90% (from 226 to 430).

- **Future projections:** California agencies have prepared and refined ZEB rollout plans that, if followed and executed on schedule, can keep the state ahead of the ICT ZEB targets, estimating a collective total of 13,300 ZEBs to be deployed statewide by 2040. Many transit agencies are proactively adjusting their plans to address the current real-world conditions for their fleets, while working diligently to meet the ICT goals.
- **Initial growth in small ZEB class:** Nationwide, small ZEBs (<30 feet in length) increased to 1,165 in 2024, with California accounting for more than half (674) of the total. That represents 15% growth overall and 24% in the transit sector for a bus type that is critical to many agencies' service needs and is now being tested in many more real-world applications. Continued progress in this area is needed to provide transit agencies with suitable bus models that meet their service needs.

Agency Milestones

California's ZEB transition is well underway, with agencies adopting a mix of BEBs and FCEBs tailored to their operational needs. While large agencies lead in scale, smaller ones are innovating in infrastructure and service models. The state is on a strong path toward meeting and exceeding its goals for low-carbon transit.

- **Leaders in full ZEB transition:**
    - Both AVTA and SMRT have fully transitioned to 100% ZEB fleets.
    - ATN has more than 80% ZEBs and aims for full conversion by 2026.
- **Large urban agencies scaling rapidly:**
    - LA Metro plans to add a significant amount of ZEBs (approximately 500) in time for the 2028 Olympics.
    - LADOT has secured more than 200 BEBs and is building major ZEB infrastructure.
    - Long Beach Transit expressed at the 2025 CTA Fall Conference that one-third of their fleet are zero emission and plans for full transition by 2030.
- **Hydrogen fuel cell pioneers:**
    - SamTrans, Foothill Transit, AC Transit, OCTA, and SunLine Transit are investing heavily in FCEBs, demonstrating and helping to continually improve the technology.
    - HTA and Santa Cruz Metro are building hydrogen fueling stations and piloting long-range FCEBs.
- **Small and rural agency innovation:**
    - Porterville, Fresno, and SolTrans are innovating with microgrids, on-demand EVs, and inductive charging solutions to meet their local service needs.
    - Humboldt Transit Authority is piloting new longer-range hydrogen buses with regional service goals.

Infrastructure Development

- **ZEB charging installations:** Charging infrastructure has expanded significantly, largely due to support from statewide transportation electrification programs (brought about by SB 350 and other legislation). Costs for TTM and BTM installations have been closely evaluated to guide cost-effective deployment. Cost per kilowatt decreases rapidly as the installed capacity increases beyond 50–100 kW. It is more cost-effective to install higher-kilowatt DC chargers. The expanded charging infrastructure in adjacent medium- and heavy-duty sectors (such as school buses and delivery trucks) greatly benefits the transit industry.

- **Hydrogen fueling stations:** There are five operational hydrogen stations in the state for transit bus fleets: Emeryville and Oakland in the San Francisco Bay Area, supporting AC Transit; and Santa Ana, Thousand Palms, and Pomona in Southern California, serving OCTA, SunLine Transit Agency, and Foothill Transit Agency, respectively. Numerous other agencies are building or expanding hydrogen stations to support new FCEB fleets, including some who are planning to offer public or shared fueling access.

Financial Support Programs

Both state and federal funding programs play a significant role in helping deploy ZEBs and enable the affordability of the new technologies. Each funding program has its strength in supporting ZEB deployment in different ways. Since 2010, more than $2.36 billion in funding from the state and federal programs has been invested in California's ZEB and infrastructure deployment. These investments range from demonstration projects to pilot projects, early commercialized ZEB deployment, and infrastructure.

- **Funding and incentives:** California has established vital programs such as HVIP and Energy Infrastructure Incentives for Zero-Emission Commercial Vehicles (EnergIIZE Commercial Vehicles) that have been fully utilized, along with federal Low-No grants, to accelerate ZEB deployments and fund related infrastructure in the early years of the ZEB transition. In addition, TIRCP and LCTOP continue to provide significant funding for ZEB deployments.
- **LCFS program support:** The LCFS program continues to provide financial support for dispensing low-carbon fuels (hydrogen and electricity) throughout the state, along with providing additional "capacity credit" support for electric charging and hydrogen fueling stations that are initially underutilized. These capacity credits provide early financial support for stations that are not yet operating at full capacity, especially when these stations share access with other fleets, but are critical for ZEB scale-up; a recent amendment extended the program through 2045.

8.3 Remaining Barriers for ZEBs

Although the transit industry has seen advancements in ZEB technologies and the necessary infrastructure since adoption of the ICT regulation, further cost reductions and performance improvements would be essential to support a complete transition to ZEB solutions. Achieving a full transition requires substantial effort and investment. Common challenges for transit agencies in deploying these technologies include:

- **High capital costs** for vehicle purchases and fueling/charging infrastructure, alongside a constricting market for domestically produced ZEBs, limiting vehicle options.
- **Operating costs** remain elevated due to low availability and high cost of hydrogen fuel, high electricity rates, and higher-than-expected maintenance expenses.
- **Infrastructure scalability**, both for hydrogen and electric charging stations, demands large capital investments and lengthy lead times.
- **Diminishing funding** to support expanding ZEB deployment and infrastructure development.

- **Workforce challenges**, including the need for coordinated training programs and resources.

The transition to ZEBs under the ICT regulation presents multiple challenges across infrastructure, workforce, funding, and operational domains. Several key challenges from the Phase II comprehensive review are outlined below.

Bus Market Challenges

- **Small market size:** The U.S. transit bus market is small, limiting economies of scale and cost reductions in ZEB manufacturing.
- **ZEB model availability:** Limited domestically produced ZEB options (both BEB and FCEB) for some bus types, such as cutaway and coach buses. Those that do meet the ICT program criteria, including Altoona testing, have limited market competition.
- **Lead times:** Long lead times for ZEB production and delivery, compounded by long timelines for the construction of hydrogen stations or charging systems necessary to operate ZEBs.
- **Different needs for small agencies:** Rural and small agencies face unique challenges in upgrading infrastructure and addressing operational demands due, in part, to limited budgets and workforce pools. Rural agencies have the added challenge of limited grid capacity and limited access to hydrogen.

Infrastructure Challenges

- **High infrastructure costs:** Median costs for charging infrastructure range between $25,000 per vehicle for TTM upgrades and $10,000 for BTM upgrades. Hydrogen fueling stations are still expensive to build, in the multimillion-dollar capital cost range; however, hydrogen stations built for large FCEB fleets of 50 or more will realize lower per-FCEB infrastructure costs compared to smaller fleets.
- **Utility delays:** Long timelines for utility upgrades and interconnection processes, often exceeding bus delivery times.
- **Reliability issues:** Charging systems face downtime due to equipment failures, software issues, and grid outages, affecting overall service reliability for BEBs.

Workforce Challenges

- **Shortage of technicians:** Aging workforce (43% over 55 years) and difficulties in attracting younger workers exacerbate recruitment and retention issues.
- **Lack of training availability:** Small agencies struggle to secure resources and funding for ZEB-specific training in critical areas like high-voltage systems and emergency response.

Funding and Cost Challenges

- **Insufficient and inconsistent allocations:** Existing funding programs are overly competitive, with restrictive deadlines that hinder long-term planning necessary for transit agencies. The inability to rely on consistent funding year over year also affects planning for ZEB and infrastructure investments.
- **High upfront costs:** The cost of ZEBs and associated infrastructure remains significantly higher than traditional buses and fueling infrastructure, making ZEB scale-up difficult, especially for smaller agencies.

Operational Challenges

- **Range limitations:** ZEBs, particularly BEBs, may not meet the daily range demands of some transit routes, especially for routes extending beyond 200 miles. This may prevent a one-for-one replacement of BEBs for all conventional buses, making it essential to also have FCEB options for all bus types.
- **Grid reliance:** Transit agencies are concerned about the grid's resilience, especially during extended outages caused by natural disasters, and the cost and complexity of adding redundancy or backup power to improve resiliency.

Reliability and Performance Concerns

- **Infrastructure reliability:** Reliability often does not meet agency expectations, with infrastructure downtime leading to service interruptions and increasing operational uncertainty for ZEB fleet scale-up.
- **Performance data gaps:** Limited real-world data for newer ZEB models and different bus types makes it difficult for agencies to track the progress of the ZEB technologies and evaluate performance, long-term reliability, and operational costs to adequately inform their ZEB fleet planning.

These challenges illustrate the complexity of deploying ZEBs at scale and highlight the need for robust funding and support programs, clear policy guidance, and continued collaboration among stakeholders to identify and implement possible solutions.

8.4 ICT 2026 Readiness

In the transit survey, the majority of the respondents from large transit agencies (10 out of 14) said they felt prepared to meet the 2026 purchase requirements for the ICT regulation, which requires 50% ZEBs for all new bus purchases for large agencies. Small transit agencies, however, were split evenly between those who feel prepared and those who do not feel prepared for the 25% ZEB purchase requirement for small agencies (Figure 58). When asked about their concerns meeting the 2026 purchase requirements, the agencies' responses primarily fell into five categories:

1. Funding support (high cost for ZEBs and infrastructure).
2. Infrastructure availability/technology readiness.
3. Vehicle availability/technology readiness.
4. Vehicle performance/reliability.
5. Infrastructure timelines/construction delays.

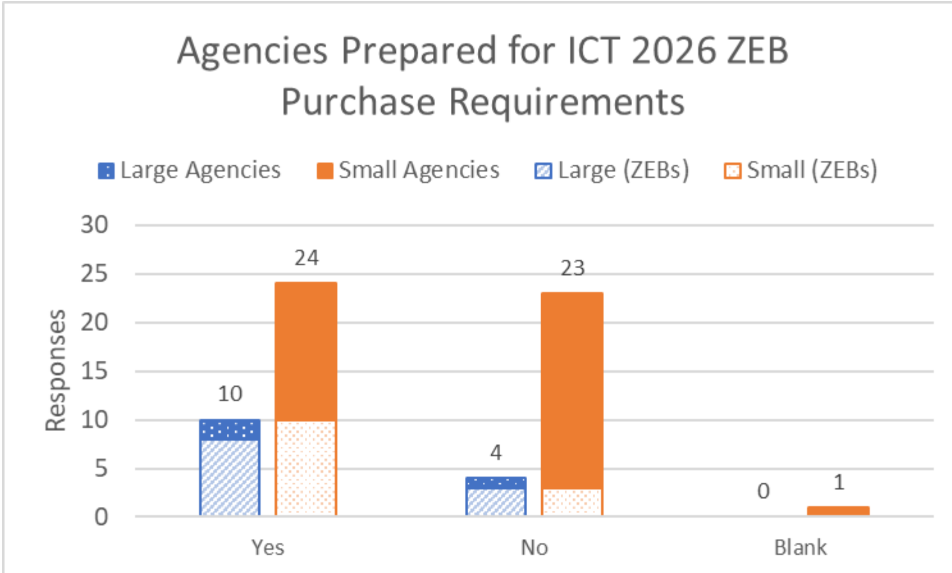

Figure 58. Number of agencies who feel prepared for the 2026 ICT purchase requirements.

Source: Survey of California transit agencies

Similarly, agencies were asked to describe the most important needs for their transit agency in order to meet the ultimate purchase requirements of 100% ZEBs for all agencies beginning in 2029. Responses covered a wide range of topic areas and specific needs that reflect the variety of transit agencies' situations and experiences related the ZEB implementation. The responses were grouped into relevant categories, shown in ranked order in Figure 59 and listed in Table 17. The top two categories—ZEB funding and ZEB infrastructure improvements—received more mentions than all other categories combined, highlighting the agencies' most significant challenges to scaling up to a full ZEB fleet. The next two categories also received a significant number of responses, which reflect the need for (1) ZEB technology improvements and testing/certification, and (2) a healthy ZEB market with more competition that provides expanded vehicle options, as well as improved vehicle procurement and delivery.

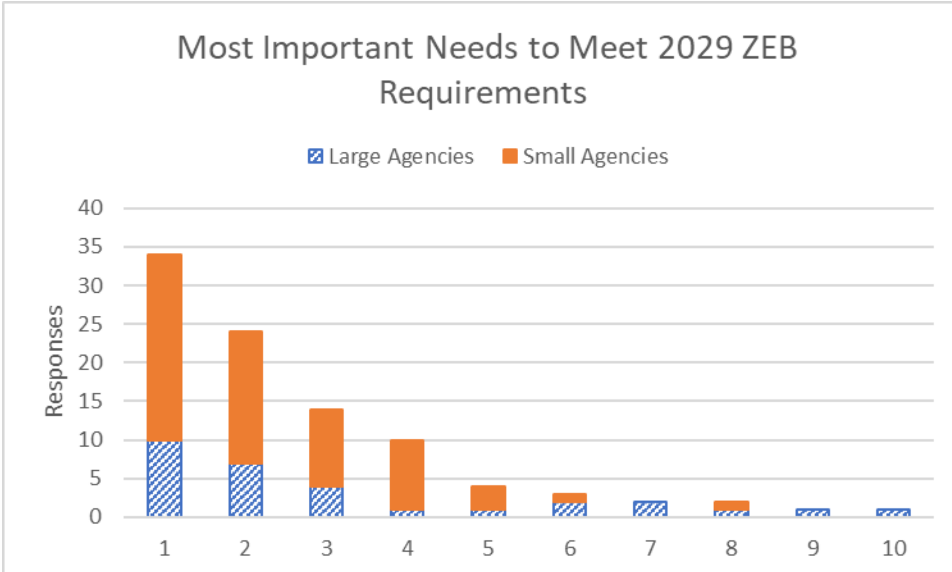

Figure 59. Most important needs to meet 2029 ZEB requirements.

Source: Survey of California transit agencies

Table 17. Most Important Needs To Meet 2029 ZEB Requirements

Rank	Topic Area
1	Funding (e.g., for ZEBs, infrastructure, facility upgrades)
2	Infrastructure installation improvements (timelines, facility/utility upgrades, property)
3	ZEB technology improvements and testing (range and reliability)
4	ZEB availability/variety, market competition, and improved procurement
5	ZEB training and workforce development
6	Political and public support and community engagement
7	Infrastructure operation improvements (e.g., reliability, capacity increases)
8	Policy and regulatory compliance support
9	Route planning and improved operational integration for ZEBs
10	Long-term cost analysis and planning

It is important to note that these responses to the transit agency survey were collected in late 2023 and early 2024, before some of the recent market fluctuations and other uncertainties were introduced, such as reduced availability of ZEB funding and vehicle models. A follow-up study is recommended to fully understand the impact of recent events on transit agency ZEB transition plans and preparedness to meet ICT requirements. Nevertheless, transit agencies have exhibited a willingness to transition to ZEB fleets and have generated momentum to start the transition. The topics highlighted in Table 17 need to be addressed to sustain and expand this momentum in order to meet the goals of the ICT program. Ongoing education and technical assistance about funding opportunities and ICT compliance supports ZEB deployment momentum.

The readiness of transit agencies to meet the ICT requirements, however, depends on several factors in the broader ZEV industry. Continued ZEB policy signals and strengthened support programs from state and federal agencies are important to help stabilize the ZEB vehicle market and supporting industries. These factors help decrease costs and streamline ZEB scale-up, enabling transit agencies to execute their zero-emission ROPs.

Key factors/considerations related to the technical readiness of ZEBs include:

1. Vehicle availability:
    - For standard and articulated buses, ZEB options (both BEB and FCEB) are commercially available that can meet most transit service needs and have been tested/matured/proven in transit service over many years.
    - For cutaway buses and coaches, the U.S. transit market is limited to only BEB options that are relatively new/untested/unproven and do not yet have the necessary range to meet many transit routes. There is no direct 1:1 replacement in some cases. This limitation could be especially challenging for small transit agencies in rural areas that have more demanding routes and less flexible fleet operations.
2. Vehicle capital costs:
    - The transit bus market is rather small on an annual production basis compared to some other vehicle markets (e.g., especially light-duty passenger vehicles), and economies of scale for production of ZEBs have not yet been realized.
    - Bus prices for transit agencies have thus not declined in recent years as expected, and in fact have escalated somewhat due to a variety of U.S. market factors, with ZEB costs increasing more than other types.
3. Reliability/durability:
    - ZEB reliability/durability is still being proven in real-world conditions over the full period of expected bus operation (e.g., 12 years).
    - When comparing the operation of BEBs and FCEBs to conventional diesel buses in the same fleet, it is typical that BEBs have excellent reliability (in terms of time between road calls) but relatively low availability, potentially due to charging/infrastructure issues. FCEBs have better availability than BEBs, but still lag behind diesel buses, and have reliability comparable to diesel hybrids but somewhat lower than conventional diesel.

There are also many critical factors in the broader transportation ecosystem impacting ZEB deployments and scale-up in transit fleets. Improvements would be needed in the following areas:

- **Funding support programs** to provide transit agencies with the necessary resources to ramp up ZEB fleet transitions.
- **Adjacent vehicle markets** to bolster/strengthen the U.S. bus manufacturing base, creating market competition that can lead to a wider array of affordable ZEB options, as well as fostering the development of markets for zero-emission trucks, delivery vehicles, and other medium- and heavy-duty vocational vehicles.

- **Infrastructure readiness** for large-scale charging and hydrogen fueling to streamline installation, contain costs, and improve station reliability.
- **A skilled workforce** trained in the latest ZEB technologies to safely and efficiently operate, maintain, and repair the advanced/next-generation transit bus fleets and supporting infrastructure.

Based on the information collected and evaluated under this comprehensive review, it appears that the **California transit industry is prepared to proceed with the 2026 purchase requirement of 50% ZEBs for large transit agencies and 25% for small transit agencies on standard low-floor and articulated transit buses**. The summary of the 2026 program readiness is listed in Table 18. This is supported by:

1. Continued bus and infrastructure technology advancements and current availability of ZEB replacement options specifically for **standard low-floor and articulated transit buses**.
2. Substantial early ZEB adoption by large transit agencies, who have gained valuable deployment experience, tested and improved ZEB technologies in transit service, and positioned the California transit industry ahead of the current ICT ZEB targets.
3. A significant majority (greater than 70%) of large agencies responding to the statewide transit survey reported that they feel prepared to meet the 2026 purchase requirements.

Many small agencies in the state will be able to meet this initial requirement, especially for standard and articulated bus types. However, expanding the ZEB transition in California may present numerous challenges, and the impacts will not be felt equally across small agencies. Individual compliance may be highly dependent on the specific circumstances of each transit agency. Key factors could include, among others, the size and type of an agency's service territory/blocks, the individual fleet composition (e.g., bus types) and specific bus replacement schedules, depot/facility characteristics, available support/coordination of infrastructure and fuel suppliers (hydrogen or electric utility), and the financial conditions for each agency.

A process to apply for compliance waivers/exemptions, on an individual basis, was designed into the ICT program to account for ZEB market limitations and unique challenges based on specific agency circumstances (including financial hardship), which may preclude or delay ZEB replacement in some cases. The overall ICT program targets may continue to be met in the near term by focusing on strategic ZEB replacement for standard and articulated buses. Additional progress and support from the broader transportation industry/ecosystem is needed to scale the ZEB transition from pilot project-based to sector-based deployment.

The other three bus types—cutaway, over-the-road coach, and double-decker buses—will need more time and support from adjacent medium- and heavy-duty vehicle markets to provide sufficient volume for these ZEB markets to take off. It is crucial to examine the potential annual purchase volume in order to understand when/whether the market is able to respond to such demand based on a sensible investment strategy. It is unclear how long or what kind of investment it may take to bring these bus types to full market availability, but they could benefit significantly with support from an adjacent market of other zero-emission medium- and heavy-duty vehicles.

Table 18. Summary of Readiness for ICT 2026

Transit Agency Size	Standard and Articulated Buses	Cutaway Buses	Coach and Double-Decker Buses
Large transit agencies (50% ZEBs)	Most ready for ZEB deployments. *Represents large percentage of large transit bus fleets (~80%)*	Ready for ZEBs in some cases. ZEB options limited to short-range BEBs only. *Represents smaller percentage of large agency fleets (~15%)*	ZEB options limited to short-range BEBs only. Early-generation BEBs not thoroughly tested/proven for transit. *Represents small percentage of transit bus fleets (~7%)*
Small transit agencies (25% ZEBs)	ZEB replacements possible for many fleets. *Represents significant fleet percentage for small agencies (>56%), especially larger and more urban fleets*	Ready for ZEBs in some cases. ZEB options limited to short-range BEBs only. Likely more suitable in larger, urban fleets than rural fleets with long or challenging routes. *Represents ~36% of small transit fleets*	

To continue a successful transition to ZEB transit fleets in California, increased government and transit agency coordination, positive market developments, and additional resources will all be necessary. Areas of focus should include:

- **Renewed progress in the ZEB market:** Expanded offerings are needed from the vehicle, equipment, and infrastructure manufacturing base to stabilize and reduce costs through increased market competition, as well as technology innovation to enhance safety and performance, enabling more extensive transit operations.
- **Effective cost containment mechanisms for the market** and dedicated, non-incentive-based financial support to enable agencies to diligently pursue their ZEB fleet transition plans.
- **Continued evolution of charging and fueling infrastructure** to improve safety, reliability, and maintainability of stations while minimizing scale-up costs, which will require advanced planning and strong coordination. This will also require an abundant supply of affordable, low-carbon hydrogen to reduce total cost of ownership for FCEBs.
- **Comprehensive and standardized training programs** to develop a highly skilled workforce that can improve the efficiency and cost of maintaining ZEB equipment while creating new jobs and ensuring safety.

8.5 Industry Recommendations

Phase II of the ICT program is a critical step in ensuring that transit agencies can meet ICT regulation requirements. It connects the initial implementation of the program—where transit agencies were piloting smaller fleets of ZEBs to test the emerging technologies and gain operational experience—to the full-scale deployment of ZEBs envisioned as the ultimate goal of the program. Many improvements have been made in the early stages of this work, but much more is still needed to ensure a successful statewide scale-up of ZEBs.

California transit agencies have taken advantage of available resources and made significant investments in necessary workforce training. Such accomplishments are reflected in the amount of early action to adopt ZEBs, especially by large transit agencies. It is crucial to note that the amount of early action may decline over time due to the ramping up of ZEB purchase requirements and other challenges facing California transit agencies. Transit agencies note that the federal government and California continue to play an important role in providing policy incentives and support to keep the ZEB deployment momentum. Continued ZEB development is key for continuous technology improvement, increased reliability, and a robust domestic bus market.

Based on the information collected and evaluated under this comprehensive review, it appears that the California transit industry would benefit from greater support in the following areas:

- Long-range models are needed for cutaway, over-the-road coaches, and double-decker buses. Developing adjacent markets for medium- and heavy-duty ZEVs is crucial, especially for the current market size of these bus types.
- Though driving range may not be a primary issue for the standard and articulated buses in the near term, longer-range options and more robust infrastructure systems will be needed for sector-wide deployment, especially for the standard buses that could operate 350 to more than 500 miles per day. Reliability improvements will be needed as well.
- ZEB purchase cost will be a prohibitive factor when the incremental cost over conventional alternatives cannot be reasonably offset. Most of the existing ZEB grants are either competitive grants or dependent on annual budget allocation, which do not provide long-term certainty. This could increase the total cost and decrease the efficiency of implementing the ICT regulation when broader ZEB deployment is limited by the grant amount. Both a cost containment mechanism and dedicated funding are needed to provide policy incentives to stimulate the ZEB market, encourage competitive pricing, and enable long-term planning for successful ZEB fleet scale-up.
- Workforce development needs to utilize a more top-down, holistic approach. Such an approach would focus on (1) identifying necessary workforce training for fleets to efficiently deploy ZEBs (not limited to vehicle operation and maintenance; it should also include project management, procurement, planning, and other fields related to ZEB deployment); and (2) developing coordinated training curriculum and identifying dedicated training funding.
- Ensuring long-term fuel supply and cost stability is crucial to supporting increased ZEB deployments. Long lead times on electrical infrastructure build-out and lack of affordable low-carbon hydrogen supply must be addressed and factored into sector-wide ZEB deployment schedules.

A number of recommendations and remaining questions to facilitate the transition to ZEBs under the ICT regulation were articulated by the California transit industry, detailed below.

Workforce Development

- **Coordinate workforce development needs with transit agencies:** CARB can work with transit agencies to identify necessary training courses, survey available training programs and curricula, identify training program gaps/needs, and develop broader plans to support widespread training needs.
- **Increase funding for workforce development:** Provide grants and vouchers to make training more accessible and affordable, particularly for small agencies. Further explore how to leverage California's workforce-related state agencies and their resources for transit-bus-related training needs.
- **Expand internal training programs:** Agencies can utilize external training programs and resources like the FTA's Transit Workforce Center, AC Transit's ZEB University, and SunLine's West Coast Center of Excellence and apply a "train-the-trainer" approach to build in-house training expertise and programs for agency staff.
- **Focus on key training areas:** Work with transit agencies to target the training areas of greatest need for the ZEB transition, including ZEB maintenance, electrical work with high-voltage systems, emergency response procedures, and bus operational diagnostics.
- **Collaborate with educational institutions:** Partner with community colleges and industry organizations for curriculum development and training implementation.
- **Examine the sufficiency and adequacy of the manufacturing and supply chain workforce:** The expansion and training of the ZEB workforce is not limited to just transit agencies. While this is a transformation of the entire industry, it is also crucial to examine the sufficiency and adequacy of the manufacturing and supply chain workforce. It is equally important to ensure the entire manufacturing and supply chain industry has sufficient and adequate workforce that can design products and build production lines to ensure product safety and performance. The manufacturing and supply chain workforce should also be able to identify gaps between vehicle design and existing charging/refueling standards and protocols for a smooth product rollout.

Funding Mechanisms

- **Streamline incentive programs:** Make funds directly available to transit agencies to reduce administrative burdens. Work with transit agencies to understand incentive program hurdles and bottlenecks, and identify solutions to make programs more workable and effective, including for small transit agencies that have less administrative support capability.
- **Increase funding allocations:** Provide consistent, multiyear funding to help agencies with long-term ZEB planning.
- **Develop innovative financing:** Develop public-private partnerships and infrastructure bonds to support ZEB deployments. Significant developments in CNG fueling infrastructure were realized in the early 2000s—when direct project capital was not fully available for station construction, financing was obtained partly through the aid of long-term fuel supply contracts. This type of mechanism reduces risk for lenders and can unlock project financing (CNG Delivery 2025). This concept could be helpful particularly for transit agency hydrogen fueling station development.

Infrastructure Improvements

- **Prioritize utility coordination:** CARB can facilitate active engagement between the transit agencies, electrical utilities, and utility regulators to ensure that transit agency fleet electrification plans are integrated into mid- and long-term plans for transmission and distribution system investments. Encourage proactive and regular communication between transit agencies and electrical utilities to ensure that utilities receive up-to-date and detailed information on transit agency ZEV adoption and electrification plans before they are ready to submit formal electric service requests. CPUC's rulemaking proceeding on "High DER Future Grid Planning" (R.21-06-017) allows IOUs to incorporate these pending loads into grid planning forecasts, which are used to justify investments in distribution capacity and plan distribution capacity upgrades. The type and completeness of data provided to the utility will help them determine how to incorporate that pending load into their forecast, based on the likelihood of a pending load materializing into a service request. Early proactive communication includes providing utilities with detailed information on BEB adoption plans and delivery timelines and charging needs such as locations, power needs, vehicle duty cycles, and downtimes. These types of utility-transit agency communications are also beneficial in public utility territories because they (1) provide greater certainty that charging needs will be met as the ZEB fleet grows; and (2) enable utilities to identify interim solutions that can support fewer buses in the near term, such as managed charging, flexible interconnect, and microgrids.
- **Focus on resilience:** Plan and execute needed grid upgrades considering utility lead times and encourage redundancy and alternative power supply solutions to enable continuous charging during outages (at least baseline or emergency level) to increase transit agency resilience. Identify opportunities for hydrogen fueling stations to operate during grid outages (even if not at full dispensing pressure).
- **Develop high-power standards:** Support R&D of higher-power (up to megawatt) charging systems to reduce charging times for transit fleets. Engage local utilities to understand infrastructure requirements for higher-power systems and delineate potential cost implications for transit agencies early in the process of potential upgrades. Identify opportunities for higher-power systems with most advantageous costs, such as single power banks that can distribute power to multiple charging port locations in transit yards.
- **Develop affordable, low-carbon hydrogen:** Today, large transit agencies are paying roughly $9.50 per kilogram of delivered hydrogen plus $25,000 per month for station maintenance contracts. When including the maintenance contract, the cost of hydrogen to the transit agency at the pump can range from $10.50 to $20 or more per kilogram depending on the size of the FCEB fleet. While several factors can affect cost at the pump such as proximity to hydrogen supply and boil-off losses during transport and storage, smaller fleets with hydrogen usage ultimately pay more than the agencies with more FCEBs. Increasing demand for low-carbon hydrogen by both FCEBs and FCETs should put downward pressure on the cost of supplied hydrogen, while training in-house technicians to perform station maintenance should reduce maintenance costs. Until scale and competition in the hydrogen supply chain are achieved, subsidies that offset higher hydrogen fuel cost may be warranted.

Collated Policy Recommendations

- **Extend tax exemptions:** Extend California Assembly Bill 2622 to exempt state taxes for ZEB purchases and incentivize deployment.

- **Promote adjacent market growth:** Support ZEV adoption in high-volume markets (e.g., trucks and delivery vans) to reduce component costs and drive innovation. Core electric drivetrain components including batteries, motors, power electronics, fuel cell stacks, and hydrogen storage tanks are in many cases similar for buses, trucks, and other large vehicles, so advances in these larger markets can create positive spillover effects for the bus market, especially considering BABA requirements that reduce the import potential of these technologies.
- **Educate on compliance:** Improve outreach by CARB to ensure agencies fully understand incentive programs and ICT compliance requirements, as well as access to available resources.

OEM and Technology Support

- **Support R&D grants:** Provide R&D funding for OEMs to design and validate new technologies for ZEBs.
- **Encourage "second movers":** Incentivize proven OEMs to deploy reliable vehicles and components, after learning from smaller companies and startups that move first (e.g., Tesla in the light-duty EV space), ensuring competitive product availability.

These recommendations aim to address workforce, policy, financial, and infrastructure challenges and ensure smooth transitions for transit agencies adopting ZEBs.

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Appendix

A.1 ZEB Purchase Projections From ROPs

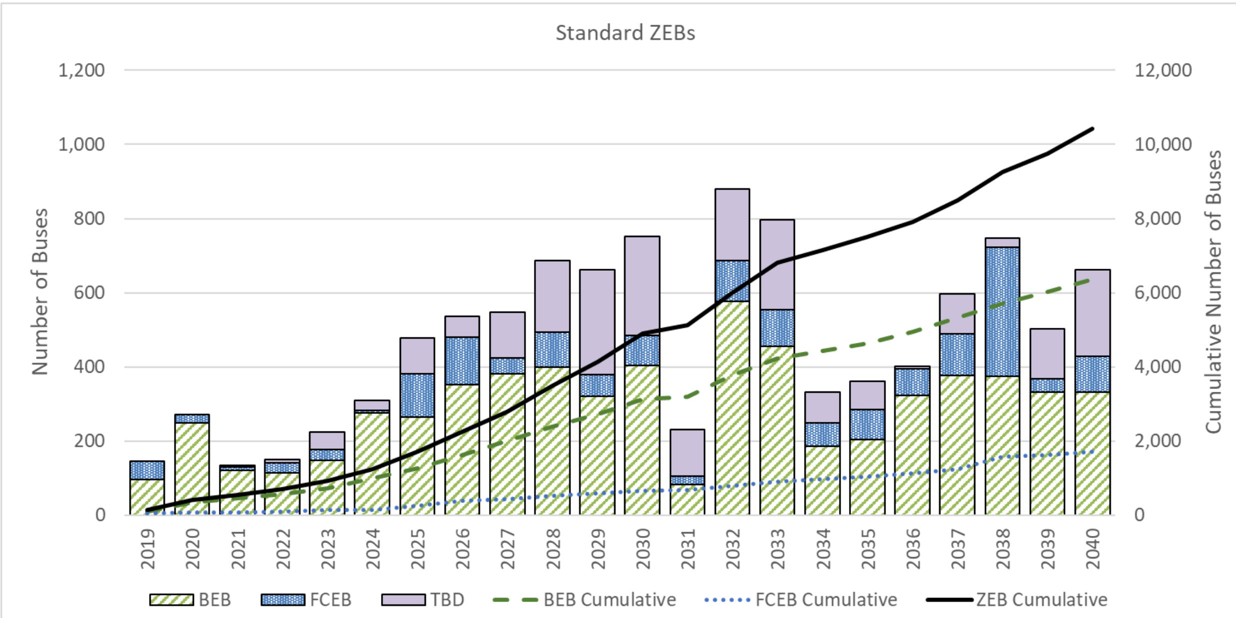

Figure A-1. Projected ZEB purchases from transit agency ROPs, standard buses

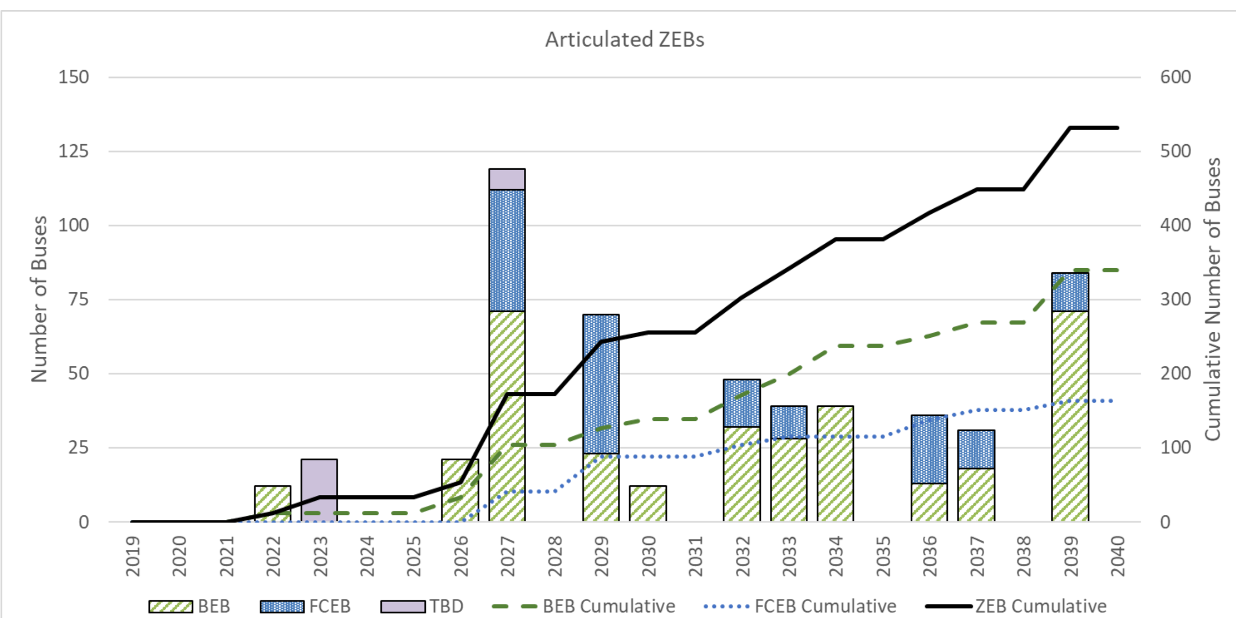

Figure A-2. Projected ZEB purchases from transit agency ROPs, articulated buses

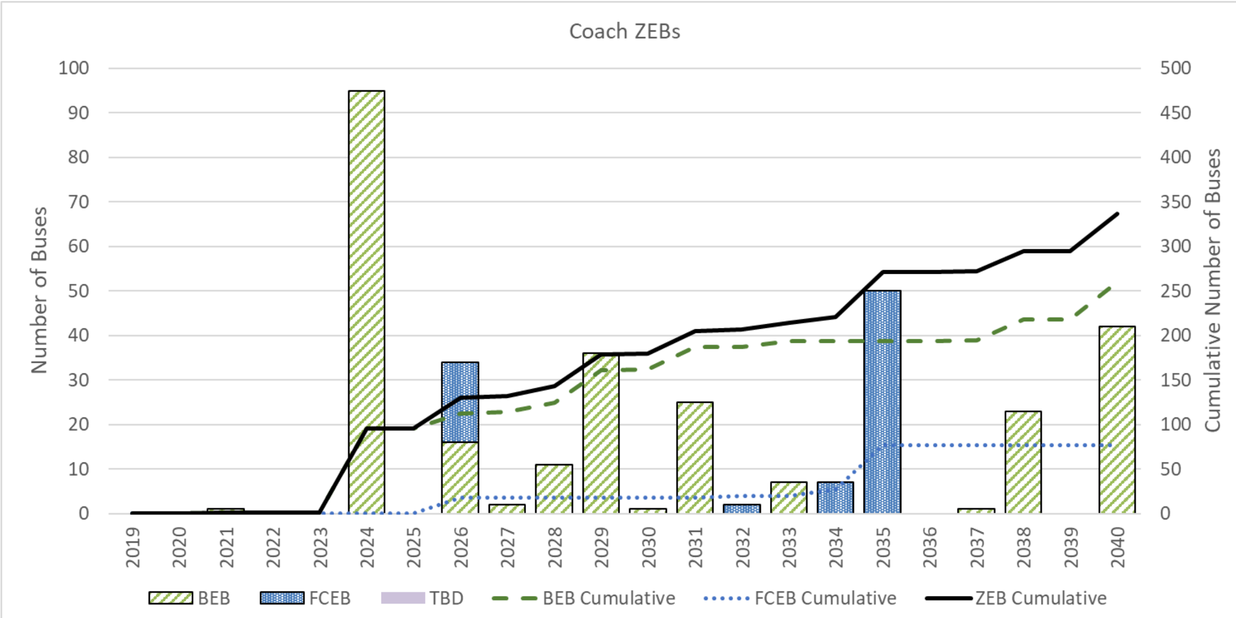

Figure A-3. Projected ZEB purchases from transit agency ROPs, coach buses

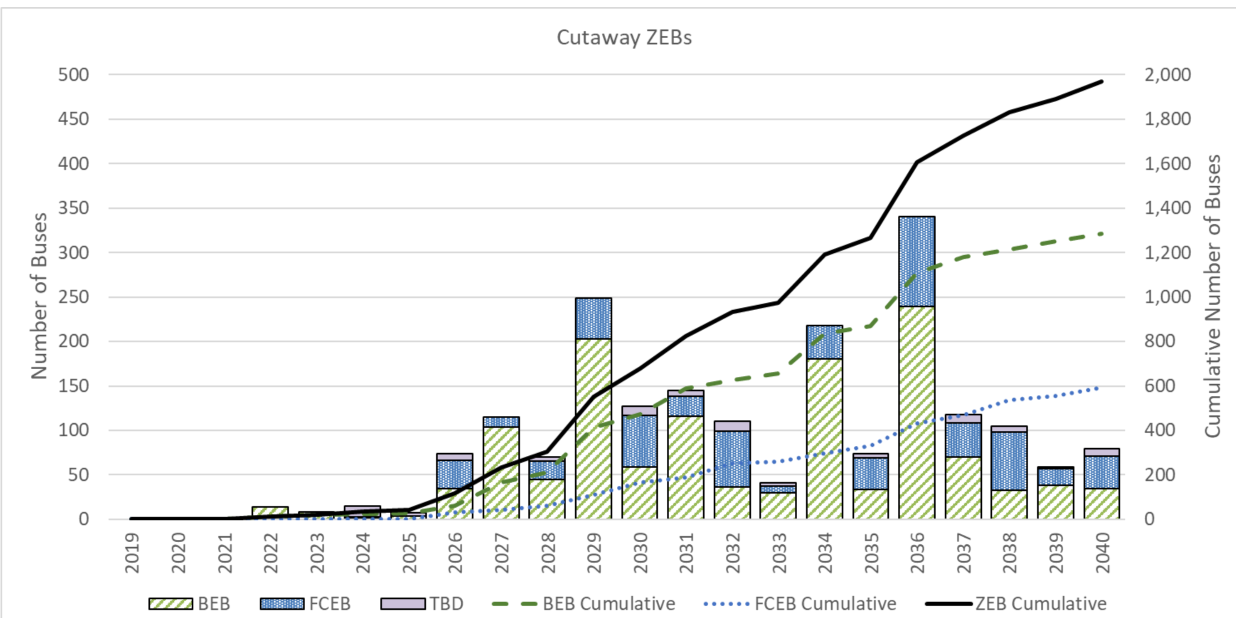

Figure A-4. Projected ZEB purchases from transit agency ROPs, cutaway buses

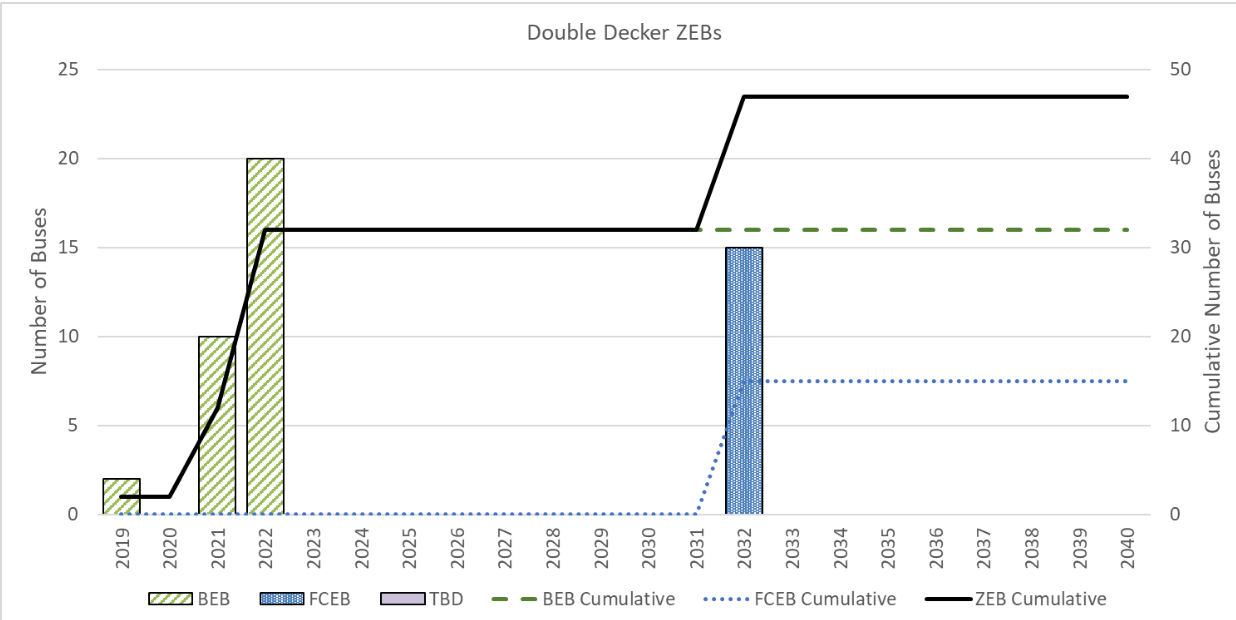

Figure A-5. Projected ZEB purchases from transit agency ROPs, double-decker buses

A.2 APTA Purchase Cost Trends for Transit Buses

The following charts show the average purchase cost trends for each transit bus type and fuel type, from costs reported in the APTA 2025 database. Each data point represents the weighted average price for purchases of that model year, with consecutive years connected by a solid line (some years and bus/fuel type combinations do not have any reported costs; dotted lines connect adjacent data points across these gaps). Where applicable, for each bus and fuel type, the California DGS statewide ZEB contract price for 2025 is included (triangle) and labeled, for reference.

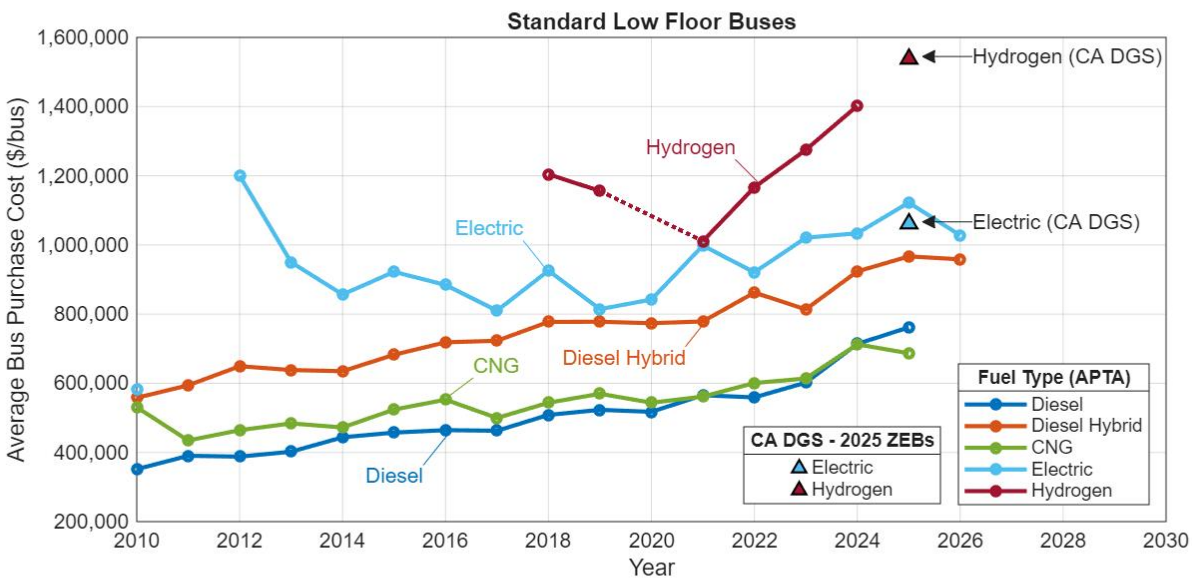

Figure A-6. APTA purchase cost trends for standard buses

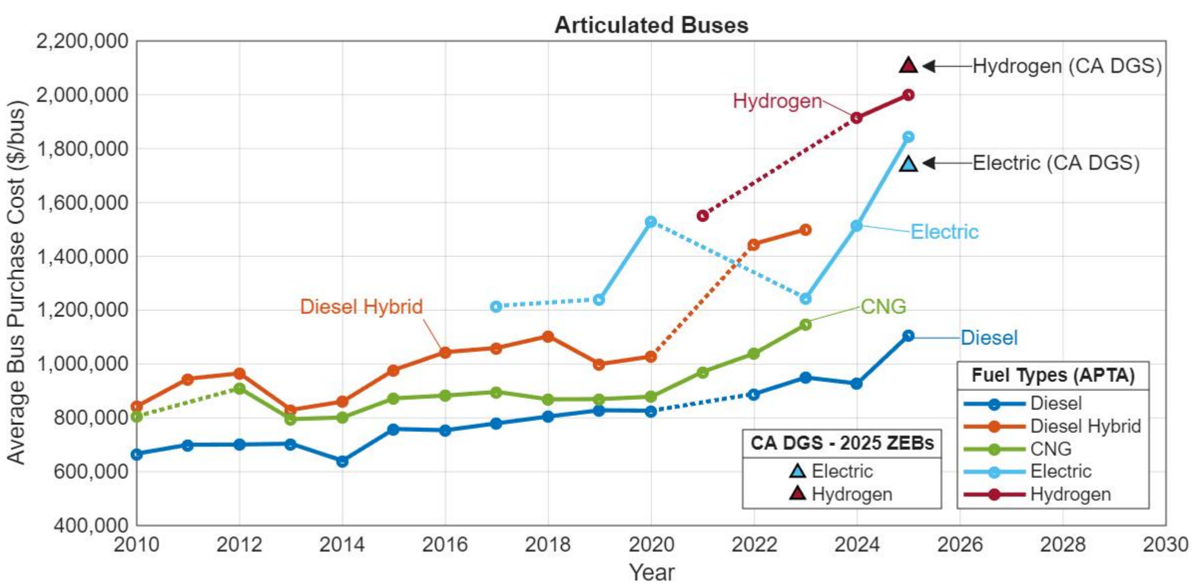

Figure A-7. APTA purchase cost trends for articulated buses

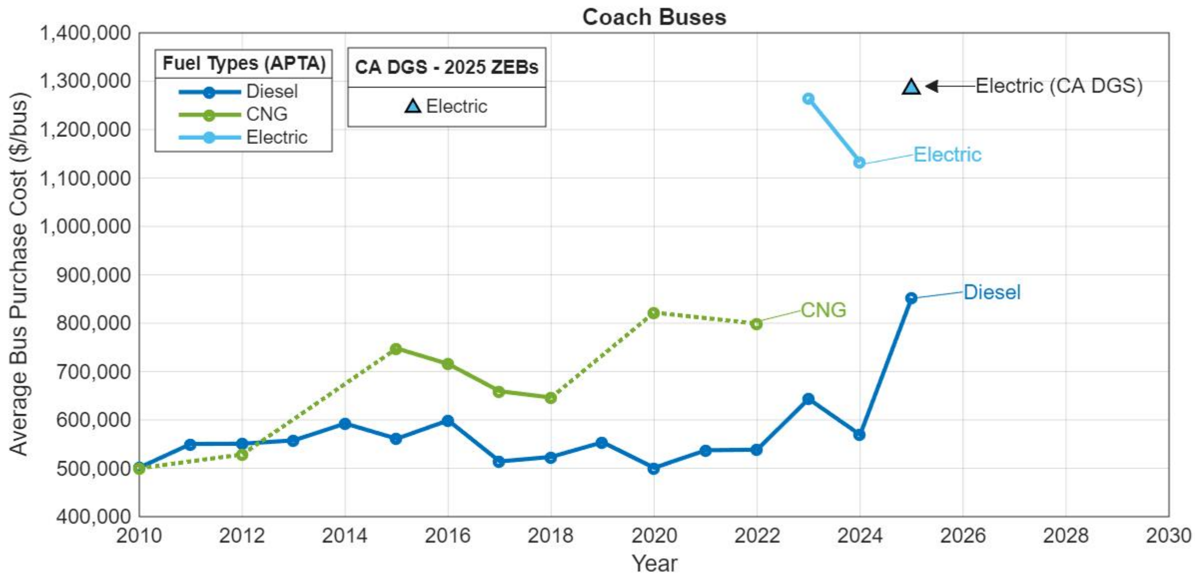

Figure A-8. APTA purchase cost trends for coach buses

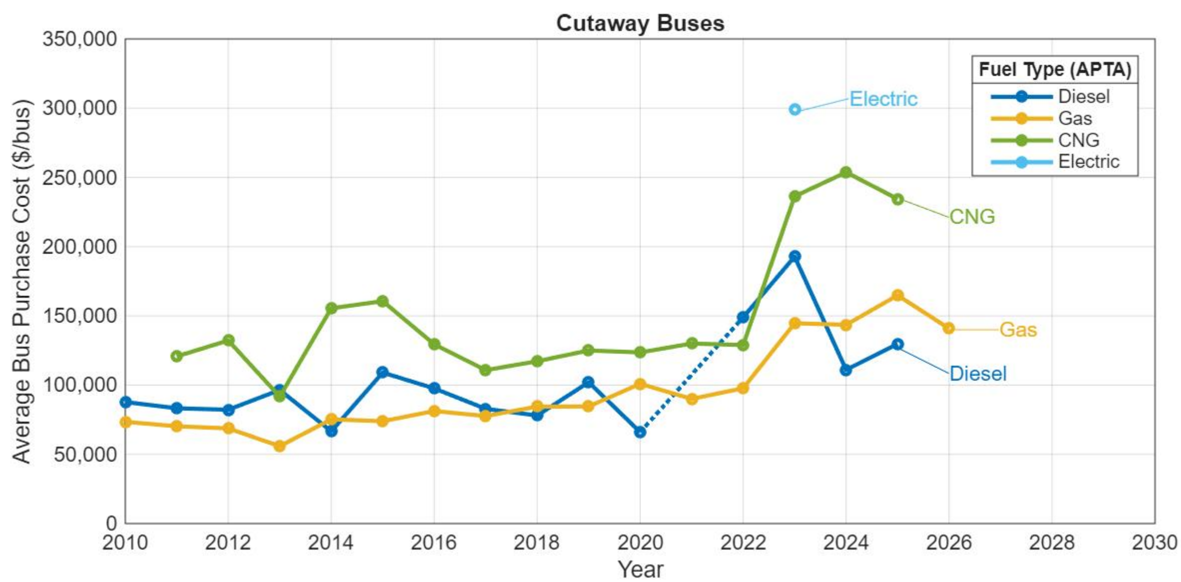

Figure A-9. APTA purchase cost trends for cutaway buses

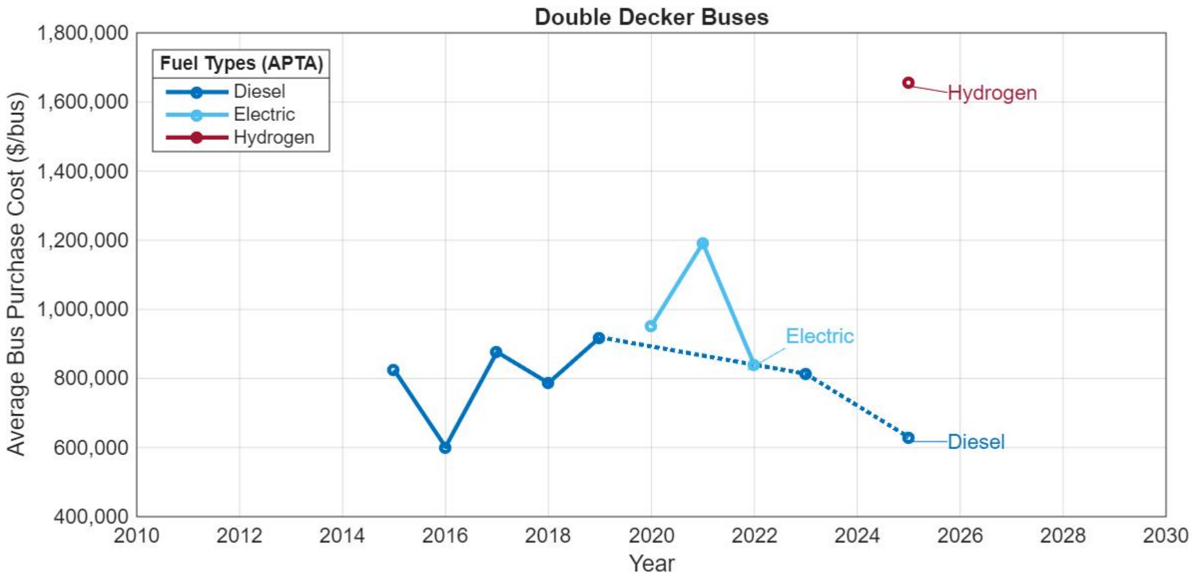

Figure A-10. APTA purchase cost trends for double-decker buses

A.3 List of Published ZEB Evaluations Included in Meta-Analysis of Performance and Cost Metrics

Table A-1. Published ZEB Evaluations

Publication Title	Date Published
Orange County Transportation Authority Fuel Cell Electric Bus Progress Report Data Period Focus: Feb. 2020 through Jul. 2021	July 2022
SunLine Transit Agency Fuel Cell Electric Bus Progress Report Data Period Focus: Jan. 2020 through Dec. 2021	July 2022
Foothill Transit Battery Electric Bus Evaluation: Final Report	June 2021
Zero-Emission Bus Evaluation Results: Long Beach Transit Battery Electric Buses	April 2020
Zero-Emission Bus Evaluation Results: Stark Area Regional Transit Authority Fuel Cell Electric Buses	Oct. 2019
Zero-Emission Bus Evaluation Results: Orange County Transportation Authority Fuel Cell Electric Bus	May 2018
Zero-Emission Bus Evaluation Results: County Connection Battery Electric Buses	Dec. 2018
Zero-Emission Bus Evaluation Results: King County Metro Battery Electric Buses	Feb. 2018
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Sixth Report	Sept. 2017
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fifth Report	June 2016
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Fourth Report	July 2015
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration Results: Third Report	May 2014
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: Second Results Report	July 2012
Zero Emission Bay Area (ZEBA) Fuel Cell Bus Demonstration: First Results Report	Aug. 2011
BC Transit Fuel Cell Bus Project: Evaluation Results Report	Feb. 2014
BC Transit Fuel Cell Bus Project Evaluation Results: Second Report	Sept. 2014
American Fuel Cell Bus Project: First Analysis Report	June 2013
American Fuel Cell Bus Project Evaluation: Second Report	Sept. 2015
Zero Emission Transit Bus Technology Analysis (Volume 1)	July 2021
Zero Emission Transit Bus Technology Analysis (Volume 2)	Dec. 2021
Zero Emission Transit Bus Technology Analysis (Volume 3)	June 2022
Zero Emission Transit Bus Technology Analysis (Volume 4)	Dec. 2022
Zero Emission Program: Annual Progress Report	June 2024
Analysis of Electric Bus Deployments at Transit Agencies	May 2020
TTC’s Green Bus Program: Final Results of TTC’s Head-to-Head eBus Evaluation	April 2022
TTC’s Green Bus Program: Preliminary Results of TTC’s Head-to-Head eBus Evaluation	April 2021
AVTA FY 2021 Monthly Maintenance Key Performance Indicators	June 2021
SFMTA Battery Electric Bus Evaluation Report: Zero-Emission and Onboard Technology, Program Delivery and Support, Transit	Dec. 2024
OCTA Zero-Emission Bus Pilot Update	Feb. 2024

A.4 Bus Price List From California DGS Statewide ZEB Contracts

Table A-2. California DGS ZEB Details and Contract Pricing

OEM	Bus Model	Fuel Type	Length (ft)	Battery Size (kWh)	Fuel Cell (kW) Hydrogen (kg)	Range (miles)	Bus Price ($)
RIDE Mobility LLC	Standard Low Floor	Battery	30	237	n/a	158	$819,500
				348	n/a	196	$889,500
	Standard Low Floor	Battery	35	348	n/a	161	$901,900
				391	n/a	179	$931,900
				435	n/a	196	$951,900
	Standard Low Floor	Battery	40	348	n/a	149	$933,500
				391	n/a	165	$953,500
				435	n/a	181	$973,500
				505	n/a	208	$993,500
	Coach High Floor	Battery	45	496	n/a	172	$1,284,700
	Articulated	Battery	60	640	n/a	193	$1,466,800
Phoenix Motorcars LLC	Standard Low Floor	Battery	35	492	n/a	240	$1,139,725
	Standard Low Floor	Battery	40	492	n/a	240	$1,163,037
				738	n/a	340	$1,313,037
	Cutaway High Floor Z400	Battery	n/a	131	n/a	150	$279,610
New Flyer of America Inc.	Standard Low Floor	Battery	35	435	n/a	220	$1,136,262
				550	n/a	228	$1,204,662
	Standard Low Floor	Battery	40	435	n/a	216	$1,141,413
				516	n/a	229	$1,190,433
				550	n/a	222	$1,209,813
				660	n/a	260	$1,272,513
	Articulated	Battery	60	520	n/a	143	$1,765,554
				602	n/a	166	$1,814,574
				770	n/a	187	$1,910,334
	Standard Low Floor	Fuel Cell	40	135	100 kW 37.5 kg	370	$1,537,778
	Articulated	Fuel Cell	60	135	100 kW 56 kg	294	$2,106,660