DRISI
Caltrans Division of Research, Innovation and System Information

Research Results

Fuel Cell Electric Bus, Battery Electric Bus, and Battery Electric Train Infrastructure

Understanding the key issues in fuel cell electric bus, battery electric bus, and battery electric train infrastructure.

Modal

SEPTEMBER 2021

Project Title:
ZEV Center of Excellence

Task Number: 3299

Completion Date: April 30, 2021

Task Manager:
Fouad Ziaa
Transportation Engineer (Electrical)
fouad.ziaa@dot.ca.gov

WHAT WAS THE NEED?

The California Air Resources Board (CARB) is developing strategies to transition the heavy-duty mobile source sector to zero and near-zero emission technologies to meet air quality, climate, and public health protection goals. The long-term vision of the Innovative Clean Transit effort is to achieve a zero-emission transit system by 2040.

Transit agencies have often been leaders in facilitating the introductions of new technologies and have been partners in addressing air quality by continuing to be instrumental in leading adoption of low nitrogen oxide engines, zero emission technology deployment in heavy duty vehicle applications, and in addressing barriers.

To meet this ambitious goal, it is important that not only electric buses and trains, but also supportive infrastructure be in place. Mapping and cataloging the infrastructure support the overall goal and policy of increasing Zero-Emission Buses (ZEBs) and Battery Electric Trains (BETs).

This research project provided an opportunity to learn about charging buses and electric trains that operate all day on battery and re-charge at night at the depot. As electric bus ranges increase, this could be an option to keep buses in service during the day and allow them to charge at night at lower utility rates, but this could have impacts in terms of bus storage needs. Most diesel buses are maintained at night and therefore additional storage/charging space would be needed as agencies transition to electric fleets. Ultimately, the research team attempted to analyze the infrastructure needed for a complete transition of public transit fleets to zero emission.

Caltrans
DRISI provides solutions and knowledge that improves California's transportation system

WHAT WAS OUR GOAL?

The goal of this effort was to assess and document the infrastructure deficiencies that hinder the adoption of ZEBs and BETs in California. The research team developed a report that catalogs, describes, and analyzes the current locations of ZEB- and BET-supporting infrastructure.

WHAT DID WE DO?

The researchers investigated existing infrastructure for ZEBs and BETS, mapping and categorizing the existing ZEB and BET infrastructure in California, determining the optimal infrastructure conditions based on ZEB and BET technology's specifications and anticipated use, and identified the deficiencies between the existing infrastructure and optimal infrastructure. The research team prepared a report to document these findings; and includes maps, technical specifications, and other materials.

WHAT WAS THE OUTCOME?

The study was organized into three tasks:

1. Catalog current infrastructure for battery electric buses (BEBs), fuel cell electric buses (FCEBs), and zero-emission multi-unit trains (ZEMUs).
2. Determine the infrastructure gaps that exist in the state's transit agencies.
3. Determine the infrastructure needs to fulfill those gaps.

Task 1 – Cataloguing Current Infrastructure
Information was collected on the 75 fixed-route public transit agencies in California to determine how many BEBs, FCEBs, and infrastructure each agency was currently operating. The information was collected either through direct correspondence, or through official reports put out by the agencies if correspondence was unavailable. The results of the survey are shown below in Table E1:

Table E1: Summary of Survey Results

Current BEBs	551
Planned BEBs	531
Total BEBs	1082
Current FCEBs	38
Planned FCEBs	8
Total FCEBs	46
Total ZEBs expected by 2025	**1128**
Total agencies operating expected by 2025	**45**
Expected average ZEBs per agency expected by 2025	**25**
Depot Chargers	165
Fast Chargers	25
Total Chargers	190
Current Train Projects	2

Currently, these buses are mostly located in the Los Angeles and San Francisco Bay areas, although many smaller pilot-scale projects exist throughout the state. A detailed geographic breakdown is available in the report.

It was found that depot charging is the current dominant method of recharging buses in California. This is due both to the upfront cost of fast chargers, and the en-route charging's increased returns on larger systems. Additionally, there are currently many more BEBs than FCEBs both planned and operating in California. The report also identifies two ZEMU projects and describes them in further detail.

Task 2 – Identifying Infrastructure Gaps
Based on information gathered in task 1, it is possible to identify a gap between the current infrastructure and level of infrastructure that would be required to meet the state's needs. The report examined the gap of the known, planned

deployments of buses within the next 5-10 years. To identify gaps, a scenario study was conducted using three scenarios (the details of the scenarios are described further in the report):

1. All depot charging – all future BEB deployments are serviced by depot chargers.
2. Constant bus-to-charger ratio – enough opportunity chargers are used to maintain the current ratio of buses to chargers statewide.
3. Size-based infrastructure mix – chargers are assigned to transit agencies based on the number of buses operated by that agency.

The scenario results are shown below in Table E2:

Table E2: Overall Scenario Results

Scenario	Total Depot Chargers	Total Opportunity Chargers
Scenario 1	678	25
Scenario 2	585	39
Scenario 3	449	60

A geographic breakdown of the results is available in the report. The results indicate that most of the new opportunity chargers would be in the greater Los Angeles area, as that region is expected to have the largest BEB growth in the next 5-10 years. For FCEBs, most of the infrastructure to support the planned deployments is already in place, as these buses are additions to existing FCEB systems, rather than new systems.

Task 3 – Identifying Infrastructure Needs

To identify the needs and possible variance in the forecast developed in task 2, a sensitivity analysis was performed on the results. The results of that analysis are shown in Table E3:

Table E3: Sensitivity Analysis Results

	S1 Depot	S1 Opp	S2 Depot	S2 Opp	S3 Depot	S3 Opp
Base Case	678	25	585	39	449	60
10% Increase in Buses	746	25	614	41	472	63
10% Decrease in Buses	610	25	556	37	427	57
10% Increase in Opportunity Chargers	678	25	557	43	407	66
10% Decrease in Opportunity Chargers	678	25	613	35	491	54

This analysis shows that the more opportunity chargers are used in the system, the less sensitive the system is overall of perturbations in the number of buses and chargers used. The report discusses cost trends and vehicle trends in more detail. Although this model is not a cost-analysis, the relative range of costs of charging equipment is given in the report. With these costs and based on the sensitivity analysis, it was estimated that the cost of the infrastructure to support this transition would cost between $41.8 million and $113.3 million.

FCEB infrastructure is not forecasted to expand greatly in the next 5 years. This is due to the high upfront costs of the refueling stations and the lack of FCEBs planned for deployment outside of existing FCEB networks. Although there are technologies on the horizon that have the potential to change the outlook of batteries for vehicle applications, these are not currently projected to impact the next 5 years of BEB deployments. Finally, COVID-19 appears to have impacted some transit agencies' plans to transition, as a decrease in ridership has led to a decrease in funding, requiring some agencies to scale back their plans for an early transition. The scale and specificity of these impacts is beyond the scope of this study.

Recommendations

The report recommends that further study be conducted on the potential savings and costs of FCEBs and their infrastructure. This is an understudied and important part of a transition to zero-emission buses that requires a dedicated study to understand. Additionally, it is recommended that Caltrans consider BEB infrastructure as a significant influence as it develops its policies. It is also important for Caltrans to keep the uncertainty of the nature of this transition in mind when developing policies, allowing adequate flexibility in the policies to allow each transit agency to transition in the manner that best suits that agency's situation.

WHAT IS THE BENEFIT?

The deployable product is a final report that identifies ZEB and BET infrastructure needs and current conditions. These needs could be met by theoretical applications that are currently in development and examined by this research, which will provide guidance on where such infrastructure should be located.

Moreover, the research findings can be a foundation for future research to assess the effectiveness and use of ZEB and BET infrastructure. It will also provide costs and benefits analysis for the infrastructure; and pinpoints the types of projects that are most effective as a source of power for ZEB and BET vehicles.