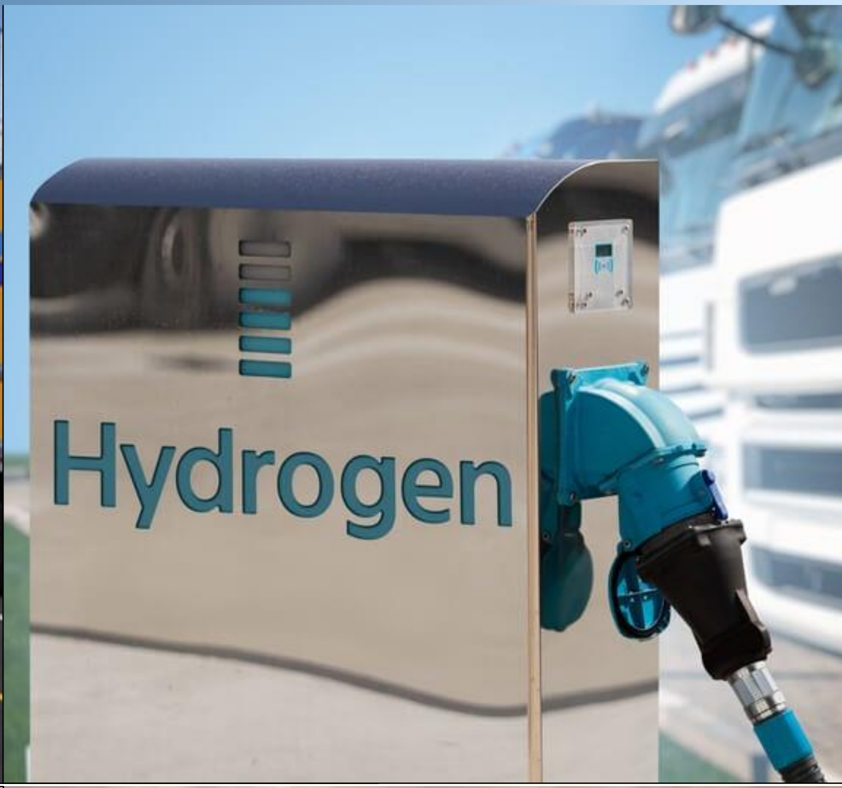
2024 Class 8 Drayage Truck Feasibility Assessment Report

June 2025

Prepared by ICF Incorporated LLC

THE PORT OF LOS ANGELES

Port of LONG BEACH
THE PORT OF CHOICE



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Acknowledgments

The following ICF team members wrote, edited, and/or contributed to the preparation of this 2024 Drayage Truck Feasibility Assessment Report:

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This report benefited from the insights, expertise, and input of numerous individuals and organizations, including but not limited to the Port of Long Beach, the Port of Los Angeles, various drayage truck fleets and representatives from a wide range of heavy-duty vehicle original equipment manufacturers (OEMs). Their contributions were critical to shaping the findings and conclusions of this report.

In addition to the direct contributors, we would like to express our sincere appreciation to the following individuals who served as peer reviewers. Their feedback helped enhance the clarity, accuracy, and utility of the final report:

Peer Reviewer	Organization/Affiliation
Lauren Dunlap	Starcrest Consulting Group, LLC
Ray Gorski	Starcrest Consulting Group, LLC

Their thoughtful comments, suggested revisions, and expert perspectives strengthened the quality of this report and contributed to a more comprehensive and credible assessment. The San Pedro Bay Port team is grateful to all contributors and reviewers for their time, collaboration, and commitment to advancing clean freight solutions in California.

Authorship and Uses

This report was prepared by a consulting team from ICF Incorporated LLC (https://www.icf.com/). Any reference in this report to a specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not constitute or imply endorsement, recommendation, or preference by the Ports or the report authors.

Glossary

ACT: Advanced Clean Trucks

ACF: Advanced Clean Fleets

AER: all-electric range

AFDC: Alternative Fuels Data Center

AQMD: Air Quality Management District

BABA: Build America, Buy America Act

BEV: battery electric vehicle

BET: battery electric truck

CA: California

CARB: California Air Resources Board

CAAP: Clean Air Action Plan

CEC: California Energy Commission

CI: carbon intensity

CRT: Charge Ready Transport

CTF: Clean Truck Fund

DGE: Diesel Gallon Equivalent

EPA: Environmental Protection Agency

EV: electric vehicle

EVSE: Electric Vehicle Supply Equipment

FCEV: fuel cell electric vehicle

FCET: fuel cell electric truck

GHG: greenhouse gas emissions

GVWR: gross vehicle weight rating

HVIP: California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project

ICCT: International Council of Clean Transportation

ICE: Internal Combustion Engine

IRA: Inflation Reduction Act

ISEP: Innovate Small e-Fleet

LADWP: Los Angeles Department of Water and Power

LCFS: Low-Carbon Fuel Standard

O&M: operation and maintenance

OEM: original equipment manufacturer

MSRP: manufacturer's suggested retail price

NACS: North America Charging Standard

NACFE: North American Council for Freight Efficiency

NPV: Net Present Value

NZEV: near-zero-emission vehicle

PDTR: Port Drayage Truck Registry

POLA: Port of Los Angeles

POLB: Port of Long Beach

POS: point of sale

RMI: Rocky Mountain Institute

SCE: Southern California Edison

SOC: State of charge

SPBP: San Pedro Bay Ports

TAAS: truck-as-a-service

TCO: total cost of ownership

TRL: Technology Readiness Level

U.S.: United States

V2P: vehicle-to-port

VIN: vehicle identification number

WAIRE: Warehouse Actions and Investments to Reduce Emissions

ZE: zero-emission

ZETI: Zero-Emission Technology Inventory

ZEV: zero-emission vehicle

Executive Summary

Key Findings of the Report

Purpose and Context

- The report supports the San Pedro Bay Ports Clean Air Action Plan (CAAP) goal of achieving 100% zero-emission (ZE) Class 8 drayage trucks by 2035.
- This is the 2024 triennial feasibility assessment, focusing on battery electric trucks (BETs) and fuel cell electric trucks (FCETs).

Assessment Framework

- *Evaluates feasibility across five key dimensions:*
  - *Technical viability*
  - *Commercial availability*
  - *Operational compatibility*
  - *Economic viability*
  - *Infrastructure readiness*

Technical & Commercial Viability

- Zero-emission (ZE) trucks reached commercial maturity by end of 2024.
- As of Dec 2024:
  - 7 BET models available (150–330 mile range; avg. 209 miles).
  - 6 FCET models available (249–500 mile range).
- Heavier curb weights (~8,000 lbs. more than diesel) reduce payload capacity.
- Build America Buy America Act (BABA) compliance is limited and raises costs/delays production.

Operational Viability

- BETs are viable for short-haul, single-shift operations (<150 miles).
- FCETs offer greater range and fast refueling (12–20 mins), better suited for longer routes and two-shift operations.
- Payload limitations due to vehicle weight affect profitability, especially for heavier-load operators.

Economic Viability

- BET total cost of ownership (TCO) is 2–2.4x higher than new diesel trucks; FCET TCO is 4.5–5x higher.
- Used diesel trucks have the lowest TCO.
- Depot charging offers lower energy costs than diesel; public charging and hydrogen are more expensive.
- Incentives reduce BET TCO by up to 34% and FCETs by 16–21%, but ICE trucks remain most affordable.

Infrastructure Readiness

- Current infrastructure can support up to:
  - ~800 BETs using 462 charging ports, (i.e., individual charging dispensers).
  - ~350 FCETs using the 6 hydrogen stations.

Full transition (~17,000 trucks) would require:

  - 6,200+ charging ports (14x current).
  - 32 hydrogen stations dispensing ~123,000 kg/day (5x current capacity).
- Infrastructure gaps remain a major barrier, especially outside the Port zone.

Overall Feasibility

- Feasibility is mixed and varies by operation type:
  - Short trips & single shifts: more feasible now.
  - Long-haul, multi-shift, high-payload: face substantial challenges.
- Significant progress since 2018:
  - Commercialization of ZE trucks.
  - Improved infrastructure (from near-zero in 2018).
- There is still a long way to go to achieve full market maturity and widespread adoption.

Executive Summary

The 2017 update to the San Pedro Bay Ports Clean Air Action Plan (CAAP)[1] established ambitious goals, including achieving 100% ZE Class 8 drayage trucks by 2035. As part of this update, the CAAP requires the Port to conduct a feasibility assessment every 3 years, evaluating the transition of Class 8 drayage trucks operating at the San Pedro Bay Ports to ZE technology.

This assessment provides a snapshot of ZE truck technology through the end of 2024, evaluating its compatibility with existing drayage operations. It should be noted that the 2024 feasibility assessment focuses exclusively on ZE Class 8 trucks, namely, battery electric trucks (BETs) and fuel cell electric trucks (FCETs). This decision, guided by the Ports' CAAP goal for ZE drayage, aligns with the State's Governor's Executive Order N-79-20, which set specific ZE targets for drayage trucks in California, as well as the Advanced Clean Fleet (ACF) regulation adopted by the California Air Resources Board (CARB) in April 2023.

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Important Caveat

On January 13, 2025, the California Air Resources Board (CARB) withdrew its waiver request to the Environmental Protection Agency, rendering the priority fleet and drayage fleet provisions *of Advanced Clean Fleet (ACF) regulation unenforceable.*[2] *Despite this, CARB has indicated that it will explore alternative strategies to achieve a similar level of electrification in the coming years. Since this report focuses on the status of technology and policy as of the end of 2024, it includes some projections, such as infrastructure estimates reflecting the full adoption of ZE technology by 2035. With the withdrawal of the ACF waiver, there is currently no mandate requiring the transition of drayage trucks to ZE technology by 2035. The CAAP goals remain unchanged, and the Ports will continue their efforts to promote the adoption of ZE drayage trucks.*

This report reflects the status of technology, infrastructure, and policy as of December 2024. Regulatory conditions and market forces after 2024, including the future of the ACF

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[1] San Pedro Bay Ports Clean Air Action Plan (CAAP). https://cleanairactionplan.org/

[2] https://www.epa.gov/system/files/documents/2025-01/ca-acf-carb-withdrawal-ltr-2025-1-13.pdf

regulation, potential revisions to the Advanced Clean Trucks (ACT) rule, and federal trade policies or tariffs, may impact the pace, cost, and feasibility of ZE truck deployment.

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Following the CAAP framework for feasibility assessments, this report evaluates the feasibility of Class 8 ZE drayage trucks across five key areas: technical, commercial, operational, economic, and infrastructure viability.

Technical and Commercial Viability

The 2024 assessment highlights significant advancements in the technical viability of both BETs and FCETs. The assessment acknowledges that these technologies have reached commercial maturity and are widely available on the market.

Please note that all findings and data presented in this report reflect information available as of December 2024. Market developments occurring after this cut-off date, such as the dissolution of Hyzon[3] or the bankruptcy of Nikola,[4] are not captured in this report. We recognize that the ZE vehicle market is dynamic and constantly evolving, with new models introduced, existing models discontinued, and companies entering or exiting the market regularly. Given this volatility and the need for consistency in the analysis, a cut-off date was necessary to preserve the accuracy and completeness of the report. This also made it possible to move forward with the required public engagement and review process prior to release. While this report provides a snapshot of the market at a specific point in time, we acknowledge that ongoing developments will continue to influence the ZE transportation landscape.

As of 2024, there are seven different makes and models of Class 8 BETs available, offering a variety of configurations with electric ranges between 150 and 330 miles, and an average

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[3] On December 19, 2024, Hyzon Motors' board of directors voted to dissolve the company, pending shareholder approval, due to financial challenges and funding difficulties.
[4] On February 19, 2025, Nikola Corporation filed for Chapter 11 bankruptcy protection, citing significant financial challenges and unsuccessful efforts to raise capital and reduce liabilities.

range of 209 miles. In comparison, FCETs provide longer driving ranges, between 249 and 500 miles, with six models on the market as of December 2024.

In addition to availability and range, payload capacity is another key factor to consider, particularly given the heavier weight of BETs and FCETs. For BETs, curb weights range from 16,994 lbs. (Freightliner eCascadia 4x2 short range) to 28,800 lbs. (Nikola Tre® BEV), averaging around 23,000 lbs., approximately 8,000 lbs. heavier than traditional diesel trucks. Similarly, FCET curb weights also range from 22,000 lbs. to 26,000 lbs., averaging about 23,000 lbs. This added weight reduces payload capacity, requiring operators to make operational adjustments.

The Build America, Buy America (BABA) Act is also another key factor in the feasibility of ZE drayage trucks, impacting costs, availability, and production timelines. It requires federally funded projects to meet strict domestic sourcing standards, with at least 55% of component costs coming from the United States. Currently, only a few Class 8 BETs and FCETs meet these requirements. Original equipment manufacturers (OEMs) report that BABA compliance increases production costs by over 10% and can delay timelines by more than six months due to limited domestic component availability.

Operational Viability

The current capabilities of ZE truck technologies demonstrate potential to meet certain operational requirements of port drayage activities but also reveal significant gaps when evaluated against the diverse needs of operators. BETs and FCETs are commercially available and can meet requirements in certain operational contexts, such as short-haul, low-mileage routes or single-shift operations. However, both technologies face limitations in areas such as range, payload capacity, refueling or charging infrastructure, and cost.

With an average range of 209 miles, BETs can support a substantial portion of drayage operations at the Ports of Los Angeles and Long Beach, where 50% of operators report trips under 100 miles per shift, and 55% run single-shift schedules. However, range limitations present challenges for the 25% of operators who travel over 200 miles per shift and fleets with multi-shift operations. Additionally, real-world BET ranges often fall short of rated values, particularly under heavy loads and varying traffic conditions, with some trucks rated for 150 miles achieving only 120 miles in practice.

With an extended range of 250–500 miles, FCETs can cover 80% of current port drayage activities, where average trip distances remain under 250 miles per shift. For the one-third of operators running two-shift schedules, FCETs can be a viable option as long as each shift stays within the truck's range. Their short refueling times of 12–20 minutes offer a significant advantage over BETs, minimizing downtime and maintaining operational efficiency. Additionally, FCETs' longer range reduces the need for frequent refueling stops, with some operators able to go days without refueling.

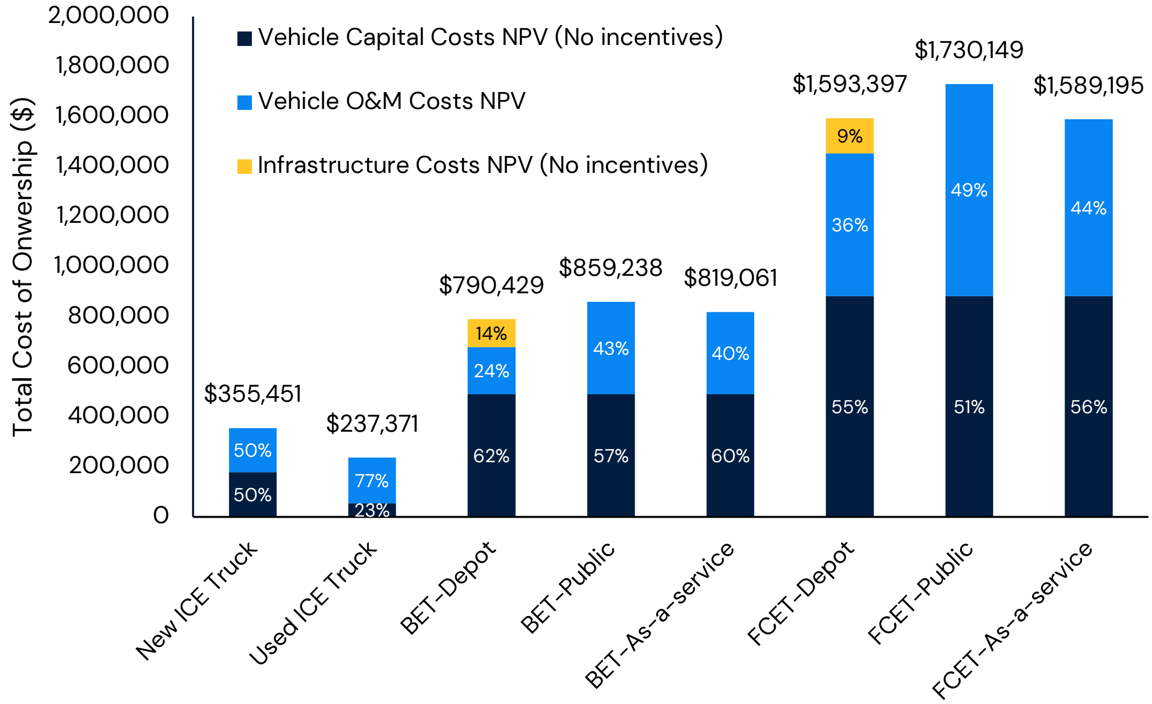
With BETs and FCET weighing approximately 8,000 lbs. more than traditional diesel trucks, their impact on payload capacity is a critical operational consideration. This added weight reduces cargo capacity, requiring adjustments for fleets that frequently transport heavy loads of 70,000 to 80,000 lbs., as reported by 33% of operators. While 54% of operators typically haul lighter loads under 60,000 lbs., the increased curb weight of BETs can still limit flexibility for occasional heavier hauls and reduce profitability by restricting cargo volume per trip.

Economic Viability

The transition to ZE technology also presents significant economic challenges, particularly due to the high upfront costs of Class 8 BETs and FCETs. To better understand the financial implications, this feasibility assessment includes a comprehensive total cost of ownership (TCO) analysis over a 5-year period, reflecting the expected ownership duration of the trucks as indicated through fleet operator surveys/interviews. The analysis establishes baseline scenarios for new and used internal combustion engine (ICE) trucks as reference points and evaluates different ZE truck options based on refueling strategies. For BETs, scenarios include depot charging (centralized charging infrastructure), public charging, and charging-as-a-service (third-party management of charging infrastructure). For FCETs, depot refueling (on-site hydrogen refueling stations), public refueling, and refueling-as-a-service are considered.

As shown in Figure ES1, the TCO analysis demonstrates that used ICE trucks have the lowest total cost of ownership at roughly $240,000. New ICE trucks are slightly higher at approximately $360,000, significantly more affordable than ZE alternatives. BETs have a TCO that is 2 to 2.4 times higher than new ICE trucks, while FCETs have the highest TCO, reaching up to around $1.7 million – 4.5 to 5 times the cost of a new ICE truck and double that of BETs. While BETs benefit from lower fuel costs when charged at depots (18% lower than diesel), public charging significantly increases expenses, making refueling costs up to 80% higher than diesel. FCETs face even steeper fuel costs, particularly in public refueling scenarios, where costs can reach more than $700,000, over six times that of diesel.

Figure ES1. Total 5-year costs of ownership without accounting for zero-emission vehicle incentives (Net Present Value[5] at 5% discount rate)



The feasibility assessment also presents a scenario incorporating incentives to highlight their impact on reducing the TCO for ZE trucks. With vehicle purchase and infrastructure incentives, TCO decreases by up to 34% for the BET scenarios, while FCET scenarios see reductions of 16% to 21%. Despite these improvements, FCETs remain the most expensive option, followed by BETs, while ICE trucks continue to have the lowest TCO. Among electric options, depot charging remains the most cost-effective, followed by public charging and charging-as-a-service models. Although incentives significantly narrow the cost gap between BETs and ICE trucks, FCETs still require substantial incentives to approach cost competitiveness with other alternatives.

Zero-Emission Infrastructure Availability

Evaluating the availability and adequacy of charging and refueling infrastructure is also a critical aspect of determining the overall feasibility of transitioning to ZE trucks. Infrastructure analysis was conducted by categorizing the geographic region into four distinct zones: the Port Area (within a 5-mile radius of the Ports), Near Port (5–15 miles from the Ports), Railyards/Intermediate Zone (15–50 miles), and the Inland Empire (50–150 miles). These zones were defined based on typical drayage truck travel patterns and

[5] Net present value (NPV) is a financial metric that calculates the present value of future cash flows, discounted at a specified rate, to determine the profitability of an investment.

operational behaviors, as identified through surveys and operator feedback. Additionally, these zones include properties not owned by the Ports and over which the Ports have no jurisdiction. The rationale for this classification was to ensure a targeted assessment of infrastructure needs where they would be most utilized by drayage trucks. For instance, trucks typically operate within a 150-mile radius of the Ports, making it essential to focus infrastructure planning within this range. This zoning also aligns with observed truck trip distances, as the majority of surveyed trucks operate within these travel limits.

The current infrastructure, both existing and under construction, within a 150-mile radius of the Ports includes 21 charging stations with 462 charging ports and 6 hydrogen refueling stations capable of dispensing 25,200 kg of hydrogen daily. Despite these existing and under construction facilities, the analysis reveals that the infrastructure is insufficient to support the future demand for ZE trucks. The current charging network in operation or under construction can support only 800 Class 8 BETs, while hydrogen refueling infrastructure can accommodate 350 Class 8 FCETs.

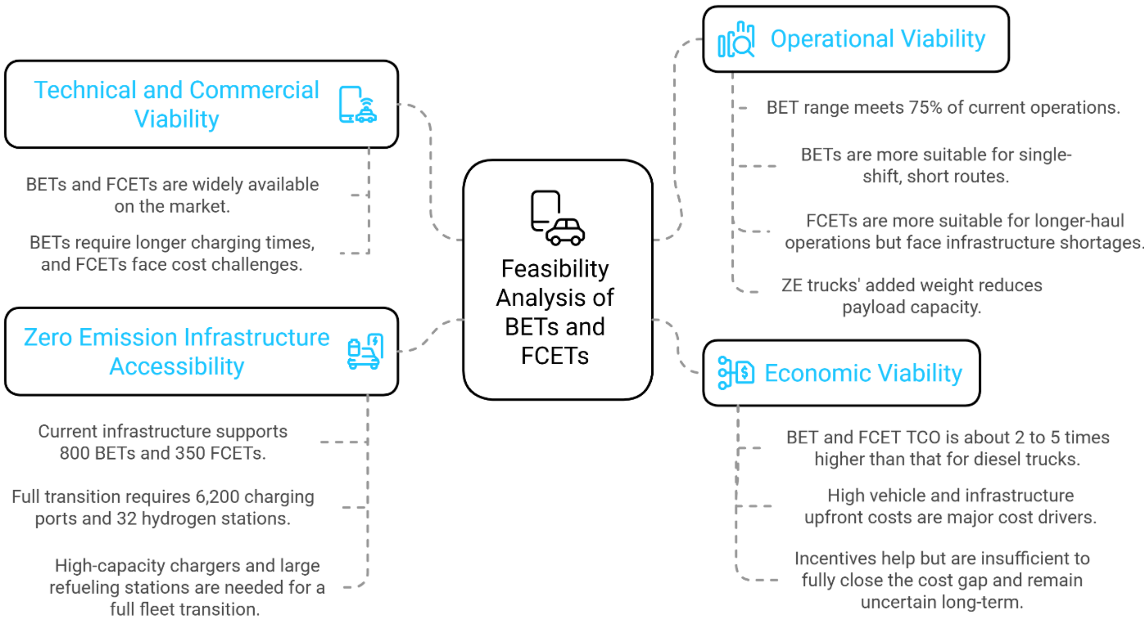
To fully transition the Ports' drayage fleet, comprising approximately 17,000 active[6] Class 8 trucks, significant infrastructure development is required. This includes a 14-fold increase in charging ports, bringing the total to around 6,200 ports, and a significant scale-up of hydrogen refueling capacity by an additional 98,000 kg/day, reaching a total of 32 stations. For BETs, the infrastructure should account for diverse operating patterns and ensure that charging stations are strategically located across key regions identified. Similarly, hydrogen refueling infrastructure needs to achieve higher station capacities and broader geographic coverage to meet operational demands.

Overall Feasibility

The feasibility of deploying ZE trucks in drayage operations at the San Pedro Bay Ports is not a straightforward “yes or no” determination but instead exists on a continuum. As illustrated in Figure ES2, certain segments of operations are more ready for transition, while others face significant challenges that limit the viability of ZE truck deployment. Based on findings from this assessment, operations involving shorter routes and single-shift schedules, particularly those with trips of less than 150 miles, are currently more compatible with ZE technology. In contrast, longer-haul operations, multi-shift schedules, and trips requiring high-payload capacities remain constrained by technological, operational, and economic barriers.

[6] Active trucks in this study are defined as those that have at least 104 moves per year, based on gate count data provided by the ports. This threshold includes a larger portion of regularly operating trucks than the “frequent” and “semi-frequent” categories used in prior feasibility assessments, better reflecting current operations and informing infrastructure planning.

Figure ES2. Feasibility status of zero-emission trucks as of 2024 for drayage trucks operating at San Pedro Bay Ports



Despite ongoing limitations, there has been steady and significant progress since the last feasibility assessments. Back in 2018, when the first assessment was conducted, zero-emission Class 8 truck technology was still in its infancy. At the time, only one manufacturer (BYD) offered a pre-commercial battery electric truck with a limited range of 100 to 150 miles and no capacity for commercial-scale production. By 2021, seven OEMs had introduced early-commercial BETs with ranges up to 230 miles, though production volumes remained low. By 2024, BETs reached full commercial maturity, with seven makes/models available offering ranges between 150 and 330 miles and fleets operating dozens of units in real-world settings. FCETs followed a similar trajectory, progressing from pilot stages in 2018 and 2021 to commercial availability in 2024, with six models on the market at the end of 2024.

While the infrastructure available to support ZE trucks remains limited, it has significantly improved since previous assessments. For BETs, charging infrastructure was nonexistent in 2018 and remained limited in 2021. Similarly, prior assessments indicated no hydrogen refueling stations were available.

This really illustrates that while certain models of ZE trucks were technically capable of performing drayage operations as early as 2021, their production was limited, real-world deployment was minimal, and charging and fueling infrastructure was still in its infancy. In less than three years, however, there has been significant progress, both in the number of trucks deployed and the expansion of supporting infrastructure. That said, there remains a long road ahead before we reach widespread availability of these trucks across the diverse range of operations within the drayage sector.

Technical Report

Section 1. Introduction

The San Pedro Bay Ports Clean Air Action Plan (CAAP)[7] is a landmark initiative by the Ports of Los Angeles (POLA) and Long Beach (POLB), targeting significant reductions in air pollution through the adoption of zero-emission (ZE) technologies. The 2017 update to the CAAP introduced significant enhancements to accelerate the POLA and POLB's commitment to reducing emissions and transitioning to ZE operations. This update set new, ambitious goals, including a 100% ZE goal for cargo-handling equipment by 2030 and 100% ZE Class 8 trucks in drayage by 2035. These goals aim to address evolving environmental and public health concerns driven by port operations, with a particular focus on reducing greenhouse gas (GHG) emissions and improving air quality in surrounding communities.

What Are Zero-Emission Trucks?

Zero-emission (ZE) truck refers to trucks that produce no direct tailpipe emissions, reducing air pollution and transportation-related greenhouse gas emissions. ZE trucks include two types of trucks: battery electric trucks (BETs) and hydrogen fuel cell electric trucks (FCETs). BETs use a battery to store electricity for the motor, and the battery is charged via outlets or stations. Hydrogen FCETs use hydrogen and oxygen to produce electricity in a fuel cell, emitting only water vapor. FCETs have rapid refueling times and longer driving ranges.

To support these goals, the CAAP mandates a series of feasibility assessments to evaluate key factors influencing the transition to ZE technologies. These feasibility assessments are designed to communicate progress toward CAAP goals, to identify whether timelines need to be adjusted given the state of technology, and to inform policy and program development toward achieving the CAAP goals. To ensure a comprehensive assessment, the CAAP has established a detailed framework that guides the evaluation of ZE technologies. The framework provides a structured approach to assessing the readiness and scalability of these technologies across key operational areas. A central component of the framework is the assessment of technical viability, which determines if ZE technologies meet or exceed the performance standards of conventional diesel equipment. This includes an evaluation of operational performance, regulatory certification status, and commercial availability. Alongside technology readiness, the framework also emphasizes the need for sufficient supporting infrastructure, such as electric and hydrogen refueling capabilities both on- and off-terminal, to meet the projected demand within CAAP timelines. Economic considerations are another core aspect of the framework. CAAP feasibility assessments evaluate both the direct costs related to ZE equipment covering acquisition, fuel, and maintenance expenses and the broader, indirect effects on workforce dynamics and goods movement. The framework also prioritizes stakeholder engagement through public

[7] San Pedro Bay Ports Clean Air Action Plan (CAAP). https://cleanairactionplan.org/

workshops, technical consultations, and comment periods to refine each assessment. The outcomes are crucial in identifying barriers, necessary actions, and potential policy adjustments, helping the Ports and industry stakeholders align efforts toward CAAP ZE goals.

Conducted every 3 years, these feasibility assessments serve as tools for evaluating progress toward CAAP goals and shaping policy, program development, timelines, and infrastructure investments to support large-scale ZE adoption. The objective of this 2024 assessment is to capture a snapshot of ZE[8] technology as it stands in 2024, focusing on its compatibility with the existing operations of drayage truck and cargo-handling equipment at the port.

The purpose of these assessments is not to make a definitive judgment on whether ZE technology is “ready” or “not ready” for widespread deployment today. Instead, the goal is to provide an accurate picture of where deployment of this technology is feasible today, where challenges remain, and which specific economic and infrastructure gaps must be bridged to enable broader viability. This approach identifies areas where ZE solutions can be effectively implemented now and highlights the support needed, whether through infrastructure expansion or targeted incentives, to make this technology practical across all relevant port operations.

Although this assessment is based on data and market conditions available through the end of 2024, the ZE truck and infrastructure landscape continues to evolve rapidly, with ongoing developments in technology, policy, and the commercial market. Industry changes in early 2025, such as manufacturer restructuring or regulatory updates, may introduce new uncertainties, but they do not alter the core findings of this report. Establishing a clear cut-off date (December 2024 for this report) was essential to ensure a consistent and feasible evaluation, given the fast-moving nature of this industry and the extensive public engagement process required for report development. While future events may influence the pace and direction of progress, the technological capabilities, operational considerations, and economic challenges identified in this report remain valid.

[8] All references to zero emissions pertain to tailpipe emissions only and do not account for life-cycle emissions.

Overview of the Report

Timeline and Applicability

This report assesses the feasibility of ZE trucks as of the end of 2024, based on the technologies available at the time and the operating conditions of drayage trucks serving the San Pedro Bay Ports. While it includes some near-term projections, these are limited to anticipated products and technology advancements announced by industry stakeholders, along with infrastructure developments already in progress.

In terms of applicability, this feasibility assessment is specifically targeted at Class 8 drayage trucks operating within the SPBP. The insights and findings presented here are intended to guide local stakeholders, such as fleet operators, port authorities, manufacturers, and infrastructure developers, who are directly involved in the transition to zero-emission vehicles (ZEVs) in this critical area. This report intends to provides relevant, location-specific information to support decision-making and highlight the current gaps that need to be addressed to facilitate a broader transition to ZE trucks in drayage operations.

Scope of Feasibility Assessment: Why Zero-Emission Trucks Only?

Unlike the 2018 and 2021 assessments, the 2024 feasibility assessment focuses exclusively on ZE Class 8 trucks, namely, battery electric trucks (BETs) and fuel cell electric trucks (FCETs), capable of performing drayage services at the SPBP. The decision to concentrate solely on ZE trucks reflects the Ports' long-term goal, as outlined in the Clean Air Action Plan (CAAP), to transition all drayage trucks visiting the Ports to ZE by 2035. This aligns with California's broader environmental objectives and the regulatory direction set by the California Air Resources Board (CARB), further underscoring the commitment to a fully ZE fleet in drayage services within the next decade.

In 2023, CARB adopted the Advanced Clean Fleets (ACF) regulation, targeting drayage trucks operating at California ports and intermodal railyards, with a mandate to transition to ZE. Under this rule, beginning in 2024, only ZE trucks can be newly registered in the drayage truck registry system, and by 2035, all drayage trucks operating at the ports must be ZE. The ACF regulation defines ZEVs as those powered solely by battery electric or hydrogen fuel cell technology, while the rule's definition of near-zero-emission vehicles (NZEVs) largely includes plug-in hybrid trucks with specific minimum all-electric range requirements.[9] It shall be noted that on January 13, 2025, CARB withdrew its waiver request

[9] To qualify as a NZEV, plug-in hybrid electric vehicles must meet specific minimum all-electric range (AER) thresholds that increase over time. For example, vehicles from model years 2021–2023 must meet a minimum AER of 10 miles; for 2024–2026, the requirement increases to 20 miles for slow-charge vehicles and 15 miles for fast-charge; for 2027–2029, 35 miles and 20 miles respectively; and by 2030 and beyond, all vehicles must meet a minimum AER of 75 miles. More details can be found at: https://ww2.arb.ca.gov/sites/default/files/2021-08/GHG%20Phase%202%20Reg.pdf and https://dieselnet.com/standards/us/ca_zev_hd.php

to the Environmental Protection Agency (EPA), making the priority fleet and drayage provisions of the ACF regulation unenforceable. Despite this, CARB plans to explore alternative strategies to support fleet electrification.

In alignment with the Ports' ZE goals and the state's objective to transition drayage trucks to ZE (e.g., Governor's Executive Order N-79-20), this assessment focuses exclusively on ZE trucks and does not consider NZEV options. This narrower focus allows the Ports to better assess the feasibility of ZE technologies that align with both state mandates and the Ports' own environmental commitments, ensuring that infrastructure planning and policy development remain concentrated on meeting these goals effectively.

Report Organization

This report is organized as follows:

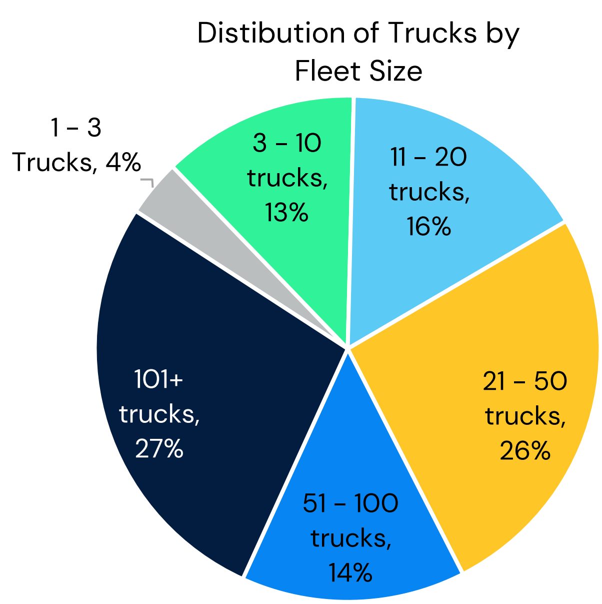
- **Section 2** provides the current operational characteristics of drayage trucks at SPBP, including the number and type of drayage trucks operating at SPBP, drayage truck purchase patterns, and the types of drayage operators. To present a clearer picture of the operational characteristics of drayage trucks, this section explains the methodology used for interviews and surveys with drayage truck operators at SPBP and associated results spanning topics such as operating shifts and the distance traveled during each shift, typical loaded operating weight, overnight parking and refueling, and duty cycles. This section also lists a number of regulatory and incentive programs.
- **Section 3** examines the feasibility of ZE Class 8 trucks in drayage services through five key pillars: technical and commercial viability, operational feasibility, economic practicality, and charging and refueling infrastructure availability. The objective of this section is to assess each of these pillars individually and then provide a comprehensive evaluation across all five to present an overall picture of feasibility as of 2024. It is important to note that this section is not intended to provide a definitive yes or no answer on feasibility but rather to highlight the opportunities and challenges associated with adoption at this stage. Additionally, this section outlines the key barriers that must be addressed for the full-scale deployment of ZE trucks in drayage operations across the SPBP.

Section 2. Overview of San Pedro Bay Ports' Drayage Trucks

Drayage Truck Characteristics

As of November 2024, the Port Drayage Truck Registry (PDTR) database records 2,156 companies operating at the POLA and POLB with at least one truck registered. While a large portion of these companies operate small fleets (64% have 10 or fewer trucks), truck ownership is concentrated among larger operators. Companies with fewer than 20 trucks (82% of companies) collectively own only 33% of all port-registered trucks (Figure 1). In contrast, fleets with more than 100 trucks, though comprising just 2% of companies, own 27% of all trucks. This disparity highlights the fragmented nature of the drayage industry in terms of company count, alongside a notable concentration of vehicles among a small number of high-volume operators.

Figure 1. Fleet size distribution



Types of Drayage Operators

The majority of truck operations at the Ports of Los Angeles and Long Beach are focused on containerized cargo, as both Ports are leading container gateways for imports and exports in the United States (U.S.). Drayage trucks are primarily responsible for transporting shipping containers to and from port terminals to nearby warehouses, distribution centers, or intermodal rail yards, facilitating the first and last miles of goods movement. While containerized cargo represents the majority of truck activity, other specialized operators also serve the Ports. Bulk carriers handle commodities like grain, cement, and petroleum products, which require specific equipment and trailers. Auto carriers are another niche segment, transporting imported and exported vehicles between the Ports and regional distribution centers. Additionally, flatbed trucks are used to move oversized cargo, such as heavy machinery and construction materials. The diversity of goods and specialized trucking needs reflects the Ports' role as multipurpose gateways for international trade, with trucking fleets tailored to the specific types of freight moving through the region. This diversity also presents unique challenges for fleet electrification and emission reduction strategies, such as the significant variation of truck configurations and usage patterns across different types of goods and operators. For the purposes of this feasibility assessment, the focus is on Class 8 tuck tractors hauling containers, which represent the majority of drayage trucks serving the Ports.

Operator Interviews and Survey

To evaluate the feasibility of deploying Class 8 ZE trucks in drayage services, it is essential to first understand the current operational practices of drayage truck operators at the SPBP. To this end, the Ports distributed a survey to drayage operators and fleets on August 19, 2024. The survey was designed to gather insights into current operations, along with the challenges and opportunities related to transitioning to zero-emission technologies. The survey period concluded on October 18, 2024, yielding a total of 42 responses out of more than 2,000 fleets registered in the PDTR (roughly 2.5% response rate).

While the overall response rate was low, the distribution of respondents, based on fleet size, operational patterns, and geographic coverage, reflects the broader composition of drayage operators at the Ports. To supplement and validate these survey findings, the project team also conducted six in-depth interviews with truck operators and fleet managers. These interviews provided valuable qualitative context and helped affirm key operational insights and transition challenges reported in the survey. These primary data sources formed the foundation of the drayage feasibility analysis and were further supported, where necessary, by publicly available datasets, relevant literature, and port-provided information, including PDTR database records. References to all supporting sources are provided throughout the report. The survey and interview question sets are included in Appendix A for reference. While the survey had a limited response rate, the overall operational patterns reported below are consistent with findings from the previous feasibility assessments, reinforcing the validity of the results.

Operation

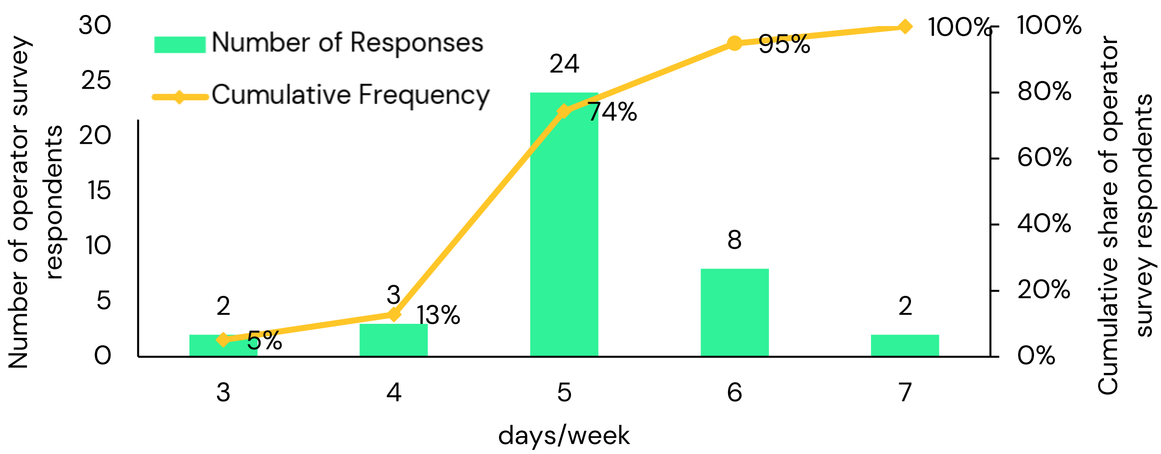
To understand the current operations of Class 8 trucks in drayage services at SPBP, ten different metrics of operational characteristics are examined as follows.

Operating Days, Shifts, and Hours

Survey results indicate that the majority of respondents (74% of the 39 who answered this question[10]) operate their trucks no more than 5 days/week (Figure 2) and nearly all respondents indicated that they do not operate more than two shifts/day (Figure 3). Over half of the respondents reported that their trucks are simply operated on a one-shift schedule each day. Among operators who operate their trucks no more than 5 days/week, half of them are on a one-shift schedule as well. Across all responses, the number of hours per shift can range from 6 hours to around 15 hours per shift. Additionally, the average shift length is about 10 hours (Figure 4).

Note that throughout this report, survey results are presented using charts that include columns along with a yellow line to help visualize responses. In these charts, the columns show the number of survey responses for each category, while the yellow line represents the cumulative percentage of total responses up to that category. In other words, the yellow line shows how the values in each column add progressively from left to right across the chart, showing how responses accumulate. This visualization makes it easier to see not just how many people selected a particular option, but also what portion of the overall group is captured up to that point. This format helps readers understand both the distribution of individual responses and how they add up across the dataset. For example, in Figure 2 showing the number of days per week that trucks operate, a taller green column over "5 days" indicates that many respondents selected that option, while the yellow line reaching 74% at that point shows that 74% of respondents operate their trucks 5 days per week or fewer.

Figure 2. Days in service for Class 8 trucks in drayage services (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)



[10] Since not all questions in the survey were mandatory, respondents had the option to answer some questions while skipping others. As a result, the total number of responses varies across questions. For example, Figure 2 reflects a total of 39 responses, whereas Figure 3 shows a total of 41 responses.

Figure 3. Number of shifts per day (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)

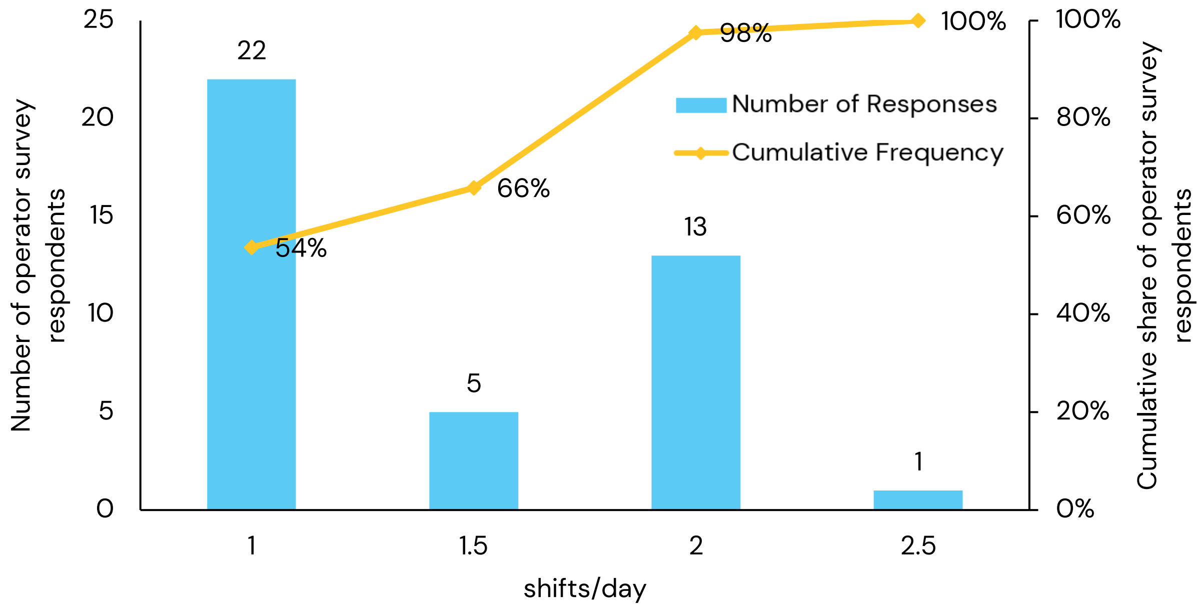
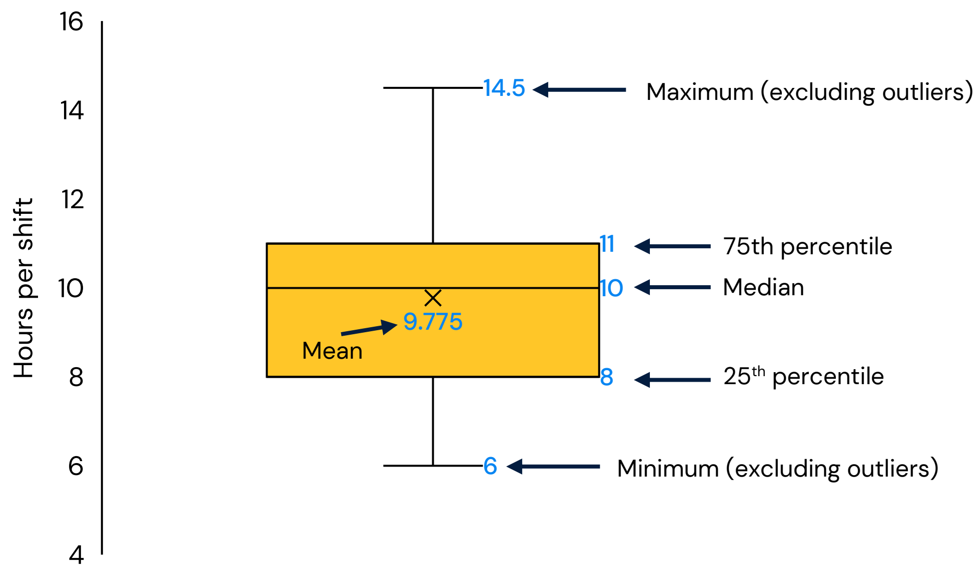


Figure 4. Number of hours per shift



Shift Range, Trip Distance, and Frequency

About 50% of the operator survey respondents reported that their trucks travel no more than 100 miles during each shift on average (Figure 5 and Figure 6). The median mileage per shift is 120 miles, while the mean is 162 miles, suggesting that a few high-mileage operations are skewing the average. In this context, the median provides a more accurate reflection of typical operating conditions across the drayage fleet by reducing the influence of outliers.

In addition to average miles per shift, the survey also asked operators to provide the maximum distance their trucks travel per shift. The maximum distance reported ranges from 60 miles to 550 miles per shift, with the majority of respondents falling between 117 and 300 miles per shift. On average, the maximum distance traveled per shift is 233 miles, with a median of 200 miles.

Figure 5. Average miles traveled per shift (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)

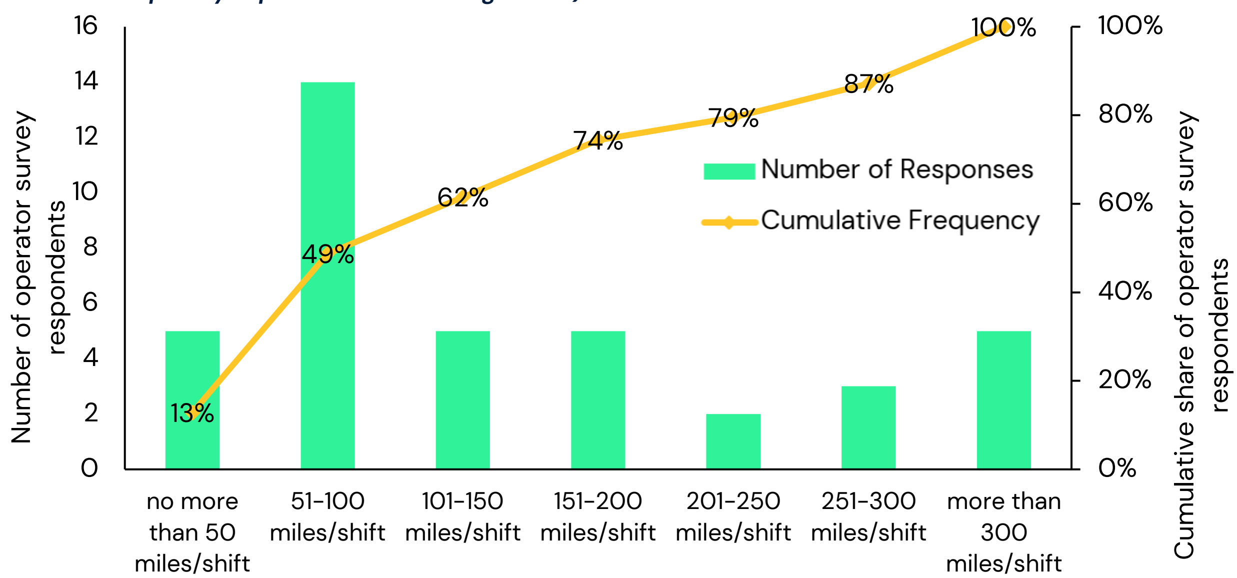
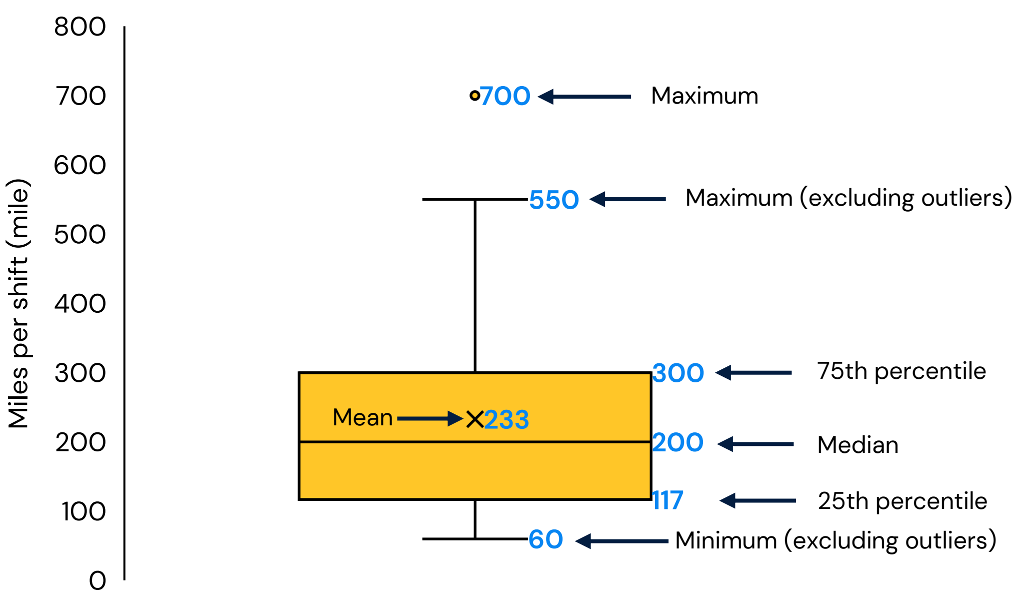


Figure 6. Maximum miles traveled per shift



On any given day, 73% of the operator survey respondents report that their trucks typically make three trips or fewer to the Ports each, with an average of nearly four trips and a median of approximately three trips per truck on any given day (Figure 7). The average distance of these trips is about 109 miles per trip, with 55% of the trips being less than 30 miles. Twelve percent of operators who participated in the survey reported the typical trip distance of their trucks from SPBP to the final destinations can exceed 100 miles. The survey also sought information on the maximum trip distances that operators may experience throughout the year. For the majority of operators that participated in the survey, the maximum trip distance for their trucks from SPBP to the final destinations ranges from 50 miles to 300 miles, with an average of 263 miles per trip (Figure 8).

The results highlight a variety of operational patterns among drayage operators at the SPBP, encompassing local, regional, and longer-distance trips. While the majority of trips are relatively short, with an average of approximately 109 miles and often less than 30 miles, indicating a strong local focus, some operators report longer typical trip distances exceeding 100 miles, suggesting regional or intrastate operations. Additionally, maximum trip distances indicate that drayage operations can extend to longer regional or even occasional interstate routes.

Figure 7. Number of trips per day a truck takes to San Pedro Bay Ports (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)

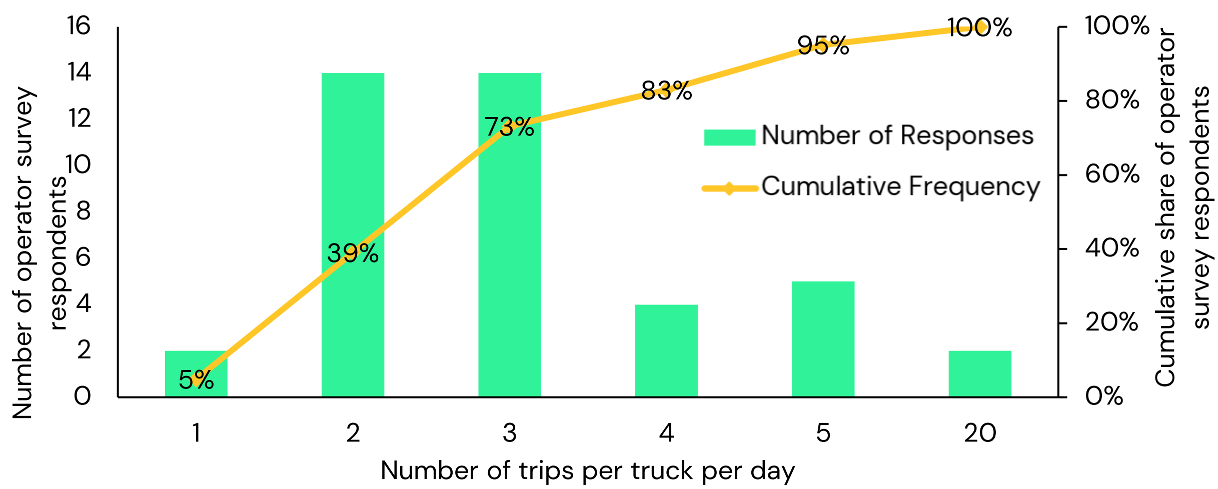
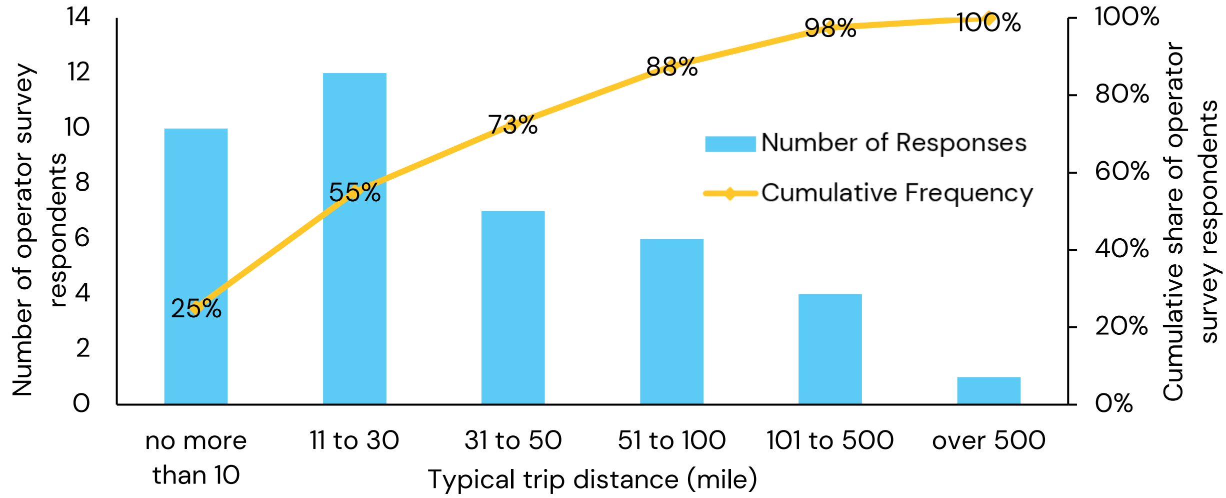


Figure 8. Typical trip distance of a truck from San Pedro Bay Ports to its destination (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)



Loaded Operating Weight

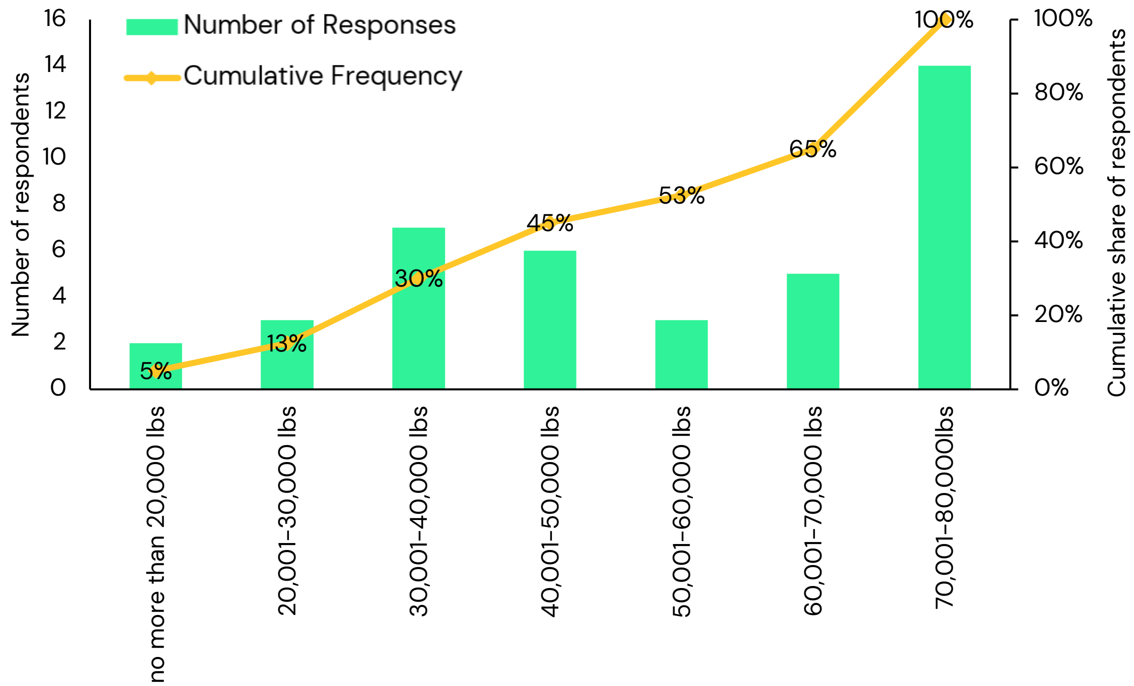
Payload capacity directly impacts drayage truck operator efficiency and profitability. Drayage operations often involve transporting heavy shipping containers between port terminals and nearby warehouses or distribution centers. A truck's payload capacity determines the weight of goods it can carry, affecting the number of trips required to move cargo and, consequently, fuel consumption, operating costs, and time efficiency. For drayage operators, who typically operate under tight schedules and narrow profit margins, maximizing payload capacity is essential to meet customer demands, comply with weight regulations, and maintain competitive pricing in a highly demanding logistics environment.

Payload capacity becomes even more critical with ZE trucks due to the additional weight of onboard battery systems (refer to Section 3 for additional information), which often reduces the available capacity for cargo, especially for fleets operating near legal weight limits[11]. Drayage operators need to maintain efficiency while adhering to strict weight limits, which makes every pound of available payload valuable. The heavier weight of ZE trucks necessitates compromises in the amount of cargo transported per trip, potentially increasing the number of trips required to move the same volume of goods. This can lead to higher operational costs and reduced profitability. Therefore, understanding the typical loaded operating weight of drayage trucks is crucial when evaluating ZE alternatives and determining their feasibility. According to operator survey results, over half (53%) of respondents reported a typical loaded operating weight below 60,000 lbs., while 35% indicated a loaded operating weight between 70,001 and 80,000 lbs. (Figure 9). On average, the typical loaded operating weight is 56,675 lbs., with a median of 57,500 lbs.

[11]The Consolidated Appropriations Act, 2019, Truck Size and Weight Provisions. https://ops.fhwa.dot.gov/freight/pol_plng_finance/policy/fastact/tswprovisions2019/index.htm. Accessed April 10, 2025

When considering the maximum loaded operating weight during current operations, most responses fell within the range of 45,000 lbs. to 80,000 lbs. The average of reported maximum weight was 65,738 lbs., with a median of 79,750 lbs.

Figure 9. Typical and maximum loaded operating weight including cargo (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)



Overnight Parking and Refueling

Understanding overnight parking practices is crucial in assessing the feasibility of Class 8 ZE trucks for drayage operators, particularly given that the majority of companies operating at the Ports are small fleets with fewer than 20 trucks. These smaller fleets are less likely to rely on depot parking and may instead park trucks at dispersed locations, such as drivers' homes or independent lots, which often lack access to charging infrastructure. This presents a significant challenge for ZE truck adoption, as reliable and accessible overnight charging is essential for operational efficiency. Evaluating where and how these smaller fleets park their trucks helps identify infrastructure gaps and supports the development of tailored charging solutions that meet their specific needs.

According to the survey, the majority of respondents (57%) have access to a depot, with more than 80% of trucks used at the SPBP parking at fleet-owned depots overnight (Figure 10). However, 31% of respondents appear to lack access to a depot, as they park fewer than 20% of their trucks at their own depots. The survey results also indicate that 54% of respondents refuel less than 20% of their trucks at their own facilities, indicating limited access to on-site refueling for a substantial share of operators (Figure 11).

The survey does not explore the reasons behind operators' varying choices for overnight parking and refueling. However, several factors may explain the results. Many respondents are likely independent owner-operators without access to a depot. Additionally, some truck operators may have depots, but their facilities lack sufficient parking space. Another possibility is that certain operators' trucks do not finish their shifts at or near the Ports, influencing their parking and refueling decisions.

Figure 10. Percentage of trucks that operators dispatch to San Pedro Bay Ports and park at one of their facilities overnight (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)

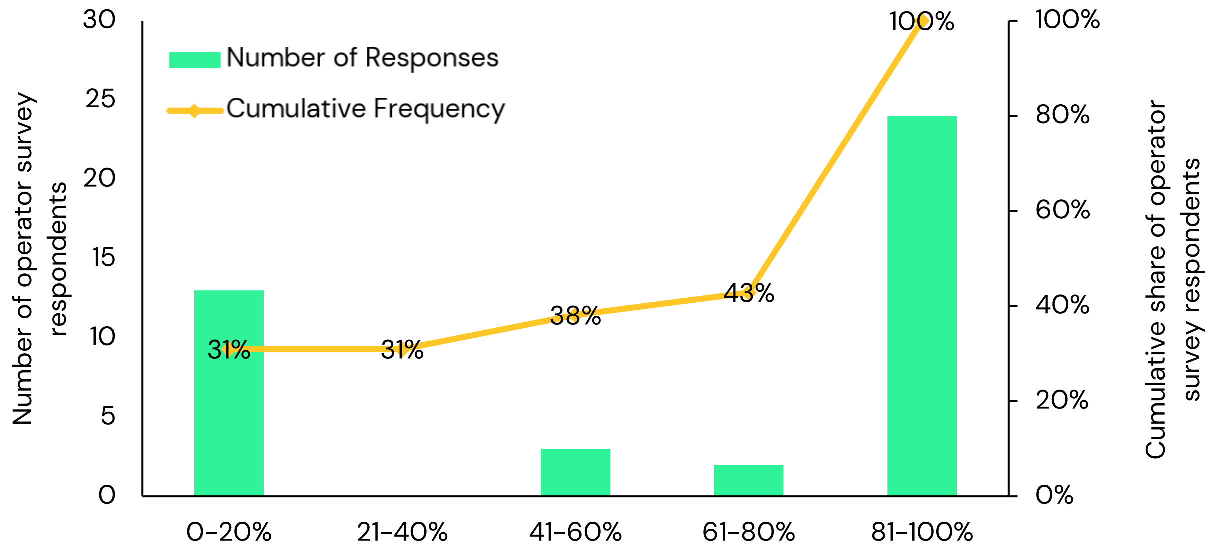
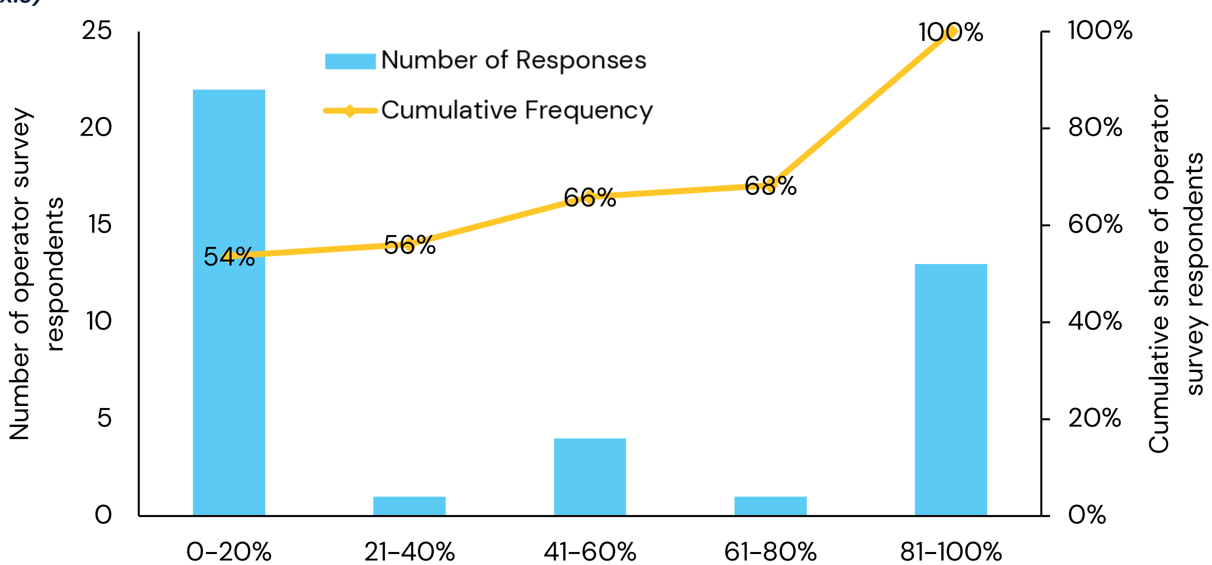


Figure 11. Share of trucks that operators dispatch to San Pedro Bay Ports and refuel at their facilities (number of responses is shown on the left axis and the cumulative frequency is presented on the right axis)



Available Time to Charge

When planning for BET operations, operators should account for real-world charging durations and battery management practices to ensure reliability. While a 500-kWh battery can theoretically charge in 1.5 hours using a 350-kW charger (if the vehicle can accept the full 350 kW rate continuously), actual charging times are often longer due to charging speed tapering at higher states of charge. Moreover, operators should avoid discharging trucks to critically low levels; maintaining a minimum state of charge around 20% helps protect battery health, preserve performance, and provide a buffer for unexpected energy needs.

There are several approaches to charging ZE trucks, each suited to different operational needs. Overnight charging is ideal for fleets with predictable schedules and significant down time, particularly those operating on a single-shift basis. This approach leverages downtime at fleet depots or parking locations, allowing trucks to fully recharge by the start of the next day. Opportunity charging involves recharging during the workday, often aligning with natural breaks in operations, such as while trucks are being loaded or unloaded or during scheduled breaks between trips.[12]

Based on survey responses and supported by interview findings, most drayage truck operators have operational patterns that could provide opportunities for charging ZE trucks without significantly impacting their operations. These patterns indicate that trucks are often idle overnight, particularly for fleets operating a single shift per day. This downtime provides a practical window for overnight charging, including opportunities for managed charging, which can help fleets avoid peak electricity rates by charging at lower power levels over longer periods. Even for fleets operating two shifts per day, strategically scheduled breaks or overnight periods could support charging without disrupting operations.

For operators whose trucks travel beyond the range of ZE trucks, mid-shift charging or charging during loading and unloading should be considered to extend their operational range. These methods can align with existing workflows, such as cargo handling, but pose implementation challenges. Coordinating charging schedules with operations requires careful planning, and the availability of high-power chargers at key locations like port terminals and logistics hubs is often limited. Additionally, ensuring charger access and minimizing wait times are critical for maintaining productivity, particularly for fleets with tight schedules or high utilization rates.

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[12] ABB. (n.d.). Fleet, Transport and Logistics. ABB E-mobility. https://e-mobility.abb.com/en/segments/logistics. Accessed April 14, 2025.

Regulatory and Incentive Programs Influencing Drayage Trucks

California has established ambitious targets for Class 8 ZE trucks as part of its efforts to reduce GHG emissions and improve air quality. In September 2020, Governor Gavin Newsom signed Executive Order N-79-20[13], which set a statewide goal to transition 100% of medium- and heavy-duty vehicles to ZE technology by 2045 where feasible. Specifically for drayage trucks, the target is even more aggressive, aiming for a complete shift to ZEVs by 2035. To enable this, CARB and local air districts, e.g., the South Coast Air Quality Management District (AQMD), have combined aggressive regulatory measures with extensive incentive funding programs. A summary of some of the key regulatory and incentive programs influencing Class 8 trucks in drayage services are as follows, with updates since the 2021 Assessment. Regarding incentive programs, while this list highlights the most relevant initiatives at the time of writing, it is important to note that program availability, design, and funding levels may change over time based on evolving administrative priorities and state or local budget decisions. Further analysis of relevant incentives and their impact on total cost of ownership is provided in the Economic Viability section. As discussed there, while incentives reduce upfront costs, they may not be sufficient to fully close the cost gap between ZE trucks and diesel alternatives.

Regulatory Programs

Advanced Clean Trucks (ACT)

California's ACT [14] regulation, approved by CARB in March 2021, mandates Class 8 truck manufacturers to sell ZE models as an increasing percentage of their annual California sales, starting at 5% for model year 2024 and reaching 40% by 2035. Beyond California, 10 other states have committed to adopting ACT regulations beginning in 2025 or 2027, signaling a broader shift toward ZE trucks nationwide.

Advanced Clean Fleets (ACF)

As a companion to the ACT regulation, CARB approved the ACF[15] regulation in April 2023, establishing ZE requirements for various fleets in California including drayage operators. Under ACF, any new drayage truck registered in California after January 1, 2024, must be ZE, with a full transition to ZE trucks required by 2035. Legacy combustion engine trucks may continue operating until the earlier of 18 years or 800,000 miles, provided they are registered with CARB by December 31, 2023, and visit a port or railyard at least once annually.

[13] State of California, Office of the Governor. (September 23, 2020). Executive Order N-79-20. https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf
[14] California Air Resources Board (CARB). (2021). Advanced Clean Trucks. Retrieved March 3, 2025, from https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks
[15] California Air Resources Board. (2024). Advanced Clean Fleets. Retrieved March 3, 2025, from https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets

On January 13, 2025, CARB withdrew its waiver request to the EPA, rendering the priority fleet and drayage fleet provisions of the ACF regulation unenforceable.[16] Despite this, CARB has indicated it will explore alternative strategies to achieve a similar level of electrification in the coming years. Since this report focuses on the status of technology and policy as of the end of 2024, it includes some projections, such as infrastructure estimates reflecting the full adoption of ZE technology by 2035. With the withdrawal of the ACF waiver, there is currently no mandate requiring the transition of drayage trucks to ZE technology by 2035. However, the CAAP goals remain unchanged, and the Ports will continue their efforts to promote the adoption of ZE drayage trucks within this timeframe.

Clean Truck Check

The California Clean Truck Check[17], formerly known as the Heavy-Duty Inspection and Maintenance, is a regulation adopted by CARB to ensure proper operations of heavy-duty vehicle emission control systems. The regulation is a CARB initiative aimed at ensuring the proper operation of emission control systems in heavy-duty vehicles. Unlike ZE-focused regulations, this program targets nearly all diesel and alternative fuel heavy-duty vehicles with a gross vehicle weight rating (GVWR) over 14,000 pounds operating on California roads. It applies to in-state and out-of-state vehicles, including commercial trucks, buses, motorcoaches, and even personal vehicles like motorhomes. The program began in January 2023 with the use of roadside emissions monitoring devices to identify high-emitting vehicles. Emissions compliance testing requirements took effect on October 1, 2024, and by January 1, 2025, all vehicles must submit a passing emissions test from a CARB-credentialed tester as part of their compliance. Tests can be submitted up to 90 days before the compliance deadline to allow time for necessary repairs. This program ensures that heavy-duty vehicles maintain controlled emissions during their operation in California.

The Clean Truck Check program could influence the transition to ZE trucks by accelerating fleet turnover. Under this regulation, fleets are required to repair any issues with their trucks' emissions control systems. However, if repair costs exceed the vehicle's resale value, operators may choose to sell or scrap their trucks rather than invest in repairs.

Warehouse Actions and Investments to Reduce Emissions (WAIRE)

The WAIRE program[18], adopted by the South Coast AQMD in May 2021, aims to reduce diesel particulate and nitrogen oxide emissions from shipping and warehousing operations

[16] California Air Resources Board. (January 13, 2025). Withdrawal of California's Request for a Waiver, Pursuant to Clean Air Act Section 209(b), and Request for Authorization, Pursuant to Clean Air Act Section 209(e)(2), for the Advanced Clean Fleets (ACF) Regulation. Retrieved from https://www.epa.gov/system/files/documents/2025-01/ca-acf-carb-withdrawal-ltr-2025-1-13.pdf

[17] CARB (2021). "Clean Truck Check," https://ww2.arb.ca.gov/our-work/programs/CTC, accessed November 21, 2024.

[18] South Coast AQMD (2021). "Rule 2035 – Warehouse Actions and Investments to Reduce Emissions Program", https://www.aqmd.gov/docs/default-source/planning/fbmsm-docs/waire-program-overview-factsheet.pdf, accessed November 21, 2024.

in Southern California. The program uses a menu-based point system, requiring warehouse operators to earn points annually based on the number of truck trips to and from their facilities, with larger trucks like tractor-trailers counting more heavily. Compliance applies to warehouses with 100,000 square feet or more of indoor space, though exemptions exist for smaller operations. For example, warehouse operators may be exempt from parts of the rule if they operate <50,000 square feet for warehousing activities. One of the ways the program encourages ZE truck adoption is by awarding WAIRE points for activities such as hosting on-site ZE truck charging or hydrogen refueling infrastructure, purchasing ZE trucks, or contracting with fleets that operate ZE trucks for deliveries and pickups. Warehouse operators can also earn points by financially supporting off-site projects that enable ZE vehicle deployment. Because many of the Port drayage trucks serve warehouses subject to WAIRE, this rule may accelerate ZE truck and infrastructure deployment.

Low-Carbon Fuel Standard

The Low-Carbon Fuel Standard[19] (LCFS) is designed to reduce the carbon intensity of transportation fuels and promote the adoption of cleaner alternatives. The regulation, which took effect in 2011, sets progressively lower carbon intensity targets for fuels used in California, encouraging fuel providers to produce and supply low-carbon fuels such as electricity and hydrogen. Entities that produce or supply fuels below the carbon intensity standard earn LCFS credits, while those exceeding the standard must purchase credits to comply.

One of the key benefits of the LCFS program is its role in accelerating the deployment of ZE truck infrastructure, including heavy-duty vehicle charging stations and hydrogen refueling stations. Charging network operators, fleet owners, and hydrogen station developers can generate LCFS credits by supplying low-carbon electricity or hydrogen to ZE trucks. These credits can then be sold, creating a revenue stream that helps offset the high upfront costs of deploying charging and refueling infrastructure.

Incentive Programs

San Pedro Bay Ports Clean Truck Fund Rate

The Clean Truck Fund (CTF) Rate is a funding mechanism implemented by the Ports to accelerate the transition to ZE trucks. Effective April 1, 2022, the Ports began collecting a $10 per twenty-foot equivalent unit (TEU) fee on loaded containers moved by non-ZE trucks entering or exiting marine terminals[20]. Revenue generated through this rate is deposited into the CTF, which is used to support the deployment of ZE trucks and related infrastructure. Through the CTF, the Ports invested a combined $60 million in POS purchase

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[19] California Air Resources Board. Low Carbon Fuel Standard (LCFS). https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard, accessed March 3, 2025.
[20] San Pedro Bay Ports Clean Truck Fund Rate Collection Begins April 1. https://polb.com/port-info/news-and-press/san-pedro-bay-ports-clean-truck-fund-rate-collection-begins-april-1-03-17-2022/. Accessed April 6, 2025.

incentives via CARB's Clean Truck and Bus Voucher Incentive Project[21]. POLB has reported plans to allocate up to 70% of its annual CTF budget to ZE truck purchase incentives in 2025, after prioritizing infrastructure in earlier program years[22]. Both Ports continue to coordinate with public and private partners, including CARB and Southern California Edison to pool funds and expand the reach of their ZE truck and infrastructure initiatives under the CAAP.

Clean Truck and Bus Voucher Incentive Project (Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project, HVIP)

The Clean Truck and Bus Voucher Incentive Project, also known as the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), is a first-come first-served, point-of-sale (POS) incentive program for vehicles from Class 2b through eight weight classes in California.

The baseline amount of funding for a Class 8 ZE truck is $120,000 per vehicle for FY23-24. Notably, except for public transit buses, HVIP cannot be combined with state-funded incentives. However, local- and federal-funded incentives may be combined with HVIP vouchers, so long as each incentive program is not paying for the same incremental costs, or the total sum of incentives does not exceed the total cost of the vehicle. Individuals who wish to purchase vehicles are allowed to request a maximum of 30 vouchers annually.

For HVIP, purchasers are not required to apply for a voucher, instead, HVIP has streamlined the process by having dealers become HVIP-approved and having dealers submit requests for HVIP vouchers to CARB. Upon approval, the voucher amount is discounted from the purchase order. This process makes it simpler for purchasers to explore the HVIP-eligible vehicle catalog[23] and work with HVIP-approved dealers[24] for direct access to incentives. Currently, HVIP includes 151 vehicles in the approved catalog, that can be found across at least 65 HVIP-approved dealers in California.

The SPBP have partnered with CARB to rapidly increase deployments of ZE trucks at the nation's busiest port complex since November 2023. To date, funding for nearly 800 ZE trucks has been allocated through HVIP at the Ports[25].

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[21] CA HVIP, "Ports of Los Angeles and Long Beach Fund Nearly 800 Drayage Trucks through HVIP", https://californiahvip.org/news/ports-of-los-angeles-and-long-beach-fund-nearly-800-drayage-trucks-through-hvip/, accessed November 21, 2024

[22] Port to Increase Investment in Clean Trucks. https://polb.com/port-info/news-and-press/port-to-increase-investment-in-clean-trucks-03-28-2025/. Accessed April 11, 2025.

[23] CA HVIP, "HVIP Eligible Vehicles," https://californiahvip.org/vehiclecatalog/, accessed November 21, 2024.

[24] CA HVIP, "A Network of Dealers to Serve You," https://californiahvip.org/dealerlist/, accessed November 21, 2024.

[25] CA HVIP, "Ports of Los Angeles and Long Beach Fund Nearly 800 Drayage Trucks through HVIP", https://californiahvip.org/news/ports-of-los-angeles-and-long-beach-fund-nearly-800-drayage-trucks-through-hvip/, accessed November 21, 2024.

In FY 2022–2023, $157 million was set aside specifically for drayage trucks and $265 million for HVIP Standard funds[26]. The FY 2023–24 budget provided $80 million to be implemented through HVIP, specifying the full amount for ZE drayage trucks[27]. While CARB staff is not proposing to allocate additional funding to HVIP for FY 2024-25[28] due to the limited funding available in the State budget and the needs in other project categories, HVIP used the remaining from previous years' appropriations. As of December 19, 2024, HVIP no longer accepts requests for Standard funds. Requests can still be submitted for the Drayage Truck Set-Aside, the Transit Set-Aside, and the Innovate Small e-Fleet (ISEF) project for fleets that qualify. Future HVIP funding allocations will depend on decisions made through the State budget process, and at this time, no projections or speculations can be made regarding additional funding availability.

Innovate Small e-Fleet (ISEF)

ISEF is a set-aside within the HVIP[29], designed to support small fleets and individual owner-operators making the transition to ZEVs. Through ISEF, small fleets have the option to request vouchers for all-inclusive leases, short-term rentals, truck-as-a-service (TAAS), assistance with infrastructure, and other alternative business models and mechanisms. ISEF is solely dedicated to innovative offerings for private or public companies, non-profits, and independent owner-operators with 20 or fewer vehicles operating in California with less than $15 million in annual revenue; public and non-profit fleets are exempt from any revenue provisions.

ISEF voucher funds can only be used for vehicle costs and the maximum funding available per voucher is capped at 90% of a commercial medium- or heavy-duty truck or bus purchase price. The vehicle purchase price does not include taxes, registration, delivery fees, service agreements, extended warranties, or other items when determining the maximum voucher amount.

Federal Tax Credits

The federal government established the Inflation Reduction Act (IRA), providing avenues for EV and charging station funding in the form of tax credits. Through the Commercial Clean Vehicle Federal Tax Credit[30], the IRA offers income tax credits for qualifying BETs and

[26] CARB. Proposed Fiscal Year 2022-23 Funding Plan for Clean Transportation Incentives. October 12, 2022. https://ww2.arb.ca.gov/sites/default/files/2022-10/proposed_fy2022_23_funding_plan_final.pdf. Accessed April 10, 2025.
[27] CARB. Proposed Fiscal Year 2023-24 Funding Plan for Clean Transportation Incentives. October 6, 2023. https://ww2.arb.ca.gov/sites/default/files/2023-10/Proposed%20Funding%20Plan%20Fiscal%20Year%202023-24.pdf. Accessed April 10, 2025.
[28] CARB. Proposed Fiscal Year 2024-25 Funding Plan for Clean Transportation Incentives. October 11, 2024. https://ww2.arb.ca.gov/sites/default/files/2024-10/Proposed%20Funding%20Plan%20Fiscal%20Yearl%202024-25.pdf. Accessed April 10, 2025.
[29] CA HVIP, "FAQs for ISEF Set-Aside," https://californiahvip.org/about/, accessed November 21, 2024.
[30] IRS, "Commercial Clean Vehicle Credit," https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit, accessed November 21, 2024.

extend tax credits for alternative fuel refueling property through 2032. Broadly speaking, this program is based on GVWR and allocates a tax credit equal to the lesser of three values depending on the GVWR. For vehicles with a GVWR greater than 14,000 lbs., the tax credit equals the least of the following options: a) 30% of the BEV purchase price, b) incremental cost of the BET compared to an equivalent ICE-equipped vehicle, or c) $40,000. There is no limit to the number of federal tax credits claimed through this program.

IRA also has the Alternative Fuel Vehicle Property Credit, which is a federal income tax credit for businesses and individuals who install alternative fuel infrastructure. This program provides the lesser of either a) 30% of the depreciable hardware cost or b) $100,000 per charging station. Permitting and inspection fees are not included as part of the covered expenses.

The Alternative Fuel Infrastructure Tax Credit[31] is direct-pay eligible, meaning that entities that do not benefit from income tax credits, such as state, local, and Tribal governments or other tax-exempt entities can elect to receive these tax credits in the form of direct payments. Eligible fueling equipment must be installed in locations that meet one of the following census tract requirements[32]: (1) the census tract is not an urban area; or (2) a population census tract where the poverty rate is at least 20%; or (3) a metropolitan and non-metropolitan area census tract where the median family income is less than 80% of the state median family income level.

Carl Moyer Memorial Air Quality Standards Attainment Program

The Carl Moyer Memorial Air Quality Standards Attainment Program (Carl Moyer Program)[33] provides funding for the replacement of older, higher-emitting vehicles and the installation of ZE infrastructure[34]. The program provides funding for cleaner-than-required engines, vehicles, and infrastructure to achieve early or surplus emissions reductions. Applicants can receive up to $410,000 per ZE truck if an older vehicle is scrapped, and up to 50% of costs for charging or hydrogen infrastructure. Funding is subject to cost-effectiveness limits and cannot be combined with other state-funded incentives for the same project, though it may be stacked with federal or local funds if total costs are not exceeded and emissions benefits are not double-counted.

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[31] IRS, "Alternative Fuel Vehicle Refueling Property Credit", https://www.irs.gov/credits-deductions/alternative-fuel-vehicle-refueling-property-credit, accessed November 21, 2024.

[32] Argonne National Laboratory, "30C Tax Credit Eligibility Locator", https://experience.arcgis.com/experience/3f67d5e82dc64d1589714d5499196d4f/page/Page/, accessed November 21, 2024.

[33] Carl Moyer Memorial Air Quality Standards Attainment Program. https://ww2.arb.ca.gov/our-work/programs/carl-moyer-memorial-air-quality-standards-attainment-program. Accessed April 11, 2025.

[34] Carl Moyer Program: Infrastructure. https://ww2.arb.ca.gov/our-work/programs/carl-moyer-program-infrastructure. Accessed April 11, 2025.

Southern California Edison Charge Ready Transport

Southern California Edison's Charge Ready Transport (CRT) Program[35] is designed to support the widespread adoption of ZE trucks and buses by facilitating the deployment of medium/heavy-duty charging infrastructure. This program is available only within SCE's service territory, including POLB. The program provides financial assistance and infrastructure support to fleet operators transitioning to BETs. CRT helps businesses, public agencies, and other fleet operators by covering a significant portion of the electrical infrastructure costs associated with installing EV charging stations, reducing the financial barriers to electrification. This includes designing, permitting, and constructing the necessary infrastructure to support medium/heavy-duty EVs, ensuring that fleets have access to reliable and scalable charging solutions.

Los Angeles Department of Water and Power Commercial EV Charger Rebate Program

The Los Angeles Department of Water and Power (LADWP) offers a Commercial EV Charger Rebate Program[36] to support the installation of medium- and heavy-duty electric vehicle chargers within its service area, including POLA. The program provides rebates of up to $125,000 per charger, depending on power output, and requires chargers to be permanently installed by a licensed contractor and remain in service for at least 5 years.

[35] Southern California Edison. Charge Ready Transport Program Overview. https://crt.sce.com/overview, accessed March 3, 2025.

[36] Los Angeles Department of Water and Power. Commercial EV Charger Rebate Program. https://www.ladwp.com/commercial-services/programs-and-rebates-commercial/commercial-ev-charging/commercial-ev-charger-rebate-program. Accessed April 10, 2025.

Section 3. Zero-Emission Truck Feasibility

Feasibility, as defined within the CAAP framework, refers to the likelihood that a technology can be successfully deployed to meet the Port's ZE goals within the established timelines. The CAAP outlines a framework for evaluating the feasibility of transitioning to ZE trucks through five key elements:

i. **Technical Viability**: Assess whether technology can meet operational performance standards equivalent to current diesel equipment. It also evaluates its commercial readiness, including certification by regulatory agencies like CARB or the EPA.

ii. **Operational Viability**: Examine whether technology can support the demanding duty cycles of port-related operations. It considers factors such as vehicle drivability, range, maintenance needs, and operator feedback.

iii. **Commercial Availability**: Ensure the technology can be produced in sufficient quantities and with appropriate warranties and support to meet market demands within the CAAP timeline.

iv. **Economic Viability**: Evaluate the TCO, including upfront capital costs, fuel and maintenance expenses, and infrastructure investments. It also considers the availability of funding incentives.

v. **Zero-Emission Infrastructure Availability**: Determine if adequate infrastructure is in place to support ZE trucks, including electric charging stations, hydrogen refueling facilities, and other necessary resources both on and off terminals.

This section will delve into each of these elements, providing a detailed evaluation of the Port's assessment for each individually. It will also combine these insights to present a holistic view of the feasibility of transitioning to ZE trucks under the CAAP framework.

Please note that all findings and data presented in this report reflect information available as of December 2024. Market developments occurring after this cut-off date, such as the dissolution of Hyzon[37] or the bankruptcy of Nikola[38], are not captured in this report. We recognize that the ZE vehicle market is dynamic and constantly evolving, with new models introduced, existing models discontinued, and companies entering or exiting the market regularly. Given this volatility and the need for consistency in the analysis, a cut-off date was necessary to preserve the accuracy and completeness of the report. This also made it possible to move forward with the required public engagement and review process prior to release. While this report provides a snapshot of the market at a specific point in time, it is

[37] On December 19, 2024, Hyzon Motors' board of directors voted to dissolve the company, pending shareholder approval, due to financial challenges and funding difficulties.
[38] On February 19, 2025, Nikola Corporation filed for Chapter 11 bankruptcy protection, citing significant financial challenges and unsuccessful efforts to raise capital and reduce liabilities.

acknowledged that ongoing developments will continue to influence the ZE transportation landscape.

The objective of this analysis is to illustrate the range of capabilities that have been demonstrated in practice and to define what may be technically achievable. This approach supports the broader goal of understanding whether ZE truck technologies can meet the Ports' deployment goals across technical, operational, commercial, economic and infrastructure dimensions.

Overview of Data Sources

A range of data sources was used to assess the technical, commercial, operational, economic, and infrastructure feasibility of ZE trucks. The operator interviews and survey described earlier informed all aspects of the analysis, offering direct insights into real-world operations. To specifically assess the technical, commercial, and operational viability from the supply side, the Ports distributed a feasibility survey to OEMs on August 19, 2024, which closed on October 18, 2024, and yielded five responses. These were supplemented by phone calls with dealerships and seven in-depth OEM interviews conducted by the project team to gather qualitative input on production timelines, challenges, and scaling strategies. Survey and interview questions are included in Appendix B. Additional information was drawn from public datasets, published literature, and data provided directly by the Ports. Sources for these materials are cited within the relevant sections of the report, where the data are discussed or applied, to ensure context.

Technical Viability

The Technology Readiness Level (TRL) approach is a framework used to evaluate the maturity of technology, progressing through stages from early research and development to full commercial deployment. TRL scales range from 1 (basic principles observed) to 9 (full commercial application), helping stakeholders assess whether a technology is ready for deployment in operational settings. Historically, this approach has been instrumental in assessing the technical viability of emerging technologies, including alternative fuel vehicles.

The 2024 ZE truck feasibility assessment is moving away from the TRL framework. This shift reflects the current state of ZE truck technologies, particularly BETs and FCETs, which have reached full commercial applications. These trucks are available in various ranges and configurations, and they have been successfully deployed in uncontrolled commercial environments. For example, in the fiscal year of 2023, CARB determined that the TRL for battery electric technology in the heavy-duty urban and regional drayage sector is 8.66 on average over a 2-year period.[39]

While we acknowledge that existing ZE truck models cannot yet meet 100% of operational needs—due to factors like limited range or payload capacity—many of these challenges stem from external constraints, such as inadequate charging or refueling infrastructure and road weight limits, rather than the technological maturity of the trucks themselves. Enhancing the range of electric trucks and reducing their weight through advancements in battery technology is essential for addressing these limitations. However, these efforts are considered technological improvements rather than indicators of different TRL levels. The ZE truck market has moved beyond the developmental stages and is now focused on scaling and refining its products to meet broader operational demands. This evolution reflects the need to adapt the feasibility assessment framework to the current realities of the market, focusing on overcoming infrastructure and policy barriers rather than questioning the fundamental readiness of the technology.

Therefore, in this round of feasibility assessment, the evaluation of technical viability focuses on the key characteristics of available ZE Class 8 trucks in the market as of the time of writing. This is to better understand the capabilities of these trucks and facilitate a straightforward evaluation against the operational needs of drayage operators to determine whether they can meet critical operational constraints. In this section, we present our findings on the technical viability of Class 8 ZE trucks, beginning with BETs and followed by hydrogen FCETs. For each category of ZE vehicle technology, the analysis addresses three key aspects: (1) makes and models currently available on the market, (2) driving range capabilities, and (3) insights from real-world deployments.

Class 8 Battery Electric Trucks

Make and models commercially available

Seven different makes and models of Class 8 BETs were commercially available in the market as of September 2024. As indicated in Table 1, some models have more than one configuration. For example, BYD 8TT Tandem Axle Tractor has two range options (i.e., 150-mile range with a 422-kWh battery, or 200-mile range with a 563-kWh battery). Freightliner eCascadia also has three range and configuration options: a 4x2 short-range (155-mile range with a 291-kWh battery), a 4x2 long-range (230-mile range with a 438-kWh battery), and a 6x4 option with a 220-mile range and a 438-kWh battery. Likewise, Volvo Group provides five different combinations with different configurations and range options: 4x2,

[39] CARB. Appendix D: Long-Term Heavy-Duty Investment Strategy. Including Fiscal Year 2023–24 Three-Year Recommendations for Low Carbon Transportation Investments. https://ww2.arb.ca.gov/sites/default/files/2023-10/fy2023-24lctfundingplan_appd.pdf. Accessed April 11, 2025.

6x2 (377 kWh battery), 6x2 (565 kWh battery), 6x4 (377 kWh battery), 6x4 (565 kWh battery).

Table 1. Class 8 battery electric truck make and model

Make	Model
BYD	8TT Tandem Axle Tractor*
Freightliner	eCascadia*
Kenworth	T680E
Lion Electric	Lion8T
Nikola	Tre® BEV
Peterbilt	579EV
Volvo Group	VNR Electric*
* indicate that this model offers more than one configuration Sources: ICF'S EV Library (2024.10.10 version) *Global Commercial Vehicle Drive to Zero's Zero-Emission Technology Inventory (ZETI) tool*[40] *DOE's Alternative Fuels Data Center (AFDC) Alternative Fuel and Advanced Vehicle Search*[41] OEMs and dealership insights	

Driving range

Across Class 8 BETs listed in Table 1, the rated, full driving range can vary from 150 miles to 330 miles, with the most being 154 miles to 271 miles (Figure 12). On average, the full range of a Class 8 BET is 209 miles as of the time of writing. The actual driving range is usually lower than the rated driving range in Figure 12**.** For instance, a Class 8 BET with a rated range of 150 miles in practice is more likely to support 120 miles or less, depending on the loaded operating weight. To support such a driving range, the battery size of a Class 8 BET can range from 291 kWh to 738 kWh, with an average of 469 kWh (Figure 13).

[40] Global Commercial Vehicle Drive to Zero, "Zero-Emission Technology Inventory (ZETI)," https://globaldrivetozero.org/tools/zeti/, accessed November 21, 2024.
[41] US DOE, "Alternative Fuel and Advanced Vehicle Search," https://afdc.energy.gov/vehicles/search, accessed September 17, 2024.

Figure 12. Class 8 battery electric truck full range (mile)

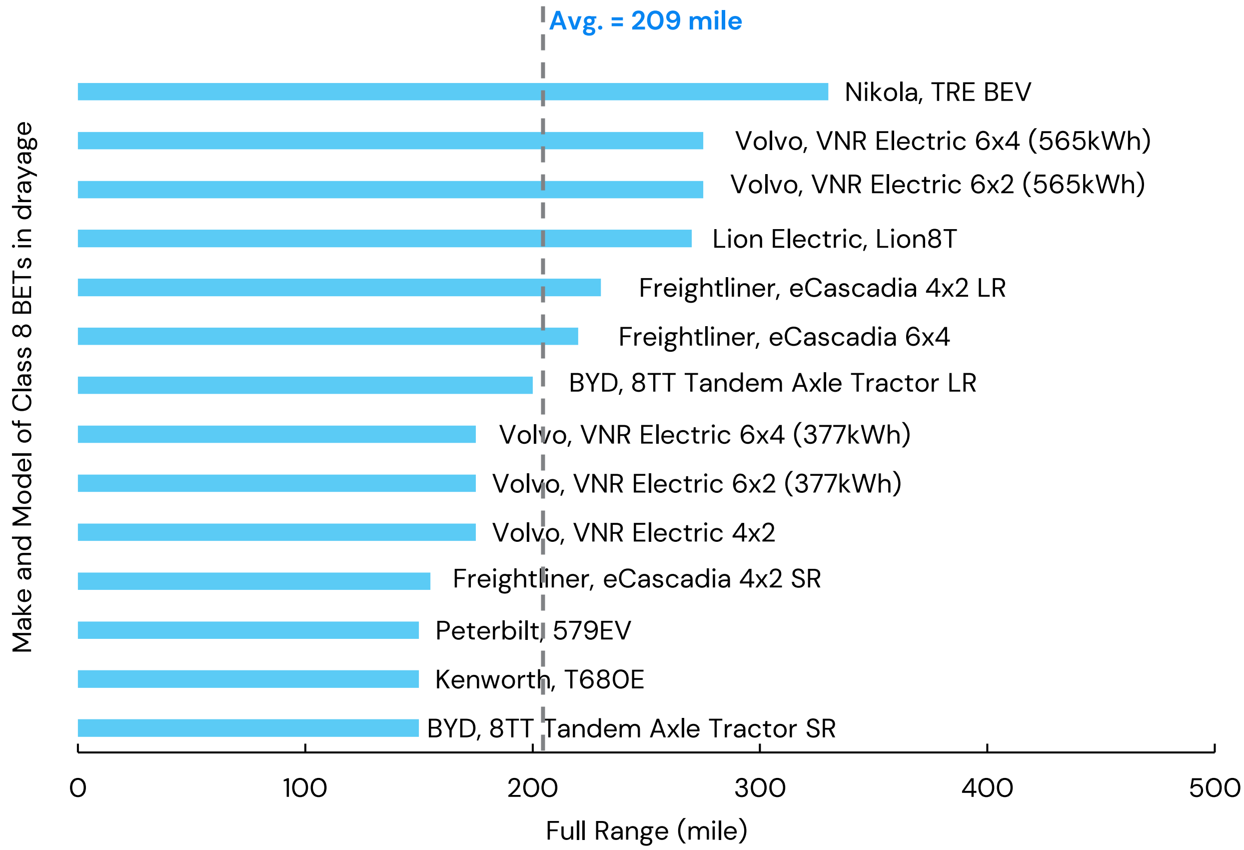
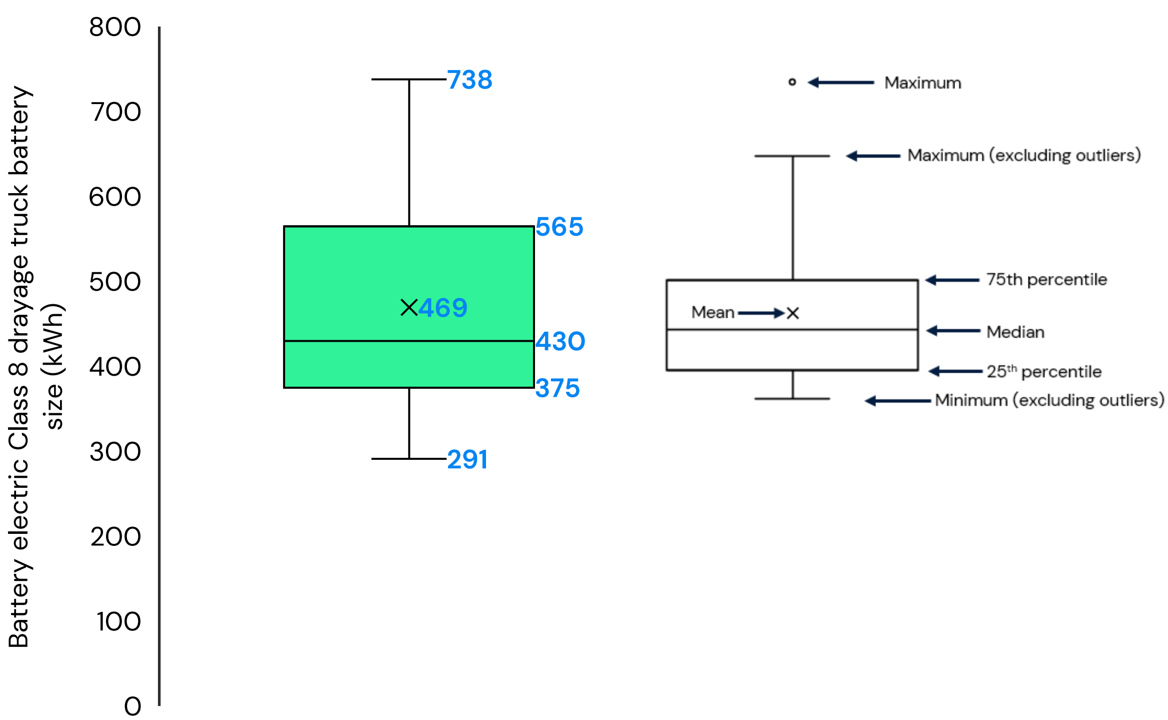


Figure 13. Class 8 battery electric truck battery size (kWh)



Curb weight

Understanding the vehicle's weight helps further examine the payload capacity of vehicles. The curb weight of Class 8 BET ranges from 16,994 lbs. to 28,800 lbs., depending on make and model, and configuration (Table 2). As shown, the curb weight increases as the truck battery size and axle configuration increases. The average curb weight of these makes and models is about 23,000 lbs., which is 8,000 lbs. heavier than a non-ZE Class 8 truck[42].

Table 2. Curb weight of different Class 8 battery electric truck makes and models

Make	Model	Curb Weight (lb.)
BYD	8TT Tandem Axle Tractor	26,235
Freightliner	eCascadia 4x2 short-range	16,994
	eCascadia 4x2 long-range	19,054
	eCascadia 6x4	21,390
Kenworth	T680E	22,500
Lion Electric	Lion 8T	26,000
Nikola	Tre® BEV	28,800
Volvo Group	VNR Electric	20,000 to 25,000

Power

Horsepower reflects not only the power of the engine but also determines the engine emission standards. For current Class 8 BET makes and models, the rated, continuous horsepower can range from approximately 320 hp to 650 hp. For example, Kenworth also has a rated horsepower of 536 hp and its peak horsepower can reach 670 hp. As illustrated in Table 3, the range of horsepower for Class 8 BETs overlaps with that for a typical Class 8 diesel truck, which usually ranges between 400 hp and 600 hp[43].

Table 3. Horsepower of different Class 8 battery electric truck makes and models

Make	Model	Typical Rated Horsepower (hp)
BYD	8TT Tandem Axle Tractor	483 (peak)
Freightliner	eCascadia 4x2 short-range eCascadia 4x2 long-range eCascadia 6x4	For single drive axle: 320 or 395 For tandem drive axle: 425 or 470
Kenworth	T680E	536 (continuous) 670 (peak)
Lion Electric	Lion 8T	Up to 536
Nikola	Tre® BEV	645 (continuous)

[42] The increase in curb weight for BETs is primarily due to the battery and electric powertrain components. This added weight can reduce allowable payload capacity depending on operational factors and how the vehicle is deployed. To help offset this impact, regulatory allowances—such as the federal 2,000-lb. weight exemption for BETs—permit higher weight limits.
[43] Cummins Inc. (n.d.). Heavy-duty trucks with available Cummins engines. Cummins. Retrieved April 14, 2025, from https://www.cummins.com/engines/heavy-duty-truck/heavy-duty-trucks-available-cummins-engines

Make	Model	Typical Rated Horsepower (hp)
Volvo Group	VNR Electric	1069 (instantaneous) 455 (continuous)

Top speed

Among the Class 8 BET makes and models examined, the top speeds (at 0% grade) are usually 65 mph or 70 mph; some makes and models like Freightliner eCascadia also have the options up to 74 mph. In the 2021 Feasibility Assessment, four other studies reported the top speed of drayage trucks serving the SPBP, which is slightly lower than 65 mph (Table 4).

Table 4. Comparison of top speed from other studies

Study	Top Speed (mph)
Roadmap for Moving Forward with Zero-Emission Technologies at the Ports of Long Beach and Los Angeles[44]	50+
Zero/Near-Zero-Emissions Drayage Truck Testing & Demonstration Guidelines[45]	60
Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach[46]	65
2024 Feasibility Assessment (Class 8 BET)	65 or 70

Maximum charging rate and refueling times

Across the commercially available Class 8 BETs, the maximum acceptable charging rate ranges widely from 150 kW to 350 kW (Figure 14). All of these makes and models are compatible with the Combined Charging System only, meaning they are not compatible with the North America Charging Standard (NACS) or CHAdeMO at the time of research and not accepting J1772 (Level 2) charging ports. While refueling time may vary for each make and model based on different levels of charging power, the fastest charging time[47] for a full charge can range from 1.5 hour to 3 hours. For example, the charging time for BYD's 8TT Tandem Axle Tractor is approximately 2 to 2.5 hours if charged at 216 kW.[48] For Volvo

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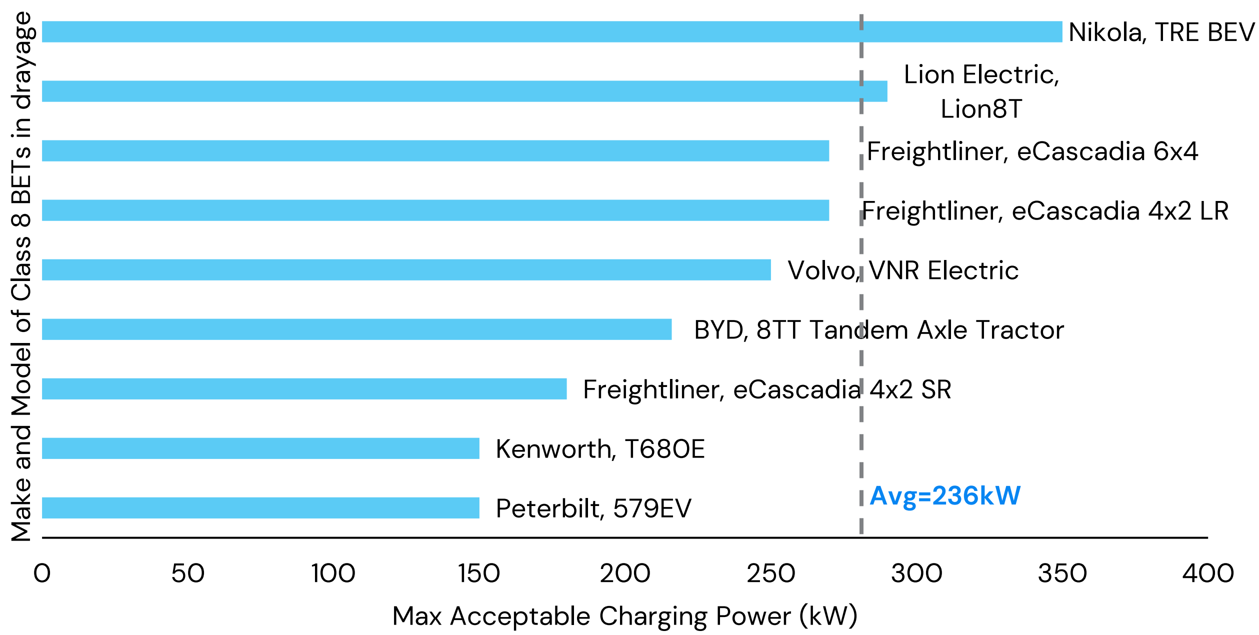
[44] SPBP (2011). "Roadmap for Moving Forward with Zero Emission Technologies at the Ports of Long Beach and Los Angeles", https://kentico.portoflosangeles.org/getmedia/31d5e97c-37f9-4519-953d-dc149968a7dc/zero-emissions-roadmap-technical-report, accessed November 22, 2024.
[45] SPBP (2016). "Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines," San Pedro Bay Ports Zero/Near-Zero Emissions Drayage Truck Testing & Demonstration Guidelines - DocsLib, accessed November 22, 2024.
[46] CALSTART (2013). "Key Performance Parameters for Drayage Trucks Operating at the Ports of Los Angeles and Long Beach," https://calstart.org/wp-content/uploads/2018/10/I-710-Project_Key-Performance-Parameters-for-Drayage-Trucks.pdf, accessed November 22, 2024.
[47] The fastest charging time is calculated as the rated battery pack size (kWh) divided by the maximum acceptable charging power (kW).
[48] Charging time ranges reflect differences in battery size or usable battery capacity.

Group's VNR Electric series, charging time is approximately 1.5 to 2 hours for a full charge if charged at 250 kW, or 1 hour to 1.5 hours if charged at 250 kW for 80% capacity.

Figure 14. Maximum acceptable charging power across different Class 8 battery electric trucks



Manufacturer's suggested retail price

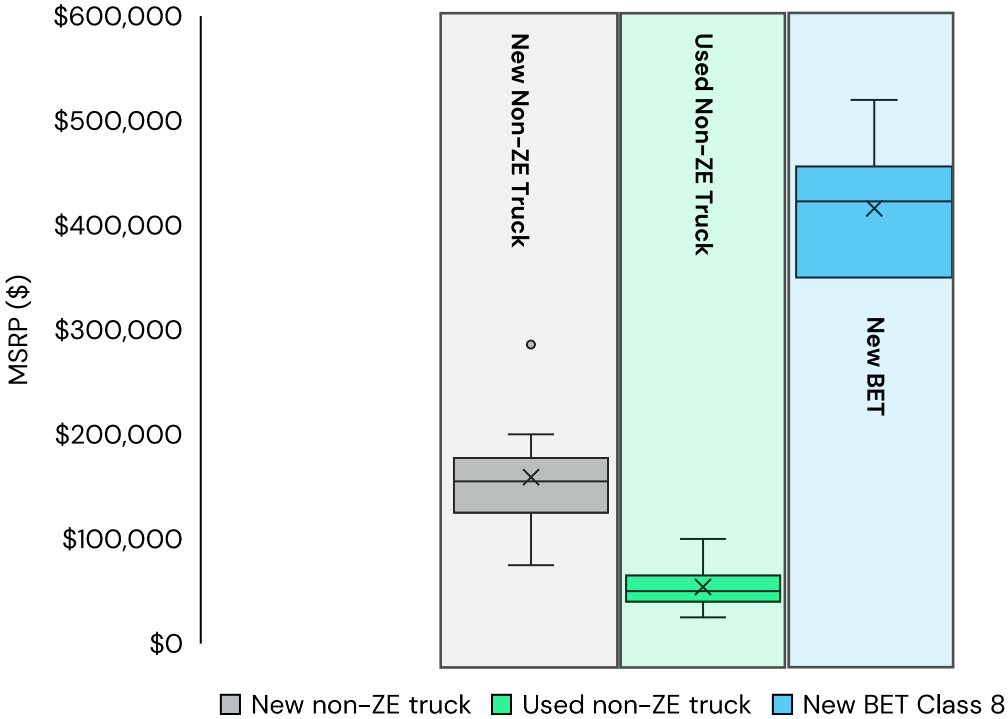
As of September 2024, the manufacturer's suggested retail price (MSRP) for a typical Class 8 BET ranges from $350,000 to $520,000, with the average MSRP being approximately $420,000 per vehicle (Figure 15). Compared to the typical purchase cost of a non-ZE Class 8 truck, the MSRP for a Class 8 BET is about three times that for a new non-ZE Class 8 truck and eight times that for a used non-ZE Class 8 truck. According to the responses received from the operator survey, the purchase cost of a new non-ZE Class 8 truck is mostly within the range of $125,000 to $178,000 per vehicle (Figure 15). The purchase cost for a used non-ZE Class 8 truck is approximately $54,000 per vehicle on average.

Most recently, CARB conducted an analysis[49] examining the pricing differences between ZE trucks in the U.S. and Europe to explore some of the factors contributing to price disparities between the two markets. The study focused on the incremental cost difference between ZE trucks and their diesel counterparts, as well as broader market trends affecting vehicle pricing. The findings suggest that ZE trucks in the EU have a lower incremental price difference than in the U.S. by approximately $94,000, even when accounting for differences

[49] California Air Resources Board (CARB). Zero-Emission Class 8 Tractor Pricing Comparisons. https://ww2.arb.ca.gov/sites/default/files/2024-12/Zero%20Emission%20Class%208%20Tractor%20Pricing%20Comparisons_ADA.pdf, accessed December 12, 2024.

in base diesel truck prices. The analysis highlights several factors influencing these cost differences. Total ZE truck sales volumes were found to be roughly comparable between the U.S. and EU, but European manufacturers have managed to increase battery sizes and vehicle capabilities while keeping prices stable. This trend is partly attributed to increased OEM price competition in Europe, driven by the upcoming Vehicle Energy Consumption Calculation Tool for CO_2 reporting requirements[50] in 2025, which encourage manufacturers to improve efficiency and reduce emissions. Additionally, historical HVIP voucher data from California shows that ZE truck prices have been rising over time, from an average of $332,757 in 2021 to $435,839 in 2024.

Figure 15. MSRP of Class 8 battery electric trucks, new and used non-zero-emission Class 8 trucks



Real-world deployment

While the majority of the operators who participated in the survey have not purchased or used Class 8 BETs in their current operations, several operators who participated in the interview reported purchases of multiple Class 8 BETs for their operations at the Ports. For example, one small fleet with around 20 trucks currently has half of their employee drivers operating Class 8 BETs and plans on electrifying the rest by the end of 2024. In another example, the fleet currently has approximately 80 Class 8 BETs; it expects to transition to

[50] European Commission. (n.d.). Vehicle Energy Consumption Calculation Tool (VECTO). https://climate.ec.europa.eu/eu-action/transport/road-transport-reducing-co2-emissions-vehicles/vehicle-energy-consumption-calculation-tool-vecto_en, accessed March 3, 2025.

100% ZE trucks by the end of 2025 and install over 40 charging stations by 2025, in addition to the 40 existing charging stations.

Fleets currently using Class 8 BETs have mixed feedback on these BETs in their current operations. On the positive side, most truck operators have mentioned the comfort of driving these BETs, including less driver fatigue and noise. Fleets also have mentioned that they do not have to pay too much for maintenance as many OEMs currently offer comprehensive aftersales support and maintenance programs. However, the majority of truck operators and fleets have owned these trucks for no more than 5 years. Thus, the maintenance costs after the first 5 years would require follow-up evaluation.

Most operators have expressed various concerns regarding the deployment of Class 8 BETs. First, despite the availability of incentives, several fleet representatives noted that the purchase price of BETs remains expensive. Some operators also pointed to challenges in accessing the incentives, citing the complexity and time-consuming nature of the application process.

Second, Class 8 BETs today still have relatively limited range options. Operators typically do not use BETs for trips above 200 miles. In contrast, diesel trucks can cover roughly 250 to 300 miles a day; therefore, for trips with longer distances, fleets still opt for diesel trucks in their current operations. Due to BET range limitations, some fleets choose to have some of their BETs stationed at the Ports, solely for taking in and bringing out containers. Some fleets also have fully charged BETs waiting in the yard so that drivers can switch to the fully charged trucks or use opportunity charging during their lunch breaks. Trucks with longer range exist; however, these trucks are typically 10,000 lbs. heavier. For some fleets, a heavier truck may introduce more limitations to their operations. Most of the operators that were interviewed and surveyed do not plan to transition their diesel trucks within the next 5 years until they see additional technology improvements to make trucks lighter and drive further.

Third, charging remains a major challenge, especially for fleets unable to build their own depot charging on-site. Some fleets indicated that they are notified when a truck's battery is below 30%; the fleets will then direct their drivers to a charging facility, either a charging facility owned by them or a third-party charging facility they contract with. In addition to charging availability, charging speed is also an issue. Some battery electric makes and models today can only charge at 150 kW and cannot charge at a higher power to reduce charging time.

Fourth, using BETs incurs various costs in addition to the high upfront costs. Fleets have to pay a higher insurance premium for BETs mainly due to the higher capital cost of BETs. Moreover, fleets have to spend more resources on workforce training and management as well as dedicated workers to manage the scheduling. This is because BET trucks are significantly different from traditional diesel trucks. To incorporate BETs in current operations, fleet managers must plan routes based on vehicle driving range, charging needs and schedules, and cost management. Additionally, given the electricity prices in California, particularly within Southern California Edison's jurisdiction (as further described in the economic viability section), BETs do not offer significant cost savings on fuel compared to diesel trucks. This lack of savings presents an additional economic barrier to BET adoption, especially when combined with the already high upfront costs and other operational expenses associated with electric trucks.

Class 8 Fuel Cell Electric Trucks

Make and models commercially available

Fuel cell technology has emerged as a solution for long-range, faster-fueling applications. Since 2023, fuel cell technology has gained significant momentum as a viable solution for applications requiring longer range, extended operating durations, and faster refueling times. Currently, there are six models of Class 8 hydrogen FCETs available on the market, offered by five different manufacturers. As indicated in Table 5, some models offer more than one configuration; for example, Hyundai XCIENT has two configurations (i.e., 4x2 and 6x2).

Table 5. Class 8 fuel cell electric truck makes and models

Make	Model
Kenworth	T680 6x4
Nikola	Tre® FCEV
Peterbilt	579HFC
Hyundai	XCIENT*
Hyzon	HyHD8-200
Hyzon	HyMax*

* This model offers more than one configuration

Driving range

Class 8 FCETs offer driving ranges between 249 miles and 500 miles, with an average range of approximately 381 miles (Figure 16). This average range is about 170 miles greater than that of Class 8 BETs currently available on the market. The refueling tank size of Class 8 FCETs ranges from 30 kg to 70 kg, with an average capacity of 51 kg[51](Figure 17). Most current FCET models support refueling at a 350-bar filling pressure, while some models, such as the Kenworth T680 are designed for 700-bar refueling. Compared to 700-bar

[51] 1 kg = 0.9 Diesel Gallon Equivalent (DGE). AFDC. Fuel Properties Comparison. https://afdc.energy.gov/fuels/properties?fuels=HY,ELEC&properties=energy_ratio,energy_comparison,energy_content_higher_value. Accessed April 9, 2025

systems, 350-bar infrastructure is less expensive, reduces complexity, increases reliability, and is more energy-efficient. However, 700-bar refueling offers the advantage of significantly higher energy storage density, enabling greater driving ranges and reducing the frequency of refueling. During interviews, some OEMs emphasized the importance of developing refueling infrastructure that supports both 350-bar and 700-bar pressures. Offering dual-pressure options increases the resilience of the hydrogen refueling network and enables refueling for a broader range of hydrogen applications, including medium-duty vehicles.

Figure 16. Class 8 fuel cell electric truck full range (miles)

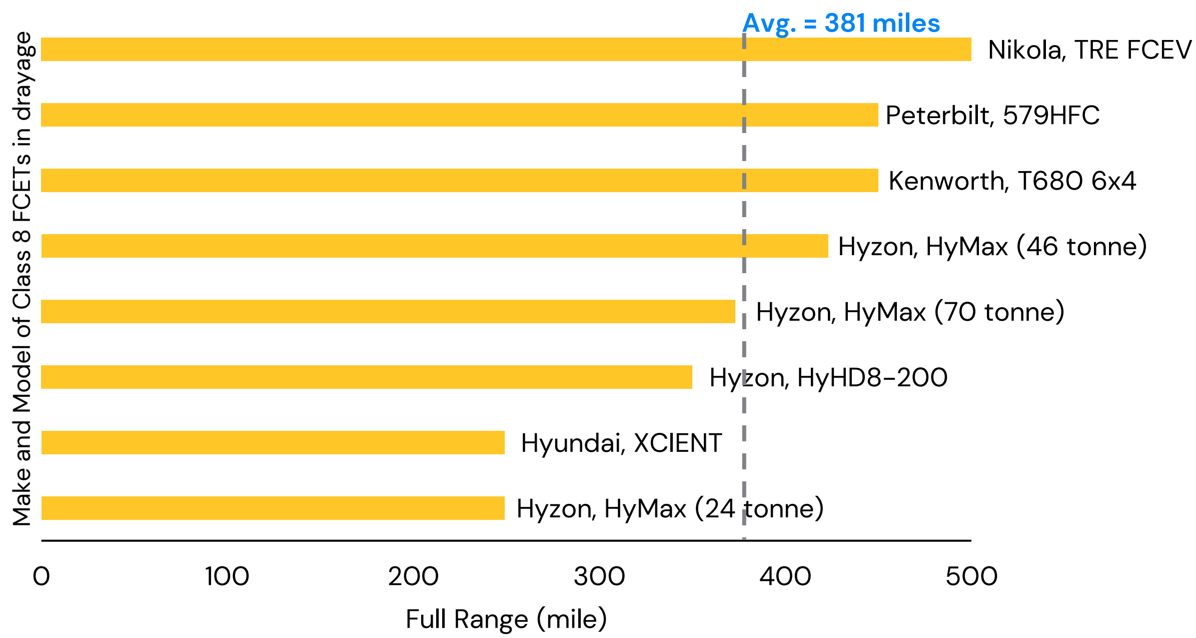
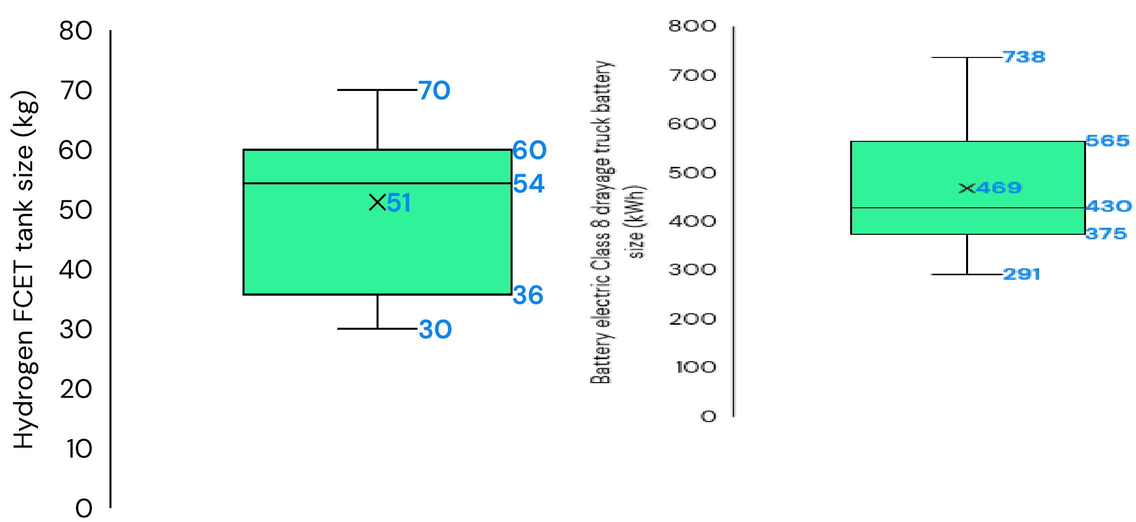


Figure 17. Class 8 fuel cell electric truck tank size (kg)



Curb weight

According to research and interviews with OEMs, the curb weight of Class 8 FCETs can range from 22,000 lbs. to 26,000 lbs., depending on make and model (

Table 6). Compared to a non-ZE Class 8 truck, the 23,500-lb. average curb weight of these FCET makes and models is slightly over 10,000 lbs. heavier. If transitioning to a Class 8 FCET, the payload capacity will likely face a reduction in the range of 9,000 lbs. to 10,000 lbs.

Table 6. Curb weight of different Class 8 fuel cell electric truck makes and models

Make	Model	Curb Weight (lb.)
Kenworth	T680 6x4	22,500
Nikola	Tre® FCEV	26,000
Hyzon	HyHD8-200	22,000

Power

For current Class 8 FCET makes and models, the rated, continuous horsepower can range from approximately 215 hp to 600 hp (Table 7), which is slightly lower compared to that for current Class 8 BET makes and models. To date, the horsepower of the majority of the Class 8 FCET makes and models falls within the range of a typical Class 8 diesel truck, which is 400 hp to 600 hp.

Table 7. Horsepower of different Class 8 hydrogen fuel cell electric truck makes and models

Make	Model	Typical Rated Horsepower (hp)
Kenworth	T680 6x4	415 (continuous)
Nikola	Tre® FCEV	536 (continuous) 733 (instantaneous)
Peterbilt	579 HFC	415
Hyundai	XCIENT	470 (continuous)
Hyzon	HyHD8-200	374 (continuous) 625 (peak)
Hyzon	HyMax	(1) For the 24-tonne configuration: 215 (continuous) and 335 (peak) (2) For the 46-tonne and 70-tonne configuration: 603 (continuous)

Top speed

The top speed for Class 8 hydrogen FCETs can be 65 mph or 70 mph, depending on the make and model. For example, Kenworth's T680 6x4 has a top speed of 70 mph, making it an attractive choice in terms of efficiency and performance.

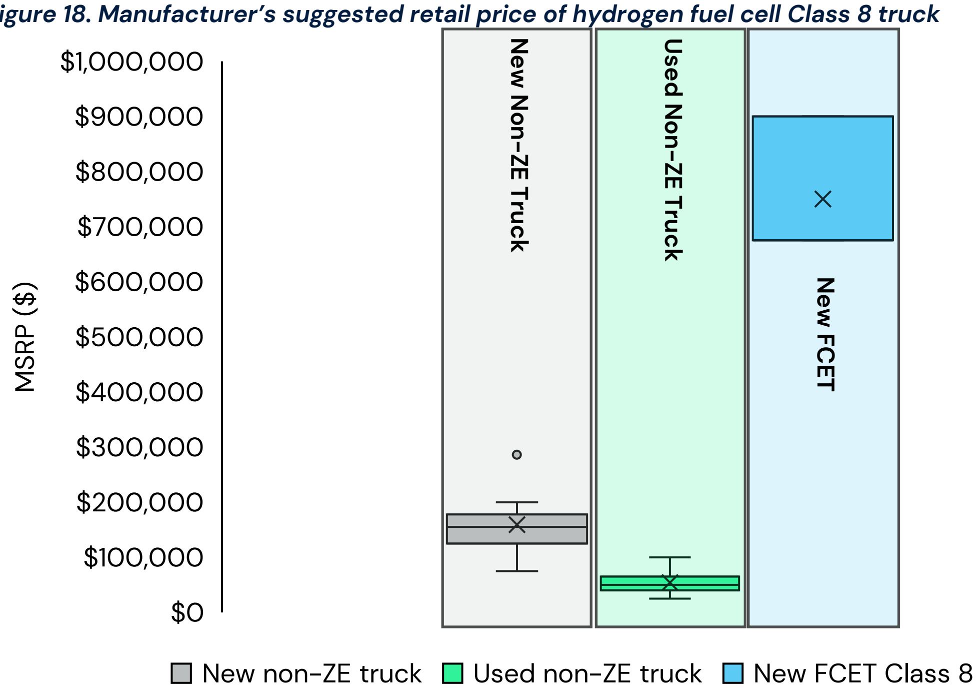
Refueling times

The refueling time for the Class 8 FCET models is typically under 30 minutes, with many customers reporting refueling durations of 12 to 20 minutes, according to some OEMs. This is significantly faster compared to the charging times required for BETs offering a notable advantage in operational efficiency.

Manufacturer's suggested retail price

The MSRP for a typical Class 8 FCET can range from $675,000 to $900,000, with the average MSRP being approximately $750,000 per vehicle (Figure 18). Compared to the typical purchase cost of a non-ZE Class 8 truck (Figure 15**Error! Reference source not found.**), the MSRP for a Class 8 FCET is about 5 times of that for a new non-ZE Class 8 truck and 15 times of that for a used non-ZE Class 8 truck. Moreover, a Class 8 FCET is priced at twice the price of a Class 8 BET on average. Many truck operators and fleets noted during interviews that, given the typical cost of a new or used non-ZE Class 8 truck, transitioning to a Class 8 FCET is currently unrealistic due to the significantly higher purchase price and other cost concerns, underscoring the continued need for incentives.

Figure 18. Manufacturer's suggested retail price of hydrogen fuel cell Class 8 truck



Real-world deployments

Based on interviews with OEMs, to date several Class 8 FCETs have been sold to drayage operators at the Ports to date and these OEMs are looking to sell more FCETs for operations at the Ports. This has been further confirmed by operators and fleets like 4Gen, which recently purchased about 15 fuel cell electric vehicles (FCEVs) for their operations.

Fleets currently using Class 8 FCETs have different feedback. As with BETs, FCETs are reported to have less noise and less vibration, which many operators are quite satisfied with. For FCETs, the battery provides instant acceleration, and the fuel cell helps provide power as the vehicle ramps up. Unlike BETs, FCETs received positive feedback for their shorter refueling time, which is usually within 20 minutes; for some customers, the refueling time can be even lower. In some user cases, FCETs do not have to be refueled on a daily basis, given that some customers only use 20 to 30 kg of hydrogen a day.

Both OEMs and operators described their challenges and concerns regarding the deployment of Class 8 FCETs during the interviews. First were concerns related to payload limitations and FCET weight. Similar to the case of BETs, operators are generally concerned about the truck weight and operators end up tailoring the FCETs to specific types of cargo most of the time to mitigate the weight issue. OEMs confirmed the weight concern they heard from their customers and mentioned that range limitation is a bigger concern than the weight and payload limitations.

On average, Class 8 FCETs have a higher full driving range than Class 8 BETs; however, the 300-mile range is still not sufficient for all customers, according to many OEMs. Some OEMs focus on selling their Class 8 FCETs to customers operating trucks within the range profile of their product. As some OEMs explained, while there is room for potential improvement in the range of FCETs, adding more hydrogen fuel cell tanks results in increases in truck size and weight, making it more difficult to balance truck weight and range.

Second, infrastructure availability and reliability remain a major hurdle for operators currently operating with FCETs. The number of public hydrogen refueling stations currently in existence is limited. Furthermore, as several OEMs noted during the interviews, one station at the Ports has remained non-operational for the entirety of the year without a clear timeline for when it will be fixed. The time required to repair a hydrogen fuel cell refueling station can vary due to several factors, including delays in sourcing specific parts and the availability of qualified technicians. Additionally, these stations have frequently been taken offline as a preventative measure to avoid equipment failure or safety risks during periods of extreme heat or heat waves. Such shutdowns have led to operational disruptions for multiple OEM customers who rely on the stations for refueling.

Third, high hydrogen fuel cost is a major hurdle for both operators and OEMs. To help customers overcome this challenge in the near term, some OEMs have negotiated large bulk quantities with major producers of hydrogen to get a better contract price than the retail price; these contracts are usually 2 to 3 years long. Many OEMs have also subsidized or covered some part of the hydrogen fuel cost[52]. However, all OEMs agree that subsidizing or covering part of the fuel cost of dispensed hydrogen is a short-term strategy to help jumpstart the market and maintain momentum.

Fourth, finding suitable funding and financing strategies for Class 8 FCETs and associated refueling stations has proven to be challenging for fleets and truck operators, especially for smaller fleets that want to embrace the technology but lack appropriate funding and financial support.

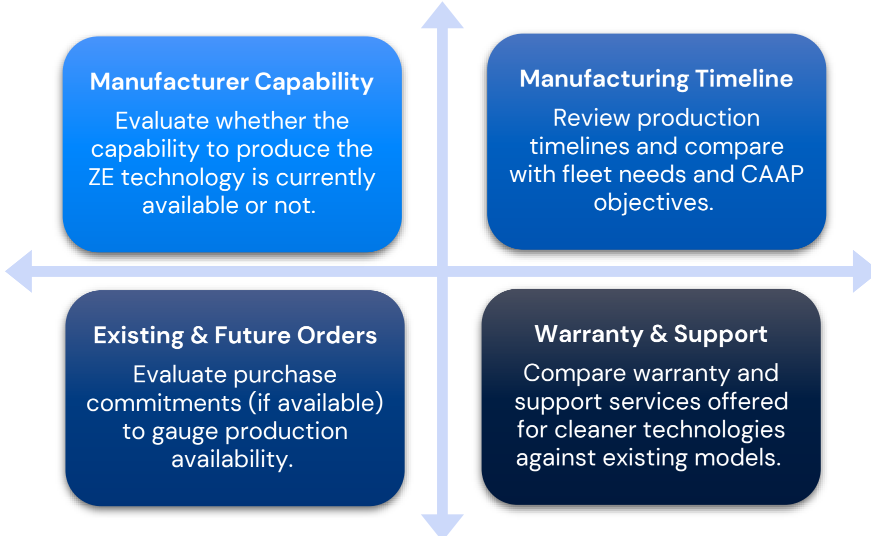
Commercial Viability

In the context of the CAAP feasibility framework, commercial availability refers to the ability of cleaner port equipment and vehicles to be manufactured and delivered in quantities and within timeframes that align with CAAP's objectives. This concept is evaluated based on several key considerations (Figure 19):

- **Manufacturing Capabilities:** Manufacturers must have the necessary manufacturing capabilities to meet the demand for cleaner technologies.
- **Timeline:** Equipment must be manufacturable within timeframes that meet the fleet's specific needs, aligning with CAAP deadlines.
- **Existing and Future Orders:** There needs to be an assessment of how new orders for cleaner technologies can be integrated within the manufacturers' current and anticipated production schedules.
- **Manufacturer Customer Support:** Manufacturers should provide warranty provisions and support services, including long-term maintenance and parts replacement, at a level equivalent to that offered for diesel equipment.

[52]Nikola Highlights its Integrated Hydrogen Solution and Introduces New Hydrogen Energy Brand "HYLA." (January 25, 2023). https://www.nikolamotor.com/nikola-highlights-its-integrated-hydrogen-solution-and-introduces-new-hydrogen-energy-brand-hyla-227

Figure 19. Commercial viability criteria for Class 8 zero-emission trucks



To assess each factor and determine the overall commercial availability metric, the project team utilized a variety of data sources. The team relied on the Global Commercial Vehicle Drive to Zero Tool, which lists current and announced ZE trucks along with key details like availability dates, range, and battery or fuel capacity. Additionally, the U.S. Department of Energy's AFDC Alternative Fuel and Advanced Vehicle Search[53] provided a comprehensive database of alternative fuel vehicle models and specifications, which helped with the identification of current Class 8 truck offerings. Industry reports and announcements were reviewed to gather insights into market trends, technological advancements, and manufacturing capabilities. The team also engaged directly with OEMs and dealerships to obtain firsthand information on production timelines, manufacturing capacity, and market readiness.

Class 8 Battery Electric Trucks

Manufacturing capabilities

As highlighted in earlier market research, seven Class 8 BET models are commercially available currently. Annual production capacities for these trucks vary widely among OEMs, influenced by factors such as market demand, ranging from approximately 200 to 5,000 units per year. Survey responses from OEMs consistently identify high production costs as the primary challenge in manufacturing Class 8 BETs. Additionally, limited consumer demand and existing technological constraints pose further hurdles for OEMs in scaling up production.

Insights from the interviews reveal that OEMs are prepared to scale up production capacity significantly over the coming years. Manufacturers currently operating at three-figure

[53] Accessed September 17, 2024.

production levels are ready to expand to low four-figure capacities, while others aim to reach five-figure production capacities by the end of the decade. However, the pace of this scaling largely depends on market demand, which is heavily influenced by regulatory measures such as state mandates like ACF and ACT. While awaiting increased demand, OEMs have plans to introduce at least 12 new Class 8 BET models over the next 5 years, as indicated by survey responses. These planned offerings are to address growing consumer needs and align with the evolving regulatory landscape.

In addition to market demand, several factors can affect the decision to scale production, including government incentives, investment in technology, and charging infrastructure, especially public charging. In general, OEMs are confident that they have all the components in place and are well-suited for scaling up their production anytime. For some OEMs, the lack of a solid dealer-retail network is a major hurdle in scaling up their manufacturing; some OEMs also are waiting to move to their high-volume facilities in the near future. Table 8 below is a summary of the production volume metrics provided by the OEMs during the interview.

Table 8. Production volume summary for battery electric trucks

OEM	Current Annual Production	Future Production Capacity	Comments
BYD	500	1,000	Production plans, state mandates, or high customer demand can significantly influence readiness.
Nikola[54]	2,400 annually (if run on three shifts per day).	can scale up to a 5-figure range within 5 years.	All necessary elements are in place and well-suited to accommodate any increase in demand.
Daimler	300 to 5000 per year		Scaling capacity largely depends on demand, which is driven by the regulatory landscape, including mandates like ACT and ACF.
Kenworth	200 BEVs	Increase to 1,000 by the decade	Capacity remains limited until transitioning to high-volume facilities, primarily influenced by demand.
Volvo Group			Prepared to scale up as market demand grows but remain concerned about external factors such as supply chain.

[54] At the time of our study, Nikola Corporation was operational. However, on February 19, 2025, Nikola filed for Chapter 11 bankruptcy protection, seeking to sell all or most of its assets due to financial challenges.

Build America, Buy America compliance

Build America, Buy America (BABA) Act compliance[55] is crucial for drayage truck feasibility as it directly impacts the cost and availability of materials and components needed for ZEV production and infrastructure development. Ensuring that trucks and supporting infrastructure meet domestic manufacturing requirements can influence production timelines and project funding eligibility.

Compliance with the BABA requires that all iron, steel, manufactured products, and construction materials used in federally funded projects meet domestic production standards. For iron and steel, all manufacturing processes must occur in the U.S. Manufactured products must be made domestically, with at least 55% of component costs sourced from the U.S. Construction materials must also be fully manufactured in the U.S. Compliance involves including BABA requirements in contracts, obtaining certifications from contractors, and maintaining documentation on material origins and manufacturing. If compliance is not feasible, waivers may be requested with proper justification.

Based on OEM interview results, two makes and models of Class 8 BETs are fully BABA-compliant, namely Freightliner's eCascadia. Many OEMs report that the BABA requirements moderately hinder their abilities to source materials for ZE trucks and impact the cost estimates for producing ZE trucks by more than 10%. Some OEMs argue that, in general, the BABA requirements would extend the production timelines for ZE trucks by more than 6 months and believe the delay would continue until certain components are made in the U.S.

Timelines

According to the OEMs interviewed, the delivery timeline for Class 8 ZE trucks typically ranges from 3 to 6 months, depending on the size of the order and production capacity. However, many OEMs emphasized that a critical concern arises after delivery, i.e., whether customers have the necessary charging infrastructure in place to support the vehicle's operation. Charging infrastructure typically needs to be in place or well underway prior to the truck's delivery to avoid deployment delays.

Existing and future orders

To date, some OEMs have delivered 100 to 500 Class 8 BETs to customers while some have delivered over 500 trucks. Currently, many OEMs can deliver about 25 to 100 BET Class 8 trucks per month. Some OEMs have mentioned that the existing (confirmed) and pending (awaiting finalization) orders of BET Class 8 trucks are about 180 to 1,000 and 50 to 600, respectively. Many of these OEMs also confirmed that among these existing and pending orders for BET Class 8 trucks, some of the orders are from customers at SPBP. This

[55] "Build America Buy America," https://www.commerce.gov/oam/build-america-buy-america, accessed November 21, 2024.

information helps illustrate the growing commercial demand and production readiness of OEMs.

Warranty and manufacturer support

As outlined in Table 9, manufacturers of Class 8 BETs offer a variety of warranty packages. Most OEMs provide maintenance services through their existing dealership networks, supported by individual operators. They also maintain dedicated aftersales teams and mobile technicians to assist dealers and customers with potential customer issues. Battery warranties typically range from 5 to 8 years or 100,000 to 500,000 miles, whichever comes first. Additionally, some OEMs offer flexible warranty options, ranging from 12 months to 6 years, to cater to diverse customer requirements.

In addition to warranty, manufacturers provide various types of aftersales support. First, some OEMs create partnerships in temporary charging solutions while waiting for permanent charging infrastructure to be built out. This temporary charging infrastructure could be deployed anywhere as long as there is enough grid power. Second, some OEMs provide complimentary consultancy to their customers with charging infrastructure, including site assessment, designing, and planning, as well as route optimization and working with local utilities on behalf of their clients. Some OEMs have specialized grant teams to assist customers with navigating and completing grant applications for charging infrastructure funding. Third, some OEMs collaborate with non-profit research organizations and institutes to provide firsthand data, helping support research aimed at forecasting future charging infrastructure needs for cities and municipalities. Additionally, some OEMs have established joint ventures with other corporations to develop public charging infrastructure, which will be essential for building a robust future charging network.

Table 9. Examples of Class 8 battery electric truck warranties

OEMs	Warranty
BYD	8-year battery warranty
Freightliner	Base (vehicle): 3 years / 150k miles; Powertrain (291 kWh pack): 5 years / 150k miles Powertrain (438 kWh pack): 5 years / 300k miles
Kenworth	5 years / 500,000 miles
Lion Electric	Vehicle: 5 years / 250k miles; Battery: 8 years / 500k miles
Nikola	5 years/300k miles
Volvo	12 months to 6 years flexible, comprehensive contract with bumper-to-bumper warranty packages.
Peterbilt	Basic vehicle: 1 year or 100k miles Battery: 5 years or 100k miles Drivetrain: 3 years or 300k miles

Class 8 Fuel Cell Electric Trucks

Manufacturing capabilities

As highlighted in earlier market research, six Class 8 FCET models are currently commercially available. Some OEMs have delivered fewer than 50 Class 8 FCETs to their customers to date, with less than 10 operating at SPBP (Table 10). On a monthly basis, OEMs can deliver 5 to 30 Class 8 FCETs. The current production capacity of OEMs for Class 8 hydrogen FCETs is around 3,000 or more per year, which is far beyond the size of the orders received to date.

Table 10. Production volume summary for fuel cell electric trucks

OEMs	How Much Have You Delivered To Date?	Production Capacity
Hyzon	Fewer than 50, with two in POLB	For 2024, the company reported approximately 120 confirmed orders
Nikola	101-500 (FCET and BET together)	As of 2024, there were 100 pending orders for both BETs and FCETs, primarily intended for South Carolina.
Kenworth	101-500 (FCET and BET together)	Production capacity remains limited due to current operations being confined to smaller facilities; however, plans are in place to transition to high-volume facilities as demand increases.
Peterbilt and Hyundai did not participate in interviews nor provide survey responses.		

The scale of future Class FCET production remains uncertain based on OEM interviews and survey responses. However, OEMs expressed confidence in their ability to scale up production if sufficient demand arises. Some OEMs also indicated plans to expand their hydrogen refueling station networks in response to growing market interest. While waiting for demand to increase further, OEMs have at least three additional Class 8 FCET models planned over the next 5 years. These plans include enhancements such as increased continuous power output and extended range options for existing models.

Build America, Buy America compliance

According to interviews with OEMs, two Class 8 FCET trucks are compliant with the BABA Act: the Nikola Tre® and Hyzon's HyHD8 and HyMax models.

Timelines

Based on OEM survey responses and interviews with OEMs, it can take about 6 to 8 months to deliver a Class 8 FCET from the moment an order is placed. As some OEMs mentioned in the interviews, while the production of ZE trucks including hydrogen fuel cell ones may not take long, it can take longer before their customers get these trucks due to long waiting times for relevant incentive vouchers being processed.

Existing and future orders

As of September 2024, some OEMs report anticipating between 100 and 120 orders for Class 8 FCETs. While additional orders from customers in other industries, potentially involving some level of port-related trips, are also possible, the total number of future orders for these trucks remains unclear. OEMs consistently highlight that future order volumes will largely depend on market demand, the availability and reliability of refueling infrastructure, and hydrogen fuel costs.

Manufacturer support

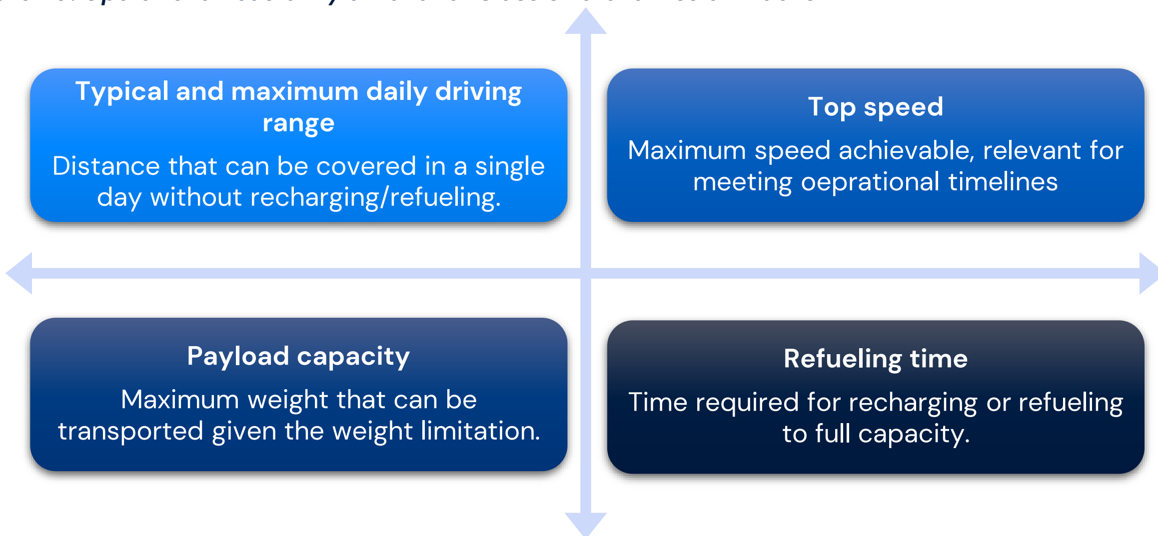
Manufacturers of the current Class 8 hydrogen FCETs typically offer warranties of 5 to 6 years or 200,000 to 300,000 miles, whichever comes first. Beyond standard warranty services, OEMs provide a range of additional support to customers purchasing hydrogen fuel cell trucks, ensuring a more comprehensive ownership experience.

Most OEMs maintain dedicated teams of technicians to support their customers through existing dealer networks. Some OEMs go further by offering consulting services, including full-time assistance to identify tailored refueling solutions that meet individual operational needs. Beyond these consulting and refueling-related services, some OEMs are taking additional steps to support customers, such as establishing temporary mobile refueling sites and subsidizing hydrogen fuel costs to reduce the TCO for hydrogen fuel cell trucks. However, while some OEMs view fuel subsidies as a valuable tool to build initial momentum for adoption, they acknowledge that it is not a sustainable long-term strategy.

Operational Viability

Operational feasibility evaluates whether technology meets or exceeds the performance standards needed to operate for port application. The viability criteria involve analyzing demonstration reports and technology evaluations to examine key factors, such as the vehicle or equipment’s ability to meet minimum performance criteria (Figure 20), its adaptability to the varied duty cycles typical of port operations, and its maintenance requirements, including repair needs and service downtime. Additionally, the assessment considers operator feedback on crucial aspects like drivability, range, refueling, and overall comfort. The viability criteria also include any limitations observed by operators who have used ZE trucks and concerns from operators who are considering transitioning to ZE trucks.

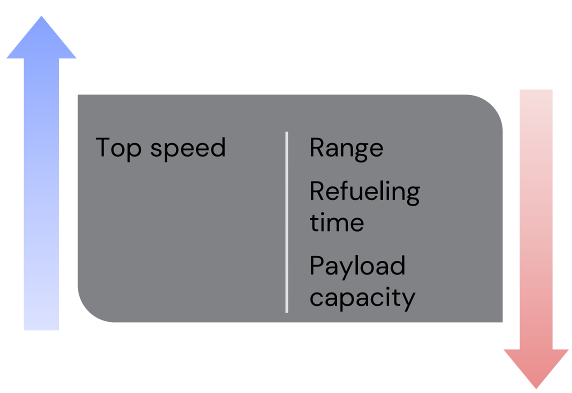
Figure 20. Operational feasibility criteria for Class 8 zero-emission trucks



Class 8 Battery Electric Trucks

Compared with the specifications of commercially available ZE trucks, current Class 8 BETs are suitable for a portion of port operations but come with significant limitations. Their driving range, which spans 150 to 330 miles with an average of 209 miles, may not meet the needs of all operators. While this range could accommodate operators traveling less than 100 miles per shift (as reported by 50% of survey respondents) and those on single-shift schedules (55% of respondents), it presents challenges for the 25% of operators whose trucks travel over 200 miles per shift. Additionally, concerns about the impact of heavier loads on range further complicate the viability of BETs for all port operations.

Charging a BET from 20% to 100%, based on the maximum charging acceptance rates of today's available models, can take at least 1 hour. This extended charging duration, compared to the refueling time for non-ZE trucks, introduces potential operational challenges, particularly for truck operators on tight schedules. This raises concerns about potential delays in reaching destinations, adding operational challenges for some operators.

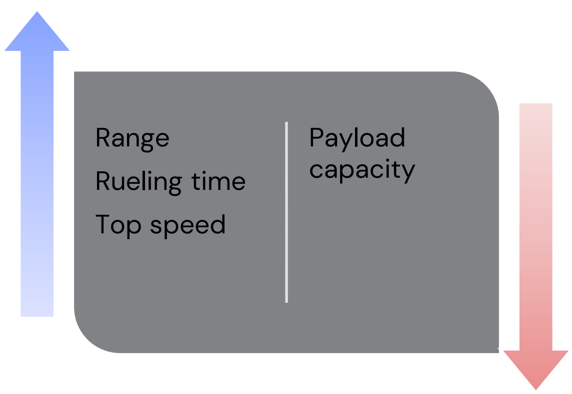


Despite the increased weight of BETs (refer to the Technical Viability subsection in Section 3), BETs remain feasible for many port operations, as 54% of operator survey respondents reported that their trucks typically operate with a loaded weight below 60,000 lbs. However, challenges may arise for the remaining operators, as 33% indicated that their trucks carry loaded weights averaging between 70,000 and 80,000 lbs., where the heavier curb weight could limit cargo capacity and operational flexibility. Given the maximum loaded operating weight for Class 8 trucks previously reported (refer to the Operation section in Section 2), operators transitioning to Class 8 BETs may need to adjust their operations, particularly for occasional or extreme cases where they haul goods at maximum loaded weights.

Additionally, the top speed for current Class 8 BETs (65 mph or 70 mph for some models) is higher than that for non-ZE trucks in drayage services, which is typically around 60 mph when fully loaded.

Class 8 Fuel Cell Electric Trucks

Currently available Class 8 FCETs are well-suited for most port operations. Their driving range, with an average of 381 miles, is generally adequate for the majority of drayage activities, as 80% of current operations involve trips under 250 miles per shift, and 55% of survey respondents reported operating on a single-shift schedule. For the roughly one-third of operators running two-shift schedules, hydrogen fuel cell trucks can also be viable, provided each shift remains within the 250-mile range.



While the maximum miles per shift can be up to 550 miles per shift[56], the relatively shorter refueling time adds a layer of assurance (refer to the Technical Viability section). While there are practical challenges related to refueling availability and cost, Class 8 FCETs are operationally feasible when their refueling time is considered. Additionally, similar to Class 8 BETs, the top speed for hydrogen FCETs is usually around 70 mph, which is higher than some battery electric models and non-ZE trucks in drayage services.

Similar to BETs, Class 8 FCETs are also heavier than non-ZE trucks in drayage services. Current models have a curb weight ranging from 22,000 to 26,000 lbs., with an average of 23,100 lbs., approximately 8,100 lbs. heavier than their non-ZE counterparts. This payload capacity is generally feasible for nearly half of port operators under typical operations. However, transitioning could pose challenges for many operators, as one-third of survey respondents reported a typical loaded operating weight of 70,000 to 80,000 lbs., with an average maximum loaded weight of 65,372 lbs.

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[56] This is an extreme scenario as indicated in the survey responses.

Technology Capability vs. Operational Needs

As described earlier, commercially available Class 8 ZE trucks in the market can meet a portion of the operational needs of drayage operators at the Ports today. While Class 8 ZE trucks show potential, significant barriers remain that must be addressed to make them fully viable for widespread adoption.

A significant barrier to adopting Class 8 BETs is their limited range. Depending on the type of goods hauled, their actual driving range after a full charge may reach up to 220 miles, according to feedback from surveyed operators, interviews, and input from dealership representatives. While this range is sufficient for approximately 75% of current operations at the Ports, it falls short of meeting the requirements for a full transition to Class 8 ZE trucks. This means that operators and fleets must invest time and resources into adjusting operations and routes to ensure Class 8 BETs can be charged as needed without disrupting operational timelines. While some OEMs do not plan to increase the range of their ZE trucks, others acknowledge that there is potential for improvement. However, extending the range would likely require larger batteries, which would add weight to the truck and increase costs, as the battery is the most expensive component in a BET. For now, many OEMs focus on targeting customers whose operational profiles align with the existing range capabilities of their ZE trucks.

An alternative to addressing the limited range of BETs is the development of high-speed charging infrastructure, particularly megawatt (MW) charging. MW charging is designed to deliver significantly higher power levels than current charging technologies, enabling much faster charging times, potentially reducing downtime for operators. Some OEMs are actively working to integrate MW charging capabilities into their future models, viewing it as a critical solution for long-haul and high-demand operations. Others have included MW charging in their long-term plans but are proceeding cautiously to better understand its potential impact on battery health and degradation. While MW charging holds promise for improving the feasibility of ZE trucks, its implementation will require substantial advancements in infrastructure technology and further study of the long-term effects on vehicle and battery performance.

Operators' Perspectives toward Zero-Emission Trucks

Drayage truck operators have mixed expectations about how ZE trucks will impact their operations. On the positive side, both OEMs and operators frequently highlight that operating Class 8 ZE trucks is quieter and more comfortable compared to traditional trucks. BET operators particularly appreciate the improved acceleration, which reduces driver fatigue, while hydrogen fuel cell truck operators value the relatively shorter refueling times.

However, significant concerns remain, even among operators already using Class 8 ZE trucks. Key challenges include unreliable access to charging and refueling infrastructure, fluctuating electricity prices, high hydrogen fuel costs, and the steep purchase and insurance costs associated with ZE trucks. While a few operators acknowledged the potential long-term benefits of ZE trucks such as environmental contributions, they believe these advantages are not achievable in the short term.

Many operators also expressed skepticism about the transition to ZE trucks and anticipated significant operational adjustments to accommodate these vehicles. A frequently mentioned challenge is the need for adequate charging infrastructure. The current charging infrastructure for ZE trucks faces numerous issues, including limited availability, reliability concerns, and high associated costs. Many operators lack access to depot charging and must rely on public charging infrastructure, which remains limited and insufficiently available. Similarly, refueling FCETs poses significant challenges due to the scarcity of public fueling stations and the unreliable operation of existing ones. Some hydrogen refueling stations frequently experience downtime, particularly during high-temperature weather in the summer when they are shut down as a precautionary measure. These shutdowns have caused considerable disruptions for operators and fleets that depend on these stations to maintain their operations.

Additionally, ZE truck operators and fleets would have to spend more resources identifying and adjusting their travel routes, given the range limitations of current ZE trucks. Even so, operators and fleets could still risk not meeting the operational timelines given the possibility of running into charging and refueling infrastructure that is not working. In this process, there are a range of cost-related concerns, such as costs for driver education and operational training and adjustments, and costs for refueling.

Operators who own ZE trucks have also noted a significant increase in insurance costs. While some operators and fleets have successfully applied incentives to offset the capital cost of the trucks, insurance premiums are still calculated based on the original value of the ZE trucks. The MSRP of today's Class 8 BETs ranges from $350,000 to $520,000, with an average of $416,000 per vehicle. For Class 8 FCETs, the MSRP ranges from $675,000 to $900,000, averaging $750,000 per vehicle. These prices are 3 to 6 times higher than the average cost of a new non-ZE Class 8 truck, which is approximately $125,000–$150,000. Since many operators typically purchase used drayage trucks to manage costs, the insurance cost for a new ZE truck presents a significant financial challenge. According to survey responses received from operators who own and dispatch Class 8 ZE trucks to the Ports, the typical monthly insurance cost can range from $1,600 to $5,200 per truck.

Some operators have observed that the assumption of lower maintenance costs for ZE trucks may not always be accurate. While most have not owned ZE trucks for more than 5 years, many report a 30% increase in tire-related maintenance expenses. This increase is partly attributed to the use of low-resistance tires by OEMs to enhance the fuel economy. However, these tires experience greater wear due to the additional strain from the heavier weight of Class 8 ZE trucks—typically at least 8,000 lbs. more than non-ZE counterparts—and the high torque generated by electric motors, which further accelerates tire wear.

Economic Viability

This section examines the economic feasibility of integrating ZE technologies into drayage truck operations compared to conventional diesel trucks. To assess the economic viability of Class 8 ZE trucks, a thorough TCO analysis was performed to provide a deeper understanding of the financial factors involved in transitioning to ZE truck technologies.

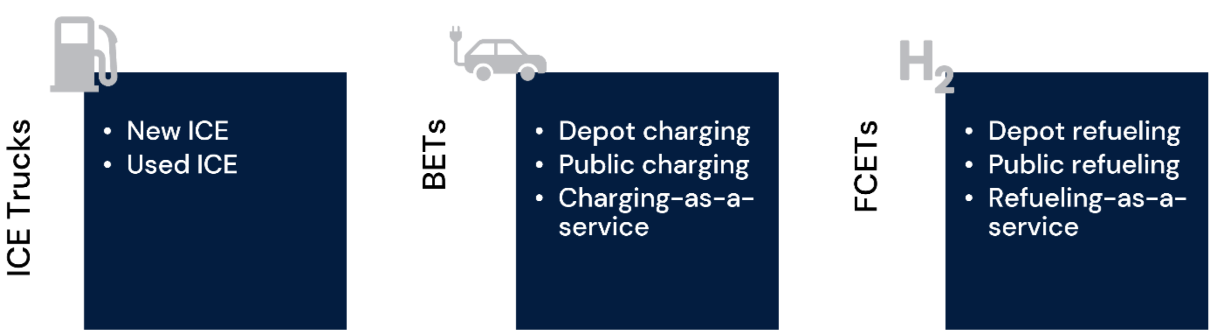
The process begins by defining the TCO model's framework and identifying various scenarios for analysis, establishing the groundwork by specifying parameters and variables. Next, all relevant cost elements, from the initial purchase price of ZE trucks to ongoing maintenance and operational costs, are identified. Key assumptions, such as the analysis period and truck operating conditions, are also established to ensure realistic conditions. Cost data are then collected from fleet operator surveys, interviews, and publicly available resources to create a comprehensive dataset. Finally, the TCO for each scenario is calculated and compared to determine the most cost-effective option, highlighting the financial impact and long-term cost savings of adopting ZE trucks.

Total Cost of Ownership Model Structure

To facilitate an informed comparison, distinct scenarios or alternatives are established based on available technologies and refueling strategies, reflecting the choices fleet operators are likely to face (Figure 21). These scenarios are informed by inputs from fleet operators through surveys and discussions, ensuring they are realistic and applicable to current industry practices.

The analysis starts with baseline scenarios, including TCO analysis for new and used internal combustion engine (ICE) vehicles, which serve as benchmark scenarios for assessing TCO under different ZE alternatives. It then explores various ZEV options, focusing on differences in refueling strategies that directly impact costs. The following paragraphs describe each alternative of the TCO model.

Figure 21. Total cost of ownership model structure



- ***New ICE Vehicles:*** This scenario represents the baseline for conventional diesel fleets, focusing on newly purchased ICE vehicles.
- ***Used ICE Vehicles:*** Used diesel vehicles offer lower upfront purchase costs compared to new models with the same ongoing expenses for fuel and maintenance and new ICEs.
- ***BETs - Depot Charging:*** This scenario assesses the TCO for BETs equipped with dedicated depot charging infrastructure. Fleet operators need to invest in the required infrastructure, including chargers and electrical upgrades. This option is ideal for fleets with access to a depot, and centralized operations that can support depot-based charging, offering the advantage of lower charging costs and assurance for access to charging infrastructure.
- ***BETs - Public Charging:*** For fleets unable to establish private depot charging, public charging stations offer a viable alternative. This option allows fleets to avoid the initial charging infrastructure capital costs but comes with the trade-off of higher per-kilowatt-hour charging costs at public stations. It is particularly suitable for fleets without dedicated facilities or those operating in areas with ample access to public charging networks.
- ***BETs - Charging-as-a-Service:*** Charging-as-a-Service provides an asset-light solution for fleets by allowing third-party providers to manage the charging infrastructure. This subscription-based model eliminates the need for fleet operators to invest in or maintain their own infrastructure. Instead, fleets pay for the service or a lower per-kilowatt-hour charging cost than the public charging scenario, making it an ideal option for those seeking flexibility without the responsibilities of infrastructure ownership.
- ***FCETs - Depot Refueling:*** Hydrogen vehicles can be paired with depot hydrogen refueling stations, where fleets invest in the infrastructure to store and dispense hydrogen fuel. This option requires a significant initial investment but offers the advantage of autonomy, allowing fleets to control their refueling costs and reduce reliance on external providers. Depot refueling is typically suitable for mid- to large size fleets (more than 20 vehicles) operating from centralized locations with the capital to invest in infrastructure.
- ***FCETs - Public Refueling:*** Public hydrogen refueling offers fleets the flexibility of utilizing existing refueling infrastructure, without needing to invest in their own refueling stations. While fleets can avoid high capital expenditures, they must account for potentially higher refueling costs associated with public hydrogen

stations, as well as limited availability in certain regions. This option is best suited for fleets operating near established public hydrogen infrastructure.

- ***FCETs - Refueling-as-a-Service:*** Similar to charging-as-a-service, refueling-as-a-service for FCETs provides fleets with the flexibility of subscribing to third-party providers for using hydrogen infrastructure. This model eliminates the need to invest in refueling infrastructure while providing ongoing access to hydrogen fuel.

Overview of Components and Assumptions

Table 11 provides an overview of the main cost components considered in the TCO analysis which include vehicle capital, vehicle operation and maintenance (O&M), and infrastructure costs. These components were evaluated for each TCO scenario and are discussed in detail in the following subsections.

Table 11. Cost components considered for evaluating the total cost of ownership for zero-emission trucks

Category	Parameter	Description
Vehicle Capital Costs	Purchase Price	Initial acquisition cost of the truck before any additional taxes or rebates.
	State Sales and Federal Excise Tax	Applicable state and federal taxes impacting overall cost.
	Resale Value	Estimated resale value at the end of its service life.
Vehicle Operation and Maintenance (O&M) Costs	Fuel Cost	Cost related to fuel consumption (electricity, and liquid fuels).
	Vehicle Maintenance Cost	Costs covering vehicle maintenance such as routine servicing, repairs, and tire replacement.
	Insurance Cost	Costs covering the premiums paid to insure each truck against risks such as liability, and physical damage.
	Labor Costs for Extended Shifts	Additional expenses incurred from extended driver shifts required for vehicle charging.
Infrastructure Costs	Infrastructure Capital and Installation Cost	Costs associated with purchasing and installing the required charging or refueling equipment (chargers or dispensers) itself.
	Infrastructure Upgrades & Make-ready	Costs covering the necessary site preparation and utility upgrades, such as trenching, transformers, switchgear, panels, or other components to enable the installation and operation of the refueling infrastructure.
	Infrastructure O&M	Ongoing costs for operating and maintaining charging and refueling infrastructure.

Cost comparisons between baseline diesel trucks and alternative ZE technologies are made on a TCO basis using average operating assumptions shown in Table 12. These assumptions, drawn from a) the survey distributed to drayage operators and fleets and b) interviews with truck operators and fleet managers (refer to section "Operator Interviews and Survey"), informed the key parameters used to assess vehicle performance and costs under typical usage patterns.

Table 12. Main vehicle operating assumptions

Main Operating Assumptions	Value	Source
Number of shifts per day	1.5	Operator Interviews and Survey
Shift distance (miles/day)	120	Operator Interviews and Survey
Operational days per week	5	Operator Interviews and Survey
Miles per day	180	Calculated (number of shifts per day × shift distance)
Miles per year	46,800	Calculated (miles per day × operational days per week × 52 weeks/year)

The TCO analysis is conducted using a Net Present Value[57] (NPV) approach, applying a 5% discount rate to reflect the time value of money over the 5-year period. The 5% discount rate used in this analysis is justified as it aligns closely with the Federal Reserve's primary credit rate of 4.50% and secondary credit rate of 5.00% as of December 2024[58]. The TCO analysis period is set based on insights gathered from surveys and interviews with fleet operators. These discussions revealed that, on average, drayage trucks are typically owned and operated for a period of 5 years before being replaced.

Vehicle Capital Costs

Vehicle purchase price

Vehicle prices vary by fuel type (ICE-diesel, electric, and hydrogen) due to differences in technology and manufacturing costs (Table 13). The vehicle prices for new and used ICE trucks are based on survey data from truck operators, with an average value calculated for each category. For ZE trucks, average MSRPs from the technical viability assessment are used as proxies, as specific purchase price data from operators was limited.

Taxes are additional costs added to the purchase of trucks. In California, vehicle purchases are subject to a sales tax, which ranges from 7.25% to 10.75% depending on the region[59]. For this analysis, a 10% sales tax rate was used, reflecting the average in Los Angeles County. In

[57] Net Present Value (NPV) is a financial metric used to evaluate the profitability of an investment or project. It represents the difference between the present value of cash inflows and the present value of cash outflows over a period of time. Essentially, NPV helps determine the current value of a series of future cash flows, discounted at a specific rate, which reflects the time value of money.

[58] Bankrate. (2024). Federal Discount Rate. https://www.bankrate.com/rates/interest-rates/federal-discount-rate/, accessed December 10, 2024.

[59] California Department of Tax and Fee Administration. California City & County Sales & Use Tax Rates (effective January 1, 2025). https://www.cdtfa.ca.gov/taxes-and-fees/rates.aspx. Accessed February 23, 2025.

addition, Class 8 trucks incur a federal excise tax of 12%, which is added to the vehicle's purchase price[60]. Used ICE trucks are not subject to the federal excise tax.

Table 13. Vehicle purchase price before and after taxes

Vehicle Type	Vehicle Purchase Price Before Taxes	Vehicle Purchase Price After Taxes
New ICE Truck	$160,000	$195,200
Used ICE Truck	$54,000	$59,400
BET	$416,102	$507,644
FCET	$750,000	$915,000

For the purposes of this analysis, it is assumed that trucks are financed with a loan term of 5 years, aligning with the TCO analysis period to match typical vehicle ownership durations. An annual interest rate of 12.50% was used, which was adopted based on the findings of the 2021 Feasibility Assessment for Drayage Trucks[61]. In that report, the Ports' Sustainable Supply Chain Advisory Committee considered input from truck manufacturers and financing entities regarding the challenges and needs for financing new natural gas and BETs in drayage. Feedback from nine organizations, reflecting various credit risk profiles, suggested interest rates ranging from 8% to 19%. An average rate of 12.5% was derived as a representative figure for the mid-range credit risk assumption. This rate was retained for consistency across reports, as it provides a relevant benchmark for financing truck purchases.

Resale value

For both diesel and ZE trucks, the resale value is calculated by applying an annual depreciation rate. To calculate the resale value of diesel Class 8 trucks, data from J.D. Power[62] and a commercial truck marketplace[63] were utilized. J.D. Power provided an average monthly depreciation rate of 3.1% for Class 8 trucks in 2020, translating to approximately 37.2% annually. This rate, while above the historic range, offers a useful benchmark for understanding market trends. Additionally, the commercial truck marketplace indicated that depreciation rates for commercial vehicles typically range from 15% to 30% annually, considering factors such as initial price, brand, usage, maintenance, and market conditions. By combining insights from these sources, a conservative annual depreciation rate of 20% was selected to provide a balanced estimate for the truck's resale value. The selected

[60] Internal Revenue Code Section 4051. https://www.govinfo.gov/content/pkg/USCODE-2011-title26/pdf/USCODE-2011-title26-subtitleD-chap31-subchapC-sec4051.pdf. Accessed November 15, 2024.

[61] 2021 Update: Feasibility Assessment for Drayage Trucks (February 2023). San Pedro Bay Ports Clean Air Action Plan, https://cleanairactionplan.org/strategies/trucks/. Accessed September 2, 2024.

[62] J.D. Power. (2020). Commercial Truck Guidelines. https://discover.jdpa.com/hubfs/Files/Industry%20Campaigns/Valuation%20Services/07.2020_Commercial%20Truck%20Guidelines.pdf. Accessed November 19, 2024.

[63] Commercial Vehicle Depreciation. https://www.mylittlesalesman.com/news/commercial-vehicle-depreciation. Accessed November 20, 2024

annual depreciation rate was applied to the truck's initial purchase price, compounding annually, to estimate its value at the end of the analysis period (Table 14).

To estimate the resale value of BETs and FCETs, normalized price data from Mao et al. (2021)[64] were used. The study's normalized price curve represented the truck's residual value over its operational period, with a value of 1 corresponding to the original purchase price. Annual depreciation rates were calculated based on the percentage change in normalized prices between consecutive years. Resale values were then computed iteratively by applying the corresponding depreciation rate to the truck's value at the beginning of each year, with each year's calculated resale value serving as the basis for the next year's depreciation (Table 14).

This methodology applies overall depreciation rates from Mao et al. (2021) uniformly to the truck's total value, as detailed cost data for individual components, such as batteries or fuel cells, is limited. While reasonable given the available data, this approach does not account for the unique depreciation patterns of power units like batteries—which retain only a fraction of their value due to degradation and second-life applications—or fuel cells, which may depreciate based on technology and precious metal recovery.

Table 14. Resale value at end of total cost of ownership analysis period (i.e., after 5 years)

Vehicle Type	Resale Value
New ICE Truck	$63,963
Used ICE Truck	$19,464
BET	$131,988
FCET	$237,900

Vehicle Operation and Maintenance Costs

Fuel costs

Fuel costs are determined by multiplying the total fuel consumption for each vehicle type by the cost of fuel per unit. The total fuel consumption is estimated by multiplying the vehicle's annual mileage by its fuel economy. As noted earlier, the annual mileage for each truck is obtained from the truck operators' survey. The fuel economy for new and used ICE trucks is based on data from the North American Council for Freight Efficiency (NACFE)'s

[64] Mao, S., Basma, H., Ragon, P.-L., Zhou, Y., & Rodríguez, F. (2021). Total cost of ownership for heavy trucks in China: Battery electric, fuel cell, and diesel trucks. International Council on Clean Transportation. https://theicct.org/publication/total-cost-of-ownership-for-heavy-trucks-in-china-battery-electric-fuel-cell-and-diesel-trucks/. Accessed November 23, 2024

2024 fleet fuel study[65], which reported an average fleet-wide fuel economy of 7.77 miles per gallon for Class 8 diesel trucks. The fuel economy for BETs is based on the average value derived from NACFE's reported range of 1.7 to 2.3 kWh per mile[66]. For FCETs, the average fuel economy (around 0.12 kg H_2 per mile) is estimated based on information from the currently available commercial models for Class 8 single-unit and combination trucks[67]. Table 15 summarizes the main parameters related to fuel costs. For cross-fuel comparison, fuel economy is also expressed in Diesel Gallon Equivalent (DGE)[68].

Table 15. Fuel consumption parameters

Vehicle type	Annual Mileage	Fuel Economy	Converted Fuel Economy	Annual Fuel Consumption
New ICE Truck	46,800 miles	0.13 gallons per mile	7.69 mi/DGE	6,023 gallons
Used ICE Truck	46,800 miles	0.13 gallons per mile	7.69 mi/DGE	6,023 gallons
BET	46,800 miles	2 kwh per mile	18.52 mi/DGE	93,600 kwh
FCET	46,800 miles	0.12 kg per mile	9.26 mi/DGE	5,733 kg

Note: Certain calculations may vary slightly, due to rounding.

Next, fuel prices are estimated for each TCO scenario, including depot refueling, public refueling, and refueling-as-a-service. Diesel fuel prices per year were obtained from the California Energy Commission (CEC)'s 2023 transportation energy demand forecast up to 2035[69] with values from $4.04 per gallon in 2024 to $4.14 per gallon in 2035 (in 2023 dollars) (Figure 22).

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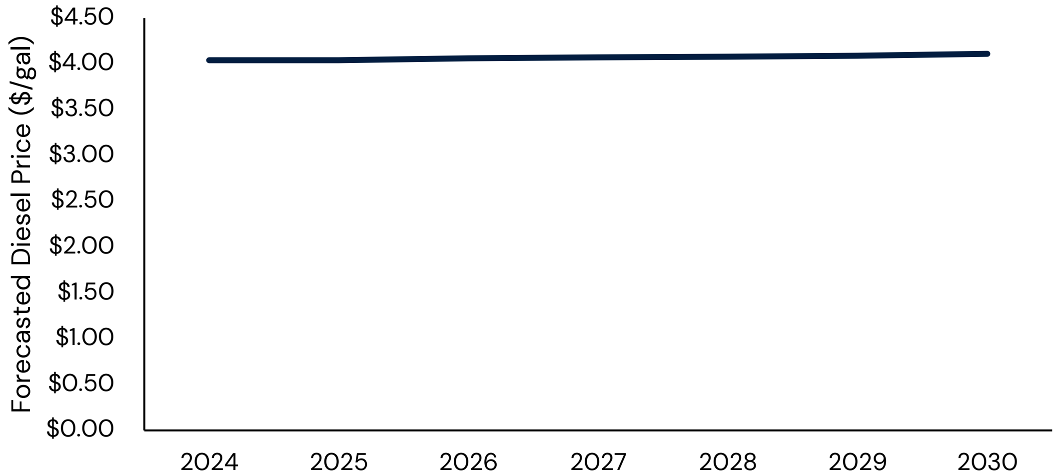
[65] NACFE (2024). 2024 Fleet Fuel Study (December 2024). https://nacfe.org/research/affs/. Accessed December 20, 2024.
[66] NACFE (2024). Electric Truck Depots are Evolving Report (May 2024). https://nacfe.org/research/run-on-less/run-on-less-electric-depot/. Accessed December 11, 2024.
[67] Assess the Infrastructure Needs, Costs, and Timelines for Battery-Recharging and Hydrogen-Refueling to Support Regulatory Requirements for Light-Duty, Medium-Duty, and Heavy-Duty Zero-Emission Vehicles. CRC Report No. SM-CR-9 (September 2023). https://crcao.org/wp-content/uploads/2023/09/CRC_Infrastructure_Assessment_Report_ICF_09282023_Final-Report.pdf. Accessed December 2, 2024. This study includes energy efficiency estimates (Appendix II) using information available through the U.S. DOE and EPA fuel economy data, California's Clean Truck and Bus Voucher Incentive Project (formerly, HVIP), and information provided by the OEM.
[68] AFDC. Fuel Properties Comparison. https://afdc.energy.gov/fuels/properties?fuels=HY,ELEC&properties=energy_ratio,energy_comparison,energy_content_higher_value. Accessed April 9, 2025.
[69] 2023 CEC Planning Library - Transportation Energy Demand Forecast: Fuel Price Forecast (up to 2035). https://www.energy.ca.gov/sites/default/files/2024-04/CA_Planning_Library_2023_IEPR_Fuel_Price_Forecast_ada.xlsx. Accessed December 4, 2024.

Figure 22. Diesel price forecast



For BETs, electricity prices vary by scenario (Figure 23). For depot charging, the average price was determined by using the rate plans from Southern California Edison (SCE) and the LADWP and assuming optimized charging (i.e. charging to avoid peak electricity rates such as overnight). SCE's rate plan (TOU-EV-9, for commercial, large demand customers)[70] was applied for the summer off-peak period (midnight to 4 p.m. and 9 p.m. to midnight), with a rate of $0.2368 per kWh. LADWP's Primary Service A-2(B) Time-of-Use plan[71] was applied for the base period, which runs from 8:00 p.m. to 10:00 a.m. on weekdays and all day on weekends, at a rate of $0.2030 per kWh. The average cost per kWh across both utility rate plans is $0.22. These rates also include demand charges, which are applied to peak demand (kW) and monthly energy usage (kWh). A peak demand of 150 kW and monthly energy usage of 7,800 kWh were assumed. The 150-kW peak reflects a practical assumption based on commonly available depot charger sizes and the vehicle's annual energy needs. The monthly usage is based on the previously discussed annual energy consumption (Table 15).

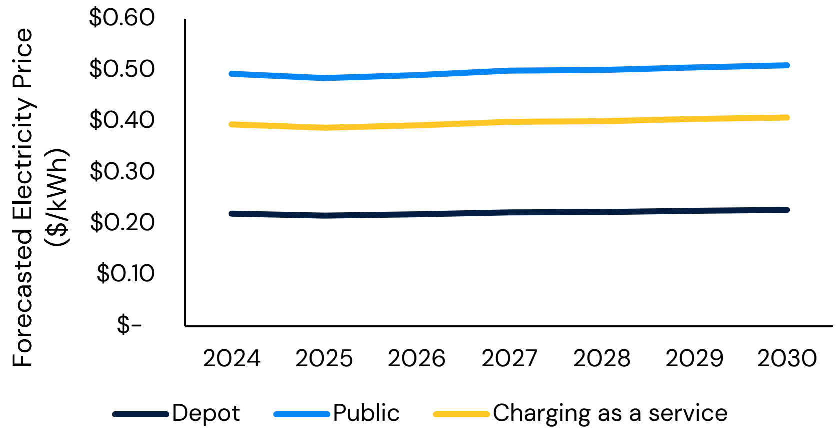
For public charging, discussions with a fleet operator in November 2024 revealed electricity prices ranging from $0.40 to $0.70 per kWh, depending on the location and the time-of-use. Additionally, EV charging pricing data were obtained from the AFDC[72], specifically referring to DC fast chargers within an approximate 200-mile radius of the Ports. The data were averaged, resulting in approximately $0.44 per kWh in 2024. The average value from both sources ($0.49 per kWh) was used in the analysis. To project depot and public

[70] SCE Rates & Pricing Choices. General Service/Industrial Rates. https://www.sce.com/regulatory/tariff-books/rates-pricing-choices?from=/tariffbooks. Accessed December 4, 2024.
[71] LADWP. Electric rate summary. https://www.ladwp.com/sites/default/files/documents/Electric_Rate_Summary_effective_7_1_2019_with_factors_referenced_rev1.pdf. Accessed December 4, 2024.
[72] Alternative Fuels Data Center (AFDC) station locator. https://afdc.energy.gov/stations/widget#/find/nearest. Accessed December 4, 2024.

charging electricity prices, the CEC 2023 Transportation Energy Demand Forecast was used, with annual growth factors for commercial electricity calculated based on this data.

The charging-as-a-service rate was assumed to be less than the public charging rate because subscription-based charging models often offer reduced prices compared to pay-per-use services. This assumption is based on interviews with charging providers. An assumed 20% discount was applied to the public charging rate, resulting in around $0.39 per kwh in 2024. However, it is important to note that this assumption is based on general pricing practices in the absence of specific subscription cost data. Future work may obtain more precise data on charging-as-a-service pricing models and potentially refine this assumption as more information becomes available.

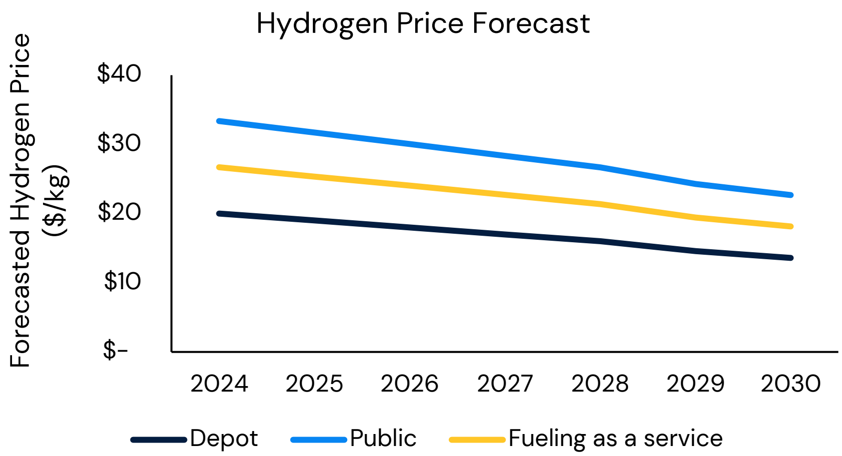
Figure 23. Electricity price forecast



Hydrogen depot refueling prices per year are sourced from the CEC's 2023 transportation energy demand forecast, which provides pricing projections from $20 per kilogram in 2024 to $10.4 per kilogram in 2035 (in 2023 dollars) (Figure 24). These costs typically include the production, transportation, and any associated logistics to ensure the hydrogen reaches the hydrogen station ready for use. The fuel price for hydrogen public refueling is based on the retail hydrogen pump price, as reported in the U.S. Department of Energy's Alternative Fuel Price Report for July 2024[73]. The price is set at $33.37 per kilogram and future projections are based on growth rates obtained from the CEC's 2023 transportation energy demand forecast for hydrogen. The fuel price for hydrogen refueling-as-a-service is assumed to be 20% lower than the retail hydrogen refueling price, based on a similar rationale used for charging-as-a-service.

[73] U.S. Department of Energy. (2024). Alternative Fuel Price Report: July 2024. https://afdc.energy.gov/files/u/publication/alternative_fuel_price_report_july_2024.pdf. Accessed December 5, 2024.

Figure 24. Hydrogen price forecast



Maintenance costs

Maintenance costs refer to the recurring expenses required to keep vehicles operational, safe, and reliable, including routine inspections, replacement of worn components, and diagnostics for vehicle systems failure. As reported in Wang et al. (2022)[74], maintenance and repair costs consist of common components such as tires, multimedia systems, brake fluids, and brake pads, which are shared across vehicle types varying in magnitude. For ICE trucks, additional costs include engine-related components, braking systems, and transmissions, while BETs incur added costs for power electronics and battery systems. FCETs further include maintenance expenses for fuel cell systems and hydrogen storage components.

During interviews with truck operators, it was noted that tire maintenance costs for ZE trucks are expected to increase by approximately 30% due to the added weight of these vehicles, whereas non-tire maintenance costs are generally lower compared to ICE trucks or FCETs, as their drivetrains require less servicing. Additionally, the truck fleet operator survey revealed that annual maintenance costs for used vehicles are higher than for new vehicles, with the average annual cost for used vehicles being approximately 39% greater. For BETs and FCETs, the survey lacked sufficient data points, prompting reliance on alternative sources.

The study by Wang et al. (2022), which provides a detailed maintenance cost breakdown in dollars per mile for ICE trucks, BETs and FCETs, served as the basis for this analysis to ensure consistency across vehicle types. For ZE trucks, the study reported both current and future costs, with future values reflecting learning curve effects. Given the publication

[74] Wang, G., Miller, M., & Fulton, L. (2022). Estimating Maintenance and Repair Costs for Battery Electric and Fuel Cell Heavy Duty Trucks. STEPS+ Sustainable Freight Research Program, Institute of Transportation Studies, University of California, Davis. https://escholarship.org/content/qt36c08395/qt36c08395_noSplash_589098e470b036b3010eae00f3b7b618.pdf. Accessed December 3, 2024.

year of the study, the time elapsed since its release, and the widespread consensus in the literature that ZEVs typically have lower (around 20–25% or more) maintenance costs than diesel trucks[75, 76], future values were deemed more representative for this analysis. The data were also adjusted to incorporate previously stated assumptions, including the 39% increase for used ICE trucks compared to new vehicles and the 30% increase in tire costs for BETs and FCETs. Table 16 presents the adjusted maintenance costs per mile (in 2020 dollars) as well as annual costs[77].

Table 16. Annual maintenance costs

Cost Component	New ICE Truck	Used ICE Truck	BET	FCET
Common components (e.g., tires, brake fluid, brake pad) ($/mile)	0.066	0.092	0.086	0.086
Engine related ($/mile)	0.097	0.097	–	–
Added costs for braking ($/mile)	0.014	0.015	–	–
Added costs for transmission ($/mile)	0.023	0.025	–	–
Power electronics ($/mile)	–	–	0.023	0.023
Battery related cost ($/mile)	–	–	0.052	–
Fuel cell and battery related ($/mile)	–	–	–	0.053
Hydrogen storage ($/mile)	–	–	–	0.007
Total maintenance & repair costs ($/mile)	0.2000	0.2295	0.1608	0.1688
Annual cost ($/year)	**9,360**	**10,740**	**7,525**	**7,900**

Insurance costs

Insurance costs cover a range of protections and liabilities including coverage for physical damage to the vehicle, liability for bodily injury and property damage caused by the truck, and protection against theft or vandalism. Additionally, insurance may cover costs related to accidents, such as medical expenses for injured parties and legal fees. For fleet operators, insurance also often includes coverage for cargo, ensuring that goods transported are protected against loss or damage. Given the higher initial purchase price and specialized components of ZE trucks, insurance premiums may be higher compared to conventional diesel trucks, reflecting the increased value and potential repair costs of these vehicles.

The cost of insurance varies based on individual fleet circumstances. For this study, both comprehensive and collision insurance, as well as liability insurance, are considered. Liability

[75] Electrification Coalition (2013). State of the Plug-in Electric Vehicle Market. https://driveevfleets.org/wp-content/uploads/2018/08/EC_State_of_PEV_Market_Final_1.pdf. Accessed April 18, 2025.
[76] Propfe, B. et.al (2012). Cost analysis of Plug-in Hybrid Electric Vehicles including Maintenance & Repair Costs and Resale Values. http://www.mdpi.com/2032-6653/5/4/886. Accessed November 16, 2024.
[77] The maintenance costs, including both parts and labor, are factored into the per-mile costs.

insurance is calculated as a fixed per-mile cost, set at $0.065 per mile,[78] [79] covering expenses for damage or injuries caused to others in the event of an accident.

Comprehensive and collision insurance typically incurs an annual cost of about 3% of the truck's market value,[40] [80] providing coverage for vehicle damage due to accidents, theft, or other unexpected events. Resale values are used as a proxy for the truck's market value and are shifted at the start of the year to align with updated market conditions. To estimate the insurance cost, it is assumed that insurance is paid at the start of each year. Therefore, the insurance cost for year 1 is based on the resale value at the end of year 0 (i.e., the vehicle purchase price). For subsequent years, the insurance cost is calculated using the resale value at the end of the prior year, ensuring the insurance is always tied to the most recent valuation of the truck.

Labor costs for extended shifts

For BETs or FCETs, drivers may need to stop more frequently to refuel, increasing their number of working hours during the day and thus, labor costs. The average hourly wage for drivers ($29.20 per hour) is obtained from the American Transportation Research Institute (ATRI)'s analysis of operational costs of trucking for 2022.[81] Additionally, it is assumed that depot refueling or charging occurs overnight or during non-operational hours, eliminating the need for extended shifts or additional labor costs in this scenario. For public charging or hydrogen refueling, it is assumed that refueling sessions during operational hours would typically last around 2 hours at a DC fast charger, and 15 minutes at a hydrogen station, based on the technical viability findings.

Given the average BET range is 209 miles (from the technical viability results), and the average miles traveled per day is 180 miles (from the truck operator survey), it is assumed that a BET will need to charge during the day. Since the truck operates for 5 days a week, it is assumed to charge five times per week, assuming each day of operation requires a full charge to cover the daily distance.

For FCETs, given the average daily mileage of 180 miles (from operator interviews and survey) and a fuel economy of 0.123 kg per mile (based on information from the currently

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[78] Basma, H., Buysse, C., Zhou, Y., & Rodríguez, F. (2023). Total cost of ownership of alternative powertrain technologies for Class 8 long-haul trucks in the United States. International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf. Accessed December 2, 2024.

[79] Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M. A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., & Boloor, M. (2021). Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains [ANL/ESD-21/4]. Argonne National Laboratory. https://doi.org/10.2172/1780970. Accessed December 2, 2024.

[80] 2021 Update: Feasibility Assessment for Drayage Trucks (February 2023). San Pedro Bay Ports Clean Air Action Plan, https://cleanairactionplan.org/strategies/trucks/. Accessed September 2, 2024.

[81] Leslie, A., & Murray, D. (2023). An analysis of the operational costs of trucking: 2023 update. American Transportation Research Institute. https://truckingresearch.org/wp-content/uploads/2023/06/ATRI-Operational-Cost-of-Trucking-06-2023.pdf. Accessed December 3, 2024.

available commercial models for Class 8 trucks[82]), the truck consumes approximately 22.14 kg of hydrogen per day. With an average fuel cell tank capacity of 51 kg (from technical viability results), the truck will need to refuel roughly every 2 days. Since the truck operates for 5 days a week, it is assumed that the truck will need to be refueled three times per week.

The labor cost is then calculated by multiplying the charging or refueling time per session during shifts by the frequency of sessions per week and the driver's hourly wage, then multiplying by the number of weeks in a year. The main parameters as well as labor costs (in 2022 dollars) are shown in Table 17.

Table 17. Labor costs for extended shifts

Parameter	BET – Public Charging/Charging As-A-Service	FCET – Public Refueling/Refueling As-A-Service
Refueling time per session (hr) during the shift	2	0.25
Frequency (times per week)	5	3
Average driver's hourly wage ($/hr) (2022)	$29.20	$29.20
Annual labor cost for extended shifts ($/year)	$15,184	$1,139

Infrastructure Costs

Infrastructure costs are considered for fleet operators who opt for depot-based charging or hydrogen refueling solutions. It is assumed that the capital expenditures, including hardware, installation, and infrastructure upgrades, constitute a one-time cost to be paid upfront, while infrastructure O&M costs are incurred on an annual basis.

Electric vehicle infrastructure

For EV infrastructure, it is assumed that each truck will be paired with a 150-kW charger. The analysis considers dual-port chargers, as they offer cost-effectiveness and better space utilization by serving up to two trucks simultaneously. Accordingly, all final depot infrastructure costs per charger were divided by a truck-to-charger ratio of 2:1 to estimate

[82] Assess the Infrastructure Needs, Costs, and Timelines for Battery-Recharging and Hydrogen-Refueling to Support Regulatory Requirements for Light-Duty, Medium-Duty, and Heavy-Duty Zero-Emission Vehicles. CRC Report No. SM-CR-9 (September 2023). https://crcao.org/wp-content/uploads/2023/09/CRC_Infrastructure_Assessment_Report_ICF_09282023_Final-Report.pdf. Accessed December 2, 2024. This study includes energy efficiency estimates (Appendix II) using information available through the U.S. DOE and EPA fuel economy data, California's Clean Truck and Bus Voucher Incentive Project (formerly, HVIP), and information provided by the OEM.

the cost per truck. More specifically, the cost components considered for EV charging infrastructure are described below[83] [84]:

Hardware and installation costs include the procurement and installation of Electric Vehicle Supply Equipment (EVSE) (i.e., "EV chargers"), as well as direct costs such as labor, materials, permits, and taxes. Hardware and installation expenses tend to fluctuate based on the charger types and the maximum power level they can deliver to a vehicle. Moreover, site conditions, accessibility, and existing infrastructure can affect installation complexity and associated costs, while permitting requirements and taxes vary across jurisdictions. It is important to note that the definition of hardware and installation costs is focused on the equipment and its direct installation and does not account for additional infrastructure enhancements, such as facility level electrical infrastructure or the grid distribution upgrades, which utilities might undertake. The EVSE equipment and installation cost assumptions are average cost data found through both market research and recent literature, including studies of the International Council of Clean Transportation (ICCT, 2019)[85], the Rocky Mountain Institute (RMI, 2020)[86], Borlaug et al. (2020)[87], EDF & GNA (2021)[88] for procurement and installation of charging infrastructure. More specifically, the Electric Power Institute (EPRI, 2013)[89] study suggests that hardware and installation costs of dual-port chargers could be only 10% higher than single-port chargers of the same power capacity (i.e., a dual-port charger with total capacity of 150 kW is 10% more expensive than single-port 150 kW charger). Based on this information, the hardware cost of a 150-kW dual-port charger is around $103,582 and the installation cost is around $52,353.

Operation and maintenance (O&M) cost represents ongoing operational and upkeep expenses for the EV charging infrastructure. These costs may include communication services, warranties, and routine maintenance. Annual warranty/maintenance costs are typically provided as a percentage of equipment (hardware) cost. Based on information obtained from industry maintenance plans and packages, O&M cost is around 4.25% of the charger hardware cost. Additionally, annual communication service costs are estimated at

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[83] The costs reported for each component are before dividing by the truck-to-charger ratio

[84] It is important to note that certain facilities, such as WattEV's in Bakersfield, may incorporate microgrids and/or battery storage systems as part of their infrastructure. These systems are not included in this TCO analysis, as the analysis assumes baseline/average conditions with typical infrastructure. The inclusion of such components may vary across different fleet operators' sites.

[85] ICCT (2019). Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas. https://theicct.org/sites/default/files/publications/ICCT_EV_Charging_Cost_20190813.pdf. Accessed December 4, 2024.

[86] RMI (2020). Reducing EV Charging Infrastructure Costs. https://rmi.org/insight/reducing-ev-charging-infrastructure-costs/. Accessed December 4, 2024.

[87]Borlaug et al. (2020). Levelized Cost of Charging Electric Vehicles in the United States. https://doi.org/10.1016/j.joule.2020.05.013. Accessed December 4, 2024.

[88] EDF & GNA (2021). California Heavy-Duty Fleet Electrification Summary Report. https://blogs.edf.org/energyexchange/wp-content/blogs.dir/38/files/2021/03/EDF-GNA-Final-March-2021.pdf. Accessed December 5, 2024.

[89] EPRI (2013). Electric Vehicle Supply Equipment Installed Cost Analysis. https://www.epri.com/research/products/000000003002000057. Accessed December 4, 2024.

approximately $405 per charger, calculated as the average of the values reported in the Argonne National Laboratory's AFLEET Tool (2023)[90] and the Great Plains Institute (2019)[91].

Make-ready costs are incurred to prepare the site for EV charging infrastructure installation, accounting for the additional electrical load from EV charging stations. These costs involve upgrading or installing new electrical infrastructure, along with associated materials and labor. Specifically, make-ready costs cover expenses related to grid distribution upgrades, such as transformer upgrades, as well as facility electrical infrastructure upgrades including panels, meters, laying conduit and cable, and trenching. The installation costs for transformers, conduits, and cables, as well as panels, were assumed to be 20% of their material costs[92]. Please note that the electrical infrastructure upgrades discussed in this document are associated with the installation of one charger. This is not always the case, as many fleets will require multiple chargers depending on the number of ZE trucks they own. In such cases, higher capacity panels and transformers should be used, and the cost of these upgrades on a per-truck basis will generally be lower due to economies of scale. Therefore, the costs presented in this document should be considered as conservative estimates (on the higher side). Considerations for each component of make-ready costs, as well as information on their associated material costs, include the following:

- ***Transformers*** adjust voltage levels to meet the specific requirements of charging equipment by stepping up or stepping-down voltage as needed to ensure compatibility with the electrical system and facilitate the effective delivery of power to charging stations. Assuming a 1:1 ratio of kW to KVA, a 150 kVA transformer may be needed for one 150-kW charger. The material cost of the transformer is around $29,600 and was obtained using high-level market research on the available transformers for sales in the market.
- ***Electric Panel*** serves as the central hub for distributing electrical power from the main supply to various charging stations. It ensures the safe and efficient allocation of electricity to charging equipment, managing the flow of power and preventing overload to support the charging needs of EVs. Panel costs are based on market standards and similar projects. Panels for EV charging infrastructure are sized to handle the estimated electrical load with an 80% derating, ensuring safe, continuous operation. For a 150-kW charger, a 182 A/480V panel is required, calculated using

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[90] AFLEET TOOL 2023. https://greet.anl.gov/afleet. Accessed November 3, 2024

[91] Great Plains Institute (2019). Analytical White Paper: Overcoming Barriers to Expanding Fast Charging Infrastructure in the Midcontinent Region. July 2019. https://betterenergy.org/wp-content/uploads/2019/08/GPI_DCFC-Analysis.pdf. Accessed November 3, 2024.

[92] This assumption is based on discussions with electrical contractors.

standard electrical formulas based on the charging load, voltage, and power factor[93]. The estimated material cost of the panel is $4,700.

- ***Trenching, Cable, and Conduit*** involves preparing subterranean paths for cables to EV charging sites as well as conducting and shielding electrical connections to EV charging units. The trenching process ensures that cables are safely routed underground, minimizing exposure to external elements and potential hazards. Furthermore, proper installation of cables and conduits ensures the safety and efficiency of electrical wiring, protecting it from environmental factors and minimizing the risk of damage or malfunction. The analysis uses trenching, conduit, and cable costs based on a typical installation scenario for sites with ≤20 chargers. For these locations, conduit and cable footage is assumed to be 125 feet per charger, with a footage factor of 0.5 applied to calculate trenching footage, resulting in 62.5 feet per charger. The cost is around $50 per foot for trenching and $10 per foot for conduit and cables based on communications with contractor bids from various cities in California.
- ***Electric Meters*** gauge electricity usage by EV charging stations for accurate billing and monitoring purposes. Installing electric meters allows for precise measurement and tracking of energy consumption, enabling effective management of costs and resources associated with EV charging infrastructure. The analysis assumed a cost of $2,500 per meter based on high-level market research.
- ***Permitting Costs for Make-Ready Infrastructure*** are typically challenging to estimate due to limited publicly available data, as most sources focus on the costs for permits related to the installation of the actual charging units, including site-specific permits and approvals. Based on the rough estimates reported in the Rocky Mountain Institute (RMI, 2020)[94], permitting costs are assumed to be approximately 2% of the base facility's electrical infrastructure cost. It is important to note that this assumption may not fully capture site-specific variations or unique permitting requirements, which could lead to higher or lower costs depending on local

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[93] Panel size is expressed in amperes (A) and voltage (V), indicating the electrical current and voltage the panel can safely handle. For example, a 182 A/480 V panel can accommodate up to 182 amps (A) of current at a voltage of 480 volts (V). The estimated 3P amperage required to supply that load is calculated based on the following standard formula:

$$I = \frac{kw \times 1000}{V \times PF \times \sqrt{3}}$$

Where I is the estimated 3P amps, *PF* is the power factor (dimensionless) assumed to be 99%, *kW* is the required EV charging load in kilowatts (kW) and *V* is the voltage required to supply the load in volts. The voltage requirements for supplying the load are determined based on the suggestions for the installation of Level 2 chargers, DC Fast Chargers at a candidate location. In cases where only DC fast chargers are proposed, a voltage of 480 V is required.

[94] RMI (2020). Reducing EV Charging Infrastructure Costs. https://rmi.org/insight/reducing-ev-charging-infrastructure-costs/. Accessed December 4, 2024.

regulations, utility processes, number of chargers at location and other project complexities.

Hydrogen infrastructure

Detailed cost information for hydrogen infrastructure is challenging to obtain due to the limited availability of data and the variability in pricing across different projects and providers. For high-level cost estimation, focus was placed on two key components for which data were available:

Capital Expense: The capital cost for hydrogen refueling stations was derived from the Hydrogen Station Network Self-Sufficiency Analysis under Assembly Bill 8[95]. This analysis provides a function to estimate installation costs based on the daily fueling capacity of a hydrogen station. For stations with a capacity exceeding 600 kg/day, the installed capital cost is estimated at approximately $5,000 per kilogram of daily fueling capacity. This cost includes the full construction cost, including any necessary power upgrades for station operation. For this analysis, several parameters are considered to determine the required fueling capacity. As previously mentioned, each truck drives an average of 180 miles per day, with a fuel economy of approximately 8.16 miles per kilogram of hydrogen. As a result, each truck needs about 22 kg of hydrogen per day to operate effectively. For an average fleet size of 40 trucks, this leads to a total daily hydrogen requirement of 882 kg for the entire fleet with a total cost of around $4.4 million. This cost is then divided by the average fleet size assumed (40 trucks) to estimate the equipment cost per truck ($110,250).

Operation and Maintenance Cost: This analysis focused on fixed operations and maintenance costs, including internet services ($2,300), fixed electricity costs ($2,100), permits ($3,700), hydrogen quality tests ($5,400), and insurance ($7,200). Additionally, property tax is estimated at 1% of the station's assessed capital expense, while fixed labor costs are 3% of the capital expense per year. Periodic major maintenance, equal to 10% of the station capital expenditure, is incurred once every 5 years. These cost estimates are sourced from the Hydrogen Station Network Self-Sufficiency Analysis conducted under Assembly Bill 8 and were also divided by the average fleet size assumed (where applicable) to estimate the cost per truck. Fixed operations and maintenance costs amount to $4,928 per year. In years when periodic major maintenance occurs (every 5 years), the total costs increase to $15,953.

Table 18 summarizes the infrastructure costs associated with depot refueling for BETs and FCETs.

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[95]CARB (2021). Hydrogen Station Network Self-Sufficiency Analysis per Assembly Bill 8. https://ww2.arb.ca.gov/sites/default/files/2021-10/hydrogen_self_sufficiency_report.pdf. Accessed December 5, 2024.

Table 18. Summary of infrastructure costs per truck

Cost Category	BET-Depot Charging	FCET-Depot Refueling
Infrastructure capital cost (one time)	$77,967	$110,250
Infrastructure upgrades/make-ready cost (one time)	$24,232	-
Infrastructure O&M cost (Annual)	$2,377	$4,928 (standard years); $15,953 (every 5 years)

Total Cost of Ownership Results

Figure 25 summarizes the results of the cost of ownership analysis and Table 19 presents a detailed breakdown of the individual cost components, offering a closer look at how each element contributes to the total TCO. Costs were adjusted to 2024 dollars on a Net Present Value (NPV) basis using a 5% discount rate.

Figure 25. Total 5-year costs of ownership without accounting for zero-emission vehicle incentives (Net Present Value at 5% discount rate)

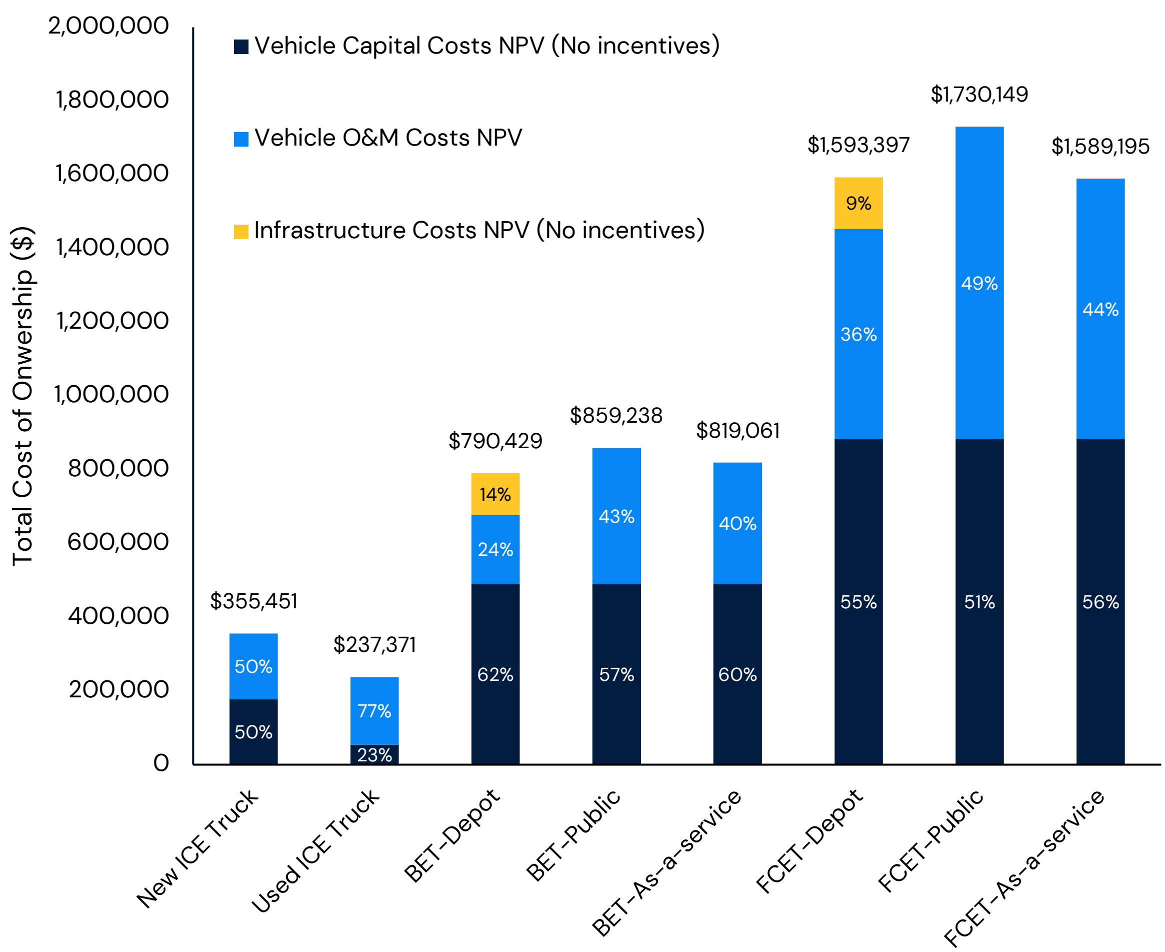

Table 19. Breakdown of 5-year costs of ownership without accounting for zero-emission vehicle incentives (Net Present Value at 5% discount rate)

Cost Category	New ICE Truck	Used ICE Truck	BET-Depot	BET-Public	BET-As-A-Service	FCET-Depot	FCET-Public	FCET-As-a-service
Vehicle capital costs								
Vehicle purchase price including taxes	$228,160	$69,430	$593,361	$593,361	$593,361	$1,069,499	$1,069,499	$1,069,499
Resale value	$50,117	$15,251	$103,416	$103,416	$103,416	$186,401	$186,401	$186,401
Vehicle Capital Costs NPV (without incentives)	*$178,043*	*$54,179*	*$489,945*	*$489,945*	*$489,945*	*$883,098*	*$883,098*	*$883,098*
Vehicle O&M costs								
Energy/fuel costs	$108,642	$108,642	$89,585	$200,884	$160,707	$432,716	$704,771	$563,817
Vehicle maintenance costs	$48,875	$56,082	$39,295	$39,295	$39,295	$41,250	$41,250	$41,250
Insurance costs	$19,891	$18,468	$58,997	$58,997	$58,997	$95,770	$95,770	$95,770
Extra labor costs	$0	$0	$0	$70,117	$70,117	$0	$5,259	$5,259
Vehicle O&M Costs NPV	*$177,408*	*$183,192*	*$187,877*	*$369,293*	*$329,116*	*$569,737*	*$847,051*	*$706,096*
Infrastructure costs per truck								
Infrastructure capital & installation cost	$0	$0	$77,967	$0	$0	$110,250	$0	$0
Infrastructure operation and maintenance cost	$0	$0	$10,407	$0	$0	$30,312	$0	$0
Infrastructure upgrades	$0	$0	$24,232	$0	$0	$0	$0	$0
Infrastructure Costs NPV (without incentives)	*$0*	*$0*	*$112,607*	*$0*	*$0*	*$140,562*	*$0*	*$0*
Total								
Total (without incentives)	***$355,451***	***$237,371***	***$790,429***	***$859,238***	***$819,061***	***$1,593,397***	***$1,730,149***	***$1,589,195***

In terms of overall TCO, used ICE vehicles have the lowest TCO at $237,371. The cost of new ICE trucks is slightly higher at $355,451 but is still significantly lower compared to both BETs and FCETs. Electric alternatives result in a 2 to 2.4 times higher TCO compared to new ICE vehicles. The hydrogen alternatives show even higher TCOs, with figures reaching as high as $1,730,149, approximately 4.5 to 5 times the cost of a new diesel vehicle and 2 times the cost of electric alternatives.

When comparing vehicle capital costs, the ICE truck (especially the used ICE) has the lowest upfront capital expenditure, driven primarily by the lower initial purchase price and relatively higher resale value. BETs and FCETs are much more expensive due to technology premiums for low-emission systems (e.g., EV batteries and fuel cells), which require substantial investment before factoring in any incentives or fuel savings. As a result, without incentives or scaling in production, ZEV technologies remain 2.8 to 5 times the capital cost of conventional new ICE vehicles.

In terms of vehicle O&M costs, costs for the used ICE trucks are slightly higher (about 3.3% more) than for the new ICE trucks due to higher maintenance costs commonly associated with older vehicles. For new depot BETs, fuel costs are notably lower than for new ICE trucks. Specifically, depot BETs have fuel costs of $89,585, which is 18% lower than the $108,642 for new ICE trucks. However, they face significantly higher insurance costs, amounting to $58,997, which is more than two times higher than the $19,891 for new ICE trucks over 5 years. For BETs using public charging or charging-as-a-service models, fuel costs increase significantly compared to both depot BETs and ICE trucks due to electricity prices. For BETs with public charging, the fuel costs rise to $200,884, which is more than 80% higher than the fuel costs of new ICE trucks. An average diesel truck's fuel cost is roughly $0.54 per mile (assuming $4.2 per gallon fuel cost and 7.77 mpg fuel economy), whereas for a Class 8 BET charging at a public charger, the cost per mile is approximately $1 (assuming $0.5 per kWh and 2 kWh per mile energy consumption rate).

Similarly, BETs face extra labor costs due to extended shifts for charging, making these models even more expensive in terms of total O&M costs when compared to both new ICE trucks and depot BETs. Nevertheless, BETs across all refueling strategies have maintenance costs that are around 20% lower than ICE trucks, with BETs incurring $39,295 compared to $48,875 for new ICE trucks.

For FCETs, maintenance costs tend to be lower than those for new ICE trucks but are higher than the maintenance costs for BETs. Specifically, the maintenance costs for depot FCETs are $41,250, which is about 16% higher than the $39,295 for depot BETs, but about 16% lower than the $48,875 for new ICE trucks. Furthermore, FCETs incur substantially higher fuel costs, especially in public refueling scenarios. For instance, FCETs with public refueling have fuel costs of $704,771, which is more than six times the cost of refueling new ICE trucks and more than three times the cost of public charging for BETs.

Infrastructure costs also play a significant role in the overall TCO. Electric depot charging infrastructure totals $112,607 per truck, while hydrogen depot refueling infrastructure is significantly higher at $140,562, making hydrogen infrastructure roughly 25% more expensive. This difference is largely due to the relative maturity of electric vehicle infrastructure compared to hydrogen refueling stations. While BET charging infrastructure is still evolving, it benefits from more widespread development and economies of scale. In contrast, hydrogen refueling stations are less mature and involve more complex and costly equipment, such as high-pressure storage systems and enhanced safety protocols, which drive up the costs.

This analysis demonstrates that incentives play a crucial role in achieving cost parity between ZE and ICE trucks. Without financial support, BETs have a TCO that is 2 to 2.5 times higher than ICE trucks, while FCETs are even more expensive at 4.5 to 5 times the TCO of ICE trucks. These significant cost differentials make ZE trucks economically unfeasible for widespread adoption in the absence of incentives. The layered approach of combining local, utility, state, and federal incentives is therefore essential to bridge this cost gap and accelerate the transition to ZE trucking. These multi-level incentive programs work together to reduce the upfront purchase price, lower operating costs, and ultimately make ZE trucks a financially viable option for fleet operators.

Incentives

Incentives have historically been critical in driving the adoption of cleaner drayage trucks by alleviating the high upfront costs of vehicle replacement. However, the long-term availability, consistency, and scale of these incentives remain uncertain. Additionally, while funding may be currently accessible for vehicle procurement, the industry faces delays in developing the necessary refueling and charging infrastructure to fully support these vehicles. This misalignment restricts the near-term utilization of available incentives. This TCO analysis evaluates both scenarios—with and without incentives. While the scenario without incentives provided a baseline view of costs, the "with incentives" analysis illustrates a generalized assessment of how current funding programs might reduce capital expenses. Table 20 summarizes the main incentives considered in this analysis. The selection of incentives is based on their relevance and applicability to Class 8 drayage fleets, focusing on programs that offer clear eligibility criteria, a tangible means of quantification, and that are available as of the writing of this report. Table 21 outlines the incentive amounts used in this analysis, followed by a discussion on estimating revenue from LCFS credits.

Table 20. Vehicle and infrastructure incentives or programs considered for evaluating the total cost of ownership for zero-emission trucks

Incentive Type	Incentive Name	Description	Funding Amount
Regulatory, Market-Based	Low-Carbon Fuel Standard (LCFS) Credits[96]	The LCFS incentivizes low-carbon fuels through tradable credits. In electric depot charging, LCFS credits count toward O&M costs, but for hydrogen, they go to producers, not vehicle owners, and are excluded from FCET TCO.	Number of credits earned x Credit price Credit price varies
State, Point-of-Sale (POS) Rebate	Clean Truck and Bus Voucher Incentive Project[97]	Provides POS vouchers to reduce the upfront cost of purchasing ZE trucks. HVIP is considered as part of the vehicle capital cost category.	$120,000 for BETs and $240,000 for FCETs
Federal, Tax Credit	Commercial Clean Vehicle Credit[98]	The federal government established the IRA, providing tax credit for the purchase of qualified commercial clean vehicles.	$40,000 for BETs and FCETs
Utility, Infrastructure Rebate	SCE Charge Ready Transport (CRT)-Customer-Built[99]	Incentive offered by Southern California Edison (SCE), reducing make-ready infrastructure costs. SCE CRT (Customer-Built option) is considered as part of the infrastructure cost category.	80% of BET charging infrastructure cost (Customer-built), covering the distribution to meter upgrades
State, Infrastructure Grant	EnergIIZE Commercial Vehicles - EV fast track & Hydrogen[100]	Provides reimbursement style grants to infrastructure projects in California that deploy ZEV charging/refueling in support of commercial fleets. EnergIIZE is considered as part of the infrastructure cost category.	BET charging: 50% of infrastructure costs with $500K cap. It is assumed that this incentive will be used to cover the facility-side make-ready infrastructure as well as charger hardware and installation costs. FCET refueling: 50% of infrastructure costs with $3M cap

[96]Low Carbon Fuel Standard (LCFS). https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard. Accessed December 11, 2024.
[97]California HVIP. https://californiahvip.org/. Accessed December 11, 2024.
[98] Commercial Clean Vehicle Credit. https://www.irs.gov/credits-deductions/commercial-clean-vehicle-credit. Accessed December 11, 2024.
[99] SCE Charge Ready Transport (CRT). https://crt.sce.com/overview. Accessed December 11, 2024.
[100] EnergIIZE Commercial Vehicles. https://www.energiize.org/. Accessed December 11, 2024.

Table 21. Incentive amounts applied in the total cost of ownership analysis

Incentive	BET-Depot Charging	BET-Public Charging	BET-As-A-Service	FCET-Depot Refueling	FCET-Public Refueling	FCET-As-A-Service
HVIP	$120,000	$120,000	$120,000	$240,000	$240,000	$240,000
Commercial Clean Vehicle Credit	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000
SCE Charge Ready Transport	$15,203	-	-	-	-	-
EnergIIZE Commercial Vehicles - EV fast track & Hydrogen	$41,550	-	-	$55,125	-	-

Note: The incentive values reflect base amounts and do not include any additional enhancements, such as drayage add-ons or incentives for being in a disadvantaged community. These conservative estimates are used to account for potential variability and uncertainty in the availability of program enhancements.

Regarding the LCFS program, the number of credits generated was estimated based on the annual truck electricity consumption and using CARB's standard methodology[101]. More specifically, credits are a function of the amount of fuel consumed (kWh), the energy displacement associated with the fuel of interest, and the difference in the carbon intensity (CI)[102] of the fuel of interest (i.e., electricity) compared to the fuel it is displacing (i.e., diesel). The CI benchmarks for diesel fuel were obtained from CARB's report for proposed LCFS amendments in November 2024[103]. These values are provided for the period of 2011 to 2045 and are still subject to change. The California grid average CI for electricity over the years was obtained from the California Transportation Supply Model[104].

Additionally, the analysis assumed an energy economy ratio of 5 for BETs, as reported in CARB's LCFS credit price calculator[105]. A credit price of $109/ton was assumed, reflecting the average price from 2013 to 2024[106]. The NPV of the LCFS revenue over the 5-year analysis period, discounted at a 5% rate, is approximately $49,134.

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[101] CARB. Attachment A-1: Final Regulation Order. Proposed Low Carbon Fuel Standard Amendments. § 95486.1. Generating and Calculating Credits and Deficits Using Fuel Pathways. November 6, 2024. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/fro_atta-1.pdf. Accessed December 10, 2024.

[102] Carbon Intensity (CI) is a measure of the GHG emissions associated with the various production, distribution, and consumption steps in the "life cycle" of a transportation fuel, denoted in units of gCO2e/MJ.

[103] CARB. Attachment A-1: Final Regulation Order. Proposed Low Carbon Fuel Standard Amendments. Table 2. LCFS Carbon Intensity Benchmarks for 2011 to 2045 for Diesel Fuel and Fuels Used as a Substitute for Diesel Fuel. November 6, 2024. https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2024/lcfs2024/fro_atta-1.pdf. Accessed December 10, 2024.

[104] California Transportation Supply (CATS) Model v0.2 – Technical Documentation for August 2023 Example Scenario. Table 11. Estimated Grid Average Electricity CI through 2045. https://ww2.arb.ca.gov/sites/default/files/2023-08/CATS%20Technical_1.pdf. Accessed December 10, 2024.

[105] The LCFS Credit Price Calculator. Version 1.3. Last modified: 3/13/2019. https://ww2.arb.ca.gov/sites/default/files/2022-03/creditvaluecalculator.xlsx. Accessed December 15, 2024.

[106] LCFS Data Dashboard. Figure 4. Last updated: 12/13/2024. https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard. Accessed December 15, 2024.

Based on these incentive amounts and LCFS credit revenue, the TCO was calculated to reflect the impact of the available funding programs. Figure 26 summarizes the results, while Table 22 provides a detailed cost breakdown.

Figure 26. Total 5-year costs of ownership accounting for zero-emission vehicle incentives (Net Present Value at 5% discount rate)

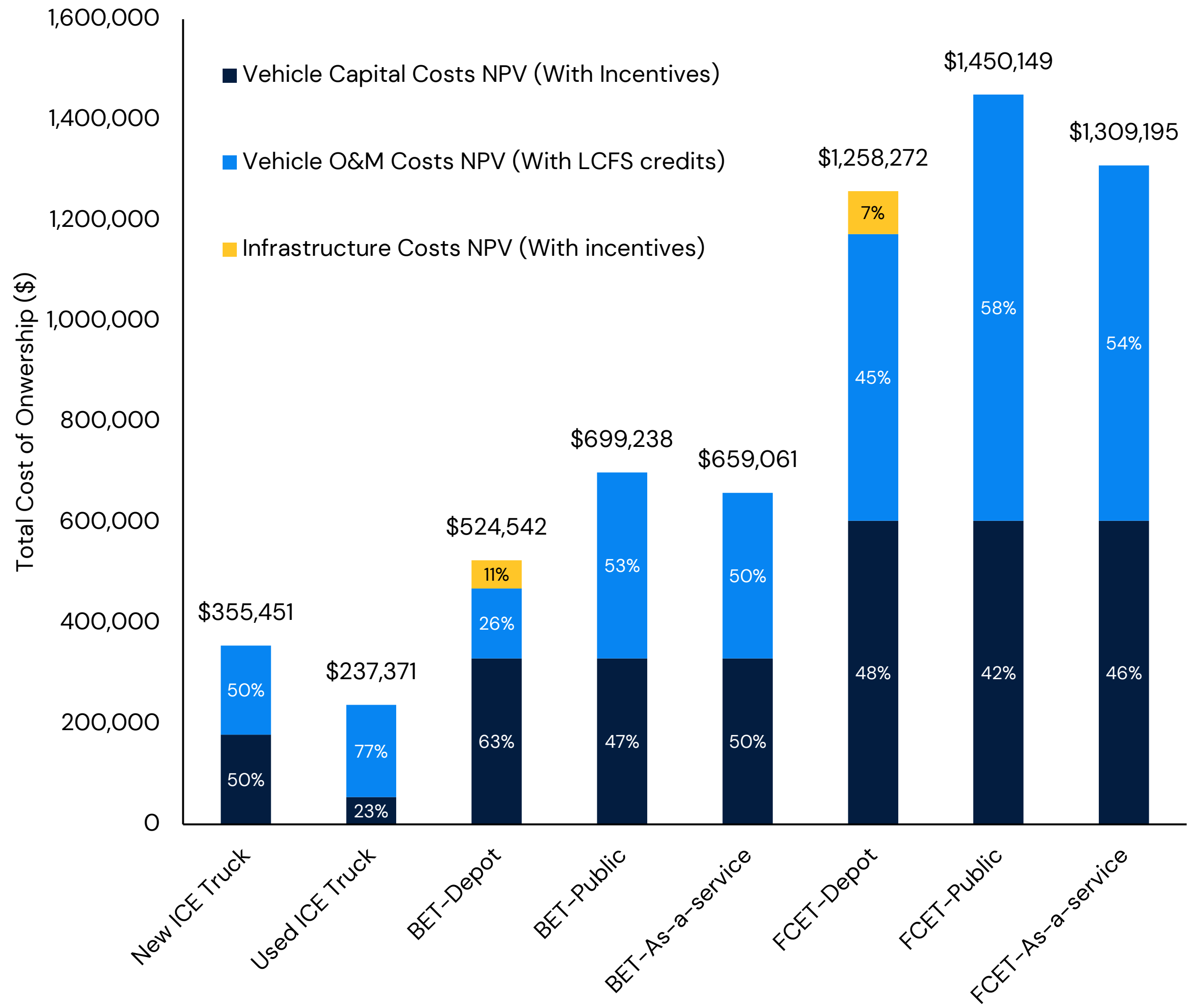


Table 22. Breakdown of 5-year costs of ownership accounting for zero-emission vehicle incentives (Net Present Value at 5% discount rate)

Cost Category	New ICE Truck	Used ICE Truck	BET-Depot	BET-Public	BET-As-A-Service	FCET-Depot	FCET-Public	FCET-As-a-service
Vehicle capital costs								
Vehicle purchase price with taxes	$228,160	$69,430	$593,361	$593,361	$593,361	$1,069,499	$1,069,499	$1,069,499
Resale value	$50,117	$15,251	$103,416	$103,416	$103,416	$186,401	$186,401	$186,401
Vehicle purchase incentives	$0	$0	$160,000	$160,000	$160,000	$280,000	$280,000	$280,000
Vehicle Capital Costs NPV (With Incentives)	*$178,043*	*$54,179*	*$329,945*	*$329,945*	*$329,945*	*$603,098*	*$603,098*	*$603,098*
Vehicle O&M costs								
Energy/fuel costs	$108,642	$108,642	$89,585	$200,884	$160,707	$432,716	$704,771	$563,817
Vehicle maintenance costs	$48,875	$56,082	$39,295	$39,295	$39,295	$41,250	$41,250	$41,250
Insurance costs	$19,891	$18,468	$58,997	$58,997	$58,997	$95,770	$95,770	$95,770
Extra labor costs	$0	$0	$0	$70,117	$70,117	$0	$5,259	$5,259
LCFS credits	$0	$0	$49,134	$0	$0	$0	$0	$0
Vehicle O&M Costs NPV (With LCFS credits)	*$177,408*	*$183,192*	*$138,743*	*$369,293*	*$329,116*	*$569,737*	*$847,051*	*$706,096*
Infrastructure costs per truck								
Infrastructure capital & installation cost	$0	$0	$77,967	$0	$0	$110,250	$0	$0
Infrastructure operation and maintenance cost	$0	$0	$10,407	$0	$0	$30,312	$0	$0
Infrastructure upgrades	$0	$0	$24,232	$0	$0	$0	$0	$0
Utility incentives	$0	$0	$15,203	$0	$0	$0	$0	$0
Other infrastructure incentives	$0	$0	$41,550	$0	$0	$55,125	$0	$0
Infrastructure Costs NPV (With incentives)	*$0*	*$0*	*$55,854*	*$0*	*$0*	*$85,437*	*$0*	*$0*
Total								
Total with incentives and LCFS	*$355,451*	*$237,371*	*$524,542*	*$699,238*	*$659,061*	*$1,258,272*	*$1,450,149*	*$1,309,195*

The introduction of incentives leads to significant reductions in the TCO of ZE trucks. For BET-depot, BET-public, and BET-as-a-service scenarios, the TCO decreases by up to 34%, due to vehicle purchase and infrastructure incentives. FCET-related scenarios also see TCO reductions, ranging from 16% to 21%. While these reductions make FCETs more cost-competitive, they still have a higher TCO compared to electric ones, reflecting the continuing need for incentives to make them more financially viable.

The relative cost rankings between different truck types remain the same whether or not incentives are applied. ICE trucks are still the cheapest option, followed by BETs, with FCETs being the most expensive. Among electric options, depot charging is the most cost-effective, followed by public charging, and then charging-as-a-service models. While BETs are consistently more affordable than FCETs, the key difference is that incentives significantly reduce the cost gap between BETs and ICE trucks, making BETs a more financially viable alternative.

Caveats

When discussing the TCO results for ZE trucks, it is important to consider certain caveats to provide a balanced and well-rounded perspective:

- ***Long-term benefits*****:** While the calculated TCO of ZE trucks may still be higher than that of diesel trucks, it is important to consider the long-term benefits, such as environmental sustainability advantages. These factors are not fully captured in the TCO calculation but are significant considerations for fleet operators focused on future-proofing their operations and meeting carbon reduction goals.
- ***Ongoing technological advancements***: ZE truck technologies are continuing to evolve. As technology improves, there is potential for further reductions in operating and capital costs, particularly in areas such as battery efficiency, fuel economy, and infrastructure development. While current TCO may be higher, future trends could shift these dynamics, especially as economies of scale and manufacturing efficiencies are realized.
- ***Fuel price sensitivity***: The fuel prices used in this analysis, including diesel, hydrogen, and electricity, are based on current projections but are subject to significant fluctuations over time. Changes in fuel prices, driven by factors such as market dynamics, policy shifts, and supply-demand imbalances, can have a substantial impact on the overall TCO.
- ***Infrastructure challenges***: The availability of refueling or charging infrastructure plays a significant role in the TCO for BETs and FCETs. Some alternatives, particularly hydrogen, still face infrastructure gaps, which could lead to higher operational costs or logistical challenges in the near term. Investment in infrastructure could help

further reduce the overall TCO for ZE trucks, but this factor is dependent on the pace and scale of deployment.

- ***Impact of incentives***: This analysis focused on incentive programs that were open and active at the time of writing and offers a snapshot of available support under standard conditions. Additionally, the incentives reflected in the analysis have an immediate impact on the affordability of ZE trucks, but they may be temporary. For example, the Drayage Set-Aside under the Clean Truck and Bus Voucher Incentive Project is closed since December 2024[107] and its future availability is uncertain. It is important to consider how future policy changes, shifts in subsidy levels, and regulatory frameworks will affect TCO and whether ZE trucks will continue to require incentives to become more affordable.
- ***Truck operational factors***: The affordability and cost-effectiveness of ZE trucks may vary depending on specific operational factors such as the exact driving patterns, frequency of charging or refueling, and proximity to available infrastructure. Fleets with longer daily routes or more frequent refueling needs may experience higher costs associated with energy use and infrastructure upgrades, whereas fleets that primarily operate within range of charging or refueling stations may find ZE trucks more cost-efficient. It is also important to consider that battery degradation over time can reduce range, potentially increasing the frequency of charging or refueling and thereby raising operational costs. While this analysis assumes an average daily mileage as a consistent measure across all fleets, variations in specific operational patterns, such as shorter or longer hauls, could lead to different cost outcomes that need to be considered when adopting ZE trucks for different use cases.

[107] California Clean Truck and Bus Voucher Incentive Project. Funding Updates. https://californiahvip.org/funding/. Accessed February 20, 2025

Zero-Emission Infrastructure Availability

This section examines current and required public charging and refueling infrastructures both on Port-owned property and regionally to map out the infrastructure enhancements needed to meet the full transition of Ports' drayage trucks to ZE technology.

Beyond identifying infrastructure needs, this section also evaluates both current and planned charging and refueling infrastructure, incorporating announced public and private sector investments scheduled for deployment in the next 3–5 years. Through a comprehensive assessment of infrastructure availability against projected demand over the 5–10-year horizon, the analysis identifies potential gaps and examines the feasibility of infrastructure development required to meet future needs. This section also includes detailed cost projections and implementation timelines, providing a strategic roadmap for achieving the Ports' ZE objectives. It is important to note that this assessment includes only publicly accessible infrastructure and does not account for private, depot-based charging facilities. As such, the estimated infrastructure gaps reflect needs based on public access alone and may not capture existing private investments by fleets.

In this section, the following terms are used:

- For EV charging infrastructure, a *charging station* refers to a distinct location where charging services are provided (analogous to a gas station). Each station may include multiple *chargers*, and each charger can have one or more *charging ports*. Each charging port is an individual connector that can charge one vehicle at a time).
- For hydrogen infrastructure, a *hydrogen station* refers to the site where hydrogen dispensing equipment is installed. Each station typically includes one or more *dispensers* (similar to fuel pumps), and each dispenser may have multiple *nozzles* used to deliver hydrogen fuel to vehicles.

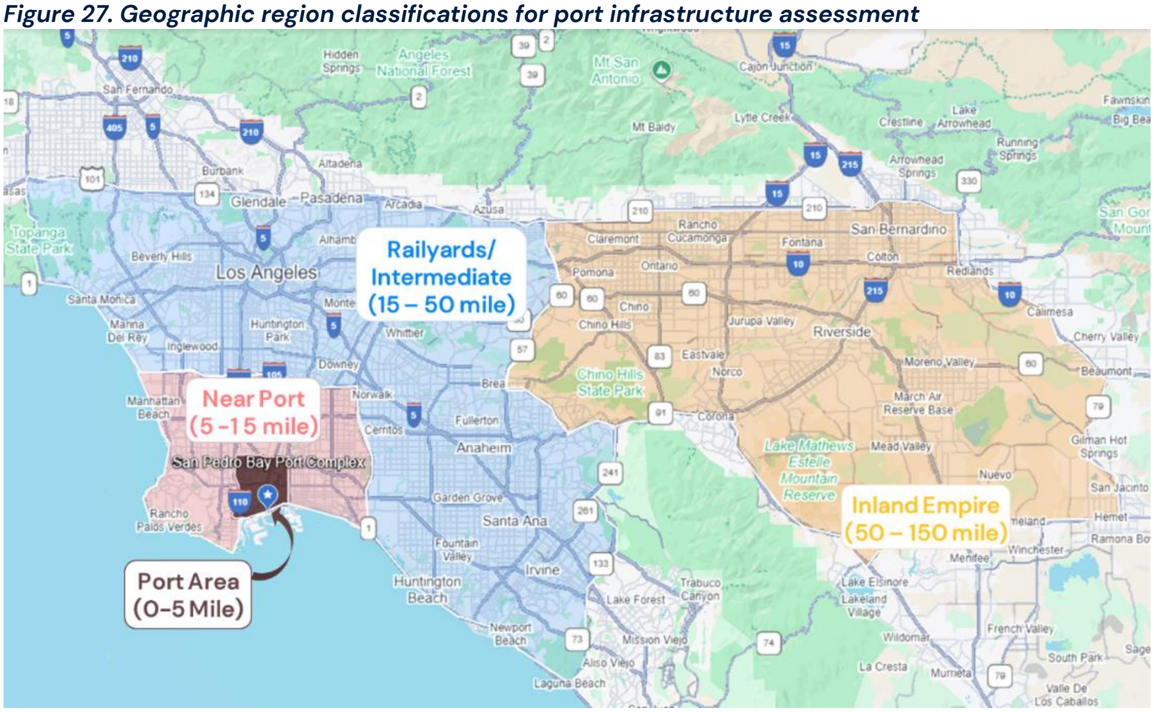
Overview of Existing Charging and Hydrogen Refueling Infrastructure

In this feasibility assessment, station locations within a 5-mile radius of the Ports, between 5 and 15 miles, between 15 and 50 miles, and between 50 and 150 miles are categorized as the Port Area, Near Port, Railyards/Intermediate Zone, and Inland Empire, respectively (Figure 27).[108] Notably, the Port Area is not the same as the harbor districts over which each Port has permitting and land-use development jurisdiction; it is a much larger area, encompassing property not owned by the Ports and over which the Ports have no control. While some trucks currently travel from locations beyond 150 miles from the Ports, only stations within a 150-mile radius of the Ports are considered for this feasibility assessment.

[108] Prokaska R., Konan A., Kelly K., and Lammert M. (2016). "Heavy-duty Vehicle Port Drayage Drive Cycle Characterization and Development," National Renewable Energy Laboratory, Heavy-Duty Vehicle Port Drayage Drive Cycle Characterization and Development: Preprint, accessed December 3, 2024.

This distance ensures that the infrastructure remains heavily utilized by drayage trucks, whereas stations beyond this range could be used more frequently for other applications such as interstate or long-haul travel. This approach aligns with findings from the operator survey, which indicates that the majority of trucks travel distances of less than 150 miles from the Ports to their destinations.

Figure 27. Geographic region classifications for port infrastructure assessment



To date, there are 83 medium- and heavy-duty truck charging and hydrogen refueling stations in 77 different locations within a 150-mile radius of the Ports[109]. Sixty-one charging stations are currently in operation, under construction or planned[110] to be installed within a 150-mile radius of the Ports. About 30% of these charging stations are located within a 15-mile radius of the Ports, namely the Port Area and Near Port (Figure 28). Over half of the charging ports are currently operational or planned to be installed in the Inland Empire (Figure 28). Seventy percent of the 61 charging stations are publicly accessible, and the rest are semi-public or have shared accessibility.

As shown in Figure 29, 22 hydrogen refueling stations are currently operational, under construction, or planned to be installed in the future within a 150-mile radius of the Ports. Approximately 36% of the refueling open or planned stations are in the Port Area and Near Port Area (Figure 29). Approximately three quarters of the dispensers are likely located in

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[109] Using the location of San Pedro Bay as the center of the circle on CALSTART website (i.e., https://calstart.org/mhd-infrastructure-map/, accessed November 24, 2024.

[110] The development status, "planned," indicates that the developer plans to build the charging or refueling station but construction has not started yet.

the Railyards/Intermediate Zone or Inland Empire (Figure 29). All these hydrogen refueling stations are publicly accessible to medium- and heavy-duty trucks.

Figure 28. Distribution of charging infrastructure at the station and port level within a 150-mile radius of the Ports

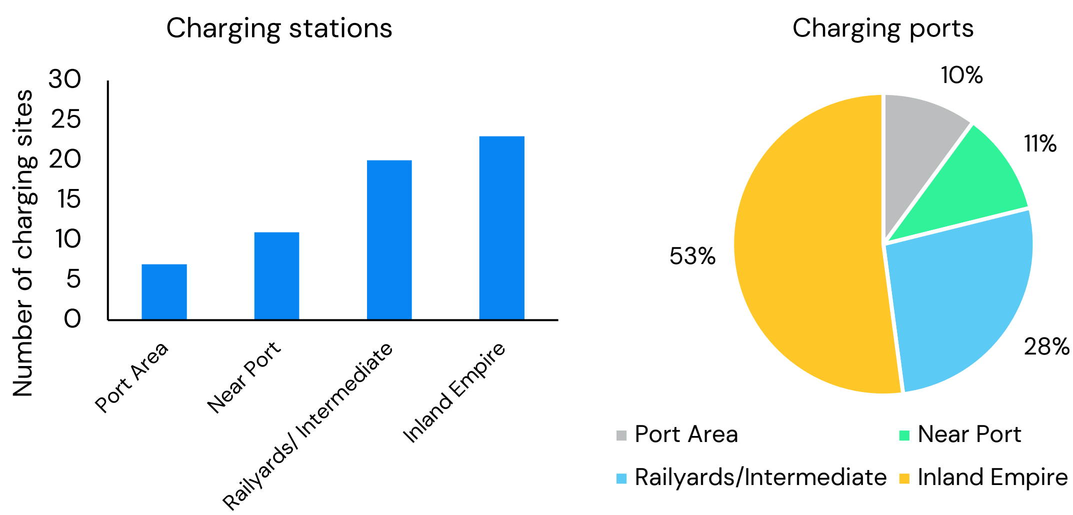
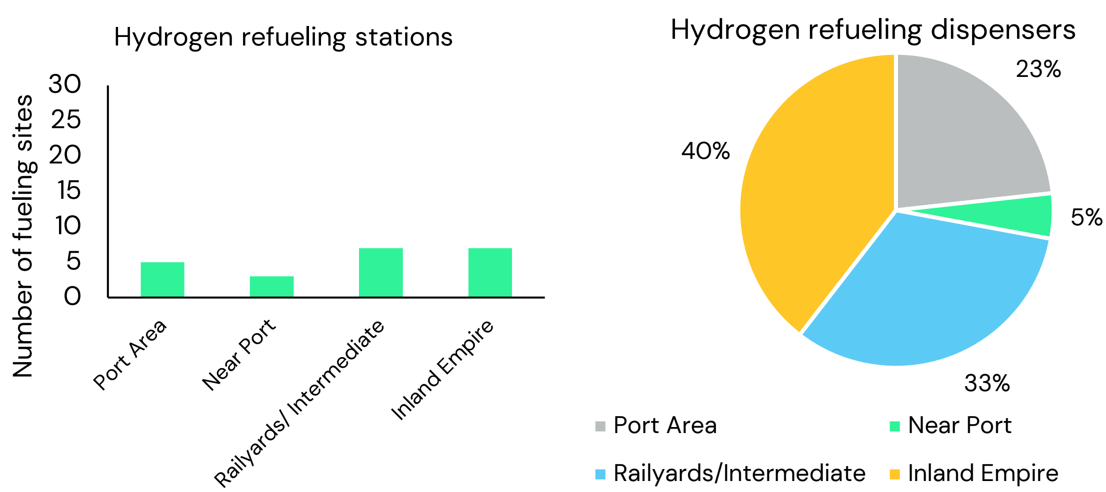


Figure 29. Distribution of hydrogen refueling infrastructure at the station and dispenser level within a 150-mile radius of the Ports



On Port-owned property, there are seven charging stations with 190 charging ports and three hydrogen refueling stations with 7 nozzles (Table 23). Six of these stations are currently open and four stations offer full public accessibility for operators to charge and refuel.

Table 23. Charging and hydrogen refueling infrastructure within the ports today

Station Name	Status	Charger / Dispenser Count	Port/ Nozzle Count	Access Type	Fuel Type	Distance to the Ports (miles)
FM Harbor - POLB	Open	25	44	Shared	Electricity	2.5
Watt EV - POLB (Pier A)	Open	13	26	Semi-Public	Electricity	3.25
Terminal Access Center - POLB	Open	2	-	Public	Electricity	3.41
4 Gen Logistics LLC	Open	30	30	Semi-Public	Electricity	2
Zeem - Long Beach	Under Development	42	84	Semi-Public	Electricity	2.29
Clean Energy	Planned	6	6	Public	Electricity	3.63
POLA	Planned	-	-	-	Electricity	3.7
Shell Long Beach	Open	4	4	Public	Hydrogen	3.23
Nikola (Hyla)	Open	-	-	Public	Hydrogen	3.86
925 Harbor Plaza (POLB)	-	2	3	-	Hydrogen	2.7

Sources:
[1] CALSTART National Zero-Emission Medium- and Heavy-Duty Infrastructure Map[111]
[2] CEC Medium- and Heavy-Duty Zero-Emission Vehicle Charging and Hydrogen Infrastructure[112]

Charging infrastructure

The 61 charging stations have approximately 1,150 charging ports. About 20% of these ports are/will be situated within the Port and Near Port Areas. Approximately 23% of the charging ports are currently open and operational for charging; the rest are under development or being planned for future construction at the time of writing this report (Figure 30). The size of each charging station varies; some stations have or may have over 90 charging ports in one station.

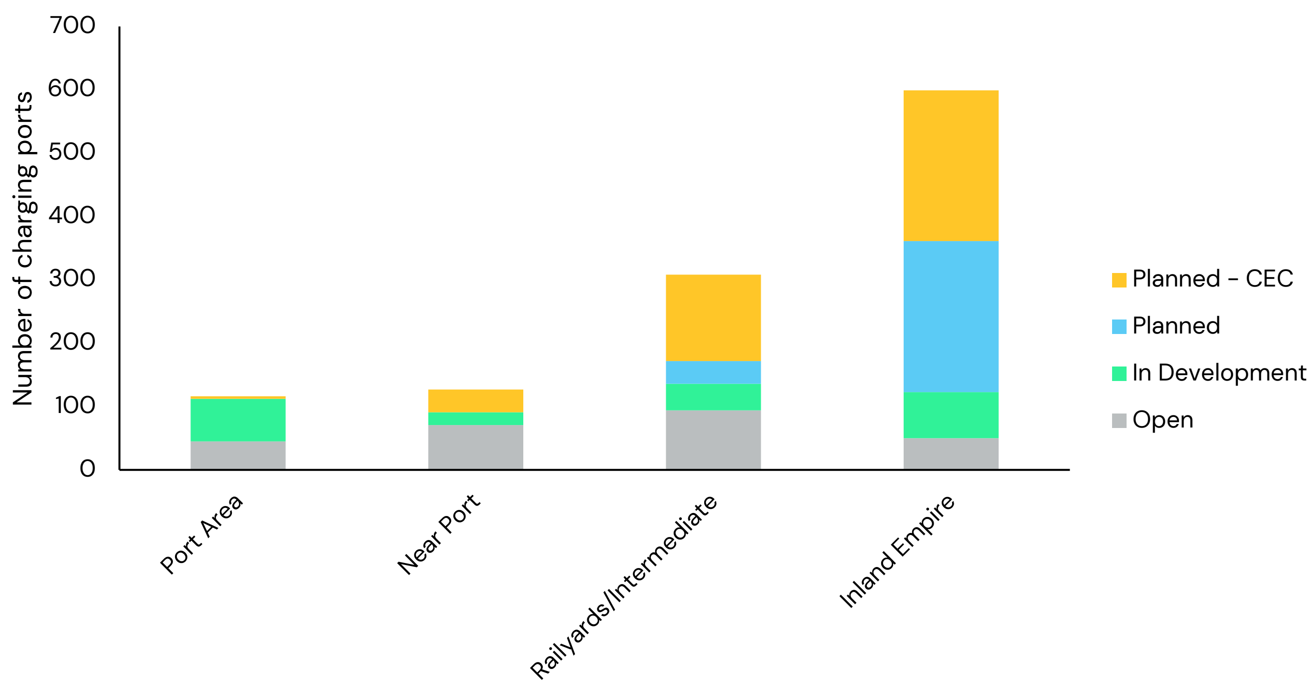
Over 70% of charging stations are assumed to be open to the public. Five stations are considered semi-public, referring to charging stations that are accessible to a specific group of users rather than the general public. These five stations are currently or will be operated by Zeem Solutions, WattEV, Electrify America, and Einride. Seven stations have shared accessibility, meaning that these stations are available to multiple users. These stations are or will be operated by Forum Mobility, Terawatt Infrastructure, and Zeem Solutions.

[111] National Zero-Emission Medium- and Heavy-Duty Infrastructure Map, CALSTART, https://calstart.org/mhd-infrastructure-map/, accessed November 25, 2024.
[112] Medium- and Heavy-Duty Zero Emission Vehicle Charging and Hydrogen Infrastructure, CEC, https://experience.arcgis.com/experience/f951c1433f804daea7f4c33c271aa935/, accessed November 25, 2024.

The charging stations offer varying power outputs, ranging from 62 kW to 1,600 kW per port. The average charging output across all stations is 417 kW, with a median output of 360 kW. In practical terms, charging at 360 kW for an hour could allow a typical Class 8 BET to travel for about 150 miles or more, depending on the truck efficiency, payload, and other factors.

It should be noted that in compiling the list of public charging and fueling infrastructure, we began with the CALSTART National Zero-Emission Medium- and Heavy-Duty Infrastructure Map. We then cross-referenced this data with the CEC database on medium- and heavy-duty ZEV charging and hydrogen infrastructure. While there was significant overlap between the two sources, which was reassuring, there were also several charging and hydrogen fueling stations listed in the CEC database that did not appear in CALSTART database. Notably, CALSTART designates stations as open, under development, or planned, while the CEC does not provide such status information. To maintain a conservative approach, we categorized any stations present in the CEC dataset but absent from CALSTART's as "Planned – CEC." These could include both existing infrastructure not yet reflected in CALSTART's data and newly funded projects that have not yet begun construction.

Figure 30. Number of charging ports within a 150-mile radius of the Ports by distance and development status



Hydrogen refueling infrastructure

There are about 22 hydrogen refueling stations within a 150-mile radius of the Ports, including both currently open stations and those planned for future development. As shown in Figure 31, these hydrogen refueling stations can dispense hydrogen up to nearly 84,500 kg/day. Stations in the Port Area and Near Port together can dispense approximately 27,500 kg of hydrogen a day.

To date, six hydrogen refueling stations are open and operational, one station is under development, and 15 refueling stations are planned for construction. One of the planned hydrogen refueling stations will be on highway I-10 near Palm Springs, which is nearly 100 miles away. The other planned refueling station will be closer to the Ports and near Commerce. Currently open and operational hydrogen refueling stations can dispense up to 21,200 kg/day (Figure 31).

Figure 31. Capacity of operational and planned hydrogen refueling stations within a 150-mile radius of the Ports

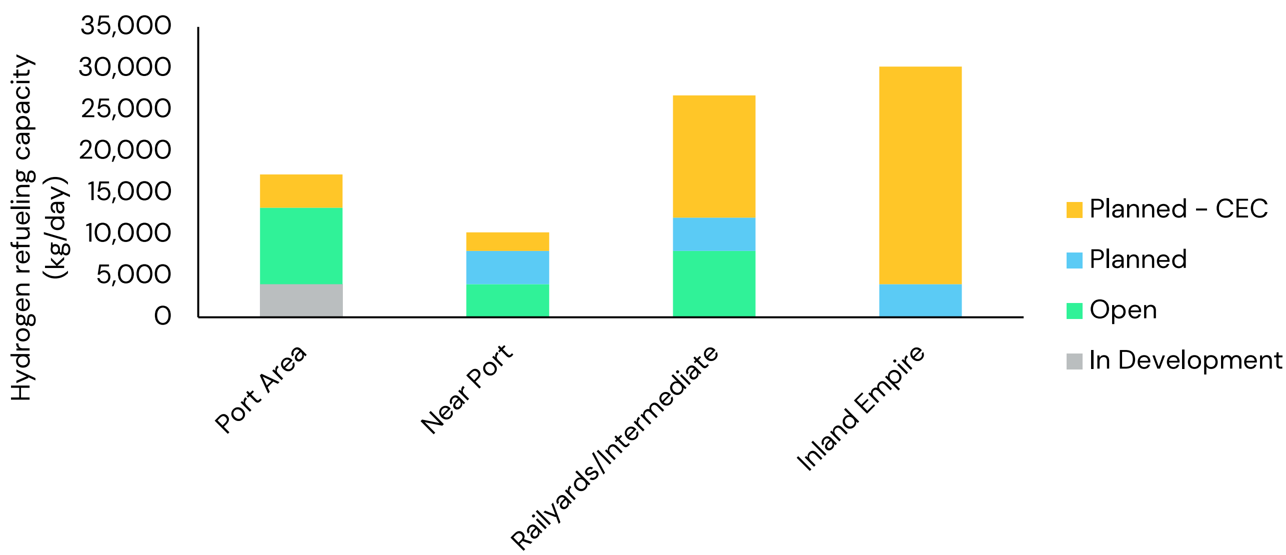
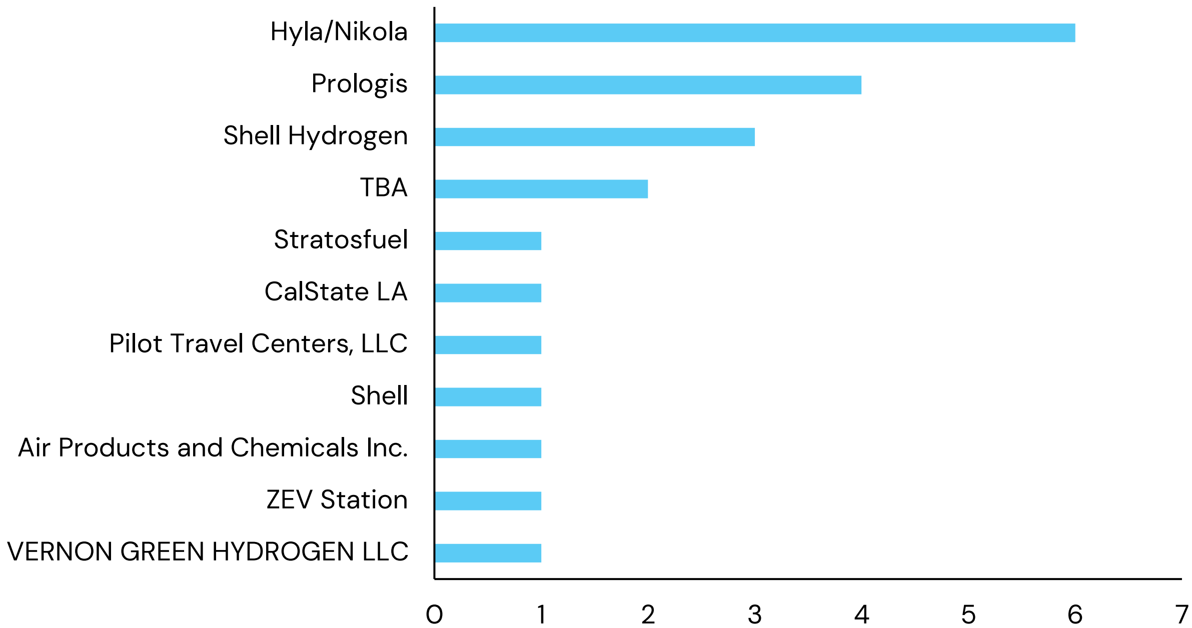


Figure 32 shows the organizations that operate hydrogen refueling stations. All of the hydrogen refueling stations identified are open to the public. These stations typically have two or four dispensers and about two to five nozzles available in each refueling location. The filling pressure for most hydrogen refueling stations is planned to deliver gaseous hydrogen at 700 bar. There are approximately four stations offering hydrogen at both 350 and 700 bar.

Figure 32. Operating agencies for hydrogen refueling stations within a 150-mile radius of the Ports



Charging and Refueling Infrastructure Needs Assessment Methodology

Based on survey responses from 42 drayage operators, representing approximately 1,030 trucks, the team evaluated charging and refueling infrastructure requirements for Class 8 drayage trucks. The surveyed fleets demonstrated diverse operating patterns, with average trip distances ranging from a few miles to over one hundred miles, and daily trips varying from 1 to more than 10 per truck. While exact fleet sizes were not collected, operators provided size ranges that enabled the team to estimate the total truck count in the survey sample.

In estimating the charging infrastructure requirements, the team assumed that the all-electric range of a typical Class 8 truck is approximately 200 miles. Charging will be necessary when the state of charge (SOC) reaches 20%. In other words, the truck will need to be recharged when the remaining range is about 40 miles. It is also assumed that trucks are expected to begin their shifts with a full 100% charge. This implies that trucks with overnight depot access will need charging infrastructure at dwelling sites, while others will require recharging at the end of their shift the previous day. According to the survey responses, approximately 15–20% of vehicles lack overnight depot access. Here, we consider the charging needs of these vehicles at the end of their shifts while excluding depot charging infrastructure assessment. We use the number of trips and average trip distance to estimate when and where charging would be required for each fleet. For instance, a truck that makes six trips a day to a destination 17 miles from the port will reach 20% SOC during the fifth trip:

$$\frac{200 \text{ mile} - 40 \text{ mile}}{17 \ {}^{\text{mile}}/_{\text{trip}} \times 2} = 4 \text{ complete round trips} + 24 \text{ miles}$$

At this time, the truck will be located 10 miles from the port.

$$17\ mile - (24\ mile - 17\ mile) = 10\ mile$$

To support the operation of this fleet, charging infrastructure will be required approximately 10 miles from the Port, in the Near Port region as previously defined. The timing of charging events is determined based on the current shift hours, with each charging session presumed to add an additional 2 hours to the existing shift. In practice, an opportunity charging session for a drayage truck during a shift may take only 1 hour. As noted earlier, this 1-hour charging session can provide over 150 miles of range—almost sufficient to fully recharge the truck to 100% SOC. However, considering the additional time needed to park the vehicle, connect it to the charger, and complete the charging process, the total time spent at the station may exceed 1 hour. Therefore, the project team adopted a more conservative estimate of 2 hours.

Once the number of charging events was determined, the team identified the 2-hour window with the most charging starts throughout the day to calculate the total number of charging ports needed. Based on the trip data from 1,030 trucks, it is estimated that 420 ports will be required to accommodate this volume if all trucks are converted to battery electric. These ports will be distributed as follows: 132 in the Port Area, 68 in Near Port, 159 in Railyards/Intermediate Zone, and 61 in Inland Empire. Each port in the Inland Empire is expected to support 3.3 charging sessions per day, while other locations are expected to support 2 to 2.5 sessions daily. On average, each vehicle requires 1.4 charging sessions per day.

The needs for hydrogen infrastructure are evaluated based on fueling capacity and demand. Assuming an average Class 8 FCEV has an average energy consumption of 137 g H_2/mile[113], if all 1,030 surveyed trucks become FCEV, the total fueling demand of a day is 41,878 kg/day. Assuming the average size of the tank is 51 kg, only 1/3 of vehicles need refueling every day. In order to ensure there is a buffer in the total hydrogen demand while ensuring station profitability, the team also assumed a 70% utilization of all hydrogen stations[114]. Consequently, a fueling capacity of 60,000 kg per day will be required to support these vehicles. This equals the need for 15 refueling stations, assuming that each station maintains an average capacity of 4,000 kg per day.

[113] Average efficiency calculated from hydrogen tank size and OEM-reported range.
[114] CARB (2020). Hydrogen Station Network Self-Sufficiency Analysis per Assembly Bill. https://ww2.arb.ca.gov/sites/default/files/2020-11/ab_8_self_sufficiency_report_draft_ac.pdf, accessed December 17, 2024.

Number of Vehicles That Existing Charging and Refueling Infrastructure Can Support

Following the methodology described in the previous section, several assumptions have been made to estimate the number of vehicles the existing charging and hydrogen refueling infrastructure can support. As shown in Table 24, there are 21 charging facilities with 462 charging stations/ports that are currently open and operational or under development at the time of writing this report. Based on the analysis of daily charging sessions per port, the project team has projected that the existing charging ports can support a total of 1,150 charging events. Assuming that the 1.4 charging events per truck remain consistent, this translates to approximately 800 Class 8 BETs.

For hydrogen refueling stations, information on the number of nozzles and maximum capacity (kg) one refueling station can dispense is available for some stations. For stations that do not specify their maximum dispensing capacity, 4,000 kg is assumed for the purpose of this estimate. The average hydrogen fuel tank size is assumed to be 51 kg based on market research (Figure 17). The hydrogen refueling station utilization rate is assumed to remain at 70%, which aligns with CARB's estimation in order to achieve station profitability.[114] As shown in Table 24, six stations are currently open or under development within a 150-mile radius of the Ports. These hydrogen refueling stations have a refueling capacity of 25,200 kg/day, which can support refueling approximately 350 Class 8 FCETs per day.

The current results (Table 24) only include stations that are operational or under development. Stations in the planning stage are excluded due to potential uncertainties and the possibility of not being commissioned. If all planned stations are included, the 61 charging stations could support more than 2,200 Class 8 BETs and the 22 hydrogen refueling stations could support more than 1,100 Class 8 FCETs.

Table 24. Estimated number of Class 8 zero-emission trucks that can be supported by charging and refueling infrastructure that are operational and under development within a 150-mile radius of the ports

Fuel type	Existing Infrastructure that are open or under development within a 150-mile radius of the Ports	Number of charging events can support	Number of vehicles can charge/refuel
Electricity	462 charging ports	1,150	~800 Class 8 BETs
Hydrogen	6 hydrogen refueling stations (with a total of 25,200 kg/day refueling capacity)	N/A	~350 Class 8 FCETs

Charging and Refueling Infrastructure Needed for Full Transition to Zero Emission

This section summarizes future charging and hydrogen refueling needs if all drayage trucks at the Ports transition to ZE. According to the gate count data provided by the Ports, approximately 23,500 unique trucks, identified by their vehicle identification numbers (VINs), visited the Ports in 2023 (Table 25). Among these, roughly 16,800 trucks are considered frequent visitors to the Ports. For this analysis, frequent visitors are defined as trucks that have more than two moves per week, which is equivalent to roughly 104 moves per year[115]. The research team cross-checked the body class of these trucks using the NHTSA VIN decoder[116] and found that 16,700 trucks among the frequent visitors are Class 8 trucks. The majority of the 16,700 Class 8 drayage trucks are currently powered by diesel and natural gas.

Table 25. Class 8 drayage truck inventory

23,500	•Number of unique trucks that visited the ports in 2023
16,800	•Number of trucks that visited the Ports frequently.
16,700	•Number of Class 8 trucks that visited the Ports frequently.

It was assumed that there would be a 90%/10% split between BETs and FCETs if all 16,670 Class 8 drayage trucks at the Ports transitioned to ZE, aligning with CARB's ACT technology penetration assumptions. [117] This will result in approximately 15,000 Class 8 BETs and 1,700 Class 8 FCETs for drayage services in the Port Area each day (Table 26). According to the analysis of sample survey responses, the average vehicle-to-port (V2P) ratio for these trucks is approximately 2.5 vehicle per port. Assuming the "charging ports-to-vehicle" ratio

[115] In this study, this threshold (104 moves per year or 2 moves per week) includes a larger portion of regularly operating trucks than the "frequent" and "semi-frequent" categories used in prior studies, better reflecting current operations and informing infrastructure planning.
[116] National Highway Traffic Safety Administration. (n.d.). VIN Decoder. https://www.nhtsa.gov/vin-decoder, accessed December 16, 2024.
[117] The first medium-duty and heavy-duty sales mandate adopted by the California Air Resources Board. More can be found at: https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks

remains consistent with the sample data, a total of 6,200 charging ports would be needed, with most of the infrastructure located in the Port Area or Railyards/Intermediate Zone.

It should be noted that the current charging infrastructure needs assessment is based on the survey responses collected, which only represent a small sample of fleets and operators. Consequently, the team adjusted some assumptions to understand the level of uncertainties involved. For instance, several responses indicated that fleets have lengthy shift hours but very short travel distances. Although this may still hold true due to prolonged docking activities, it leads to a significantly extended charging window. The team adjusted shift lengths to ensure the daily average speeds of all trucks are between 5 and 55 mph, creating a more aggregated shift window for fleets and leading to more frequent coincidental charging. Consequently, the V2P ratio dropped to 2.3 instead. In another scenario in which a shorter charging window (i.e., 1-hour charging window) or faster charging (e.g., MW charging) is considered, the V2P ratio could increase to 2.7. Based on this sensitivity analysis, the number of charging ports needed throughout the region to support a full transition for 15,000 Class 8 BETs would range from 5,500 to 6,600.

if we assume that the "refueling capacity-to-vehicle" ratio remains consistent with the sample data and that the hydrogen station capacity and utilization rates remain unchanged, supporting a total of 1,700 FCETs will require a total of 32 hydrogen refueling stations throughout the region. Future station capacity is likely to increase beyond the team's current assumption of 4,000 kg/day. Consequently, the number of required stations may be fewer than our present estimate, provided that the overall total capacity remains consistent.

Table 26. Future charging and hydrogen refueling infrastructure needed to support a full transition at the ports

Fuel type	Number of Class 8 ZE trucks	Number of charging ports / hydrogen refueling stations that would be needed
Battery electric	~15,000	~6,200 charging ports
Hydrogen fuel cell	~1,700	~32 hydrogen refueling stations (with a total of 123,200 kg/day refueling capacity)

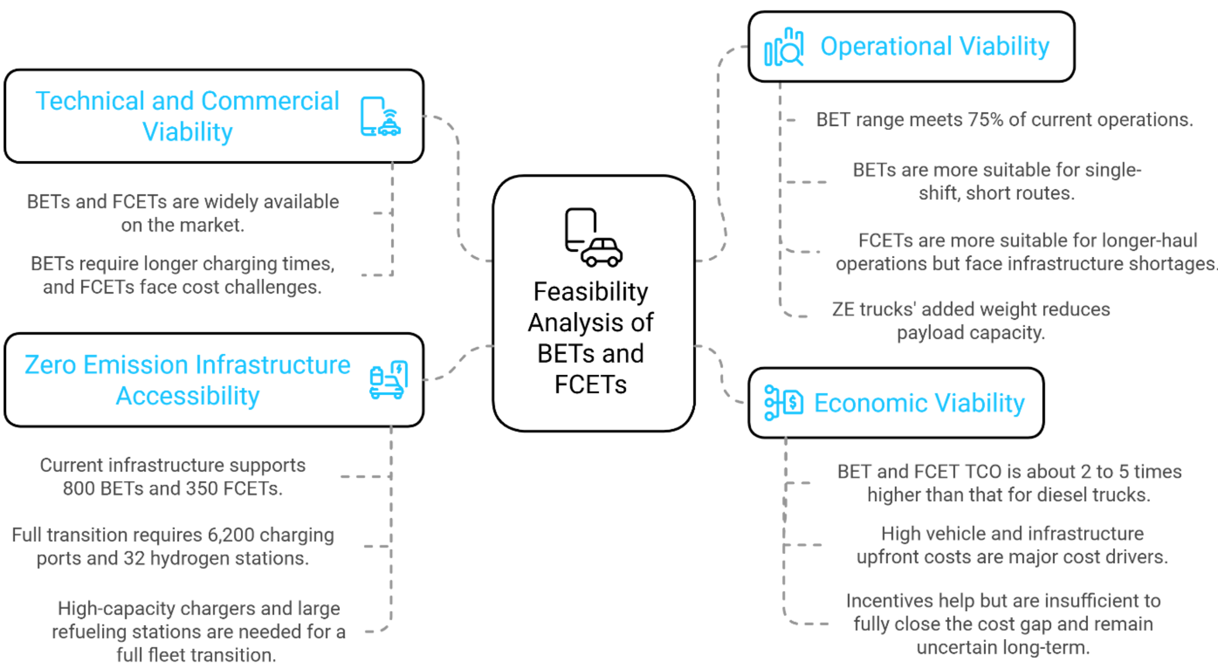
Overall, the number of charging ports needed to support 15,000 Class 8 BETs is approximately 14 times the number of charging ports that are currently open or under construction within a 150-mile radius of the Ports (6,200 ports needed versus 462 available today). For hydrogen refueling, compared to the refueling stations and capacity that are currently available or under development, another 25 stations or an additional 98,000 kg/day refueling capacity would be needed to support 1,700 Class 8 FCETs. While this section provides an estimate of the charging and refueling infrastructure needs, the actual infrastructure deployment is still dependent on the capability of local utilities to provide adequate grid capacity.

Overall Feasibility

As illustrated in the report, the feasibility of deploying ZE trucks for drayage operations is not a simple yes-or-no proposition. Instead, it exists on a continuum, where feasibility varies significantly based on the operational context, infrastructure readiness, and economic considerations. It is more accurate to assess where and under what conditions ZE trucks are feasible and where challenges remain.

Rather than presenting feasibility across the five pillars as a simple yes-or-no determination, this section explores the challenges and opportunities associated with the adoption of ZE trucks in port operations. For each pillar, with technology and commercial viability combined, we assessed the feasibility of adopting ZE trucks, identifying key barriers and the critical factors that impact feasibility within each category. Figure 33 provides a visual overview of this assessment, summarizing the current readiness and challenges across all pillars. The subsequent subsections then offer a detailed breakdown of feasibility within each pillar, outlining the necessary conditions and potential pathways for ZE truck adoption in port operations.

Figure 33. Feasibility status of zero-emission trucks as of 2024 for drayage trucks operating at San Pedro Bay Ports



Technical and Commercial Availability

From a technological standpoint, ZE trucks, including BETs and hydrogen FCETs, have reached a level of maturity that makes them commercially available for certain drayage applications. Seven BET models and six FCET models are currently available in the Class 8 category, offered by manufacturers such as Freightliner, Kenworth, Lion, Peterbilt, Volvo, BYD, and Hyundai. BETs currently offer ranges between 150 and 330 miles, with an average of 209 miles, making them suitable for shorter, single-shift operations or low-mileage routes. On the other hand, FCETs provide a longer range of 249 to 500 miles, averaging 381 miles, which positions them as a more viable option for longer-haul drayage operations or multi-shift schedules. These technological capabilities enable ZE trucks to meet the needs of a substantial portion of drayage operators, particularly those with predictable, lower-mileage routes.

Despite these advancements, significant technological improvements are required to achieve full viability across all drayage operations. One of the primary challenges is the curb weight of ZE trucks. The average curb weight of both Class 8 BET and FCET is approximately 23,000 lbs., which is nearly 8,000 lbs. heavier than conventional diesel trucks. The added weight reduces payload capacity, especially for operators transporting heavy goods, creating challenges for high-payload operations and restricting the broader applicability of ZE trucks in heavy-duty freight.

Another critical technological limitation of BETs is their charging acceptance rate. Currently, only one commercially available BET, the Nikola Tre®, supports a maximum charging rate of 350 kW. All other BET models have lower charging acceptance rates, significantly extending the time required to recharge batteries. For BETs to achieve operational parity with diesel trucks and support higher-intensity drayage operations, charging acceptance rates must increase to megawatt levels. Megawatt charging technology, capable of delivering over 1 MW of power, could drastically reduce charging times, enabling quicker turnaround and higher utilization rates. However, the development and deployment of MW chargers will require substantial advancements in both vehicle and infrastructure technology, as well as significant investment.

Operational Viability

Operational feasibility examines how well ZE trucks meet the performance and adaptability requirements of drayage operations. BETs align well with operations involving single-shift, low-mileage routes, particularly when charging infrastructure is accessible either at depots or along the route. Based on the survey data, approximately 75% of operators could transition to BETs based on daily range requirements, as their operations typically involve routes of less than 200 miles, which aligns with the average range of current BET models. However, for payload considerations, around 67% of operators could feasibly adopt BETs, as these trucks' heavier curb weights limit cargo capacity.

FCETs provide significant operational advantages, including longer driving ranges and refueling times of under 20 minutes, a stark contrast to the one to 2 hours required for BET charging. These characteristics make FCETs well-suited for two-shift schedules and longer-haul operations. However, their deployment is heavily constrained by the limited availability of hydrogen refueling stations. Additionally, like BETs, FCETs face challenges regarding load capacity due to their heavier curb weights, which can reduce their ability to haul maximum payloads.

Economic Viability

The cost of ZE trucks presents one of the most significant barriers to widespread adoption. As illustrated in the TCO analysis, the TCO for BETs is approximately 2 to 2.5 times higher than that of diesel trucks, even with current incentive programs. For FCETs, the TCO is 4.5 to 5 times higher. The primary drivers of these cost disparities include the high upfront purchase price of ZE trucks, which ranges from $416,000 for BETs to $750,000 for FCETs (before taxes), compared to $160,000 (before taxes) for new diesel trucks. Insurance premiums, maintenance costs, and extended labor costs due to longer refueling or charging times further contribute to the higher TCO of ZE trucks.

Incentive programs at the state, federal, and local levels play a critical role in offsetting these costs. For example, incentives like the Clean Truck and Bus Voucher Incentive Project (HVIP) and the Commercial Clean Vehicle Credit can reduce the upfront cost of BETs by up to $160,000 and FCETs by up to $280,000. Despite these subsidies, the economic disparity remains significant, particularly as the long-term availability of such incentives is uncertain.

Zero-Emission Infrastructure Availability

Infrastructure represents another critical pillar of ZE truck feasibility. Currently, the available infrastructure within a 150-mile radius of the SPBP can support approximately 800 Class 8 BETs and 350 Class 8 FCETs. This includes 462 charging ports and 25,200 kg/day of hydrogen refueling capacity across operational and under-construction facilities. While this is sufficient to support a limited number of ZE trucks, a full transition to ZE drayage operations requires a dramatic expansion of infrastructure.

To fully transition the fleet of 16,700 Class 8 drayage trucks operating at the Ports to ZE truck, approximately 6,200 charging ports and 32 hydrogen refueling stations with a total capacity of 123,200 kg/day will be required. This represents a 14-fold increase in charging infrastructure and a near five-fold increase in hydrogen refueling capacity compared to what is currently available. Addressing these gaps will require significant investments in infrastructure development, including high-power megawatt charging stations and large-capacity hydrogen refueling facilities.

Overall, while commercially available ZE trucks meet a subset of operational needs, significant barriers remain. The existing infrastructure and technology enable a partial transition, supporting approximately 1,000 ZE trucks. However, achieving full fleet electrification will require substantial advancements in technology, reductions in vehicle costs, and a massive expansion of charging and refueling infrastructure. These challenges highlight the need for coordinated efforts across technology development, policy support, and infrastructure investment to realize the goal of ZE drayage operations.

Comparison with Previous Assessments

This assessment underscores the remarkable transformation and rapid advancement of ZE Class 8 truck technologies since the first feasibility assessment in 2018. In the 2018 feasibility assessment, only one OEM (BYD) offered a pre-commercial Class 8 BET, with no other manufacturers actively selling or delivering vehicles. At that time, range was limited to around 100–150 miles, and there were no commercial-scale production lines. By 2021, this landscape had improved significantly, with seven OEMs introducing pre-commercial or early-commercial BET models, providing ranges between 150 and 230 miles. Production volumes were still low (below 1,000 units per year) but multiple OEMs had announced intent to ramp up manufacturing by 2022. By 2024, BETs had reached full commercial maturity, with seven makes/models commercially available offering ranges between 150 and 330 miles. Certain OEMs offer more than one configurations and fleets now operate dozens of BETs in real-world operations with plans to scale further.

According to the 2018 and 2021 feasibility assessments, FCETs remained in pilot or demonstration stages. No Class 8 FCETs were commercially available, and OEMs were still developing their platforms. The 2021 assessment noted increased activity and intent to commercialize by 2023–2024, but still no FCETs were sold as commercial products. By 2024, the first commercial FCET models had entered the market, with six makes/models available.

While technical and commercial progress has occurred for ZE trucks since 2018, the gap in TCO compared to diesel trucks (excluding incentives) has not meaningfully narrowed. ZE trucks continue to exhibit significantly higher TCOs, primarily driven by high initial vehicle costs, infrastructure expenses, and fuel or energy costs.

Infrastructure availability to support ZE trucks remains limited but has shown notable improvement since previous assessments. In 2018, there was no charging infrastructure for BET, and it remained limited in 2021. Similarly, earlier assessments reported no available hydrogen refueling stations. However, the availability and accessibility of both EV charging infrastructure and hydrogen refueling stations have significantly increased in recent years.

APPENDIX A. Operator Interviews and Survey

Truck Operator Interview Guiding Questions

1. Can you give us an **overview** of the Class 8 trucks you are operating? For example, how many within your national fleet versus those operating solely in Southern California? How many of them are trucks whose service is exclusively providing drayage to/from the Ports?

2. Do you buy mostly new or used trucks? How many years do you usually keep your trucks for?

3. Could you provide us with some general information about your operations? For instance, how many shifts do you operate, what is the duration of each shift, how many trips are made per shift, and what is the typical distance of each trip?
    a. What is the average payload of your trucks operating at the Ports of Los Angeles and Long Beach?

4. Does your fleet operate any zero-emission Class 8 trucks? If yes, how many of your Class 8 zero-emission trucks provide drayage services to the Port of Los Angeles and the Port of Long Beach? How do you operate these trucks (same as your diesel or differently)? Please elaborate.

5. What are the main cost components associated with owning, operating, and dispatching non-zero-emission and/or zero-emission trucks? Could you provide a rough estimate per truck for these components (e.g., fuel costs, maintenance and repair costs, and insurance costs)?

6. For trucks you dispatch to the Ports, do you park and refuel / charge at your facilities overnight?

7. Setting aside the cost and charging & refueling infrastructure accessibility, what do you see as the biggest challenges to transition to ZE trucks?

8. How do you think ZE trucks could impact your operation?

9. [If own/operate ZE trucks] What has been your experience operating zero-emission Class 8 trucks?

10. [If own/operate ZE trucks] Could you describe how you handle maintenance and repairs for these trucks, and how does that compare to the maintenance processes for your diesel trucks?

11. [If own/operate ZE trucks] Have you used any existing public charging infrastructure near the Port? If so, how was your experience?

12. [If own/operate ZE trucks] Have you utilized any incentive programs to purchase ZE Class 8 trucks? For example, California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), utility programs, federal tax credits, etc.

13. Are there any survey questions you want to elaborate on in this interview?

14. Are there any other comments, current challenges, worries, stories you would like to share with us, regarding ZE Class 8 truck operation and charging/refueling?

Truck Operator Survey Questions

This survey is intended to inform the San Pedro Bay Ports' 2024 zero-emission truck feasibility assessment. Through this survey, we plan to gather information on how you are currently operating your fleet of drayage trucks and to understand the opportunities and challenges that transitioning to zero-emission technology presents. Your insights will be invaluable in shaping this round of feasibility assessment and the actions that Port can take to facilitate the transition.

General Information on Truck Fleet

1. How many Class 8 trucks do you operate/dispatch (including trucks operated by contractors)? If you are operating nationally, please select the option that applies to your national fleet.
   - Less than 10
   - 10-20
   - 21-50
   - 51-100
   - 101-250

- o 251-500
- o More than 500

2. How many of those Class 8 trucks that you operate/dispatch are operating in Southern California?
   - o Less than 10
   - o 10-20
   - o 21-50
   - o 51-100
   - o 101-250
   - o 251-500
   - o More than 500
3. Of your trucks that operate in Southern California, please indicate the percentage of trucks whose service includes at least some drayage to/from the Ports.
   - o 0-20%
   - o 21-40%
   - o 41-60%
   - o 61-80%
   - o 81-100%
4. Of your trucks that operate in Southern California, please indicate the percentage of trucks whose service is exclusively providing drayage to/from the Ports.
   - o 0-20%
   - o 21-40%
   - o 41-60%
   - o 61-80%
   - o 81-100%

5. What is your typical monthly fuel cost for the non-zero-emission port trucks that you dispatch?
   $_______per truck per month

6. What is the typical annual maintenance/repair cost of the non-zero-emission port trucks that you dispatch?
   $_______per truck per year

7. What is the typical monthly insurance cost of the non-zero-emission port trucks that you dispatch?
   - o Enter the monthly insurance cost per truck per month:__
   - o We do not have a per-truck insurance cost.
     Please provide an estimated monthly cost for the entire non-zero-emission fleet and explain:

- o Prefer not to say

8. Do you perform maintenance in-house or use third-party services?
   - o In-house
   - o Third party
   - o Both

9. For those trucks <u>serving the ports</u>, please provide your best estimates of the following data points for a typical truck.

   a. How many trips does a truck take to the port on any given day?

   ______ trips

   b. What are the typical trip distances for your trucks (from port to their destination)?

   ______ miles

   c. What is the maximum trip distance that your truck may take (from port to their destination)?

   ______ miles

   d. How many shifts does each truck typically operate per day?
   ______ shifts

   e. What is the maximum number of shifts a truck operates in a day?
   ______ shifts

   f. What is the average number of hours per shift?
   ______ hours

   g. What is the average miles traveled per shift?
   ______ miles

   h. What is the maximum miles traveled per shift?
   ______ miles

i. How many days per week is each truck typically in service?
   ______ days

j. What is the typical loaded operating weight, including cargo, in pounds (lbs.)?
   ______ lbs.

k. What is the maximum loaded operating weight, including cargo, in pounds (lbs.)?
   ______ lbs.

l. Do you use Power Take Off (PTO) for your typical operation?
   - Yes
   - No

10. What percentage of the trucks that you dispatch to the Ports park at one of your facilities overnight?
    - 0-20%
    - 21-40%
    - 41-60%
    - 61-80%
    - 81-100%

11. What percentage of trucks that you dispatch to the Ports refuel at your facilities?
    - 0-20%
    - 21-40%
    - 41-60%
    - 61-80%
    - 81-100%

12. If you own some or all of your trucks, do you typically buy these in new or used condition?
    Please select one:
    - New
    - Used

13. How long do you keep your trucks?
    _____ years

14. If you own some or all of your trucks, what is the average purchase price that you pay for those trucks? Please provide data only for your class 8 non-zero-emission trucks.

- New Non-Zero-Emission Truck Purchase Price:
  $______

- Used Non-Zero-Emission Truck Purchase Price:
  $______

Zero-Emission Trucks

15. Do you operate/dispatch zero-emission Class 8 trucks? Select all that apply.

    - ☐ Battery electric trucks
    - ☐ Hydrogen Fuel Cell trucks
    - ☐ None

    How many of your class 8 trucks that you operate/dispatch are battery electric trucks?

    _____

    How many of your class 8 trucks that you operate/dispatch are hydrogen fuel cell trucks?

    _____

16. How many of your Class 8 zero-emission trucks provide drayage services to the Port of Los Angeles and the Port of Long Beach? Select all that apply.

    - ☐ Battery electric trucks: ______ trucks
    - ☐ Hydrogen Fuel Cell trucks: ______ trucks
    - ☐ None

Question Block A (if they own class 8 zero-emission trucks)

17. What is the average purchase price that you had to pay out of pocket for those trucks? Select all that apply.
    - ☐ Battery electric Trucks Purchase Price:
      $______

- ☐ Hydrogen Fuel Cell Trucks Purchase Price: $______

18. Have you utilized any incentive programs to purchase zero-emission Class 8 trucks? Please select all that apply.
    - ☐ Yes, California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)
    - ☐ Yes, utility programs
    - ☐ Yes, federal tax credits
    - ☐ Yes, other:____
    - ☐ No
    - ☐ Not sure

19. What are the typical daily miles traveled of your zero-emission trucks?

    _____ miles

20. What is the typical annual maintenance cost of your zero-emission trucks?
    $_______per truck per year

21. What is the typical monthly insurance cost of the zero-emission port trucks that you dispatch?
    - o Enter the monthly insurance cost per truck per month: __
    - o We do not have a per-truck insurance cost.
      Please provide an estimated monthly cost for the entire zero-emission fleet and explain: ___
    - o Prefer not to say

22. Do you typically charge your battery electric trucks at your own facility?
    - o Yes
    - o No

23. Have you used the existing public charging infrastructure near the port?
    - o Yes
    - o No

24. How do you evaluate your experience?
    - o Satisfied
    - o Neutral
    - o Dissatisfied

Question Block B (for all respondents)

25. Do you own your facility or lease it?
    - o Own
    - o Lease
    - o Not applicable

26. Do you have sufficient space at your typical facility to deploy fueling/charging infrastructure?
    - o Yes.
      Please provide any additional details or comments on the space availability: ___
    - o No
    - o Not sure

27. What do you perceive as major challenges in operating zero-emission Class 8 trucks? Please select the top three:
    - ☐ Range limitations
    - ☐ Infrastructure availability
    - ☐ Infrastructure costs
    - ☐ Power availability/Ability of the grid to support zero-emission trucks
    - ☐ Leasing or owning facilities, including obtaining permission to install infrastructure
    - ☐ Refueling/recharging times
    - ☐ Payload capacity
    - ☐ Battery lifetime
    - ☐ Fuel costs
    - ☐ Maintenance costs
    - ☐ Insurance costs
    - ☐ Limited financial incentives
    - ☐ Driver comfort
    - ☐ Other (please specify): ___________

Comments

28. How do you anticipate zero-emission trucks will impact your operations?

29. What changes do you foresee needing to make in your operations to accommodate zero-emission trucks?

30. What kind of support or collaboration do you need from manufacturers, policymakers, and other stakeholders to successfully transition to zero-emission trucks?

31. Do you have any additional comments? Please include any thoughts on what might have been missed or other factors to consider.

32. If you are willing to provide further contact details for follow-up purposes, please enter your contact information below. This is entirely optional, and your responses will remain confidential.

    Full Name: ___________

    Position:____

    Email Address:___________

Thank you for taking the time to complete this survey. Your input is greatly appreciated

APPENDIX B. OEM Interviews and Surveys

OEM Interview Guiding Questions

1. Can you please describe your current ZE offerings and plans for future ZE expansion if any?

2. To the extent possible, can you let us know if you have any existing/pending orders of these offerings from customers at the Ports of Los Angeles and Long Beach? If yes, can you give us a range of orders? (e.g., <50, 50–100, 100+)
    a. What level of demand do you expect for ZE Class 8 trucks statewide and outside of CA?

3. To the extent possible, can you tell us more about your existing and potential future production capacity of your ZE Class 8 trucks? In other words, how many ZE trucks do you think you can deliver in 2024/2025 period? What are the expectations over the next 5 years?
    a. How do you plan to scale up manufacturing?

4. If you have not responded to our survey, can you help us with the following data points:
    a. Approximate MSRP for each of your Class 8 ZE offerings
    b. Range
    c. Approximate payload capacity (excluding the curb weight of the power unit itself)
    d. Maximum acceptable charging power (in kW)
    e. Are you actively pursuing megawatt charging integration into your vehicles? If so, when do you expect to have that on your trucks; and if not, can you tell us why?

5. What do you think are the biggest challenges for deployment of zero-emission Class 8 trucks in drayage application today? (e.g., performance, cost, infrastructure, lack of service support, etc.)

   a. Do you have any plans to improve the range of your vehicles?
   b. How do you and OEMs support customers whose vehicles are experiencing issues?
   c. What kind of warranties are you providing?
   d. How do you minimize the downtime for ZE Class 8 trucks?

6. What are your expectations for the **future** of zero-emission Class 8 trucks? For example, its price, weight, and charging / refilling time.

7. What are your views on the (Build America, Buy America) BABA Act requirements? Are there any challenges you are expecting? Are you complying with BABA requirements for ZE trucks?
   a. Do you have any plans expanding manufacturing in the U.S.?

8. Can you tell us more about ZE Class 8 truck charging infrastructure now? Do you have any programs in place to assist customers with charging and facility upgrades?

9. If possible, could you please share couple of useful feedback that you received from customers using your zero-emission trucks?

10. Are there any survey questions you want to elaborate on in this interview?

11. Do you have any additional thoughts you would like to share with us about Class 8 truck feasibility at the Ports? It can be anything you want to stress or things that people usually fail to fully consider or discuss enough in their conversations around ZE transition for Class 8 trucks.

OEM Survey Questions

The purpose of this survey is to gather information from Original Equipment Manufacturers (OEMs) to assess the commercial viability of zero-emission Class 8 trucks specifically for transitioning drayage trucks operating at the Ports of Los Angeles and Long Beach to zero-emission. These questions are intended to understand your current and potential future offerings, as well as your manufacturing capabilities in meeting the potential market demand for zero-emission drayage trucks.

Current ZE Truck Offerings

What types of zero-emission Class 8 trucks do you currently offer? Please select all that apply.

- ☐ Battery Electric:
- ☐ Hydrogen Fuel Cell Electric:
- ☐ None

How many battery electric Class 8 truck models do you currently offer?

_____

How many hydrogen fuel cell electric Class 8 truck models do you currently offer?

_____

Future ZE Truck Offerings

What types of zero-emission Class 8 trucks are you planning to introduce in the next 5 years? Please select all that apply.

- ☐ Battery Electric Trucks (BETs): _____models
- ☐ Hydrogen Fuel Cell Electric Trucks (FCETs): ____models
- ☐ None
- ☐ Not sure

How many BET models are you planning to introduce in the next 5 years?

_____

How many FCET models are you planning to introduce in the next 5 years?

_____

Do you expect the prices (MSRP) of future zero-emission Class 8 trucks to be:

- Lower than current models
- About the same as current models
- Higher than current models

Technology Characteristics

What is the maximum payload capacity of your Class 8 Battery Electric Trucks (BETs) in pounds (lbs.)?

____

What is the maximum payload capacity of your Class 8 Fuel Cell Electric Trucks (FCETs) in pounds (lbs.)?

____

What is the maximum allowable charging rate for your existing BETs?

____ kW

How fast can your FCET trucks be filled in?

___ min

Commercial Availability

How many zero-emission Class 8 trucks have you delivered to customers to date?

- None
- Fewer than 50
- 50 to 100
- 101 to 500
- More than 500

What is the typical delivery time for your zero-emission Class 8 trucks from the date of order placement?

____ months for BETs

____ months for FCETs

How many zero-emission class 8 trucks can you currently deliver per month?

____ units of BETs

____ unit of FCETs

Do you have existing (confirmed) or pending (awaiting finalization) orders for zero-emission Class 8 trucks? Select all that apply.

- ☐ Yes, existing orders:
- ☐ Yes, pending orders:
- ☐ No
- ☐ Not sure

How many existing and/or pending orders for zero-emission Class 8 trucks do you have?

____ existing orders

____ pending orders

What is the typical warranty period for your zero-emission Class 8 trucks compared to diesel Class 8 trucks?

____ Years or _________ miles whichever comes first for BETs

____ Years or _________ miles whichever comes first for FCETs

Challenges Faced and Factors Affecting Production

What do you perceive as the primary challenge in producing zero-emission Class 8 trucks? (Select the top three)

- ☐ High production costs
- ☐ Lack of demand
- ☐ Limited availability of key components
- ☐ Supply chain disruptions
- ☐ Technological limitations

- ☐ Difficulty in scaling production
- ☐ Other (please specify):____

What are the key factors that influence the decision to scale production of zero-emission Class 8 trucks? (Select all that apply)

- ☐ Market demand
- ☐ Availability of components
- ☐ Production capacity
- ☐ Investment in technology
- ☐ Government incentives
- ☐ Other (please specify):____

BABA Requirements

What challenges do you anticipate in meeting the Build America, Buy America (BABA) requirements for your zero-emission trucks? (Select all that apply)

- ☐ Production costs
- ☐ Supply chain
- ☐ Production timelines
- ☐ Other (please specify):___

To what extent do the BABA requirements impact cost estimates for producing zero-emission trucks?

- o More than 10%
- o Between 5–10%
- o Less than 5%
- o No impact
- o Other (please specify):___

How do BABA requirements affect the ability to source materials for zero-emission trucks?

- o Significantly hinder
- o Moderately hinder
- o Slightly hinder
- o Do not hinder
- o Other (please specify):___

How do BABA requirements influence production timelines for zero-emission trucks?

- o Extend timelines by more than 6 months

- Extend timelines by 3-6 months
- Extend timelines by less than 3 months
- No impact on timelines
- Other (please specify):___

What is your current level of compliance with BABA requirements for zero-emission trucks?

- Fully compliant
- In the process of becoming compliant
- Not compliant yet

Port-specific

Do you have existing (confirmed) or pending (awaiting finalization) orders for zero-emission Class 8 drayage trucks from customers at the Ports? Select all that apply.

- ☐ Yes, existing orders
- ☐ Yes, pending orders
- ☐ No
- ☐ Not sure

Do you think your zero-emission trucks are capable of meeting the operational requirements for drayage at the Ports?

- Yes
- No
- Unsure

Do you have programs in place to assist customers with charging infrastructure and facility upgrades?

- Yes
- No
- Unsure

Comments

What feedback have you received from customers using your zero-emission trucks?

Do you have any additional comments? Please include any thoughts on what might have been missed or other factors to consider.

If you are willing to provide further contact details for follow-up purposes, please enter your contact information below. This is entirely optional, and your responses will remain confidential.

Full Name: _____________

Position:_______________

Email Address:___________