EPRI

2024 TECHNICAL UPDATE

Battery Electric Truck Status Technical Memo

Electric Truck Research and Utilization Center (eTRUC) Project (Task 3.2)

CALSTART

eTRUC

Battery Electric Truck Status Technical Memo

Electric Truck Research and Utilization Center (eTRUC) Project (Task 3.2)

3002029229

Technical Update, June 2024

eTRUC Project Managers
A. Rogers, EPRI
N. Fernandez, CALSTART

eTRUC Principal Investigators
W. Collins, EPRI
J. Tomic, CALSTART

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

DISCLAIMER OF WARRANTIES AND LIMITATION OF LIABILITIES

THIS DOCUMENT WAS PREPARED BY THE ORGANIZATION(S) NAMED BELOW AS AN ACCOUNT OF WORK SPONSORED OR COSPONSORED BY THE ELECTRIC POWER RESEARCH INSTITUTE, INC. (EPRI). NEITHER EPRI, ANY MEMBER OF EPRI, ANY COSPONSOR, THE ORGANIZATION(S) BELOW, NOR ANY PERSON ACTING ON BEHALF OF ANY OF THEM:

(A) MAKES ANY WARRANTY OR REPRESENTATION WHATSOEVER, EXPRESS OR IMPLIED, (I) WITH RESPECT TO THE USE OF ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT, INCLUDING MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, OR (II) THAT SUCH USE DOES NOT INFRINGE ON OR INTERFERE WITH PRIVATELY OWNED RIGHTS, INCLUDING ANY PARTY'S INTELLECTUAL PROPERTY, OR (III) THAT THIS DOCUMENT IS SUITABLE TO ANY PARTICULAR USER'S CIRCUMSTANCE; OR

(B) ASSUMES RESPONSIBILITY FOR ANY DAMAGES OR OTHER LIABILITY WHATSOEVER (INCLUDING ANY CONSEQUENTIAL DAMAGES, EVEN IF EPRI OR ANY EPRI REPRESENTATIVE HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES) RESULTING FROM YOUR SELECTION OR USE OF THIS DOCUMENT OR ANY INFORMATION, APPARATUS, METHOD, PROCESS, OR SIMILAR ITEM DISCLOSED IN THIS DOCUMENT.

REFERENCE HEREIN TO ANY SPECIFIC COMMERCIAL PRODUCT, PROCESS, OR SERVICE BY ITS TRADE NAME, TRADEMARK, MANUFACTURER, OR OTHERWISE, DOES NOT NECESSARILY CONSTITUTE OR IMPLY ITS ENDORSEMENT, RECOMMENDATION, OR FAVORING BY EPRI.

THE FOLLOWING ORGANIZATIONS PREPARED THIS REPORT.

EPRI
CALSTART
Cambridge Systematics
Southern California Association of Governments (SCAG)

CALIFORNIA ENERGY COMMISSION LEGAL NOTICE

THIS REPORT WAS PREPARED AS A RESULT OF WORK SPONSORED BY THE CALIFORNIA ENERGY COMMISSION (CEC). IT DOES NOT NECESSARILY REPRESENT THE VIEWS OF THE COMMISSION, ITS EMPLOYEES, OR THE STATE OF CALIFORNIA. THE COMMISSION, THE STATE OF CALIFORNIA, ITS EMPLOYEES, CONTRACTORS, AND SUBCONTRACTORS MAKE NO WARRANTY, EXPRESS OR IMPLIED, AND ASSUME NO LEGAL LIABILITY FOR THE INFORMATION IN THIS REPORT; NOR DOES ANY PARTY REPRESENT THAT THE USE OF THIS INFORMATION WILL NOT INFRINGE UPON PRIVATELY OWNED RIGHTS. THIS REPORT HAS NOT BEEN APPROVED OR DISAPPROVED BY THE COMMISSION, NOR HAS THE COMMISSION PASSED UPON THE ACCURACY OR ADEQUACY OF THE INFORMATION IN THIS REPORT.

This is an EPRI Technical Update report. A Technical Update report is intended as an informal report of continuing research, a meeting, or a topical study. It is not a final EPRI technical report.

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at 800.313.3774 or e-mail askepri@epri.com.

Together…Shaping the Future of Energy®

ACKNOWLEDGMENTS

The following organizations prepared this report:

EPRI
3420 Hillview Avenue
Palo Alto, CA 94304

Author
K. Lim

CALSTART
48 S Chester Ave
Pasadena, CA 91106

Authors
E. Hellier
T. Chi

Cambridge Systematics
515 S. Figueroa Street, Suite 1975
Los Angeles, CA 90071

Author
S. Zneimer

Southern California Association of Governments (SCAG)
3403 Tenth Street #805
Riverside, CA 92501

Author
J. Raspa

This report describes research sponsored by EPRI and California Energy Commission (CEC) under Grant Agreement EPC-21-010.

This publication is a corporate document that should be cited in the literature in the following manner: *Battery Electric Truck Status Technical Memo: Electric Truck Research and Utilization Center (eTRUC) Project (Task 3.2).* EPRI, Palo Alto, CA: 2024. 3002029229.

ABSTRACT

The Electric Truck Research and Utilization Center (eTRUC), California's premier research hub for electric technologies in truck applications, aims to accelerate the commercial adoption of the high-power, combined charging system (CCS) and megawatt (MW)-level technologies in heavy-duty (HD) drayage trucks.

The Battery Electric Vehicle (BEV) Truck Status Technical Memo aims to provide a complete and accurate picture of current studies, reports, available data, and original equipment manufacturer (OEM) truck information related to truck technology readiness collected throughout the eTRUC project. This Memo provides a basis of knowledge to be incorporated into the final Fleet Charging Infrastructure Needs and Technology Maturity Assessment.

This memo reviews relevant studies, tools, assessments, and other resources to describe fleet operational needs, and assess the market status of Battery-Electric Trucks (BETs), high-power charging equipment, and supporting infrastructure. A comprehensive literature review was conducted to assess technology innovation and market readiness for Megawatt Charging System (MCS) integration. The memo will feed into the overall Fleet Charging Infrastructure Needs and Technology Maturity Assessment.

Keywords

Electric vehicles (EVs)
Battery-electric vehicles (BEVs)
Heavy-duty vehicles (HD vehicles)
High-power charging
Megawatt charging system (MCS)
Electric vehicle supply equipment (EVSE)

ACRONYM/TERM LIST

Acronym/Term	Meaning
ACT	Advanced Clean Trucks
BaaS	Battery-as-a-service
BET	battery-electric truck
BEV	Battery Electric Vehicle
CAAP	Clean Air Action Plan
Caltrans	California Department of Transportation
CARB	California Air Resources Board
CCR	California Code of Regulations
CCS	combined charging system
CHE	cargo handling equipment
CSF2TDM	California Statewide Freight Forecasting and Travel Demand Model
DOT	Department of Transportation
EEI	Edison Electric Institute
EER	energy efficiency ratio
EMFAC	Emission FACtors
eTRUC	California's Electric Truck Research and Utilization Center
EV	electric vehicle
FAF	Freight Analysis Framework
GHG	Greenhouse gas
GREET	Greenhouse gases, Regulated Emissions, and Energy use in Technologies
HD	heavy-duty
HEVI-Pro	Heavy-Duty Electric Vehicle Infrastructure Projections
HEVIPro/HEVILoad	Medium- and Heavy-Duty Electric Vehicle Infrastructure Projections
ICCT	International Council on Clean Transportation
ISO	International Organization for Standardization
JMC	Jiangling Motors Corporation Limited
kWh	kilowatt-hour
LBNL	Lawrence Berkeley National Laboratory
LE	low-emission
LFP	lithium iron phosphate
LIGHTS	Low Impact Green Heavy Transport Solutions

Acronym/Term	Meaning
MCS	Megawatt Charging System
MD-HD	medium duty and heavy duty
MHDV	medium- and heavy-duty vehicle
NMC	nickel manganese cobalt oxide
NREL	National Renewable Energy Laboratory
NZEV	Near Net Zero Emission vehicles
OEM	Original Equipment Manufacturer
PEVs	plug-in electric vehicles
PGE	Portland General Electric
POLA	Port of Los Angeles
SPBP	San Pedro Bay Ports
TEMPO	Transportation Energy & Mobility Pathway Options
ZANZEFF	Zero-Emission and Near Zero-Emission Freight Facilities
ZE	zero-emission
ZE-MHDV	zero emission medium- and heavy-duty vehicle
ZETI	Zero-Emission Technology Inventory

EXECUTIVE SUMMARY

California's Electric Truck Research and Utilization Center (eTRUC) is a stakeholder-driven consortium of industry, government, academia, and community partners committed to the development, advancement, and deployment of innovative HD high-power charging infrastructure along key freight corridors that promote the adoption of Class 7 and 8 battery electric zero-emission (ZE) trucks. This project is intended to support planning, research, design, and deployment of innovative high power public corridor charging strategies that will extend the range and increase the operational flexibility of HD battery electric trucks beginning with an initial focus on drayage operations. The Battery Electric Vehicle (BEV) Truck Status Technical Memo summarizes relevant studies, available data, and OEM and Tier 1 suppliers' interview results to provide better understanding of the current technology capabilities and the expected path to support megawatt charging.

The memo aims to provide a comprehensive literature review of current studies, pilot programs and investment to assess the market status of BETs, high-power charging equipment and supporting infrastructure. Key takeaways include:

- California is leading the market in the U.S. but practitioners should look for technology solutions and lessons learned from outside the United States. For instance, European counterparts are developing high-power charging technology and are in the process of deploying pilots, therefore it is important to monitor and understand lessons learned. China is also developing high-power charging; however, they are also exploring battery swapping as alternatives.
- HD long-haul trucks are the least attractive modes for zero emission vehicle adoption and will require policy changes and financial incentives to drive change. Investments along high demand freight routes should be prioritized to quickly accommodate the needs of long-haul trucks.
- The number of EV medium duty and heavy duty (MD-HD) vehicles models available and number of EVs purchased continue to raise domestically and internationally.
- High-power charging infrastructure is being developed nationally and internationally, it will be important to establish a standard like the MCS that works in China, Europe, and North America.
- Improvements in battery technology is helping develop lighter, longer lasting, more stable, and better compatibility for fast/high-powered charging.
- Diversifying the materials used to develop batteries beyond existing lithium batteries could help aid in the transition to decarbonized vehicles and make supply chains more resilient.

Planning for MCS deployment is essential when assessing the scale of transformation needed to HD charging needs. MCS will need to be rolled out at scale and require significant amounts of power and investment to meet this anticipated demand. Key industry stakeholders such as Tier 1 suppliers and truck OEMs are currently monitoring and planning to integrate MCS as early as 2030. Financial incentives should be invested to drive businesses into developing public charging options to accommodate MCS. With the assessment of technology and market readiness completed, the next phase of eTRUC will be focused on utilizing the above assessment of technology readiness into corridor deployment planning.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

This section reviews relevant studies, tools, assessments, and other resources to describe fleet operational needs, and assess the market status of BETs, high-power charging equipment, and supporting infrastructure.

As with the many regulatory and planning efforts to accelerate the transition of MD-HD trucks to ZEVs, there have already been a myriad of studies, pilot programs, and investments that evaluated the feasibility of ZE technology in MD-HD fleet operations in California (Table 1, on next page).

This review is split into two main sections: Needs and Market Status. The Needs section summarizes reports, studies, and estimates done to see how many medium- and HD trucks might be needed to meet state mandates, and the supporting infrastructure. The Market Status section talks about existing fleet models and charging technology, San Pedro Ports, Infrastructure readiness from the utility side, and existing pilots and deployments.

Table 1. Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Assembly Bill 2127 Second Electric Vehicle Charging Infrastructure Assessment: Assessing Charing Needs to Support Zero-Emission Vehicles in 2030 and 2035	2024	CEC	Examines charging needs to support California's plug-in electric vehicles (PEVs) in 2030 and 2035. The report finds additional 114,500 chargers are needed to support the 157,000 medium- and HD vehicles (MHDV) anticipated for 2030.
Advanced Clean Truck Credit Summary Through the 2022 Model Year	2023	CARB	Summary of annual vehicle sales data in California reported by manufacturers, credit balances, and credit transactions as required by the Advanced Clean Trucks (ACT) regulation (title 13, California Code of Regulations (CCR) section 1963.5).
California Freight Mobility Plan 2023	2023	Caltrans	Statewide plan governing California's immediate and long-range freight planning activities and capital investments.
Global Zero-Emission Truck and Bus Market Update June 2023	2023	CALSTART	Semi-annual report that provides insight into the fast-developing zero emission medium- and HD vehicle (ZE-MHDV) market. This report is intended to assist stakeholders and decisionmakers in implementing technology-driven strategies by highlighting salient trends for ZE-MHDVs.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
SB 671 Clean Freight Corridor Efficiency Assessment	2023	CTC	Identifies 34 priority freight corridors and "top 6" corridors for recommended initial focus, based on freight volume and air pollution impacts.
Near-Term Infrastructure Deployment to Support ZE MDHD Vehicles in the US	2023	ICCT	Report analyzes charging infrastructure needs for the transition to ZE MHDVs. In the near-term, California and Texas are standout priorities for infrastructure deployment, while other large metropolitan areas are next. As the market develops, deploying charging infrastructure along corridors that connect large industrial hubs, or metropolitan areas, will accommodate up to 85% of the charging needs for long-haul trucks.
Global EV Outlook 2023	2023	International Energy Agency	Analyzes the financial performance of EV-related companies, venture capital investments in EV-related technologies, and trade of electric vehicles (EVs). Finally, the report makes available two online tools: the Global EV Data Explorer and Global EV Policy Explorer, which allow users to interactively explore EV statistics and projections, and policy measures worldwide.
Locking in ZEV Charging Infrastructure	2023	CALSTART / Government of the Netherlands	Describes ten success factors to ensure charging infrastructure for commercial vehicles is developed at the speed required able to satisfy fleet needs.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Vehicle and Mobility Technologies 2023 Annual Impact Report	2023	National Renewable Energy Laboratory (NREL)	This report focuses on emerging technologies/projects/studies across the US that are relevant to clean energy transportation that NREL is participating in. The most relevant projects mentioned in the report: • NREL study of truck electrification at the ports of New York/New Jersey for drayage movements • 21st Century Truck Partnership report "Changing Needs for Electric Semi-Trailer Trucks" • Electric Power Research Institute Partnership Advances HD BETs Shell Energy and NREL's Novel Aging Experiments Support Electrification of HD Vehicles and More Quickly Map Degradation Physics
Connect SoCal 2024 The 2024–2050 Regional Transportation Plan/Sustainable Communities Strategy, Goods Movement Technical Report	2024	SCAG	Goods Movement Technical Report, offers a broad overview of goods movement in Southern California by defining what the goods movement system is, including its most critical components; highlighting its importance and connections to the economy and local industrial sectors; summarizing international and domestic trade flows and their relations to the region; addressing environmental and air quality issues; articulating a regional vision and how it can be achieved; and illustrating the path to 2045 by promoting an effective set of regional strategies.
Zero-Emission Drayage Trucks – Feasibility Assessment for Drayage Trucks	2023	Tetra Tech / Gladstein, Neandross & Associates	Provides 2021 Feasibility Assessment for Drayage Trucks. Infrastructure availability for BEV charging is assessed by 4 criteria: dwell time at station, station location and footprint, infrastructure buildout, existence of/compatibility with standards. Given the uncertainties and challenges, it is highly unlikely that a full-scale charging infrastructure for drayage trucks could be built and operational by 2024.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Zero-Emission Planning and Grid Assessment for the Port of Los Angeles (POLA)	2023	EPRI	Ports, including POLA, are aiming to reduce greenhouse gas (GHG) emissions and local air-quality impacts. However, electrification of cargo handling equipment (CHE) at ports poses technical challenges. Lithium-ion battery technology costs are currently high, and technology availability is limited. Demonstrations of new electric technologies at the ports are in process, but widespread adoption has not yet been achieved. Complying with regulatory requirements and responding to local resolutions, including a mandate for ZE CHE by 2030 at POLA, places challenges. POLA needs to maintain its competitiveness, while overcoming technical complexities and ensuring response and compliance. Another important topic this project addresses is the need to understand the grid impact of supplying the ZE (electric) CHE equipment.
Electric Vehicle Sales and the Charging Infrastructure Required through 2030	2022	Edison Electric Institute (EEI)	Focuses on light duty vehicles sales and supporting technologies including the battery development and charging infrastructure.
Charging Solutions for Battery Electric Trucks	2022	ICCT	Provides an overview of charging solutions for BETs, their cost, and timeline for implementation. Additionally, electricity demand and grid impacts are estimated in two case studies of Germany and the United States, emphasizing the need for upfront planning and grid upgrades, and the potential of smart charging. Finally, the paper catalogs and synthesizes lessons from policies and pilot programs across China, Europe, and North America.
Clean Truck Technology Comparative Report	2022	LA Metro	Report that 1) describes current state of fueling infrastructure technology for diesel, natural gas, EV supply equipment, and hydrogen in LA County, 2) models the projected energy and fueling needs to charge LA County's HD truck fleet, 3) projects costs to transition to alternative fuel types.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Transportation Energy Data Book (2021)	2022	Oak Ridge National Laboratory	This book is meant to be used as a reference guide for statistical info regarding US vehicles and energy usage covering many different topics. Most relevant chapters are Chapter 5 Heavy Vehicles and Characteristics; Chapter 6 Alternative Fuel and Advanced Technology Vehicle and Characteristics; Chapter 8: Fleet Vehicles and Characteristics. In general, info is not always available by vehicle class or state. The information on fleets is mostly focused on the federal fleet.
Volvo Lights Guidebook (2022)	2022	Volvo Group North America	The Volvo LIGHTS project aimed to design a blueprint to introduce zero-tailpipe emission BETs and equipment into the market at scale. The guidebook suggests that the fleet, OEM, and dealer should work together to understand a fleet's operational details and identify ideal customer routes, and that fleets consider a good mix of high- and low- power DC fast-charging stations with futureproofing charging solutions. To build public charging infrastructure, existing state laws must first allow entities other than existing utilities to re-sell electricity to ZE truck owners.
Fueling the Future Fleet: Assessment of Public Truck Charging and Fueling Near the Port of Long Beach (2021)	2021	Port of Long Beach	The purpose of this study is two-fold: (1) to identify the opportunities and challenges associated with deploying public charging and fueling infrastructure near the Port and specifically within the Harbor District, and (2) to establish a framework by which the Port can evaluate potential charging or fueling sites going forward. Although faster charging rates are on the horizon, the truck manufacturers are not yet designing to those standards.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
SPBP Feasibility Assessment for Drayage Trucks	2023	Port of Long Beach, The Port of Los Angeles	The Ports of Long beach and Los Angeles have set a goal to transition to 100% ZE drayage truck fleet by 2035. This report assesses the deployment of publicly hydrogen accessible electric and infrastructure including challenges and opportunities of building public ZE infrastructure near the Port.
Zero-Emission Medium- and Heavy- duty Truck Technology, Markets, and Policy Assessments for California	2020	University of California Institute of Transportation Studies	This report assesses ZE-MHDV technologies, their associated costs, projected market share, and possible policy mandates and incentives to support their adoption in California. It conducts an economic analysis of transitioning to ZE technologies by vehicle type, finding that long-haul trucking is one of the least attractive modes for adoption. It provides recommendations to match the economic incentives to transition by each vehicle type and category.
California's Advanced Clean Trucks Regulation: Sales Requirements for Zero-Emission Heavy-Duty Trucks	2020	CARB	Policy updates from the California Air Resources Board (CARB) on the new standards and requirements for ZE HD trucks starting in 2024.
West Coast Clean Transit Corridor Initiative – Report and Tech Memo	2020	HDR	An ongoing collaborative effort among 16 utilities to support the development of EV charging facilities for heavy- and medium-duty freight and deliver trucks along I-5 from San Diego to British Columbia. The 2020 report provides their initial assessment and recommendations.
Medium- and Heavy-Duty Electric Vehicle Infrastructure Projections (HEVIPro/HEVILoad)	2020	LBNL / CEC	PowerPoint presentation on Medium-and HD Electric Vehicle Infrastructure Projections (HEVI-Pro) presenting on August 8, 2020 by the Lawrence Berkeley National Laboratory (LBNL) to the California Energy Commission. Presented by Bin Wang, Ph.D., Research Scientist. They present preliminary findings on the energy consumption needs of medium and HD EVs in the state of California.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Southern California Edison's Blueprint for Integrated Electrification	2019	IEEE Electrification Magazine	Southern California Edison conducted decarbonization scenarios in order to meet electricity demands. The paper focuses on how SCE can reach 100% carbon-free energy by 2045 and procure 50% of energy from renewable sources by 2026.
Comparison of MDHD technologies in CA	2019	ICF	The report considers scenarios that would bring California in line with its own public health goals through the adoption of alternative fuels for Med and Heavy Duty vehicles. The report looks at three different impacts emissions, total cost of ownership for operators, overall economic impacts for the state. The main takeaways are: • a large amount of medium/heavy duty electrification is necessary for California to meets its own health/emission goals • Electric trucks are currently too expensive for owners without the intervention of policy incentives though this likely won't be the case by 2030 assuming ongoing price reduction in EVs and increase costs of traditional diesel fuel Investments in electrification are more likely to have local economic impacts within CA and have net positive benefits in terms of state income and overall employment (assuming a pretty high ratio of job creation)

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Developing Markets for Zero Emission Vehicles in Goods Movement	2018	Genevieve Giuliano et al	This multifaceted study investigates the benefits and barriers to adoption of electric HD vehicles for short drayage trips (moving goods from a port to a warehouse or some other intermediate facility). The study models a regular day of operation using traditional trucks and EVs, case studies of actual truck companies, interviews with EV manufacturers and operators who are demoing EV vehicles, and a series of surveys. In 2020, models suggest EVs could replace about 75% of traditional trucks at a port and in 2030, due to expected improvements in charging times and efficiency, about 96%.
Battery Electric Truck and Bus Energy Efficiency compared to conventional Diesel Vehicles	2018	CARB	Compares the energy usage, measured by the energy efficiency ratio (EER), from battery electric trucks and buses when compared to energy usage from similar conventional diesel vehicles operated in the same duty cycle.
Medium-Duty Electric Trucks: Cost of Ownership	2018	North American Council for Freight Efficiency	Analyzes the cost of ownership through interviews of people with firsthand knowledge of Medium Duty Commercial BEVs at fleets, OEMs, industry groups and agencies. It concludes that more miles of fleet use are needed to predict performance, maintenance costs, residual markets, and other key factors with confidence. Additionally, early fleet adopters will be better positioned to take advantage of future improvements in technology and drive innovation.
California Sustainable Freight Action Plan	2016	Caltrans	Action plan intended to integrate investments, policies, and programs across several California state agencies to help realize a sustainable freight transport system.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
California Statewide Freight Forecasting and Travel Demand Model (CSF2TDM)	NA	Caltrans	The California Department of Transportation (Caltrans) has developed the CSF2TDM to provide Caltrans and other transportation partners with an advanced multi-modal tour/activity-based travel demand model that forecasts short and long distance travel by California residents as well as all commercial vehicle travel throughout the state. CSF2TDM is fully integrated to capture passenger and freight trips together.
The Zero-Emission Technology Inventory (ZETI) tool	NA	CALSTART/ Government of the Netherlands	The ZETI tool is an interactive online resource to establish a current and shared knowledge base for worldwide commercially available offerings of MHDVs. The tool aims to provide fleets and governments with comprehensive information including regions where ZE brands are available for purchase, and the timeline over which additional models are expected to become available. Commercial availability is defined as availability for immediate production based on placed orders.
Emission FACtors (EMFAC)	NA	CARB	This tool features: • Emissions inventory – On road and offroad mobile sources estimated from models, available at various geographies, years 2000-2050, vehicle categories • Project Analysis - Emissions rates based on user-provided meteorological conditions. • Scenario Analysis – On road emissions based on user-provided vehicle activities Fleet Database - vehicle population estimates for California at CBG level, based on vehicle registration data from CA DMV.

Table 1 (continued). Summary of relevant studies, tools, and assessments

Document	Year	Author	Details
Argonne National Laboratory GREET Tool	NA	Argonne National Laboratory	Simulates energy use and emissions output of various vehicle and fuel combinations including road, air marine and rail. Considers the full life cycle - from well to wheels for fuels and from raw material mining to vehicle disposal for automobiles.
Port of Los Angeles Demonstration Projects	NA	Port of Los Angeles	Funding for cargo-handling BEV equipment like tractors and forklifts and their associated charging infrastructure, not charging infrastructure for trucks

Source: Cambridge Systematics and Southern California Association of Government staff.

2 EXISTING NEEDS ASSESSMENTS

MD-HD ZE technology encompasses a wide variety of vehicle types, applications, and infrastructure needs. The technological development, commercial readiness, and cost-effectiveness of the various segments are evolving differently. This section first provides an overview of the considerations industry, government, and others need to consider assessing the transition needs, then provides a snapshot of work done nationally, then at the state level, and finally looks at different tools that have been developed to assess need.

The Locking in ZEV Charging Infrastructure Report[1] (created in partnership between CALSTART and the Government of New Zealand) identifies three immediate priorities for transitioning to ZE technology: 1) Set long-term targets and regulations to drive ZE commercial vehicle adoptions, 2) Establish a governance structure that can assign responsibilities and accelerate deployment; and 3) identify future electricity needs and develop long-term plans that ensure the grid is ready to satisfy future demand. It also identifies ten success factors that are needed in order to complete the transition:

1. Electric trucks are on the market to create demand.
2. Plans to increase charging infrastructure are in place.
3. Grid connections and upgrades respond to demand.
4. Land slots are made available for charging sites.
5. Permitting is accelerated while maintaining safeguards.
6. Charging infrastructure and services are operational.
7. Data for planning and construction of charging infrastructure and related grid connections are available, accessible and shared. This includes: truck movements, charging points availability, and grid usage.
8. Business and finance models support the transition.
9. Broader social, economic and environmental effects are managed. These include circular economy system for e-trucks, batteries, and equipment, just transition that addresses the social and economic effects of the switch to e-trucks, supply chain resilience to geopolitics, climate impacts, and other disruptions.
10. Stakeholders are informed and collaborate.

[1] https://globaldrivetozero.org/site/wp-content/uploads/2023/11/Locking-in-ZEV-Charging-Infrastructure_FINAL.pdf

National Needs Assessment

In the United States, California is a leader in Zero Emission MHD vehicle readiness and deployment.

ICCT Charging Solutions for BETs (2022) provides an overview of charging solutions for BETs, their cost and timeline for implementation. It highlighted that early electric trucks have relied on light-duty infrastructure, but more powerful standards are ready for commercialization to aid both overnight and opportunity charging. Additionally, novel alternatives to wired stationary charging are being tested to increase flexibility. These alternatives of battery swapping, wireless charging, or overhead catenary charging could reduce charging downtime and reduce the upfront costs of BETs due to reduced battery size.

In response to national interest in decarbonizing these fleets, the International Council on Clean Transportation (ICCT) published a working paper on the infrastructure needed to support a 100% ZE tractor-trailer fleet in the United States by 2040. Due to the nature of the fleet movements, the paper uses depot charging for battery-powered short-haul tractor-trailers as the starting point for transitioning to BEVs. They imagine these vehicles would depot charge overnight and have additional charging points at regular trip locations like distribution centers. Acknowledging that not all vehicle operators have the resources and space to house charging depots, they also project the need for a network of publicly accessible charging points. The working paper considers both battery-electric and hydrogen trucks. Their methodology assumes that California would be the first state to transition to all ZE sales (due to having the most stringent executive orders and laws in effect) and that other states would follow. They propose 100% sales of short-haul tractor trailers in California would be ZE by 2030 (2040 in the remaining states) and 100% of long-haul trailers by 2035, and that combustion engines would be used until the end of their lifecycle.

The ICCT report identifies a lag between sales of new vehicles and changes in the in-use fleet, projecting that by 2030 there will only be 100,000 ZE tractor-trailers (or just 3.3% of the vehicles nationwide) requiring 127,000 charging points and 220 hydrogen refueling stations. By 2050 they expect a greater percentage of ZE vehicles operating – 2.4 million vehicles, making up 78% of the total fleet – requiring 2.5 million charging points and almost 7,000 hydrogen fueling stations nationwide. They estimate this as a $122 billion investment. Notably they did not consider other necessary infrastructure costs like upgrades to the electric grid.

Other current efforts focus less on infrastructure needs, and more on what building infrastructure might do to vehicle adoption. For example, the Transportation Energy & Mobility Pathway Options (TEMPO) model was developed by the NREL, to explore and test different incentives and variables for adopting renewable energy in transportation. Their aim is to provide a holistic look at the transportation ecosystem and travel needs to see what different investments – like EV infrastructure incentives – might do to passenger and freight adoption.

In their model they represent MHDV by considering vehicle class, vehicle technology, shipment distance, and vehicle application (Table 2). They combine this information with a total cost of driving to see when fleet owners might be incentivized to transition their fleets. While this

model helps project when fleets might transition to zero emission vehicles, it does not fully help understand the charging demand of these fleets.

Table 2. Summary of TEMPO model inputs for MHDVs

Vehicle Class	Technology	Shipment Distance Bins	Vehicle Applications
• **Light Medium** (Class 3) 10,000-14,000 lbs. • **Medium** (Class 4-6) 14,000 – 26,000 lbs. • **Heavy** (Class 7-8) 26,000+ lbs.	• Hybrid EV • Internal combustion engine vehicle • Fully EV with 3 different battery electric ranges	• Eight shipment distance bins starting at 0-99 miles all the way up to 2,000+ miles • This is used to differentiate between short-haul and long-haul vehicles	• **Freight trucks** based on Freight Analysis Framework (FAF) activity • **Non-freight** activity

Source: NREL

Statewide Infrastructure Needs Assessments

Zero emission infrastructure investments are essential for the transition to zero emission technology; however, several questions remain about the quantity, distribution, and characteristics of stations, how they can support different technologies, fuel types, operational requirements, and the policies and regulations needed to drive scalability.

The *California Freight Mobility Plan 2023* is a statewide plan that governs California's immediate and long-range freight planning activities and capital investments. The transition to a ZE freight system will rely on both public and private investments in countless infrastructure projects, vehicle and equipment purchases, technology applications, and system management approaches. ZE vehicles and equipment are heavier than their standard diesel-fueled counterparts, it is yet unknown what the effects of the extra weight will have on existing infrastructure such as aging rural roadways, culverts, and bridges. Some investments in ZE truck technologies have led to advancements in engine torque to reduce speed differentials and system mechanics that help reduce wear and tear on roadways.

California AB 2127 requires the CEC to conduct biennial assessments of EV charging infrastructure and charging needs to support ZE vehicles in 2030. The document considers all vehicle types in its assessment but provides useful guiding principles for how to examine and think about medium- and HD charging needs in the state. In it they calculate how many chargers would be needed to support travel demand using five models. Most relevant to this study is the HEVI-LOAD model, developed in tandem with LBNL which looked at infrastructure needs for more than 70 MHDV types in the state. The study authors gave these vehicles two options – charge overnight (which does not work for all industries) or during the day on the maximum DC charging power.

The HEVI-LOAD model was used to evaluate different vehicle application types, use patterns, regions, and charging behavior to assess what infrastructure would be needed to support different types of vehicles. Factors included if the vehicle pattern were a fixed route (like transit, or school bus or drayage trucks), or non-fixed routes, (like short and long-haul trucks, farm trucks, and last mile delivery vehicles), when the vehicle could charge (overnight, between trips, before or after trips, during trips), and energy consumption while driving (Figure 1).

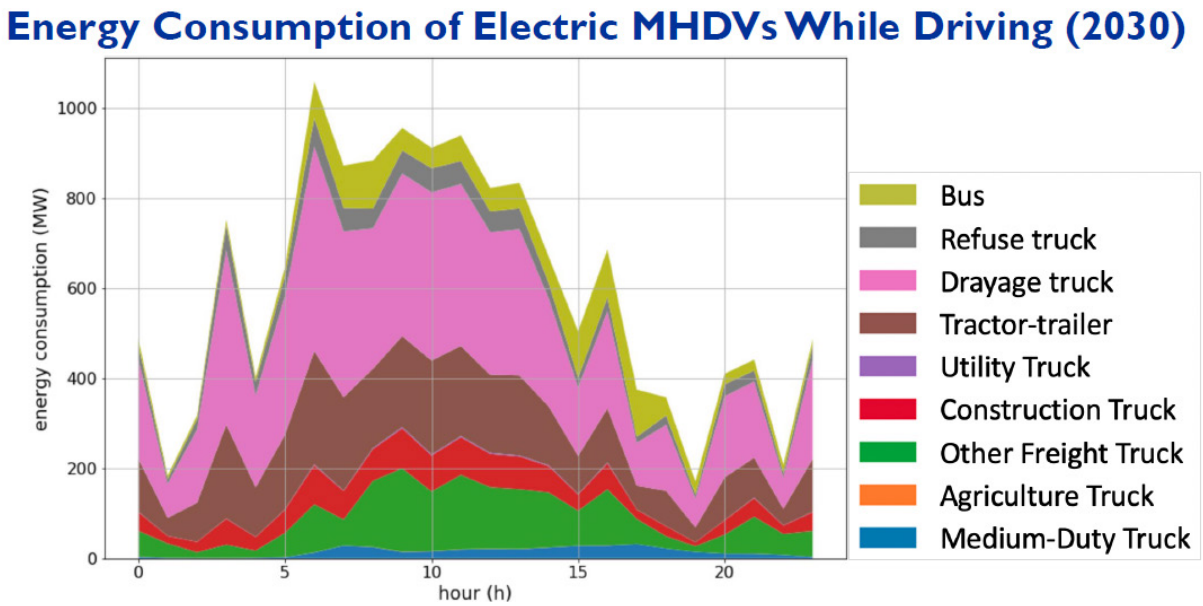

Figure 1. The 2030 projection of energy consumption of electric medium and HD vehicles while driving. *Source: LBNL*

In *Zero-Emission Medium- and Heavy- duty Truck Technology, Markets, and Policy Assessments for California* (2020), researchers at University of California ITS conducted an economic analysis of transitioning to ZE technologies by vehicle type and found that long-haul trucking is one of the least attractive modes for adoption. To combat this, it ultimately recommends making policies and economic incentives to transition by each vehicle type and category.

In addition to providing an overview of CARB's final rules for Advance Clean Trucks, *California's Advanced Clean Trucks Regulation: Sales requirements for zero-emission HD trucks* (2020) also provides a cost-benefit analysis for the ACT regulation. They calculated a combination of emissions reductions, health benefits, climate benefits, and economic benefits that may result from the regulation and estimated the overall cumulative benefit to be $11.2 billion between 2020 and 2040. Direct annual costs for the regulation are projected to peak in 2028 (as there are large upfront costs to transitioning the fleet and supporting infrastructure) but net saving begin quickly after in 2030.

The *California Sustainable Freight Action Plan* released in July 2016 set forth a Zero Emission Technology Target to deploy over 100,000 freight vehicles and equipment capable of zero or near-zero emission operation by 2030. It included a System Efficiency Target to improve freight

system efficiency 25 percent by increasing the value of goods and services produced from the freight sector, relative to the amount of carbon that it produces by 2030, and a Competitiveness and Economic Target. Six years later, these economic targets are still under development and not much progress has been made since the plan's adoption.

In Addition to the *California Sustainable Freight Action Plan*, SCAG has proposed an ambitious technology advancement roadmap in 2020 through *Connect SoCal (the 2020–2045 Regional Transportation Plan/Sustainable Communities Strategy, RTP/SCS)* to chart a path towards a more sustainable, mobile, and prosperous goods movement system by adopting ZE and near-ZE technologies. To comply with these statewide incentives, Connect SoCal proposed a four-phase approach to advance and accelerate the introduction of cleaner technology within the region (Figure 2)

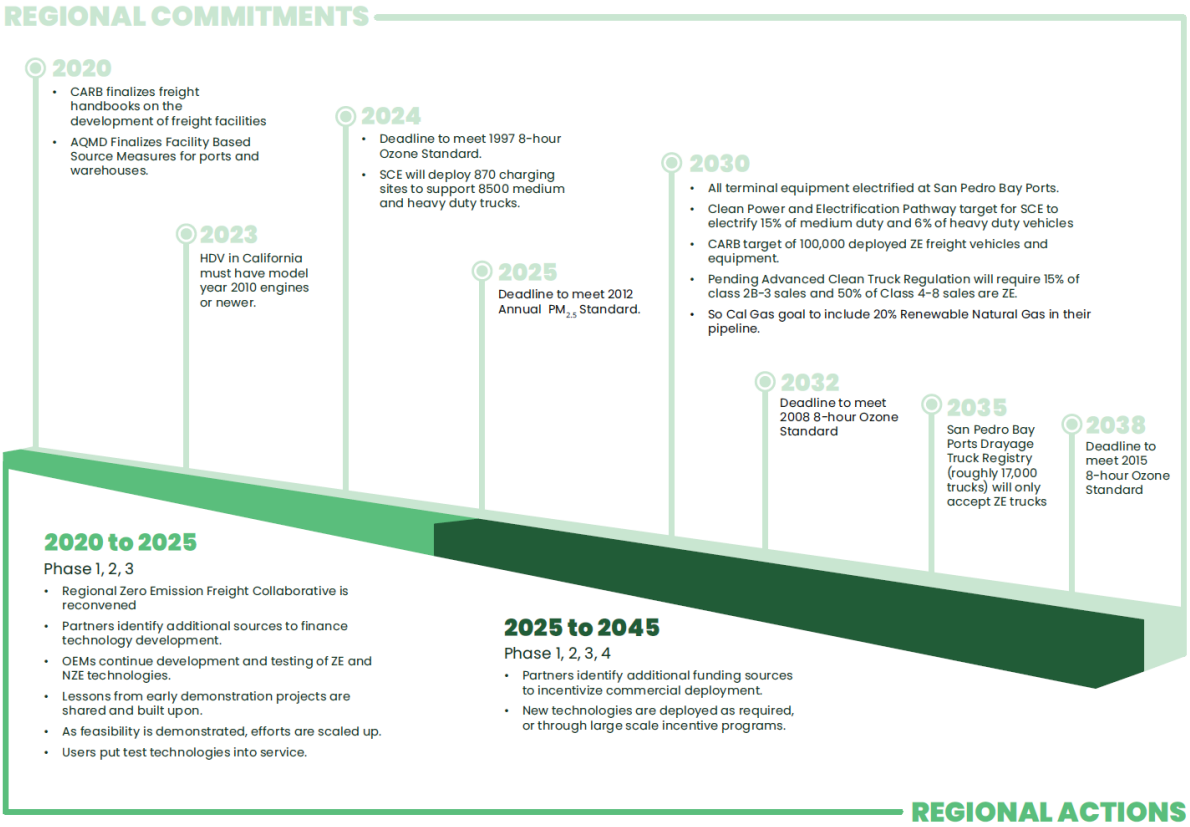

Figure 2. Timeline and action steps towards clean technology deployment proposed by Connect SoCal.
Source: Southern California Association of Governments

Tools and Models Used to Assess Need

There are a variety of existing tools used to assess the needs of ZE MHD vehicles in the state. Including:

The *CARB Emission FACtors (EMFAC)* website provides California's emissions inventories of on-road and off-road mobile sources to perform project-level assessment with custom meteorological conditions and scenario analysis with custom vehicle activity. It also provides detailed vehicle registration information aggregated up to the census block group level.

The *Greenhouse Gases, Regulated Emissions, and Energy use in Technologies (GREET) Model* is an analytical tool that simulates energy use and emissions output of various vehicle and fuel combinations including road, air, marine and rail. Environmental regulatory agencies frequently update national and regional standards related to energy use and emissions outputs of various vehicle and fuel combinations. In response, industries must take steps to ensure they meet these standards or face penalties, who may use the GREET Model to consider the full life cycle in order to obtain a complete picture of the energy and environmental impacts of a technology.

The *California Statewide Freight Forecasting and Travel Demand Model (CSF2TDM)* by the Caltrans provides Caltrans and other transportation partners with an advanced multi-modal tour/activity-based travel demand model that forecasts short and long-distance travel by California residents as well as commercial vehicle travel throughout the state. CSF2TDM is fully integrated to capture passenger and freight trips together

3 MARKET STATUS

IEA Global EV Outlook Report (2023) analyzes the financial performance of EV-related companies, venture capital investments in EV-related technologies, and trade of EVs globally. In 2022, 220 electric HD vehicle models entered the market, representing 800 available models from over 100 OEMs. Over 90% of these models are battery electric. Of the commercially available models, 60% (over 500 models) were produced by OEMs headquartered in China, 20% were produced by North American OEMs, and 15% by European OEMs. 27 governments have pledged to achieve 100% ZEV bus and truck sales by 2040 not including the US. Though the United States and European Union have proposed stronger emissions standards for HD vehicles.

Vehicle Considerations

Battery Electric Truck and Bus Energy Efficiency compared to conventional Diesel Vehicles compares the energy usage, measured by the EER, from battery electric trucks and buses when compared to energy usage from similar conventional diesel vehicles operated in the same duty cycle. They found a statistical correlation between heavy duty conventional diesel fuel efficiency and comparable heavy duty electric fuel efficiency based on the vehicle's average operating speed. The EER can be used to estimate total energy used by a BEV when the average speed and fuel consumption of the conventional diesel vehicle is known, which allows for more accurate costs and emissions benefit calculations. In addition, charger-battery system inefficiencies should also be taken into consideration.

EEI's *Electric Vehicle Sales and the Charging Infrastructure Required through 2030* (2022) focuses on light duty vehicles sales and supporting technologies including the battery development and charging infrastructure. Since EEI's last EV forecast in 2018, the EV market has accelerated rapidly. The first major milestone of one million cumulative EV sales was achieved in 2018, more than eight years after the introduction of the first mass market EVs in late 2010. Fewer than three years later, the next milestone of two million in cumulative sales was achieved in mid-2021. The report highlights improvements and inventions in battery technology that are improving affordability.

Existing battery technology continues to improve driving costs down. In addition, new companies have entered the market with entirely new battery technology, like solid state batteries, capable of significant increases in energy density and reduced cost. Solid state battery technology could result in EV batteries that are more stable, lighter, longer lasting, and capable of faster charging compared to current EV batteries. Volkswagen, Ford, GM and Nissan all have announced significant investments or partnerships with solid state battery technology.

Declining battery costs and growing customer demand for EVs act as an accelerant to EV sales. This will enable longer-range EVs, increase cost-competitiveness with ICE vehicles, and result in automobile manufacturers producing a wider variety of EVs to better meet customer demand. Between 2010 and 2021, battery pack costs declined by nearly 90 percent in real terms. Bloomberg New Energy Finance estimated average battery pack costs in 2021 at $132 per

kilowatt-hour (kWh) compared to $1200 per kWh in 2010[2]. Recent supply chain issues have potentially reversed the downward trend in battery prices in the near term, but the long-term projections of continued decreases in battery cost have not changed.

ICF Comparison of MDHD technologies in CA (2019) considered different scenarios for alternative fuel adoption in heavy and medium duty vehicles. The study is heavily informed by California and national policies and compares each scenario again California own public health and emission goals. The most robust finding is that scenarios adopting improved combustible technologies including traditional diesel as well as natural gas and biofuels are insufficient to meet 2030 and 2050 NOx emission standards. Widespread adoption of EVs is necessary in any scenario, and focusing on EV technology could be successful in the short term for meeting 2030 health and emission goals, but the current price of EVs is a major barrier. Furthermore, to meet 2050 goals, the state would likely need to adopt policies that would accelerate the replacement of traditional vehicles. The study suggested for instance the retirement of pre-2024 diesel engines as well as several other policy proposals. The study economic impacts for the state under each scenario and concluded the EV scenario would lead to a major shrinkage in certain industries. The ratio of jobs gained to lose however was favorable around 5 to 1.

Medium-Duty Electric Trucks: Cost of Ownership (NACFE) analyzes the cost of ownership through interviews of people with firsthand knowledge of Medium Duty Commercial BEVs at fleets, OEMs, industry groups and agencies. It concludes that additional data from more miles of fleet use is needed to predict performance, maintenance costs, residual markets, and other key factors with confidence. There are currently many unknowns because there is little long-term field history. Additionally, early fleet adopters will be better positioned to take advantage of future improvements in technology and guide innovation.

ORNL Transportation Energy Data Book (2021) is desk guide for industry professional of key statistics related to wide range of concepts – vehicle production, fuel production and usage, fleet statistics, and many others. The reporting on electric medium and HD vehicles is minor among the rest of statistics focused on vehicle availability with no reporting on the overall rates of adoption. This technology is clearly cutting edge and future reports will likely provide much more information regarding this specific topic.

Market Availability

Vehicle range and payload requirements are the two most important factors when assessing if zero emissions vehicles are ready to meet the demands of freight movement. The Global Drive to Zero project tracks the existing commercially available vehicles, paying special attention to these measures. According to data from the U.S. Department of Transportation (DOT), approximately two-thirds of trucks travel no more than 50 miles from their base each day, and more than 80% travel no more than 100 miles (U.S. DOT, 2022).

[2] Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite | BloombergNEF (bnef.com)

According to the *Global Zero-Emission Truck and Bus Market Update* (June 2023) the ranges reported by OEM in ZETI are higher than distances trucks travel every day, implying electric trucks can meet duty-cycle requirements in most cases if fleets plan their routes and charging properly. Overall ZE-MHDV modal availability has grown by almost 40 percent since 2021, but transit buses still make up the largest share of ZE vehicle types. As of June 2023, the median range of global ZE HD trucks is 157 miles, a range that meets the demands of most local and regional hauling. The payload ranges from 12,390 pounds to 82,000 pounds. Vehicles in the U.S. and Canada have higher average payloads (just over 52,000 pounds) compared to vehicles in Europe and China (just over 36,000 and 42,000 pounds respectively).

In December 2020, Volvo officially launched its VNR Electric Class 8 truck model for sale in the U.S. and Canada. In January 2022, Volvo announced production of an enhanced VNR Electric model, including new vehicle configurations, an operating range of up to 275 miles, and the ability to achieve an 80% charge in 90 minutes for the six-battery package and 60 minutes for the four-battery version.

The *Zero-Emission Technology Inventory* (ZETI) tool is part of the Global Drive to Zero initiative. It's an interactive online resource to establish a current and shared knowledge base for worldwide commercially available offerings of ZE-MHDVs. The tool aims to provide fleets and governments with comprehensive information including regions where ZE brands are available for purchase, and the timeline over which additional models are expected to become available. The tool shows that BEV availability in the United States and Canda has been increasing steadily since 2021 (Figure 3).

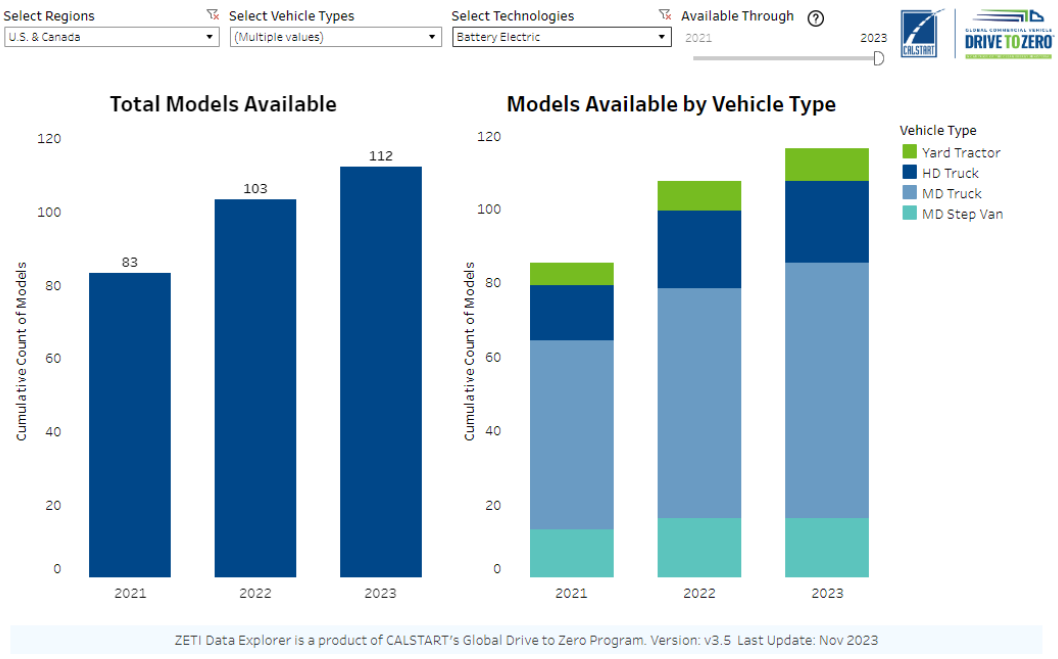

Figure 3. ZETI Tool Snapshot United States and Canada Battery Electric Medium- and Heavy- Duty Vehicle availability in 2023.

Source: CALSTART

The top ten OEM of HD vehicles by vehicle range (in order from highest claimed mileage range to lowest) are Tesla, Einride, Nikola, Volvo, Freightliner, Lion, XOS, Peterbilt, BYD, and Battle Motors (Figure 4).

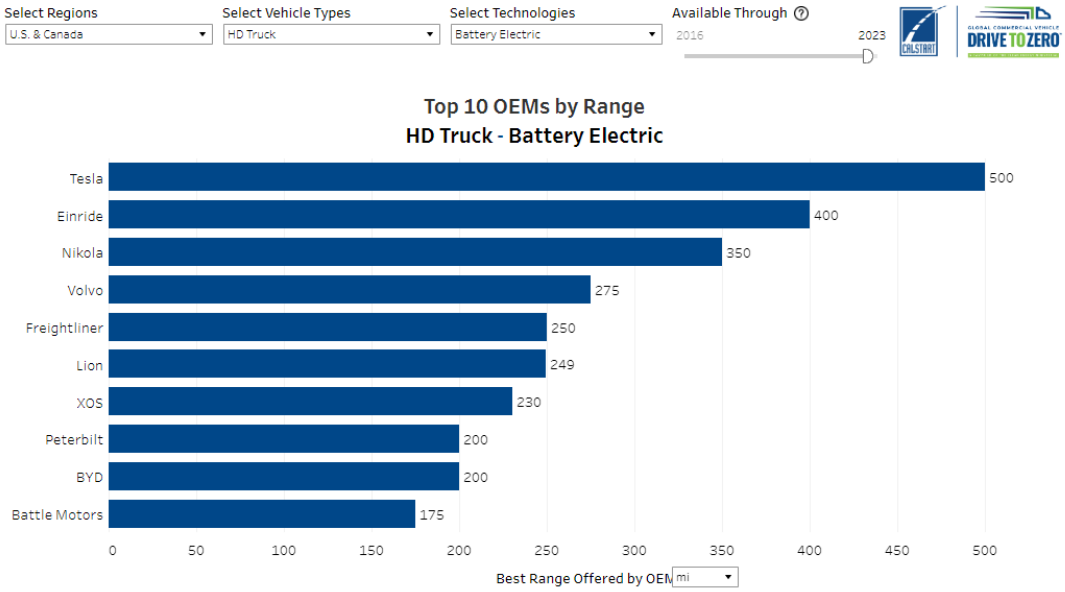

Figure 4. ZETI Tool Snapshot US & Canada Battery Electric HD Truck Top 10 OEM by Range.
Source: CALSTART

Most vehicles on the market today fall in the 150-200 mile range (Figure 5). top HD performers being Tesla with a claimed range of 500 miles per charge and an estimate payload of 82,000 lbs., Nikola Tre BEV with a 350 miles per charge, and 40,000 lbs. payload, and Volvo with a 275 miles per charge and 66,000 lbs. of payload.

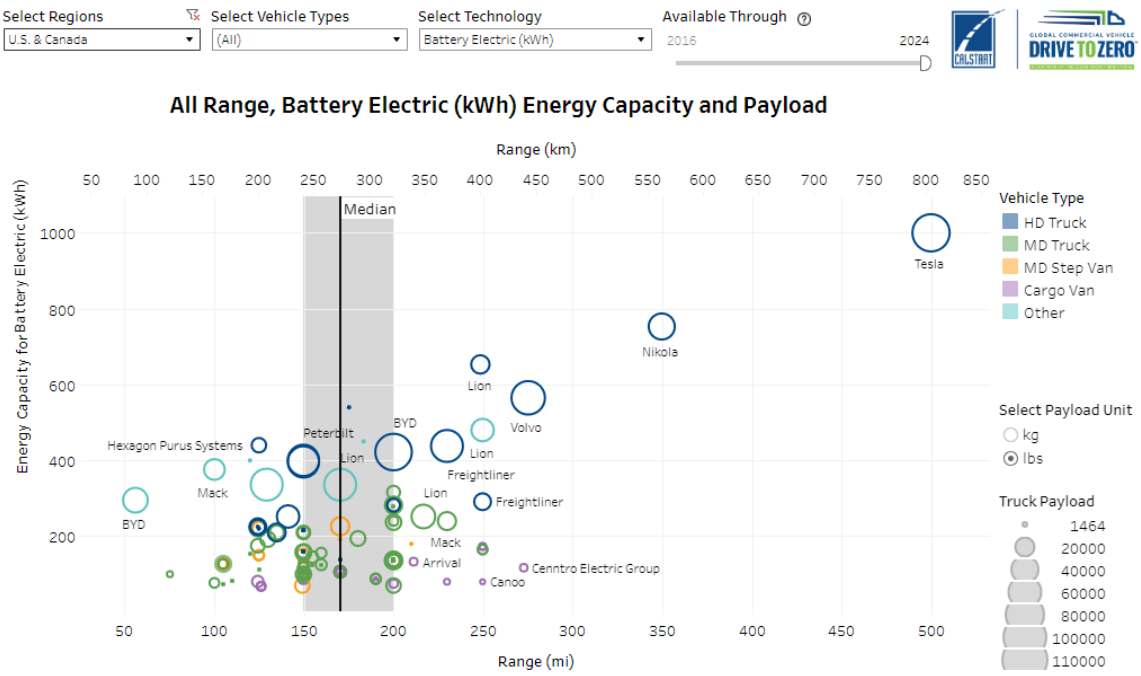

Figure 5. ZETI Tool US & Canada Snapshot Showing Payload Capacity, Vehicle Type, Mileage Range, and Vehicle Capacity.

Source: CALSTART

In California CARB puts out a summary of annual vehicle sales data reported by manufacturers, credit balances, and credit transactions required by the ACT regulation called The Advanced Clean Truck Credit Summary Through the 2022 Model Year. According to their most recent summary update (October 13, 2023) reported in 2022, ZEVs represented 7.5% of total sales when no ZEV truck purchase or manufacturer sales requirements were in effect. To put this in context, the statewide ZEV sales requirement in 2024 is about 6% of total annual sales. In 2022, Volvo delivered ZEV tractors for sale at a rate of 5.2% of annual sales which is higher than the 5% ZEV sales requirement that applies to Class 7-8 tractor sales in 2024.

In 2022, of the 104,558 total 2022 Model year MHDVs produced and delivered for sale, 7,639 were Zero Emission vehicles. Rivian sold 5,289 ZEVs, the most of any manufacturer, followed by Ford at 1,727. The other manufacturers sold less than 200 ZEVs each: Blue Bird (97), BYD (38), Daimler (26), eMoters (43), Lion Electric (4), Navistar (111), Nikola Moto (13), Paccar (49), Volvo (153), and XOS Trucks (89). No Near Net Zero Emission vehicles (NZEV), defined as on-road hybrid EV that has the capability to charge the battery from an off- vehicle conductive or inductive electric source and achieves minimum all-electric range, were sold in California in 2022. When looking at just Class 7-8 Tractor Sales, a total of 11,809 vehicles were sold with 218 or X% of these being zero emission. CARB also provides a comprehensive list of commercially available ZEV models by vocation types (Figure 6) during the rule-making process for the ACF regulation.

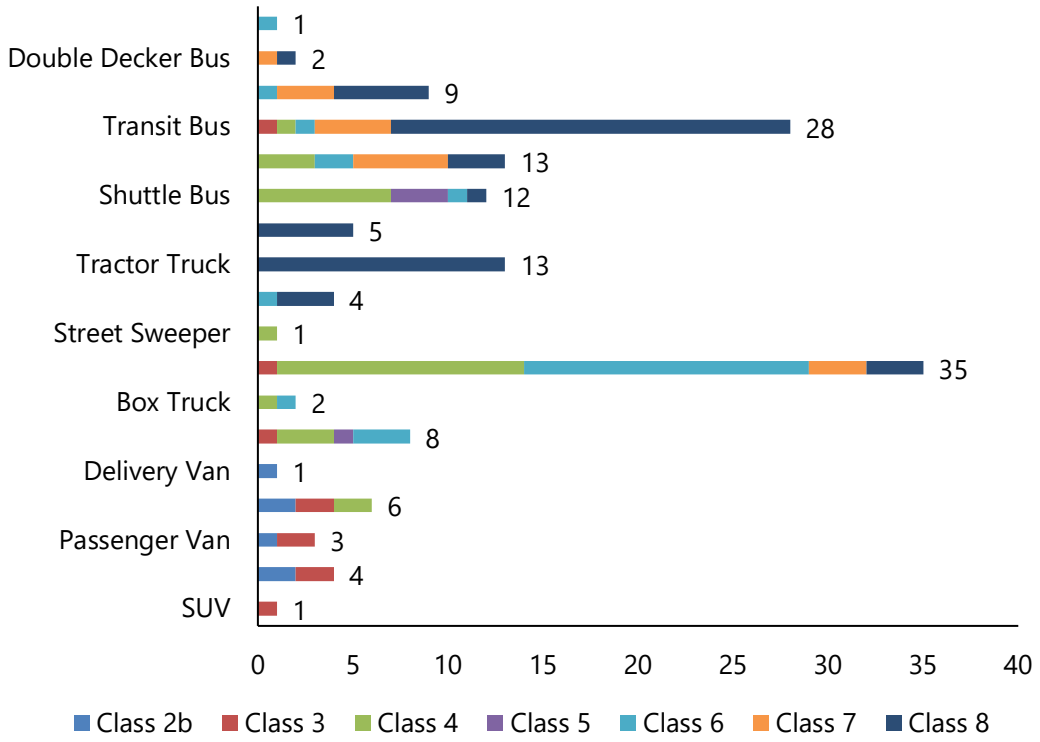

Figure 6. Number of Commercially Available ZEV Models.
Source: CARB

The *Clean Truck Technology Comparative Report*, conducted by LA Metro, examines the current state of medium-duty and HD ZE truck technology, as well as its future potential in response to industry announcements and regulatory actions. The report considers the unique needs and characteristics of local fleets, such as vocation and duty cycle requirements, to showcase how battery electric trucks and fuel cell electric trucks can replace traditional combustion engine vehicles. The 2021 SPBP Feasibility Assessment for Drayage Trucks has followed a similar approach, assessing available ZE truck models to determine their compatibility with current drayage operations.

Drayage Specific Zero-Emission Efforts

In 2006, San Pedro Bay Ports (SPBP) became one of the first seaports globally to adopt an air quality plan - the Clean Air Action Plan (CAAP) - to address the rampant issue of pollution from freight transportation emissions. While PM from heavy duty trucks has decreased by 97% from 2005 levels, new targets for reducing GHG emissions from port-related sources were introduced as part of the 2017 CAAP. The 2017 CAAP Update also established the need to prepare feasibility assessments to evaluate the status of technology and supporting infrastructure that will be required to achieve the various CAAP strategies. Several studies have been published looking at overlapping components of the CAAP deployment at the ports and nearby region.

The latest SPBP Feasibility Assessment for Drayage Trucks (2023) updates prior assessment performed in 2018 and 2021 to evaluate the current state of ZE and low-emission (LE) fuel-technology platforms suitable for drayage-capable Class 8 trucks – including infrastructure readiness to fuel and service them. Infrastructure availability for BEV charging is assessed by 4 criteria: dwell time at station, station location and footprint, infrastructure buildout, existence of/compatibility with standards.

The Assessment's overarching objective is to characterize feasibility for near-term (2021 to 2024), large-scale deployments of drayage trucks using such platforms. While the 2021 Assessment demonstrated that important changes have occurred since 2018 regarding the commercial and technological maturity of Class 8 trucks using ZE fuel-technology platforms, the 2023 assessment added that novel alternatives to wired stationary charging are being tested to increase flexibility - battery swapping, wireless charging, and overhead catenary charging.

Relatedly, over the last two years CARB has adopted its ACT regulation that helps address the "supply side" for ZE Class 8 trucks. It appears plausible that within two to three years, multiple OEMs will annually produce hundreds or thousands of commercially viable Class 8 ZE BETs. Meanwhile, multiple Class 8 OEMs are making steady progress to advance the technological and commercial maturity of ZE hydrogen fuel cell trucks. However, it remains uncertain how rapidly new charging stations and subsequent EV charging loads will be deployed, and how fast the utilities can develop long-term infrastructure plans for a fully electrified port system. In addition, it is also unclear if there will be sufficient industry will or investment to build-out the full extent of the charging infrastructure needed to serve the drayage fleet. Given these current uncertainties and challenges, it appears highly unlikely a full-scale charging infrastructure for drayage trucks could be built and operational by 2024.

Developing Markets for Zero Emission Vehicles in Goods Movement (2020) conducted by the National Center for Sustainable Transportation further investigated operational constraints in the SPBP region. The multifaceted study focused on the potential deployment of ZE HD vehicles for drayage movements using actual port movement data as well as interviews/surveys with local operators currently participating in pilot deployments of EV trucks on behalf of OEMs. Using modeling techniques on previous port flow data and estimates of efficiency of electric HD trucks, the study authors found that for a single 8 hour day of operation 75% of all good movements could feasibly be replaced by ZE EVs but would require a twofold increase in the

fleet size – 36 vehicles overall. Assuming the onboard battery technology is improved with higher capacity batteries and more efficient energy usage, the study estimates that 96% of all trips could be replaced by EVs with the overall fleet increasing by about a third, 27 vehicles overall. These exercises were constrained in several ways – notably assuming that charging time would remain the same despite emerging technology as battery capacity will also increase and assuming EVs only charge at the port facility itself.

The study also utilized interviews and surveys of operators conducting pilot runs of electric trucks. These interviews revealed important operational limitations such as the availability of qualified personnel and mechanics, charging infrastructure, and the price of vehicles. The timing of downtime for vehicles to charge was also a major issue for operators who conduct business 24 hours or day or rely on monetary incentives from ports to conduct deliveries during the night. Operators also noted that for short drayage trips weight limitations (EVs are much heavier) and effective range in non-highway conditions limited usefulness of the EV.

High-Power Charging

The *IEA Global EV Outlook Report* (2023) provides an update on other high power charging EV deployments and advances that are taking place in the field. In 2022 Traton, Volvo, and Daimler established an independent joint venture, Milence, to help scale up fast or ultra-fast charging to make regional and long-haul operations technically and economically viable. In China, co-developers China Electricity Council and CHAdeMO's "ultra ChaoJi" are developing a charging standard for HD EVs for up to several megawatts. In Europe and the United States, specifications for the CharIN MCS, with a potential maximum power of 4.5 MW, are under development by the International Organization for Standardization (ISO) and other organizations. The final MCS specifications, which will be needed for commercial roll-out, are expected for 2024. After the first megawatt charging site offered by Daimler Trucks and Portland General Electric (PGE) in 2021, at least twelve high-power charging projects are planned or underway in the United States and Europe, including charging of an electric Scania truck in Oslo, Norway, at a speed of over 1 MW, Germany's HoLa project, and the Netherlands Living Lab HD and Green Transport Delta Charging Stations, as well as investments and projects in Austria, Sweden, Spain and the United Kingdom.

Battery Swapping

The IEA Global EV Outlook Report (2023) also details advances in Battery-as-a-service (BaaS), separating the purchase of the truck and the battery, and establishing a lease contract for the battery, which substantially reduces the upfront purchase cost (by as much as 50%).

China is at the forefront of battery swapping for trucks due to significant policy support and use of technology designed to complement cable charging. Battery swapping innovation in China leverages lithium iron phosphate (LFP) batteries instead of the typical lithium nickel manganese cobalt oxide (NMC) batteries. This results in safer and more affordable solution for battery swapping applications. In 2021, China's MIIT announced that several cities would pilot battery

swapping technology, including HDV battery swapping in three cities. Almost all major Chinese heavy duty truck manufacturers, including FAW, CAMC, Dongfeng, Jiangling Motors Corporation Limited (JMC), Shanxi Automobile, and SAIC, have now launched a battery swapping-enabled model of their battery electric trucks. In 2022 alone, more than 12,000 battery swapping-enabled electric trucks were sold in China.

4 EXISTING MEDIUM AND HEAVY-DUTY PILOTS AND DEPLOYMENTS IN CALIFORNIA

In 2015, the *California Collaborative Advanced Technology Drayage Truck Demonstration Project*, which brought together major manufacturers, including BYD, Kenworth, Peterbilt and Volvo, to deploy 44 battery electric and plug-in hybrid drayage trucks at major California ports. This demonstration project forged the way for the Zero-Emission and Near Zero-Emission Freight Facilities (ZANZEFF) program, a sub-program under the CARB's Low Carbon Transportation Program, which has 11 projects throughout the state and more than $400 million invested.

NREL's *Vehicle and Mobility Technologies 2023 Annual Impact Report* (2023) is a yearly report highlighting the wide breadth of their work from the previous year. In 2023 they focused on various technologies related to EVs including in the medium and HD space. These include pilot projects at New Jersey and New York ports, modeling exercises to estimate potential infrastructure needs at regional scales, and scientific studies looking at battery chemistry and testing methods. This important work is ongoing but highlights widespread efforts to deploy this technology as quickly as possible using studies and experiments, marking NREL as important source of information and potential partner for other efforts in the country.

The Volvo Low Impact Green Heavy Transport Solutions (LIGHTS) Project

The Volvo LIGHTS project was another ZENZEFF grant that targeted facilitating ZE goods movement around the Ports, with a total cost of $91 million. Under LIGHTS, the Volvo Group has teamed with South Coast AQMD and multiple private-sector partners to deploy 59 pre-commercial and commercial Class 8 vehicles and infrastructure at freight handling facilities, including:

- 30 Class 8 BETS (28 under LIGHTS and 2 from the Clean Air Technology Initiative).
- 29 Off-road battery electric tractors and forklifts.
- 56 Non-proprietary Level 2 and 50 kW and 150 kW DC fast chargers.
- 864 kW solar at DHE, 640 kW solar at NFI

This project, concluded in September 2022, has provided valuable insights on smart charging strategies for fleets, as well as challenges in utility interconnection approvals for integrated solar/energy storage at fleets due to different requirements.

The Volvo LIGHTS project developed a blueprint to introduce zero-tailpipe emission BETs and equipment into the market at scale. The Volvo Lights Guidebook (2022) shares learnings from the project and suggests that fleets, OEMs, and dealers should work together to understand a fleet's operational details and identify ideal customer routes, and that fleets consider a good mix of high- and low- power DC fast-charging stations with futureproofing charging solutions. Volvo also suggests that to build public charging infrastructure, existing state laws must first

allow entities other than existing utilities to re-sell electricity to ZE truck owners. Volvo also mentioned California sales tax relief for ZE trucks and utilities helped buy down the capital equipment cost for their customers.

Private Sector Projects

The private sector is also active in demonstrating and deploying HD zero emission vehicles. As an example, TeraWatt Infrastructure, a company powering electrified fleets with charging centers network, has announced plan to build the first network of high-powered charging centers for MD-HD electric trucks along the I-10 highway, stretching Los Angeles, California to the El Paso, Texas area. The TeraWatt Charging Centers will be located approximately 150 miles apart to support the mileage range of commercially available electric trucks. These sites are located less than one mile from the nearest highway exit for ease of access, and range in size between four to 100 acres, depending on location.

WattEV, a California-based company also aiming to build a nationwide network of charging infrastructure at strategic locations, is developing four Medium and Heavy Duty charging stations in California: at the Port of Long beach (open), Gardena, Bakersfield, and San Bernadino (set to open in 2024).[3]

Another recent example is Einride's partnership with Voltera in developing North America's largest operational charging site for electric heavy duty freight near the Ports of Los Angeles and Long Beach along the I-710. The Einride Smartcharger Station currently provides 65 chargers and capacity to charge up to 200 vehicles a day.[4]

[3] Heavy-Duty Charging Stations | WattEV | Electrifying Heavy Duty Transport

[4] Einride Smartcharger Station Unveiled in Los Angeles, North America's Largest Operational Charging Site for Electric Heavy Duty Freight (volterapower.com)

5 CONCLUSION

The aim of the BEV Truck Status Technical Memo is to provide a complete and accurate picture of current studies, reports, available data, and OEM truck information related to truck technology readiness collected throughout Task 3. This Memo provides a basis of knowledge to be incorporated into the final Task 3.4 Fleet Charging Infrastructure Needs and Technology Maturity Assessment. Key takeaways from this assessment include:

- California is leading the market in the U.S., however, there are opportunities to look for technology solutions and lessons learned from outside the United States. In Europe, they are developing high-power charging technology and are in the process of deploying pilots, important to monitor and understand lessons learned.
- In China, they are developing on high-power charging and exploring battery swapping approaches as an alternative.
- Operating publicly accessible charging infrastructure is not an attractive business model as it stands today, and will either require incentives or innovation to make it viable. An example may include pairing public charging with other businesses or services that could meet driver needs while vehicles charge.
- Investments along high demand freight routes should be prioritized to accommodate the needs of long-haul trucks more quickly.
- The number of MD-HD BEV models available and number MD-HD BEVs purchased continue to raise domestically and internationally.
- High-power charging infrastructure is being developed nationally and internationally, it will be important to a standard like MCS that works in China, Europe, and North America.
- Improvements in battery technology will help develop lighter, longer lasting, more stable, and better compatibility for fast/high-powered charging.
- Diversifying the materials used to develop batteries beyond existing lithium batteries could help aid in the transition to decarbonized vehicles and make supply chains more resilient.
- HD long-haul trucks are the least attractive modes for zero emission vehicle adoption and will require policy change and financial incentives to drive change.

The next phase of the eTRUC project will be focused on utilizing the above assessment of technology readiness into corridor deployment planning. For instance, key takeaways related to forecasted MCS market penetration timelines will be incorporated into the Lawrence Berkeley National Lab's 2030, 2035, 2040 infrastructure needs forecasting to ensure the deployment plans provide an accurate forecast of charging infrastructure needs in California.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

Program

Electric Transportation

3002029229

EPRI
3420 Hillview Avenue, Palo Alto, California 94304-1338 USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com