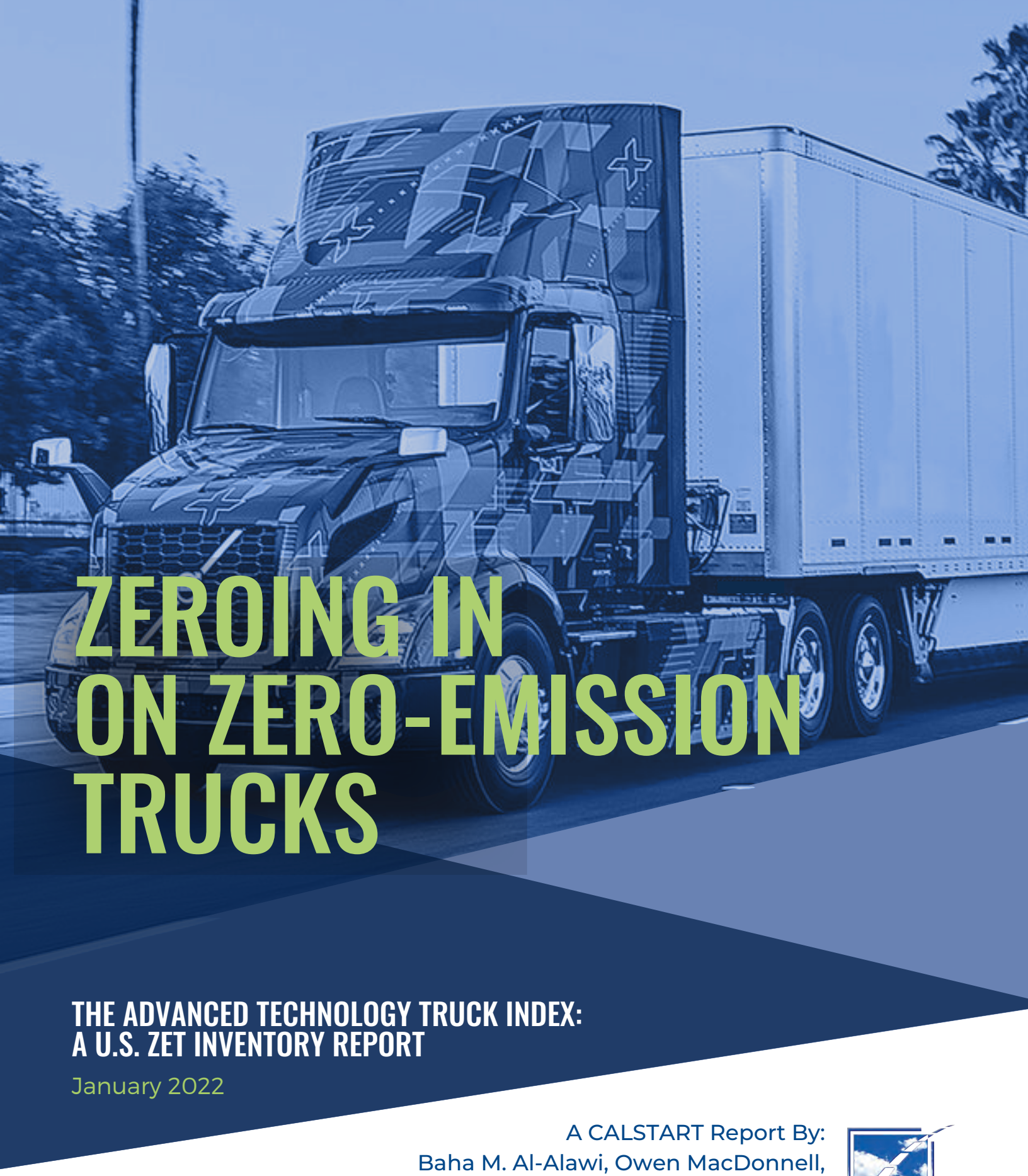

ZEROING IN ON ZERO-EMISSION TRUCKS

THE ADVANCED TECHNOLOGY TRUCK INDEX: A U.S. ZET INVENTORY REPORT

January 2022

A CALSTART Report By:
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List of Acronyms

ACT	Advanced Clean Trucks
APCF	Air Pollution Control Fund
AQIP	Air Quality Improvement Program
AQMD	Air Quality Management District
BEV	Battery-Electric Vehicle
CARB	California Air Resources Board
CaaS	Charging-as-a-Service
CEC	California Energy Commission
CMAQ	Congestion Mitigation and Air Quality
CO2	Carbon Dioxide
CORE	Clean Off-Road Equipment
DC	Direct Current
DERA	Diesel Emission Reduction Act
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EV	Electric Vehicle
FCET	Fuel Cell Electric Truck
FUSO	Fuso Truck and Bus Corporation
FY	Fiscal Year
GF	General Fund
GHG	Greenhouse Gas
GGRF	Greenhouse Gas Reduction Fund

GVWR	Gross Vehicle Weight Rating
HD	Heavy-Duty
HVIP	California's Hybrid and Zero-Emissions Vehicle Incentive Voucher Program
kWh	Kilowatt-hour
MD	Medium-Duty
MHD	Medium- and Heavy-Duty
MOR-EV	Massachusetts Offers Rebates for Electric Vehicles
MOU	Memorandum of Understanding
MW	Megawatt
NHTSA	National Highway Traffic Safety Administration
NJZIP	New Jersey Zero-Emission Incentive Program
NOx	Nitrogen Oxides
NYCCTP	NYC Clean Trucks Program
NYTVIP	New York Truck Voucher Incentive Program
OEM	Original Equipment Manufacturer
PM	Particulate Matter
RRGI	Regional Greenhouse Gas Initiative
SAE	Society of Automotive Engineers
TaaS	Transportation-as-a-Service
TCO	Total Cost of Ownership
VW	Volkswagen
ZET	Zero-Emission Truck
ZETI	Zero-Emission Technology Inventory

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Executive Summary

Zero-emission trucks (ZETs) are relatively new to the U.S. commercial automotive market, but with numerous pending orders and purchase commitments now in place and increasing regulatory policy action at the state level, these vehicles are poised to see significant increases in deployments over the next few years. Key factors, such as model availability, technical capability, and vehicle cost, are changing rapidly and show that ZETs are ready to deploy across multiple commercial vehicle market segments.

This report seeks to quantify and track the number of deployed Class 2b (8,501-10,000 lbs.) to Class 8 (33,000 lbs. and above) on- and off-road ZETs over time, providing a forward-looking summary of near-term, imminent deployment commitments that will be updated periodically as the commercial ZET market grows (**Table ES-1**). The number of vehicles cited in this report will change frequently, but the intent is to accurately capture the correct quantities and deployment stage at the time of writing. Many ZETs now in demonstration and pilot phases are providing the critical "first look" for early adopters and potential fleet buyers. This report captures both these longer demonstrations as well as commercial sales of ZETs.

Table ES-1: U.S. ZET Deployments and Market Share (As of December 2021)

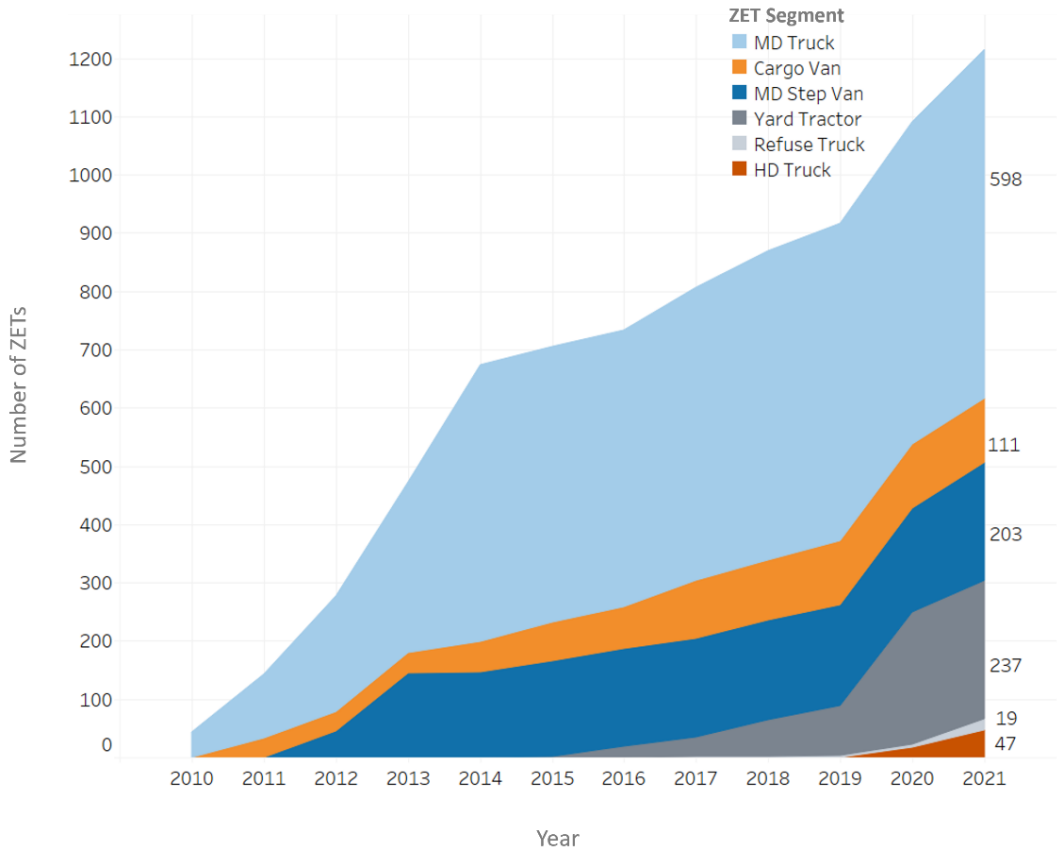
Category	Data
U.S. ZET Deployments	1,215
U.S. ZET Share of Registered Medium- and Heavy-Duty (MHD) Trucks	0.005%
California ZET Deployments	738
15 State and District of Columbia Joint Memorandum of Understanding (MOU) Signatory ZET Deployments[1]	986
ZET Models Available for Purchase	145

[1] MOU signatories include California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and Washington D.C.

At this time, commercially deployed ZETs primarily consist of battery-electric trucks (BETs). While numerous hydrogen fuel cell electric trucks (FCETs) are under development and being demonstrated in the United States, these vehicles are a small percentage of the ZET population. CALSTART's Zero Emission Technology Inventory (ZETI) tool captures details of available trucks in the market. As of December 2021, ZETI shows availability of over 145 different ZET models from over 30 manufacturers. Most of the available truck models are medium-duty (MD) (Class 3-6) and are currently offered by manufacturers providing retrofit propulsion systems into existing chassis. Electric vehicle (EV)-only manufacturers and manufacturers who currently offer conventionally fueled trucks are increasing model availability and introducing these into the market at a fast pace. This report shows that the highest number of deployed ZETs in 2021 were also MD trucks (**Figure ES-1**).

As of December 2021, over 145 different ZET models are available from over 30 manufacturers, with Class 3-6 (MD) ZETs having the highest number of deployments.

Figure ES-1: Cumulative ZET Deployments in the United States (2010-2021)



Over 163 customers have deployed ZETs in their operations, the majority of which (78%) are private organizations such as third-party logistics and private fleets. The remaining 22% are public organizations, namely municipalities and school districts. Just 20 customers make up 50% of all

current ZET deployments and are responsible for operating a cumulative 388,597 total fleet trucks, regardless of fuel type. These customers are "test-driving" ZET technology and, if successful, will hopefully continue to convert their conventionally fueled fleets to zero-emission technology.

While current ZET deployment numbers are low compared to total U.S. MHD truck registrations, there are currently over 140,000 pending orders for commercial ZETs to be fulfilled.

While current deployment of ZETs is low compared to total MHD truck registrations in the United States, deployments are expected to grow significantly over time. There are over 140,000 pending orders for commercial ZETs, which will be fulfilled across different time scales depending on manufacturer capacity and order size. This number includes large pending orders such as Amazon's commitment to purchase 100,000 delivery vehicles over the next eight years. In California, the state's Hybrid and Zero-Emissions Vehicle Incentive Voucher Program (HVIP) alone has pending orders for about 1,200 ZETs (roughly double current ZET deployments in the state), which are expected to be completed within 18 months of voucher redemption.[2] HVIP expects this number to continue to rise over the next few years. Additionally, 280 Class 8 battery-electric and fuel-cell electric drayage trucks will be deployed as a part of the joint California Air Resources Board (CARB) and California Energy Commission (CEC) Zero Emission Drayage Truck and Infrastructure Pilot Project.

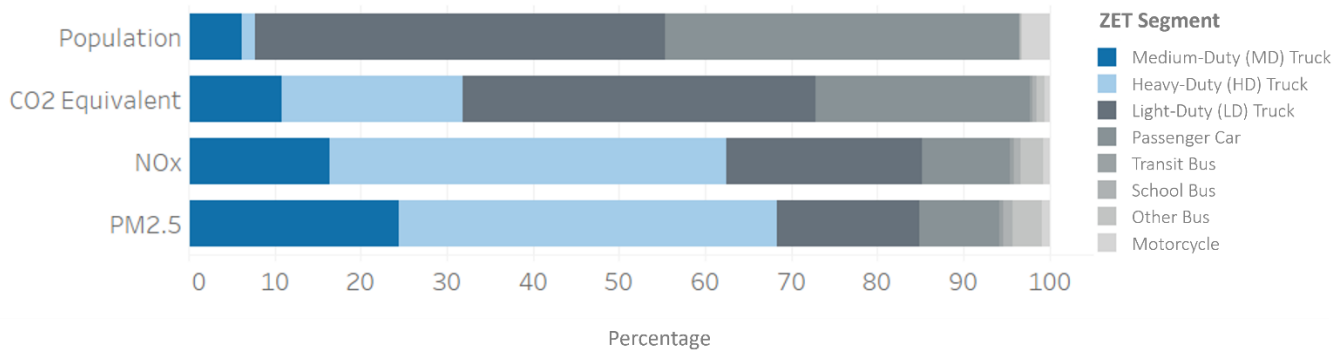
[2] It is not uncommon for HVIP orders to be voided due to unforeseen circumstances.

I. Introduction

Zero-Emission Truck (ZET) Demand

Zero-emission trucks (ZETs) are a vital part of the global climate solution and an important tool in the fight for cleaner air. As shown in **Figure 1** below, currently medium- and heavy-duty (MHD) trucks in the United States make up only 8% of on-road vehicles, but these trucks are responsible for approximately 32% of on-road greenhouse gas (GHG), or carbon dioxide (CO2) equivalent, emissions; 63% of on-road nitrogen oxide (NOx), a precursor to photochemical smog; and 68% of on-road emissions of particulate matter with a diameter of 2.5 microns or smaller (PM2.5) (EPA, n.d.).

Figure 1: U.S. Vehicle Population and Emissions by ZET Segment (Source: EPA)



A complete transition to ZET technology would not only help mitigate the impacts of climate change and poor air quality but could eventually lower total cost of ownership (TCO) for fleets and create job growth in the United States. A 2019 report prepared for the California Electric Transportation Coalition forecasts that by 2030, all MHD battery-electric trucks (BETs) in California will have a lower TCO than their counterpart diesel trucks—even without state incentives (ICF, 2019). These cost reductions are primarily driven by declining battery costs and lower operational costs. The same report predicts that a state strategy focused on MHD BETs could generate between 763,000 and 1.31 million more job-years[3] in California alone compared to current policies, depending on the specific policies employed to promote BETs.

[3] A job-year is defined as a full-time work opportunity for one person for one year.

Recognizing the benefits and necessity of a transition to electrified MHD trucking, private companies and state and local governments have begun to invest and develop policies that are accelerating the commercialization of ZET technologies. In June of 2020, the California Air Resources Board (CARB) passed the Advanced Clean Trucks (ACT) rule, which will begin to require truck manufacturers to sell an increasing number of ZETs in California starting in 2024 (CARB, 2020). The ACT rule will eventually require manufacturers to sell between 40-75% ZETs by 2035. In July of 2020, 15 states and the District of Columbia signed a Joint Memorandum of Understanding (MOU) to advance and accelerate the market for trucks and buses with a goal of 100% of sales to be zero-emission by 2050, with an interim target of 30% by 2030[4]. The MOU signatory states of Washington, Oregon, New Jersey, New York, and Massachusetts have now also adopted the ACT rule (Washinton Department of Ecology, 2021; Oregon Department of Environmental Quality, 2021; New Jersey Department of Environmental Protection, 2021; New York State, 2021; Massachusetts Department of Environmental Protection, 2021). Additionally, California is developing a complimentary rule—the Advanced Clean Fleets rule—that will require fleets to purchase and deploy increasing numbers of zero-emission vehicles starting in 2025 (CARB, 2021).

In addition to regulation, several states currently offer monetary incentives to bring down the incremental cost of ZETs through voucher incentive programs. California funds both on- and off-road vehicles through its Hybrid and Zero-Emissions Vehicle Incentive Voucher Program (HVIP) and Clean Off-Road Equipment (CORE) program. New York funds ZET purchases through the New York Truck Voucher Incentive Program (NYTVIP) and the City of Chicago funds ZET purchases through Drive Clean Chicago. Colorado funds the replacement of conventionally fueled vehicles through ALT Fuels Colorado. Several other voucher incentive programs are being piloted by MOU states.

Regulatory policy, monetary incentives, and unprecedented market opportunity for clean trucks have led many major original equipment manufacturers (OEMs) in the United States to begin developing and selling a wide variety of ZET models. Most major U.S. OEMs also have goals to reduce the majority of or eliminate fossil fuel-powered vehicles from their fleets by 2040-2050 (Garcia Coyne, 2021). Other start-up manufacturers have emerged that focus solely on BETs and/or fuel cell electric trucks (FCETs). In 2021, CALSTART's Zero-Emission Technology Inventory (ZETI) tool[5] indicated there were over 145 ZET models available for purchase in the United States.

The combination of public policy and private investment has led to an increase in ZET deployments, but accurately quantifying this growth is a challenge due to the multitude of data sources and closely held deployment information from private fleets. While a comprehensive summary of ZET deployments in the United States would be valuable for a wide range of decision-makers, no such calculation currently exists. This report leverages CALSTART's unique position as a

[4] MOU signatories include California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and Washington D.C.

[5] Drive to Zero's Zero-Emission Technology Inventory (ZETI) tool is available online at https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

transportation technology advocate, accelerator, and incentive program administrator to track all known ZET deployments in the United States and analyze ZET market trends. Tracking this data will aid decision-makers and provide important context into the United States' progress toward adopting ZET technology.

The ZET market is moving at an ever-quickening pace, so this report will be continuously updated as new deployments and market trends occur. Data in this report is compiled from several sources, including market information providers, incentive program records, public press releases, and private correspondence with OEMs. See **Appendix A** for a more detailed breakdown of these sources and data. CALSTART implores readers to help facilitate ongoing corrections and improvements to the data in this report by contacting the authors:

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- Ross McLane, Technical Project Manager, rmclane@CALSTART.org

Definition and Segmentation of ZETs

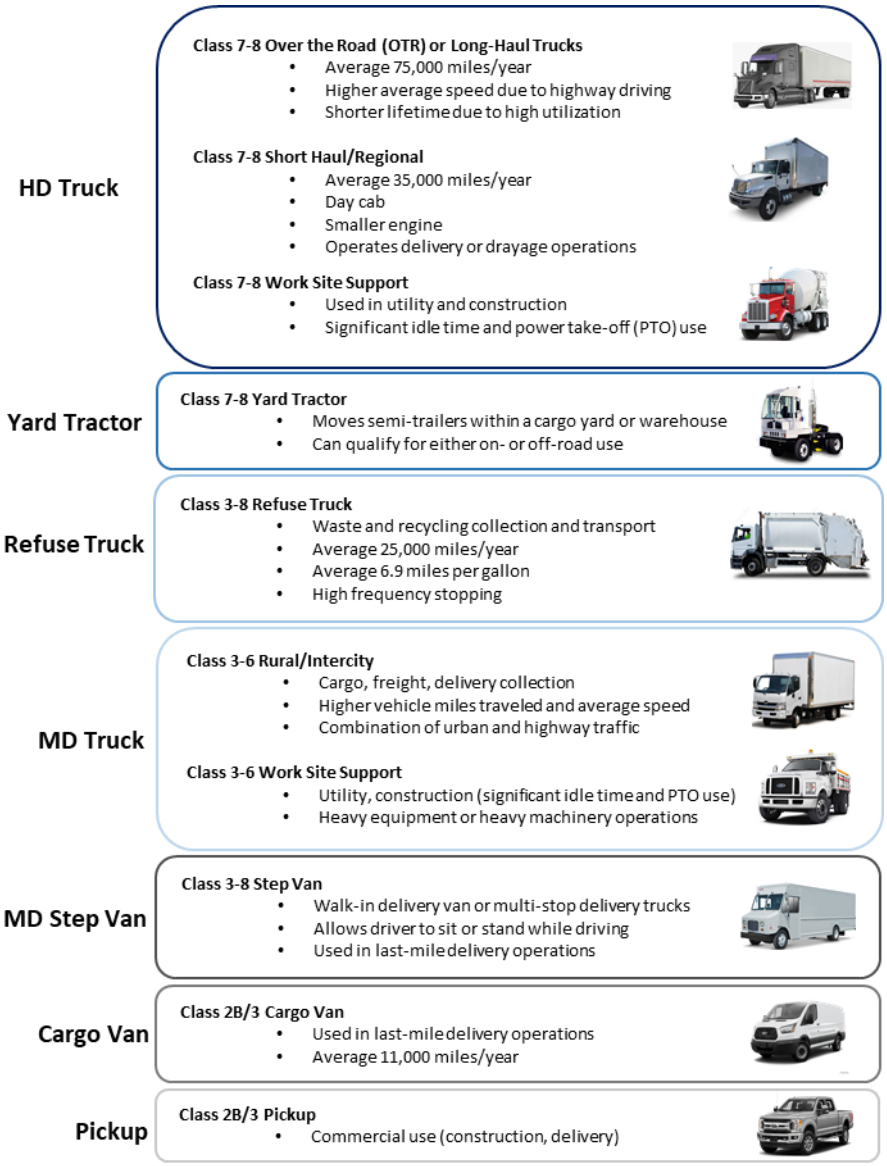
This report focuses exclusively on ZETs, which CALSTART defines as vehicles that do not emit exhaust gas or other pollutants from their onboard power source. This definition includes battery-electric and hydrogen fuel cell vehicles and excludes low-emission technologies like natural gas (compressed, liquid, or renewable), hybrid electric, and biodiesel vehicles.

Trucks in this report are segmented according to the ZETI tool's categorization scheme, which divides trucks into seven distinct segments (**Figure 2**). Commercial trucks in the United States are classified according to their gross vehicle weight ratings (GVWR). For this analysis, only Class 2b (8,501-10,000 lbs.) to Class 8 (33,000 lbs. and above) vehicles are considered. For the purposes of this report, Class 2b-8 trucks that fall into one of the segments in **Figure 2** are simply referred to as trucks.

This report will also track yard tractors. Yard tractors may not be registered as on-road vehicles, but they provide a critical function related to moving freight in the United States, are provided by manufactureres of on-road vehicles, and will provide market acceleration opportunities for on-road components and technology.

ZET deployment statistics for this report are calculated based strictly on "deployed" ZETs, defined as trucks which have both been sold, delivered, and placed into service on U.S. roads or in off-road applications. Due to data constraints, no distinction is made between vehicles that continue to be in active service and those that have been removed from service.

Figure 2: Vehicle Segmentation Based on ZETI

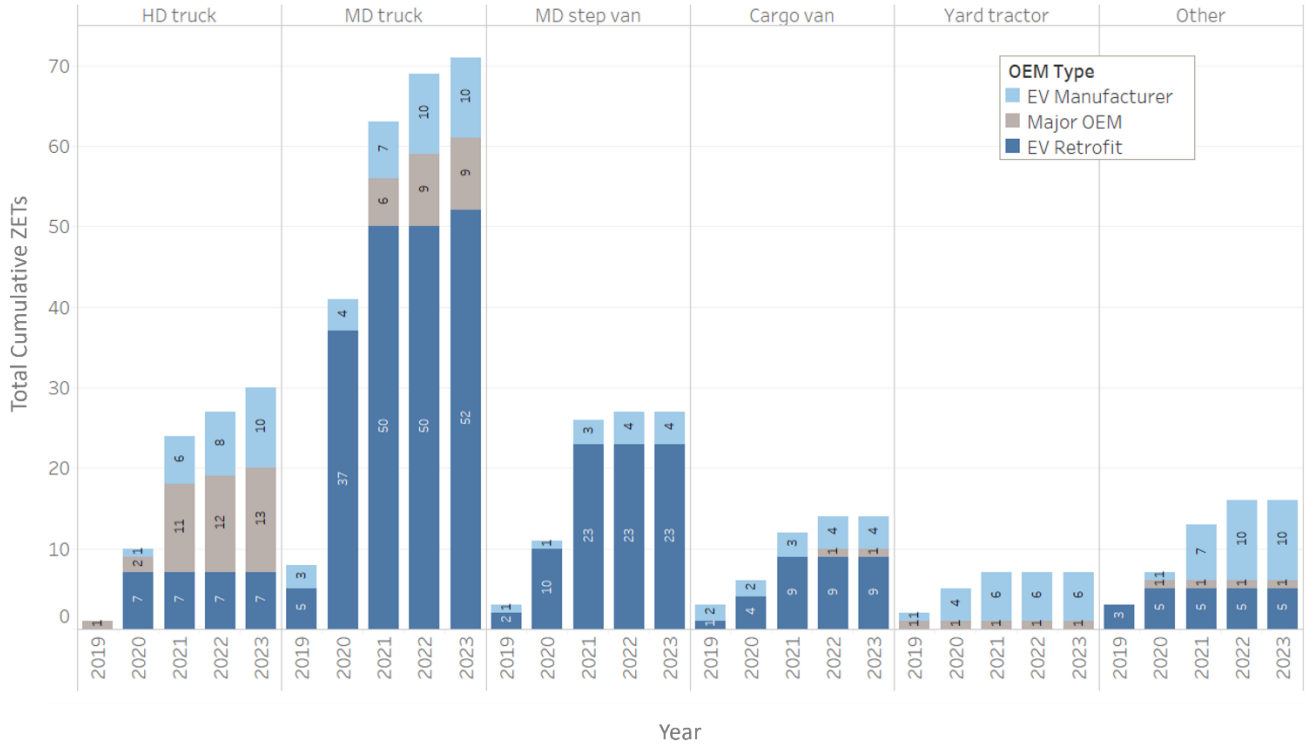


II. U.S. ZET Market Update

ZET Model Availability

A combination of technological, market, and regulatory factors have led to a recent explosion in ZET offerings. According to ZETI (**Figure 3**),[6] in 2019, there were 20 models of Class 2b-8 ZETs available for purchase in the United States. In 2021, that number rose to 145 models (a 625% increase) and is anticipated to rise to 165 models by 2023.

Figure 3: ZETI Model Availability in the United States (2019-2023)



Of available 2021 ZET models, 65% were produced by manufacturers that either repower existing chassis or produce their own chassis and powertrains for existing vehicle frames (e.g., Motiv Power Inc., Lightning eMotors, SEA Electric). Manufacturers that produce the entire electric vehicle (EV) and only produce EVs (e.g., BYD, Orange EV) comprised 22% of ZET models, and manufacturers that also produce conventional gasoline and diesel vehicles (e.g., Daimler, Paccar, and Volvo)

[6] "Other" primarily includes refuse and construction trucks.

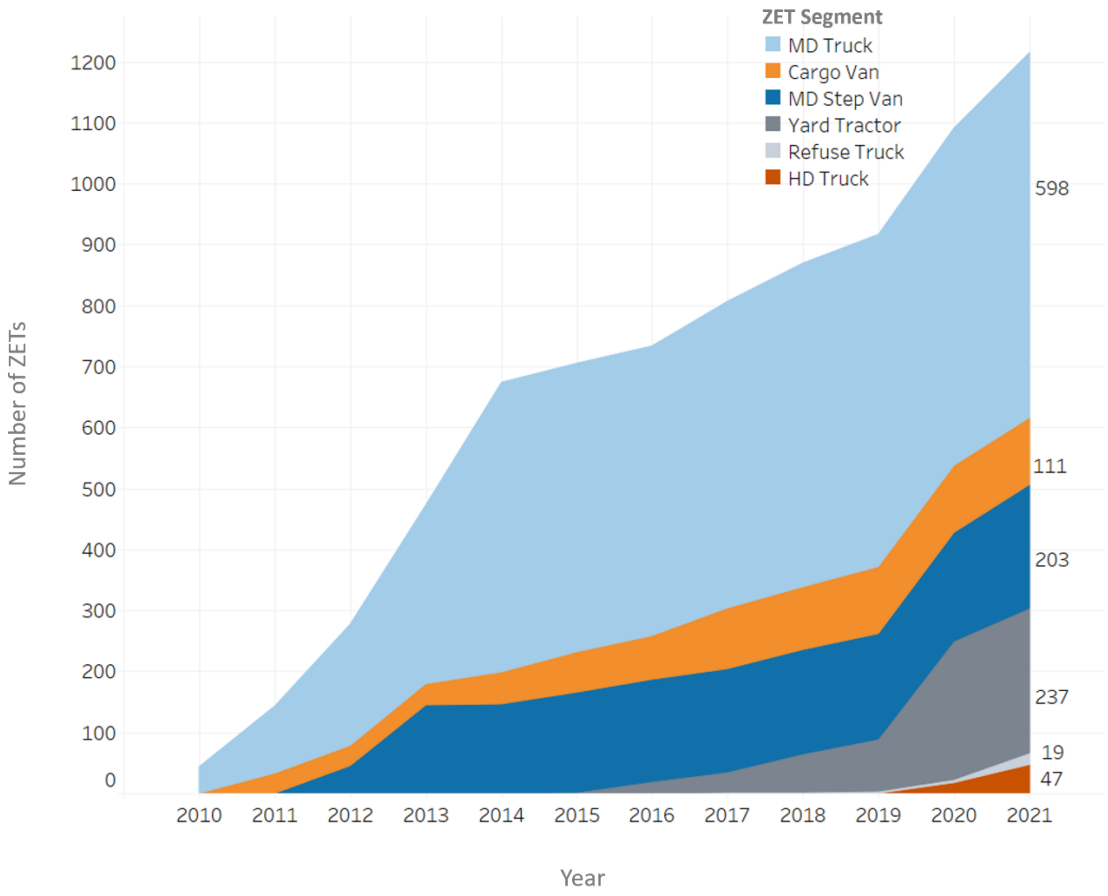
produced 13% of ZET models.

In 2021, MD trucks were the largest constituent of available models (43%), demonstrating the wide range of commercial applications that MD trucks can fulfill and the many different body types and vocations this broad category encompasses. Notably, 24 HD truck models were available for purchase in 2021, up from 10 models in 2020. This growth was driven exclusively by the release of HD truck models from major OEMs and EV-only manufacturers such as Volvo, Paccar, and Lion Electric.

ZET Deployments by Application

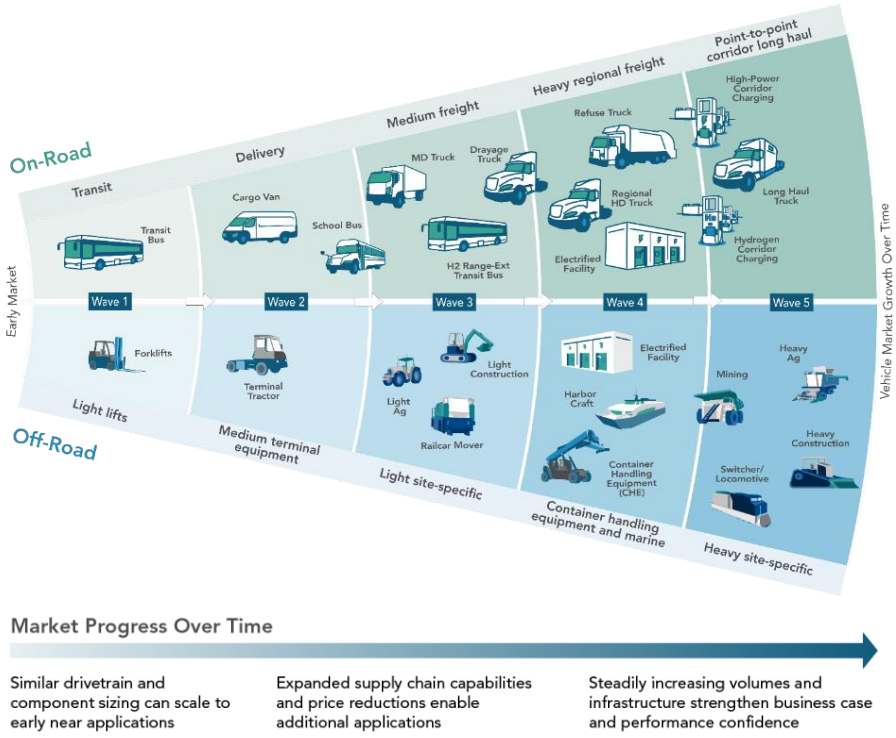
Despite the robust model offerings, ZET deployments still only account for a very small percentage of total registered trucks in the United States. As of December 2021, 1,215 ZETs have been deployed in the United States across over 163 fleets (**Figure 4**). For context, Europe has deployed over 2,300 MHD ZETs as of 2021, and China deployed over 20,000 MHD ZETs as of 2021 (ACEA, 2021; IEA, 2021). As of late 2020, there were roughly 23 million Class 2b-8 trucks registered and in-use on U.S. roads, meaning deployed ZETs make up just 0.005% of the registered MHD truck population (MJB&A, 2021).

Figure 4: Cumulative Truck Deployments in the United States (2010-2021)



The ZET deployments to date are largely consistent with the Beachhead Theory of Change, a strategy pioneered by CALSTART and CARB, which predicts how zero-emission technology will propagate throughout various MHD vehicle segments. In the Beachhead Theory of Change, now widely recognized across the clean transportation industry, vehicle segments with applications and duty cycles more suited to zero-emission technology transition first, influencing the development of subsequent harder-to-electrify segments (**Figure 5**).

Figure 5: The Zero-Emission Beachhead (CARB, 2021a)



The Beachhead Theory of Change can be seen materializing in **Figure 4**, where MD trucks, MD step vans, and cargo vans—all vehicle types well-suited for electric drivetrain and battery technology—were the first to electrify between 2010 and 2015 and have influenced the later development of harder-to-electrify segments like HD trucks and refuse trucks starting in 2019.

MD trucks, cargo vans, and MD step vans were deployed five years before the deployment of any other ZET segment. Together these segments comprised 75% of all truck deployments in 2021, as seen in **Figure 4**, and are deployed in 22 states not limited to one geographic region (though over half of these vehicles are deployed in California). The early dominance of these truck segments can be attributed to a multitude of favorable technical and economic factors:

- Daily driving ranges are typically in line with currently available battery technology.
- Return-to-base operations allow for overnight charging with L2 chargers.
- These vehicles rarely operate at max GVWR, which makes the generally heavier weight of a ZET (due to battery weight) a non-issue.

- The incremental cost over diesel vehicles is smaller than for heavier-duty ZETs due to the relatively smaller battery sizes required to accomplish daily driving ranges. (A lower incremental cost also leads to a faster pay-back period and lower TCO.)[7]

Yard tractors are the second largest segment of deployed ZETs at 20% of all deployed trucks in 2021. The high deployments of yard tractors can be explained by a combination of high demand from operators and the ability of manufacturers to meet that demand. Yard tractors are used to move semi-trailers within a cargo yard or intermodal facility and never travel far from available depot charging ports. Zero-emission yard tractor operators can therefore benefit from the lower operating costs of zero-emission models without the range anxiety usually associated with on-road ZETs. California has made the electrification of port operations, including yard tractors and other cargo handling equipment, a priority through its Sustainable Freight Action Plan (CARB, 2021b). As of 2017, California provides dedicated incentives for off-road equipment, including yard tractors through CORE. Demand for yard tractors has been met by manufacturers with relatively high production capacity. The majority of deployed zero-emission yard tractors in the United States are operating in states with large ports such as California, Illinois, New York, and New Jersey.

HD trucks made up only 4% of 2021 deployments, but this number is expected to grow due to increasing HD truck model availability and an abundance of HD truck orders (discussed in greater detail in **Section III**). Most zero-emission HD trucks deployed as of December 2021 were engaged in large pilot projects to demonstrate their ability to satisfy fleet duty cycles. Notably, 15% of deployed zero-emission HD trucks employ fuel cell electric powertrains, which may prove to be a promising technology, especially for longer-haul or regional trucking operations. Zero-emission HD trucks are mostly deployed in California due to the combination of a mature and well-funded voucher incentive program and a variety of zero-emission technology and demonstration projects led by CARB, the California Energy Commission (CEC), and regional air quality management districts (AQMDs).

While refuse trucks only made up 2% of 2021 ZET deployments, they were deployed in a wide variety of states, including Idaho, Maine, and Maryland, where total ZET deployment numbers are generally low. Refuse trucks deployed in these states were mostly funded by state allocations of the U.S. Environmental Protection Agency's (EPA) Diesel Emission Reduction Act (DERA) grants and Volkswagen (VW) Settlement Funds, which fund the replacement of diesel vehicles.

Commercial pickup trucks are not currently represented in zero-emission deployment data because there have been no zero-emission commercial pickup truck deployments to date. While Rivian has begun to ship its Class 2b R1T pickup truck to customers, all known shipments as of December 2021 are for personal use and are not included in this analysis. Ford's F150 Lightning commercial use pickup truck is expected to start shipping to customers in 2022 and GM's Chevy Silverado EV is expected the following year.

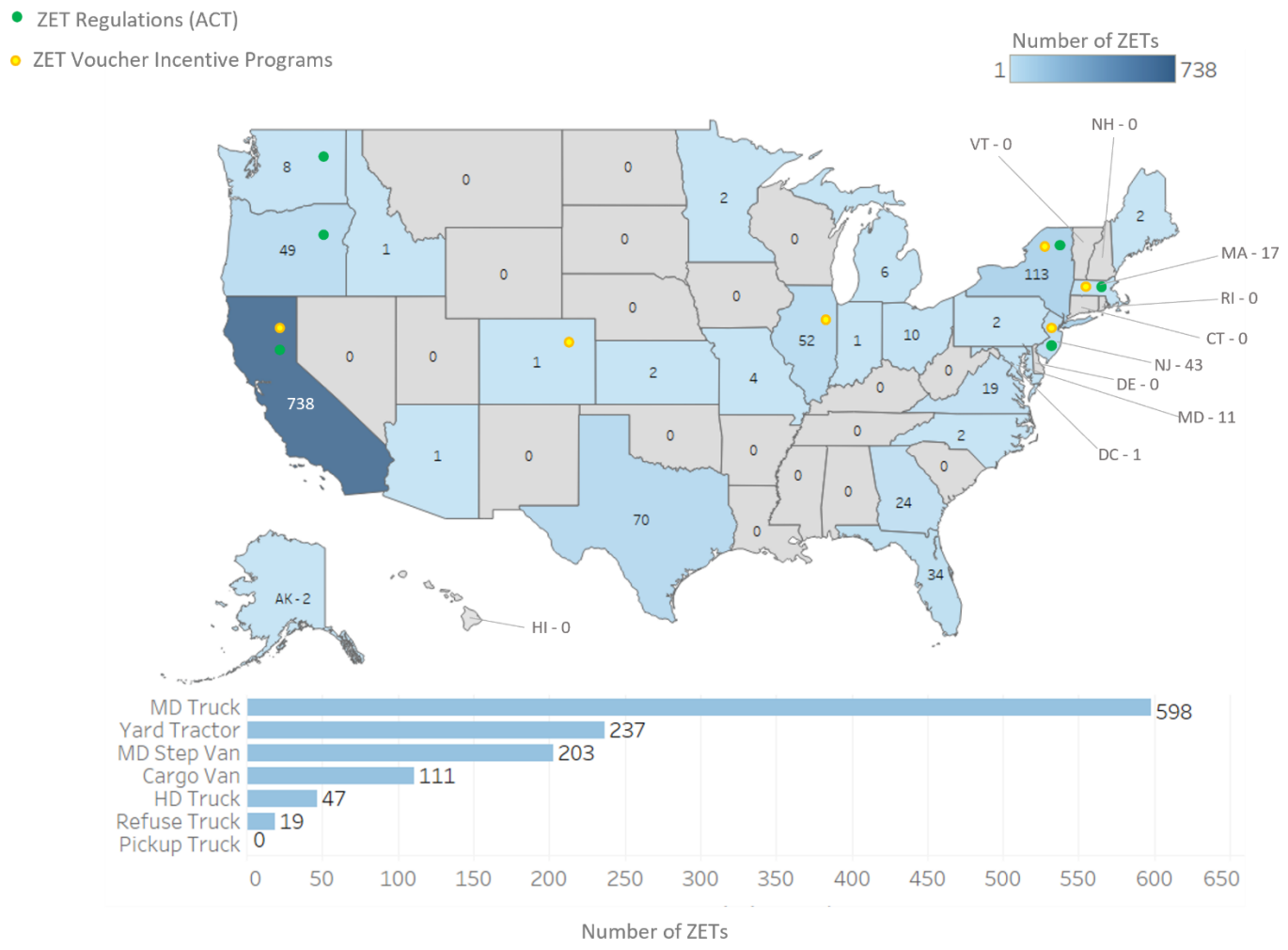
[7] See Appendix D for a detailed breakdown of incremental cost, daily mileage, and available battery ranges by ZETI segment.

ZET Deployments by State

ZET deployments are not distributed evenly across the United States—rather, they are concentrated in areas with supportive electric truck policies and regulations, as seen in **Figure 6**.[8] Because of the current high incremental cost of a ZET over a conventional gasoline or diesel truck, states with significant incentive or grant funding opportunities attract the most ZET purchases and deployments.

An exception to this rule is federally funded ZET deployments. The U.S. Department of Energy (DOE) has helped fund the deployment of over 400 ZETs, some of which have been deployed in states like Texas, Florida, and Georgia, which have no regulation for ZET adoption and no significant incentive or grant funding opportunities for ZET purchases.

Figure 6: ZET Deployments by State (As of December 2021)



[8] ZET incentive programs included in Figure 6 are only voucher incentive programs. A full list of incentive programs is found in Appendix B.

California is a clear leader in ZET deployments, responsible for 61% of all ZET deployments to date. Behind this dominance is a robust suite of ZET policies and incentives that together have catalyzed deployments across the state. HVIP, a point-of-sale voucher program, is the largest source of funds for ZET purchases in the state. Over the last 12 years, HVIP has provided over $314 million for zero- and low-emission truck and buses in total and $179 million for specifically zero-emission vehicles as of December 2021 (HVIP, n.d.). CORE is another significant source of funding for off-road equipment, including yard tractors and other cargo-handling equipment, and has provided over $28 million in its first year.

New York has the second highest concentration of ZETs (9.2%) behind California. New York runs the New York Truck Voucher Incentive Program (NYTVIP), which funds clean trucks in New York State, and the New York City Clean Trucks Program (NYCCTP), which funds clean truck purchases specifically in NYC Industrial Business Zones.

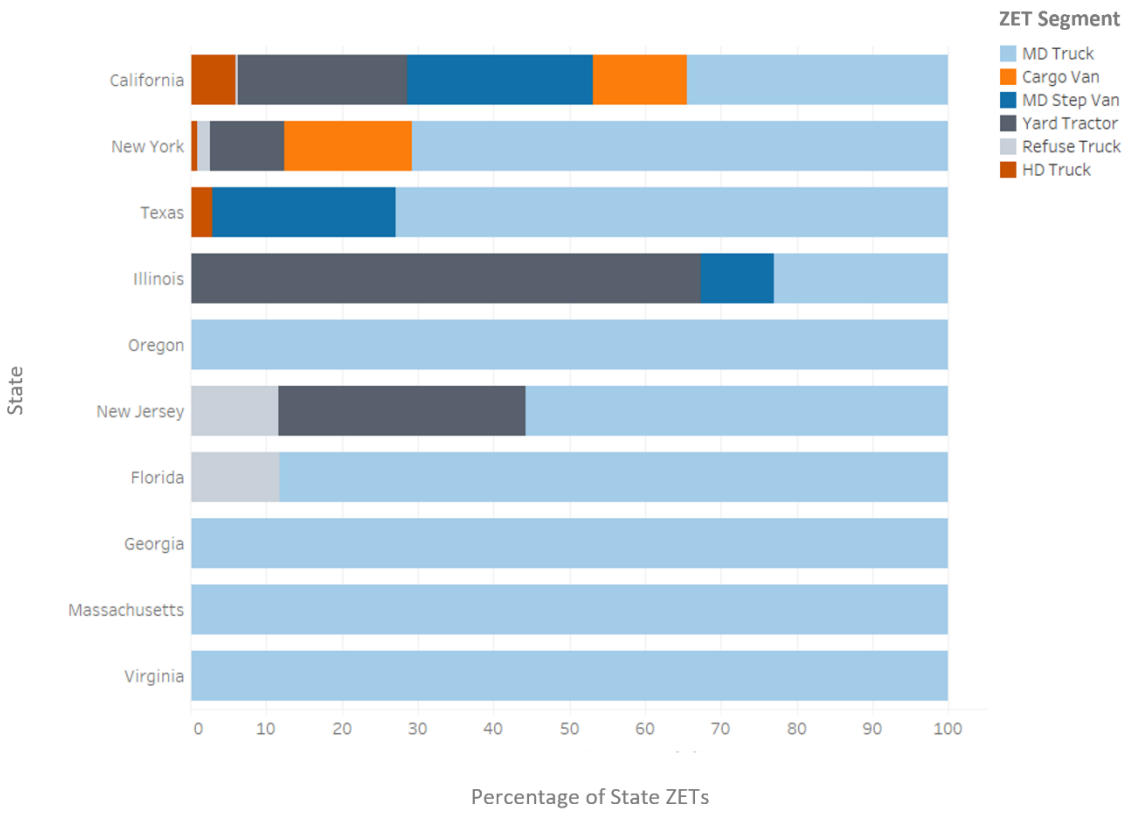
New Jersey and Illinois are two other states with high concentrations of ZETs when compared with the rest of the country. New Jersey has funded the majority of its ZETs through its allocation of the VW Settlement Fund. Additionally, New Jersey has a new voucher incentive program, the New Jersey Zero-Emission Incentive Program (NJZIP), which opened in 2021 and has a total voucher pool of $44.25 million; however, it has not redeemed any vouchers to date. Illinois runs the Drive Clean Chicago voucher incentive program, which has funded $11 million worth of hybrid and all-electric trucks and buses.

Texas, Oregon, Florida, Georgia, Virginia, and Massachusetts also have relatively large amounts of ZETs, which have been funded by one of two federal grants through the DOE. The majority of ZETs deployed in Texas were funded with a grant from the DOE's National Energy Technology Laboratory (Automotive Fleet, 2015). Most vehicles in the other states were funded as part of a DOE evaluation project with funding from the American Recovery and Reinvestment Act of 2009.

There are 32 other state-run monetary incentive programs which can be used to fund ZET purchases, replacements, or repowers. Many of these programs are funded by either VW Settlement, EPA DERA, or National Highway Traffic Safety Administration (NHTSA) Congestion Mitigation and Air Quality Improvement (CMAQ) allocations. To date, however, very few of these programs have been used to fund ZET technology, funding instead other qualifying vehicle segments (e.g., buses, light-duty vehicles, off-road equipment) or low-emission trucks (e.g., CNG, hybrid electric, low NOx, propane). More information on these monetary incentive programs is detailed in **Appendix B.**

Each of the top 10 states for ZET deployment in **Figure 7** below has a composition of ZET segments that reflects the demand in that state as well as the diversity of available state funding sources for ZETs.

Figure 7: Top 10 ZET States Breakdown by Segment

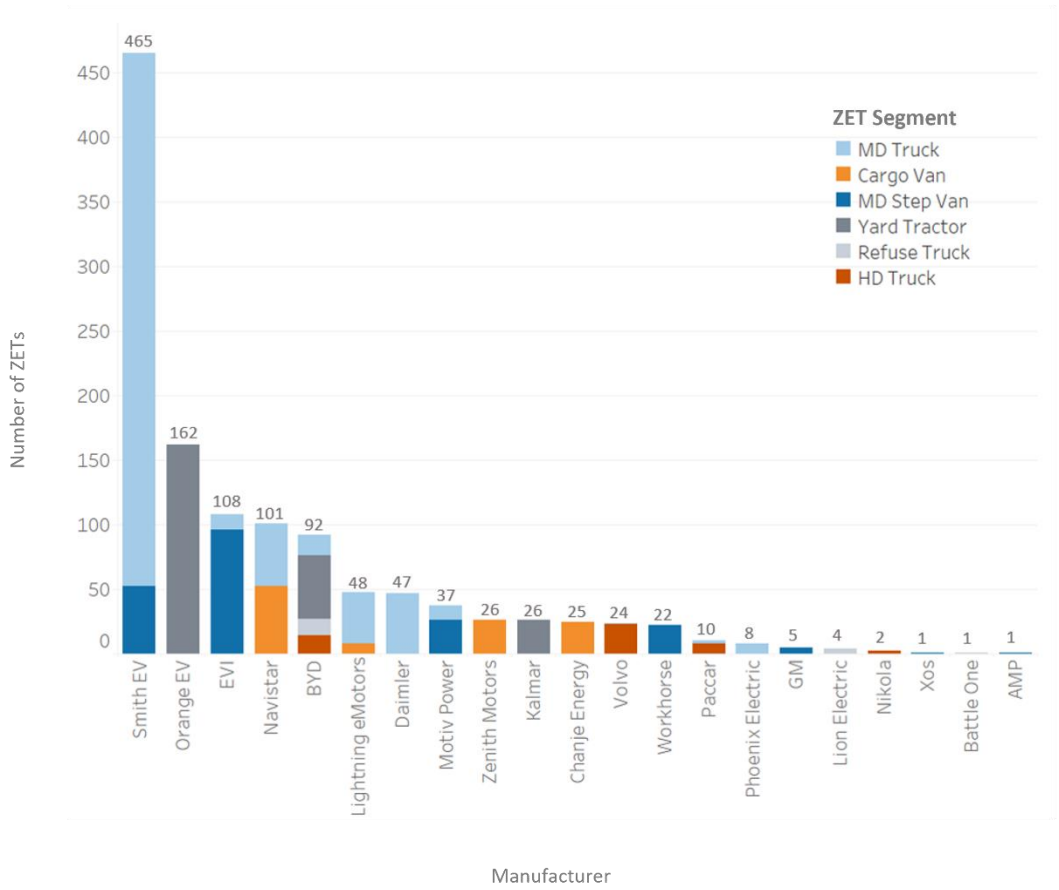


California, with a diverse set of ZET funding sources, has a comparably diverse distribution of vehicle segments, with no one segment comprising the majority. New York has a large proportion of MD trucks mostly employed in urban delivery around New York City. New Jersey also has a large number of MD trucks employed in urban delivery but also has a significant yard tractor population employed at Port Newark. The Illinois ZET population is also dominated by yard tractors, mostly employed in and around the Port of Chicago. Texas, Oregon, Florida, Georgia, Virginia, and Massachusetts are dominated by MD trucks and MD step vans employed in federally funded demonstrations projects, many of which are believed to no longer be in operation.

ZET Deployments by Manufacturer

The emerging U.S. ZET market is diverse, and in contrast to the conventional MHD truck market, no manufacturer or small set of manufacturers has claimed majority market share.

Figure 8: Deployed ZETs by Manufacturer (As of December 2021)



As seen in **Figure 8**, the manufacturer with the largest share of vehicles is Smith EV with 465 vehicles deployed between 2011-2014. Smith EV, however, suspended production of its electric trucks in 2014. In 2017, the company suspended all operations indefinitely. At least 165 of these Smith EV MD trucks have been reported "non-operational" in California, but the status of the other trucks around the country is unknown. Without dedicated servicing from Smith EV, they have likely also been taken out of service by their operators.

Similarly, the majority of EVI, Navistar eStar, Chanje, and Workhorse vehicles are non-operational due to support or operational performance issues, or were removed from service for additional testing (Alamalhodaei, 2021). Together over 60% of ZETs that have been deployed in the United States are believed to be currently non-operational. A new generation of MD trucks and step vans has since emerged, built with improved battery chemistry, operational range, and performance capabilities.

Of all operational ZETs, Orange EV, a yard tractor manufacturer, has the most deployed vehicles in the United States. Behind Orange EV, BYD has deployed over 90 electric trucks, distributed across their HD truck, refuse truck, yard tractors, and MD truck models. BYD, originally a battery manufacturer, displayed early dominance in the global bus market where it sold over 23,000 electric buses in China as of 2019 and has sold over 750 electric buses in the United States as of 2021. BYD's experience in the bus market assisted its expansion into MHD BET segments. With a robust battery supply chain for MHD battery-electric buses, BYD is likely able to obtain lower battery pack prices than many of its competitors (Beaty, 2021). As of 2019, BYD sold over 3,500 electric trucks in China and is the single largest on-road ZET manufacturer (with operational vehicles) in the United States.

Lightning eMotors and Motiv Power Systems both deployed between 30 and 50 MD trucks and vans, respectively. By the nature of their business models, these "retrofit" manufacturers bypass the establishment of costly production lines for the entire ZET body and chassis and therefore have been able to bring ZETs to market much faster than most other manufacturers.

Daimler has also deployed close to 50 eCanter MD trucks throughout the United States through its subsidiary the Mitsubishi Fuso Truck and Bus Corporation (or FUSO). In 2020, FUSO announced it would be exiting the U.S. and Canada markets but will continue to provide parts and service for customers through 2028.

The largest U.S.-based OEMs in **Figure 8**—Daimler, Volvo, Navistar, and PACCAR, which are cumulatively responsible for the entire 2020 U.S. on-road conventional HD truck market—have deployed only 45 HD ZETs to customers as of December 2021.[9] While current deployments are mostly pilot and demonstration focused, each of these manufacturers is moving quickly to take large orders for their HD ZETs. In addition to these four manufacturers, Nikola, at the end of 2021, delivered two of their TreBev battery-electric tractors to the Port of Los Angeles for drayage service.

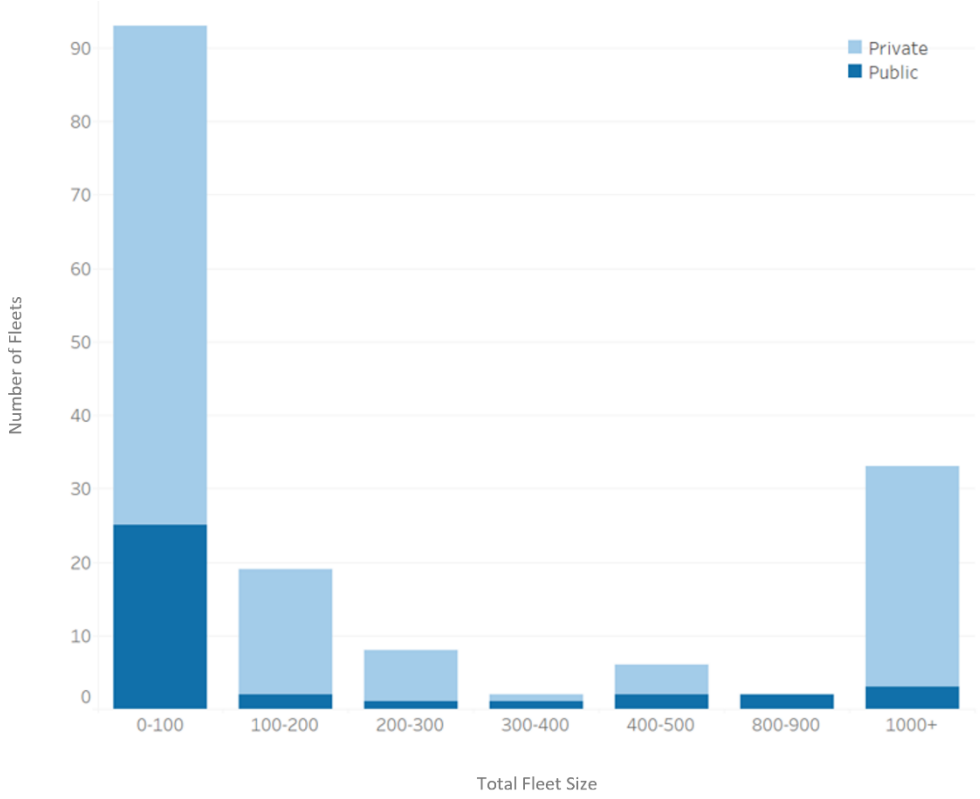
There were only five deployed FCETs as of December 2021. These trucks were produced by Kenworth, a subsidiary of PACCAR, in collaboration with Toyota. All FCETs are employed in drayage demonstrations and pilots at the Port of Los Angeles.

9 Daimler (through their brand Freightliner) has deployed 38 HD ZETs through its Freightliner Customer Experience and Innovation Fleets. These vehicles are being tested by customers while Daimler collects data on the vehicles' operations. These trucks have been purposely excluded from this analysis because customers are testing, not permanently deploying, these vehicles. More information about these projects can be found here: https://daimler-trucksnorthamerica.com/PressDetail/one-million-real-world-electric-miles-freightliner-s-2021-10-05.

ZET Customers

There are 163 known ZET customers as of December 2021 (**Figure 9**). Most ZET customers are private organizations (e.g., third-party logistics providers and private fleets). Public customers make up only 22% of all customers and mostly consist of municipalities and schools.

Figure 9: Distribution of Total Fleet Size Across ZET Customers



While the majority of customers are small fleets, large fleets purchase the majority of ZETs. Just 20 customers make up 50% of all current ZET deployments, and those fleets are responsible for operating a cumulative 388,597 total fleet trucks, regardless of fuel type. These customers are often "test-driving" ZETs in smaller numbers to determine how zero-emission technology will work with their operations. If the trials are successful, many of these customers will hopefully continue to electrify their large fleets.

III. Future Growth and Technology

The over 1,200 ZETs that have been deployed as of December 2021 are only the beginning of a structural transformation taking place in the MHD truck industry. Learnings from the more mature zero-emission bus segment have allowed many manufacturers to refine their HD ZET technology, and upcoming pilots and demonstrations will continue to prove ZETs capable in the HD truck market. Rapidly falling battery prices, complemented by increased state ZET incentives, will make the economic prospect of ZET adoption increasingly attractive for fleets. Additionally, ZET legislation and regulation, pioneered by the State of California and CARB, is gaining momentum among MOU signatory states and will provide strong signals to manufacturers and customers to integrate zero-emission trucking into their long-term strategies.

Upcoming Demonstrations and Pilots

Most pilot and demonstration projects currently underway are seeking to prove the concept of HD zero-emission technology, as MD technologies are largely proven and further along the path to commercialization. It is anticipated that the HD ZET models engaged in pilots and demonstrations will be deployed in larger numbers shortly after project conclusions.

One of the largest sources of HD ZET research and development funding is the SuperTruck 3 Initiative run by the DOE Office of Energy Efficiency and Renewable Energy. This program is the third iteration of the SuperTruck initiative that seeks to improve MHD truck efficiencies in the United States. The SuperTruck 3 program will provide over $127 million to five major truck OEMs to develop and test MHD battery-electric and fuel-cell electric trucks over the next five years (DOE, 2021). These federal contributions will be matched by the truck OEMs: Paccar, Daimler, Volvo, Ford, and GM.

In California, a joint CARB-CEC Zero Emission Drayage Truck and Infrastructure Pilot Project is providing funding for the demonstration and operation of 280 Class 8 drayage trucks (battery-electric and hydrogen fuel cell), as described in **Table 1** below:

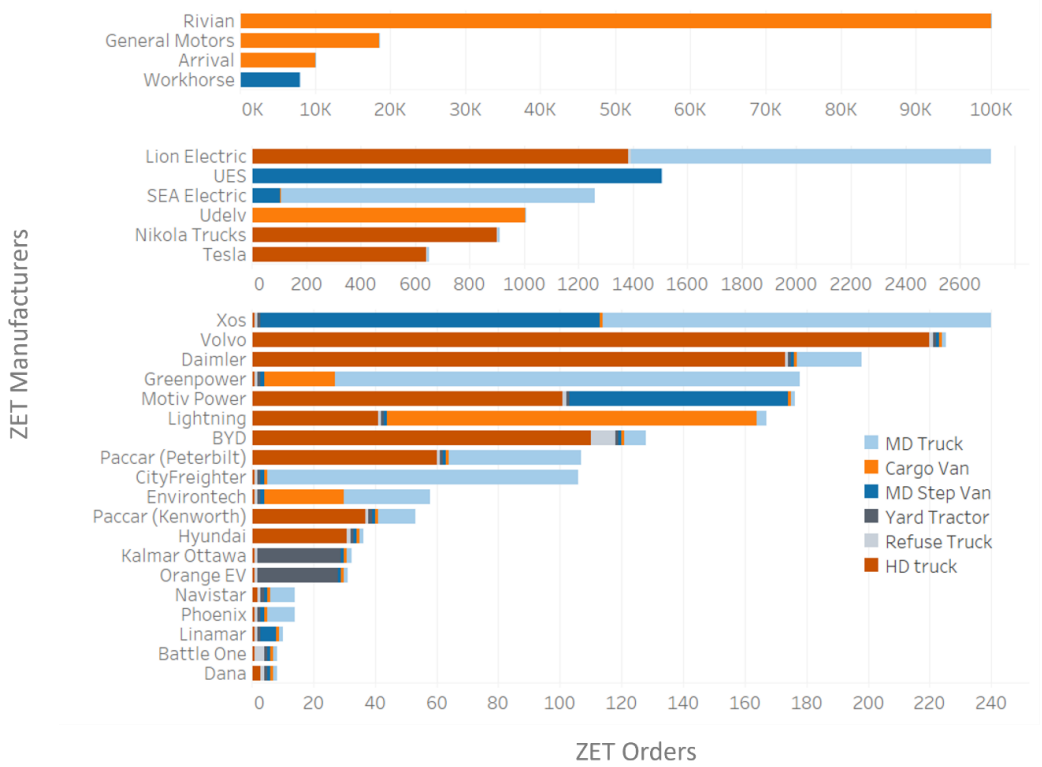
Table 1: CARB-CEC Zero Emission Drayage Truck and Infrastructure Pilot Project

Project/Fleet(s)	Number of ZETs Deployed	Truck Manufacturer	Type/Model
South Coast AQMD / NFI & Schneider	100	Volvo (20), Daimler (80)	VNRe, eCascadia
Center for Transportation and the Environment / NorCAL Drayage	30	Hyundai	XCIENT Fuel Cell Electric
San Joaquin Valley APCD / Pepsi	50	Tesla	BET Class 8 Semi
San Joaquin Valley APCD / Albertsons	50	Volvo	VNRe
California Hispanic Chamber of Commerce Foundation / Gonzales Logistics Inc	50	Lion	Lion8T Drayage

Pending Orders

Many fleets, including some of the largest fleets in North America, have committed to deploying MHD ZETs and have been placing orders to back up their ambition. Across all ZET manufacturers, 146,102 ZETs have been ordered (see **Figure 10**). In general, these orders are a mixture of firm (legally binding) and non-binding orders and range from expected delivery times of one to ten years depending on the manufacturer's current production capacity and the size of the order. Please note that orders may change based on fleet demand, OEM manufacturer capabilities and capacities, or other market drivers.

Figure 10: ZET Orders (As of December 2021)



The largest order is by Amazon for 100,000 Rivian delivery vans. Rivian aims to have the first 10,000 delivery vans delivered to Amazon by 2022 and all 100,000 delivered by 2030 (Lewis, 2021). The United Postal Service's order of 10,000 Arrival delivery vans is expected to be completed between 2020 and 2024, while Pride Group Enterprises' order of over 6,320 Workhorse C-Series electric delivery trucks is expected to be delivered between 2021 and 2026 (Arrival, 2020; Workhorse, 2021)[10].

Included in **Figure 10** are 1,200 pending California HVIP orders at various stages of the voucher redemption process (roughly doubling the total number of deployed ZETs in the United States). These vehicles are expected to be delivered within 18 months. However, there is some flexibility depending on supply chain or infrastructure issues. While some HVIP orders are ultimately canceled, it is anticipated that these 1,200 ZETs represent the number of orders that will be fulfilled within HVIP in the next year and a half as any cancelled vouchers are typically made available to other requesters.

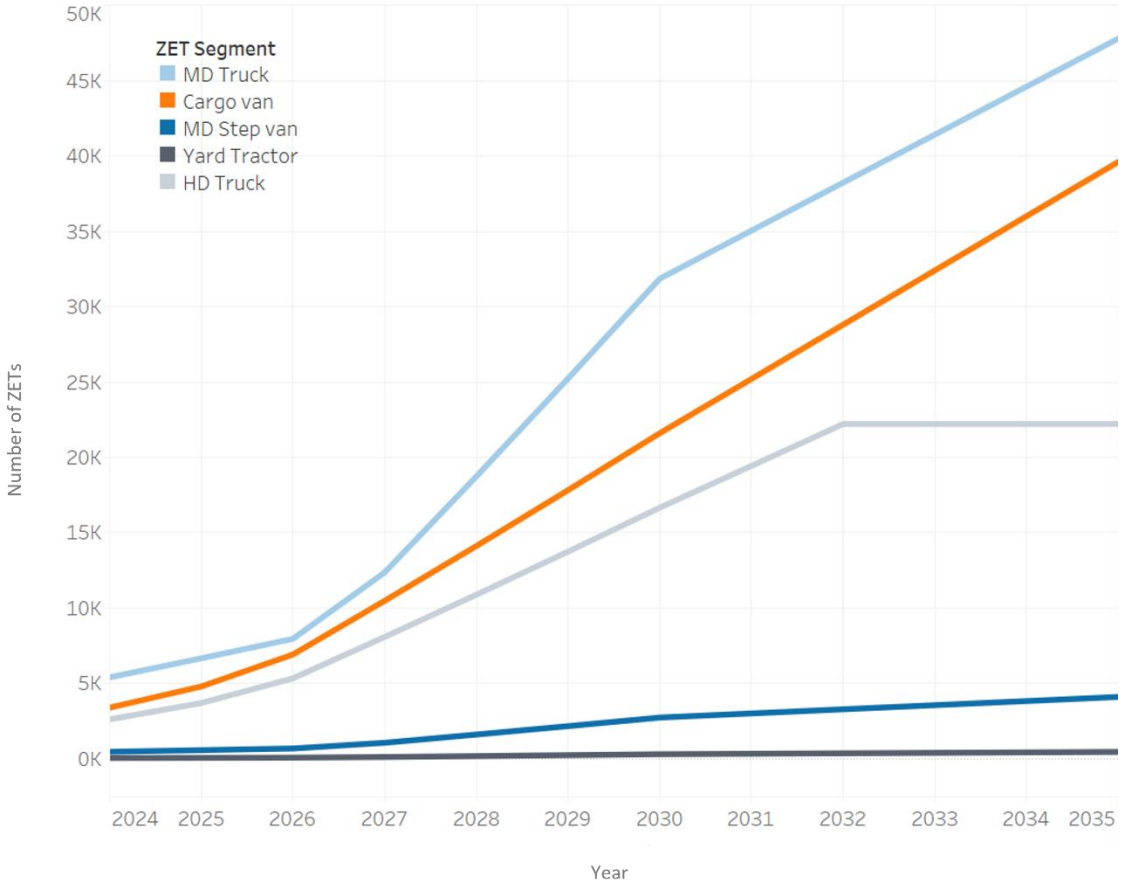
Policy-Driven Growth

Because of the current high incremental cost of ZETs over their diesel counterparts, short-term deployment is highly dependent on state incentives, which can close the cost gap for customers and accelerate manufacturers towards larger production volumes and ultimately lower production costs.

2022 will be a year of unprecedented ZET incentive funding. In California, Fiscal Year (FY) 2021-2022 funding for HD and off-road equipment is just over $873 million, nearly equal to the historical cumulative amount of $881 million that was allocated for HD and off-road equipment from FYs 2013-2020 (CARB, 2021c; CARB, 2020a). In addition, MOU states are taking California's lead in pairing strong targets and regulations with the targeted financial incentives for ZETs. In January 2021, New Jersey began piloting NJZIP, a voucher incentive program like those operating in California and New York (New Jersey Economic Development Authority, 2021). In February of 2021, Massachusetts expanded its Massachusetts Offers Rebates for Electric Vehicles (MOR-EV) rebate program to also include vouchers for MHD BETs and FCETs.

[10] In September 2021, Workhorse suspended deliveries of its C-1000 delivery vans and recalled 41 vehicles due to the need for additional testing to comply with federal safety standards.

Figure 11: Projection of MOU State ZET Adoption Assuming ACT Adoption (2024-2035)



In addition to increased funding, ZET deployments will be driven by regulatory action on the state level. The ACT rule has now been approved by six state environmental agencies, and more MOU states are expected to approve it in the coming years. **Figure 11** shows what ZET sales are projected to look like if all MOU signatory states, responsible for 34% of the total MHD market, adopt the ACT rule.[11] Under this scenario, ACT regulation would drive over 756,000 ZET deployments between 2024 and 2035.

New Technologies and Business Models Driving ZET Market

- **Lower cost batteries**: Despite average U.S. light-duty battery pack prices having reached $136 per kilowatt-hour (kWh) in 2020, commercial vehicle battery pack prices are higher and vary widely ($300/kWh - $1,000/kWh) depending on a vehicle manufacturer's experience, organization capability, and production volume (Beaty, 2021). As sales and production of commercial zero-emission vehicles increase and manufacturers are able to provide battery producers with higher levels of demand and certainty, battery pack prices are expected to decline and bring MHD zero-emission vehicles closer to TCO parity with their diesel

[11] These calculations are based on 2019 IHS registration data. A further breakdown of data for MOU states is included in both Appendix A, and see Appendix C for a breakdown of market share of all registered Class 2b-8 trucks across MOU and Non-MOU signatory states based on 2019 IHS registration data.

counterparts.

- **Fuel cell technology**: FCETs generally have longer ranges than BETs with faster refueling times. However, the economics of FCETs are complicated by currently low production volumes, lack of refueling infrastructure, and an immature fuel production system. Projections show that FCETs in the United States will not be at TCO parity with diesel counterparts by 2030, when BETs are expected to reach parity (ICF, 2019). This forecast could change with policy action, technological innovation, and increased production scale. In 2021, five Kenworth fuel cell electric T680 trucks were delivered to the Port of Los Angeles (with five more on the way) for a twelve-month demonstration project co-funded by CARB. Nikola, another FCET manufacturer in the United States, is currently track testing its Class 8 Tre FCET in Germany and Arizona, after which it plans to deliver some models for customer pilots. Additionally, as mentioned in **Table 1,** Hyundai plans to deliver 30 XCIENT FCETs for demonstration projects in California by early 2023. These developments are promising steps towards the commercialization of FCETs for heavy-duty truck applications. Other major OEMs and powertrain suppliers have recently announced development of fuel cell propulsion systems and include Navistar, Cummins, Volvo, Daimler, Ford, GM, Hino, and Hyzon.
- **Transportation-as-a-Service (TaaS):** TaaS is a business model that allows operators to use ZETs without being responsible for the full upfront cost of the vehicles and charging equipment, which can be a prohibitory cost. Instead, under a TaaS model, an operator pays a recurring fee to the service provider, who in exchange provides ZETs, vehicle maintenance, installation and management of charging infrastructure, and vehicle charging management. One example of the ZET TaaS model is Zeem Solutions, which provides leasing, servicing, parking, charging, and energy storage for small- and medium-sized fleets looking to adopt Class 3-8 zero-emission commercial vehicles but avoid their high upfront costs. Another TaaS provider, WattEV, aims to provide similar services for HD trucks and has broken ground on an electric truck charging station in California, which will be able to charge up to 200 trucks per day (WattEV, 2021). A similar business model, Charging-as-a-Service (CaaS), is being pioneered by companies like AMPLY Power and Electrada, which will provide fleet charging infrastructure installation and management in exchange for a recurring fee. Similar to TaaS providers, CaaS providers can ease the upfront capital costs and provide the expertise needed to transition to a ZET fleet.

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Appendix A: Data Sources

All data sources for this report are provided in **Table A-1** below.

Table A-1: Data Sources

Data Source	Description	Specific Data Used
IHS Markit	Global provider of information and analysis on world markets and industries	U.S. truck registrations as of May 2019
EV Volumes	Database of sales statistics, charging infrastructure, batteries, car models, and sales forecasts for plug-in cars	Stock and deployed sales of electric trucks as of January 2022
California HVIP	California's Hybrid Zero-Emission Truck and Bus Voucher Incentive Program	ZET sales through HVIP as of December 2021
California CORE	California's Clean Off-Road Equipment Voucher Incentive Program	Zero-emission yard tractor sales through CORE as of November 2021
Drive Clean Chicago	Voucher incentive program administered by the City of Chicago	ZET sales as of December 2021
NYVIP	Truck voucher incentive program administered by the State of New York	ZET sales as of December 2021
Public Press Releases	Press releases from OEMs announcing delivered sales	ZET deployments and upcoming orders as of December 2021
Private Correspondence	CALSTART correspondence with OEMs	ZET deployments and upcoming orders as of December 2021

Appendix B: ZET Incentive Programs

A comprehensive list of all incentive programs for ZETs is listed in **Table B-1.** Federal funding sources include the Volkswagen Settlement Fund (VW Settlement), National Highway Traffic Safety Administration's Congestion Mitigation and Air Quality (CMAQ) fund, and the Diesel Emissions Reduction Act (DERA) fund. State specific funds include California's General Fund (GF), Greenhouse Gas Reduction Fund (GGRF), Air Pollution Control Fund (APCF), and Air Quality Improvement Program (AQIP), and the Regional Greenhouse Gas Initiative (RGGI) funds from Massachusetts and New Jersey.

Table B-1: State Incentives Providing Funding for ZETs (Source: DOE Alternative Fuels Data Center)

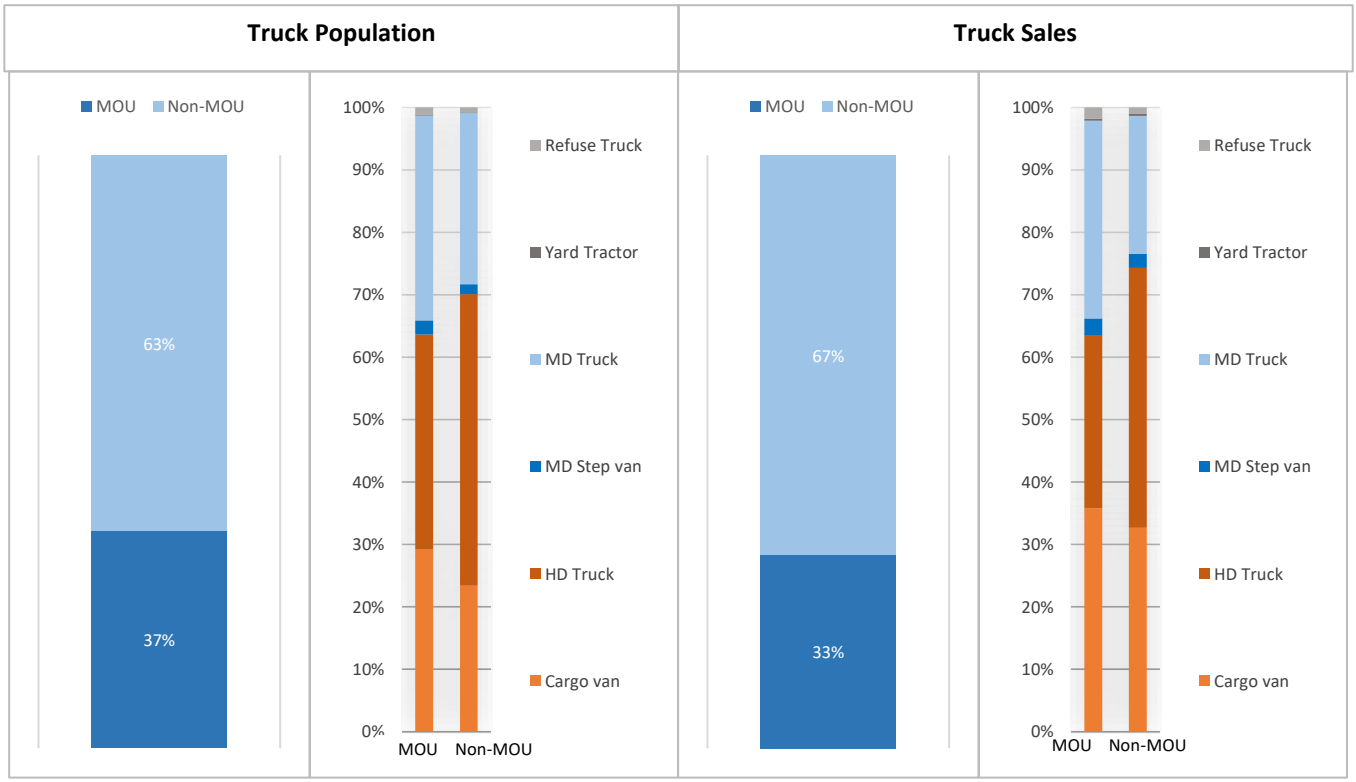
State	Incentive Name	Incentive Type	Funding Source
Alabama	Medium- and Heavy-Duty Diesel Vehicle Replacement Rebates	Rebate	VW Settlement
California	Low Emission Truck and Bus Purchase Vouchers (HVIP)	Voucher	GF/GGRF/APCF/AQIP
California	Clean Off-Road Equipment (CORE) Voucher Program	Voucher	GF/GGRF/APCF/AQIP
California	VW Mitigation Trust	Grant	VW Settlement
Colorado	ALT Fuels Colorado	Grant	VW Settlement/CMAQ
Connecticut	Heavy-Duty Vehicle Emissions Reduction Grants	Grant	VW Settlement
Delaware	Medium- and Heavy-Duty Emissions Reductions Funding	Grant	VW Settlement
Idaho	Medium- and Heavy-Duty Diesel Vehicle Replacement Rebates	Grant	VW Settlement
Illinois	Diesel Emission Reduction Grants	Grant	VW Settlement/DERA/CMAQ
Illinois	Drive Clean Chicago	Voucher	CMAQ
Indiana	Medium- and Heavy-Duty Grant Program	Grant	VW Settlement
Indiana	Diesel Vehicle Retrofit and Improvement Grants	Grant	VW Settlement/DERA
Iowa	Diesel Emissions Reduction Project Funding	Grant	VW Settlement
Maine	Diesel Emissions Reduction Project Funding	Grant	VW Settlement
Maryland	MSEC Clean Energy Grants	Grant	-
Massachusetts	Diesel Emissions Reductions Grants	Grant	DERA
Massachusetts	Zero-Emission Truck Rebates (MOR-EV)	Voucher	RGGI
Michigan	Medium- and Heavy-Duty Grant Program	Grant	VW Settlement
Minnesota	Off-Road Diesel Replacement Grants	Grant	DERA

State	Incentive Name	Incentive Type	Funding Source
Nebraska	Diesel Refuse Truck Replacement Program	Grant	VW Settlement/DERA
Nevada	Heavy-Duty Vehicle Emissions Reduction Grants	Grant	VW Settlement
New Hampshire	Diesel Emissions Reduction Grants	Grant	DERA
New Jersey	Clean Truck Replacement Program	Grant	DERA/CMAQ
New Jersey	New Jersey Zero Emission Incentive Program	Voucher	RGGI
New Mexico	Diesel Emissions Reduction Funding	Grant	VW Settlement
New York	Clean Truck Replacement Program	Grant	DERA/CMAQ
New York	New York Truck Voucher Incentive Program	Voucher	CMAQ/VW Settlement
New York	NYC Clean Trucks Initiative	Voucher	CMAQ/DERA
Ohio	Diesel Emissions Reduction Grant Program	Grant	CMAQ
Pennsylvania	Medium- and Heavy-Duty Vehicle Rebates	Grant	VW Settlement
South Dakota	Diesel Emissions Reduction Grant Program	Grant	VW Settlement/DERA
Tennessee	Vehicle Emissions Reduction and EVSE Project Funding	Grant	VW Settlement
Texas	Medium- and Heavy-Duty Vehicle and Infrastructure Grant Programs	Grant	VW Settlement
Vermont	Heavy-Duty Vehicle Emissions Reduction Grants	Grant	DERA
Virginia	Port Drayage Truck Replacement and Retrofit Incentive	Grant	CMAQ
Wisconsin	Clean Diesel Grant Program	Grant	DERA
Wyoming	Diesel Emissions Reduction Project Funding	Grant	VW Settlement

Appendix C: MOU State ZET Market Statistics

Figure C-1 shows the market share of all registered Class 2b-8 trucks across MOU and Non-MOU signatory states based on 2019 IHS registration data.

Figure C-1: MOU vs. Non-MOU States Share of Class 2b-8 Trucks



Appendix D: Breakdown of ZET Incremental Cost, Mileage, and Available Battery Ranges

Table D-1 shows the incremental cost, daily mileage, and available battery ranges by ZETI segment.

Table D-1: Incremental Cost, Daily Mileage, and Available Battery Ranges by ZETI Segment (Source: ICF and ZETI)

ZETI Segment	Typical ZET Incremental Cost Over Diesel (Source: ICF)	Daily Mileage (mi) (Source: ICF)	Battery Range of Available Models (mi) (Source: CALSTART ZETI)
HD Truck	$138,748 - $183,868	100 - 600	100 - 500
Refuse Truck	$202,500	40 - 80	56 - 250
Yard Tractor	$74,950 - $159,950	-	-
MD Truck (Class 6)	$102,201 - $172,387	30 - 175	75 - 250
MD Truck (Class 4-5)	$88,095	30 - 175	75 - 250
MD Step Van	$54,777	30 - 150	75 - 200
Cargo Van	$44,068	30 - 150	100 - 205
Pickup	$7,610 - $9,890	30 - 150	300 - 315