BRIEFING PAPER

How Zero-Emission Heavy-Duty Trucks Can Be Part of the Climate Solution

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Heavy-duty trucks (HDTs) have long been disregarded as a feasible segment of the transportation sector to decarbonize in the near term. As the most disproportionate polluters on the road—affecting both the environment and public health—HDTs should be a major target for immediate action by governments, manufacturers, and fleets. Major barriers such as range and operational feasibility are largely being overcome for specific segments and duty-cycles, providing a tangible path forward for faster adoption. With cost parity between zero-emission and diesel technologies expected to be reached by 2030 or sooner, stakeholders must seriously consider the role of these vehicles to reduce climate change and air pollution while advancing technology innovation and clean technology jobs. As total available zero-emission models increase each year, and leading governments and manufacturers signal the beginning of this transition through sales announcements and policies, other regions must recognize and legitimize these developments with equally—if not more—ambitious policy and action to continue to accelerate the market.

Nations around the globe are setting commitments to address climate change – the United States just set a new goal to halve its greenhouse gas (GHG) emissions from 2005 levels by 2030. The United Kingdom aims to cut emissions by 78% by 2035. Japan will cut emissions by 46% by 2030 from 2013 levels. Despite these plans, many nations – including climate leaders - still fall short of what they must do to address one of the most dangerous sources of emissions and pollution: heavy-duty trucks.

Currently composing only four percent of the global on-road fleet, heavy-duty trucks are responsible for

about 27% of global on-road fuel and GHGs, and more than 60% of on-road nitrogen oxides (NOx) (Figure 1). NOx contributes to dangerous air pollution and serious health impacts like decreased lung function particularly for lower-income and communities of color (CALSTART, 2020).[i]

From an economics, logistics, and consumer demand perspective, heavy-duty trucks play a major role in moving goods from region to region, urban delivery, and a variety of other applications from port drayage to refuse collection. The value these heavy-duty vehicles provide is quintessential to a well-functioning society, even more so now in the midst of an e-commerce boom due to COVID-19 (CALSTART, 2020a).[ii]

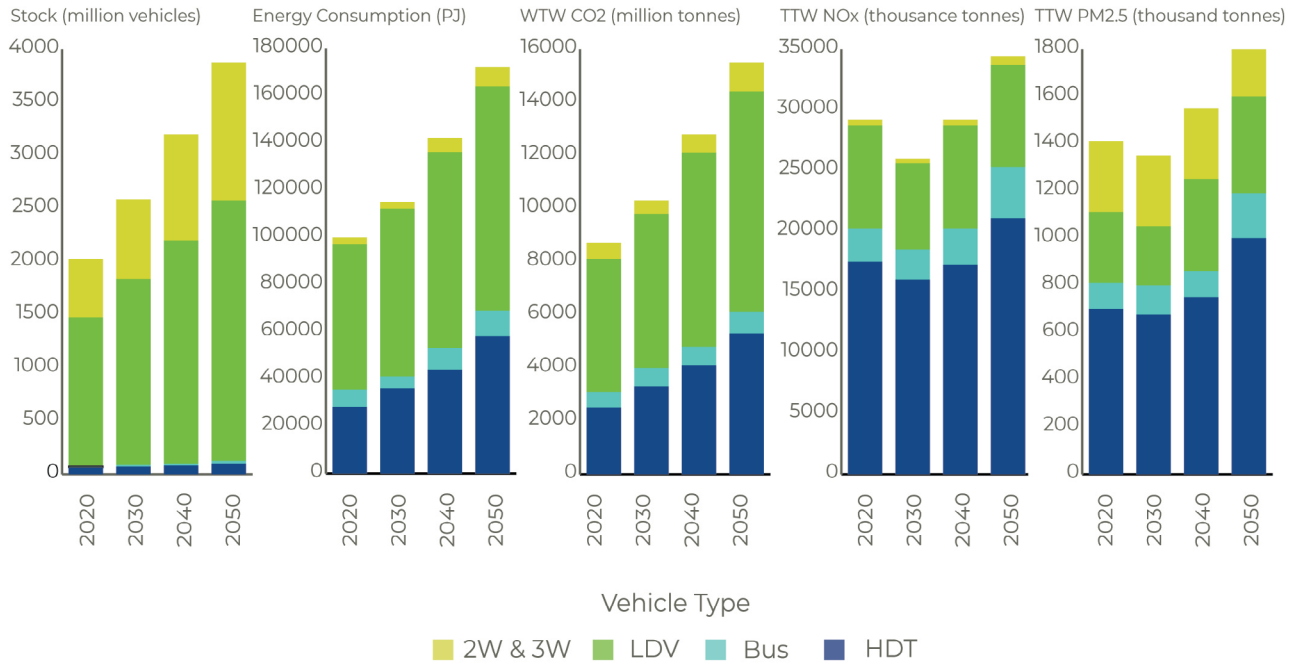
So, why are many nations neglecting to address this critical sector in their climate action plans?

Heavy-duty vehicles (HDVs) - in particular those traveling over longer distances along highways - are often pinned as the most difficult, least feasible segment of the road transportation industry to decarbonize. However, the pace of battery price drops and improvements in battery energy density are accelerating much faster than predicted and as a result, zero-emission heavy-duty trucks are farther along in the commercialization process than expected (Berkley, 2021).[iii]

Today, according to the CALSTART's Drive to Zero™ Zero-Emission Technology Inventory (ZETI), there are already more than 58 available for purchase models of zero-emission heavy-duty trucks (ZEHDTs) in North America, Europe, and China alone (CALSTART, 2021).[iv]

Range is accelerating so quickly that today many available ZEHDTs are already capable of driving 300 kilometers (185 miles) on a single charge. This range hits the sweet spot for urban deliveries, drayage and other operations that do not require extreme ranges. Based on current manufacturer announcements, ZEHDTs capable of longer distances (600-km/370-mi) will be available later this year and 2022, and those with extreme ranges (over 1,000-km/620-mi) after 2023 (CALSTART, 2021a).[v]

Figure 1. "Business as usual" projections in global truck stock, energy consumption and tailpipe emissions (CALSTART, 2020)[vi]



BARRIERS TO TECHNOLOGY ADOPTION

Despite rapidly increasing technology development and model availability, many fleets express concerns about the financial, operational, and environmental performance of zero-emission technologies for commercial vehicles (Table 1).[1] Top concerns include higher up-front costs, the extra weight of batteries impacting payload and truck utilization, and the costs, as well as logistics, of charging. While these apprehensions are valid for fleet owners to consider, solutions to many of the concerns posed have been resolved for select duty-cycles and segments of ZEHDTs. Ranges are available, batteries are becoming cheaper and more efficient, and as production scales up across supply chains, costs are dropping rapidly.

Table 1. Financial, operational and environmental performance of zero-emission technologies for commercial vehicles

TECHNOLOGY	BARRIERS AND SOLUTIONS
Battery Electric	**Financial and Operational Barriers:** High cost of batteries + other critical components; Extra weight associated with batteries; potential reductions in payload and truck utilization; Limited range; Charging time and convenience; Lack of confidence that technology can fulfill operational requirements **Environmental Performance:** Zero tailpipe emissions, but upstream emissions depend on grid's energy mix. **Solutions:** Economies of scale and increasing pace of technology development will continue to lower the price and weight of batteries (Bloomberg, 2020);[vii] Many available ZEHDT models boast ranges that exceed duty-cycle requirements in select segments (CALSTART, 2021a);[viii] A plethora of case studies and demonstration projects showcase the reliability and benefit of ZEHDT in operations (California Climate Investments, 2021)[ix]
Hydrogen Fuel Cell Electric	**Financial and Operational Barriers:** High technology and infrastructure costs; Concerns about energy efficiency of hydrogen production; Cost/scaling up of hydrogen fuel production.; Refueling infrastructure not built out; Safe storage and handling or hydrogen fuels **Environmental Performance:** Zero tailpipe emissions, but upstream emissions depend on how hydrogen is produced. Energy conversion losses from hydrogen production are also mentioned as possible concerns. **Solutions:** Economies of scale will reduce cost; innovative and energy-efficient ways to produce hydrogen can be implemented for various use cases (DOE, 2021);[x] Investments toward infrastructure such as "hydrogen highway" can enable feasibility; Relatively safe compared to other fuels (NRDC, 2021)[xi]

1 This list is limited to battery electric and hydrogen fuel cells, which have zero tailpipe emissions.

ECONOMIC CONSIDERATIONS – ZERO-EMISSION TRUCKS WILL ACHIEVE COST PARITY BY 2030

According to a recent analysis, by 2025-2030 electric trucks will be less expensive than their diesel counterparts (CALSTART, 2020).[xii] Reports pinpoint the reduced cost of key components like batteries and motors as production volumes increase as the reason behind the price drop (ICCT, 2019).[xiii] Additionally, rising fuel costs will undercut the higher efficiency of diesel trucks between 2025-2030, further bridging the gap.

Despite the short horizon for projected cost parity, fleets today typically operate at razor-thin margins. As a result, higher technology costs hinder faster adoption of zero-emission trucks. Uncertain fleet demand can in turn limit the ability of suppliers and original equipment manufacturers (OEMs) to shifting production towards zero-emission models. Even so, this gridlock between perceived supply and demand must be broken. Numerous market analyses have shown that the future will be zero-emission and it is simply a matter of time (Trucks, 2021).[xiv] Contrary to the dominant narratives surrounding the industry today, that time may be sooner than projected.

Infrastructure is also often regarded as a major barrier towards faster ZEHDT adoption, both in terms of availability, and installation and upgrade costs. The table below outlines charging infrastructure for three different use cases and the respective impact on cost per ZEHDT versus diesel. The key conclusion is that infrastructure utilization is a major driver for cost parity with diesel. Similar assessments were carried out for hydrogen fuel cell trucks and it was determined that the infrastructure is more costly for long-haul and delivery applications, but less expensive for drayage trucks, highlighting the need for different technology types across applications and the importance of considering all fuel types with their various pros and cons (ICCT, 2019).[xv]

Table 2. Charging infrastructure for increasing electric truck volume in three applications (ICCT, 2019)[xvi]

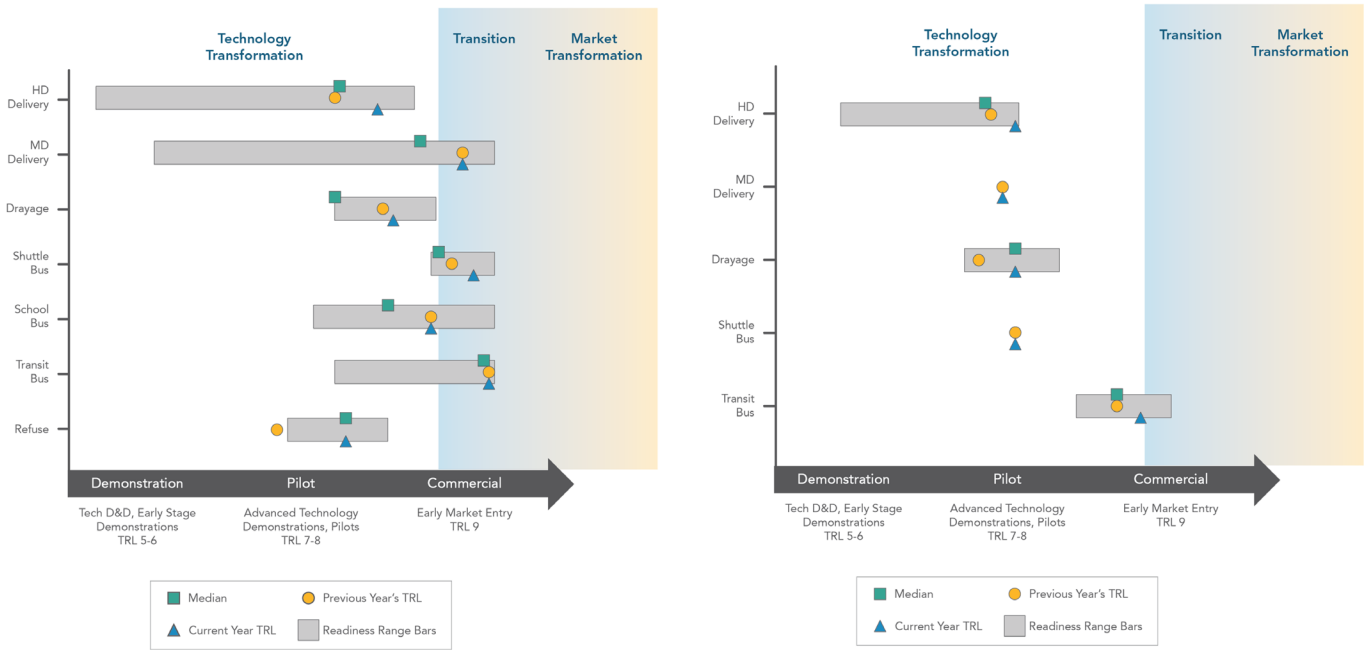
APPLICATION	CASE	NUMBER OF TRUCKS	CHARGING OUTLETS	INFRASTRUCTURE COST PER TRUCK (THOUSAND)	VEHICLE OWNERSHIP COST VERSUS DIESEL
Delivery (Class 6, 9.75 - 13 tons)	Low volume	100	130	$82	0% to +5%
	Medium volume	1,000	820	$40	-15% to -10%
	High volume	10,000	6,300	$27	-25% to -20%
Drayage (Class 7-8, 13+ tons)	Low volume	100	100	$58	+10% to +25%
	Medium volume	1,000	810	$38	0% to +5%
	High volume	10,000	7,300	$28	-15% to -10%
Long haul (Class 8, 16.5+ tons)	Low volume	100	150	$189	+13% to +18%
	Medium volume	1,000	1,200	$114	+5% to +10%
	High volume	10,000	9,700	$71	-5% to 0%

Targeted financial incentives can help accelerate cost parity between ZE and conventional technologies, while increasing volumes will generate economies of scale and further reduce costs in the long term. As battery and fuel cell costs drop, operational savings from ZE technologies will generate a positive total cost of ownership (TCO) and strengthen the business case (CALSTART, 2021b).[xvii] Innovative finance models (e.g., transportation as a service, lease, first-loss protection) must be explored, and will further open opportunities for smaller carriers to operate ZE technologies and reap on their economic benefits (CALSTART, 2021b).[xviii]

TECHNOLOGY READINESS

ZEHDV uptake has been a slow but steady progression that has recently reached a critical point - there are models available now that are capable of replacing diesel vehicles and running their routes without performance trade-offs. To better understand the progress made technologically, a metric known as "technology readiness level" (TRL) has been employed to track the status of zero-emission technologies. Drawing from the California Air Resource Board's (CARB) Long-Term Heavy-Duty Investment Strategy, TRLs have been compared for various vehicle applications and propulsion types (CARB, 2021).[xix] The figure below compare battery electric and fuel cell vehicles by segment.

Figure 2. On-road Battery electric (left) and fuel cell (right) electric vehicles technology status snapshot



The above figures highlight both the progression and current state of commercialization for various vehicle segments from a technology standpoint. Heavy-duty platforms, namely delivery, have made significant year-over-year progress and continue to edge closer to commercialization status. Long-haul platforms still have a way to go before wide-scale adoption and uptake is possible, but much of the progress and technological advancements that are happening in other platforms are transferrable to the platforms that are lagging. Drayage has not yet broken the threshold of commercialization, but

continues progress closer, playing a critical role in port operations. Many bus models have reached commercialization status and have proven their effectiveness in terms of performance and efficiency in leading regions globally where they transport millions of passengers daily (WRI, 2017).[xx]

The progress tracked in this data indicates increased technology development for HD delivery, drayage, and transit. Other noteworthy segments where ZEHDVs have had great success is in off-road applications. Though not pictured in this set of figures, vehicles like yard hostlers, transportation refrigeration units, railcar movers, and ground support equipment for aircraft are all platforms that have made significant headway, many of which sit comfortably in the commercial early market entry. The progress outlined by TRLs aligns with Drive to Zero's Beachhead strategy—Drive to Zero's technology development, commercialization and investment strategy for accelerating ZE technologies (CALSTART, 2020b).[xxi] The strategy describes how certain vehicle segments, based on duty-cycle criteria, are more easily transitioned to zero-emission alternatives. Heavy-duty segments, once thought to be further in the future, are proving to be accelerating more quickly than expected.

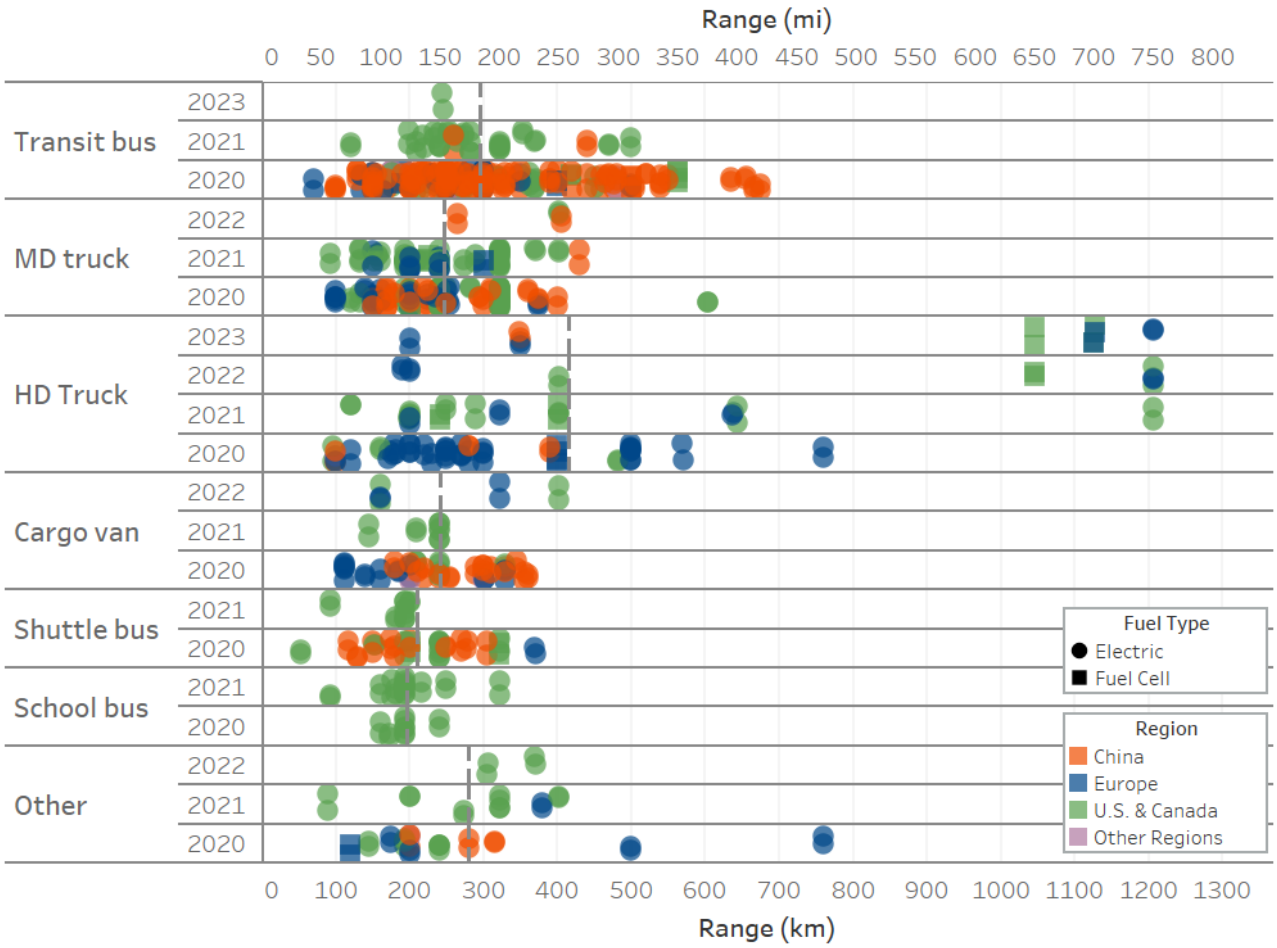
Forward-thinking fleet operators have played an integral role in speeding commercial viability through major projects that demonstrate the real-world feasibility of ZEHDVs. Frito-Lay's Modesto project, Anheuser-Busch's fleet investments, and California's Project 800 among many others, provide tested examples of successful heavy-duty vehicle deployments, carrying out operations that diesel vehicles once performed now with no emissions, significantly lower fuel costs, and improved worker conditions (Trucks, 2019)[xxii] (Spectrum, 2021).[xxiii]

OPERATIONAL CONSIDERATIONS – ZERO-EMISSION TRUCKS ALREADY HAVE RANGES COMMENSURATE WITH FLEET NEEDS

Duty-cycles vary widely across vehicle types and applications, and ZE technologies can already fulfill many operational requirements for local and regional transportation. Those vehicles can be deployed while the cost and performance of ZE technologies improve for long-distance applications in the next 3 to 5 years. The following section uses data from real fleets to understand where the technology is now, compared to the operational ability of ZEHDT offerings.

Range is no longer a major barrier for ZEHDTs. All else aside, a truck's ability to fulfill operational needs is a top priority when considering alternatives to conventional models. Figure 3 below illustrates the ranges of available and upcoming ZEHDTs. This data on its own is not very illuminating unless put into context of the real world—can these vehicles meet operational needs? In short, the answer is yes. While long-haul duty-cycles (characterized by an operational range of 1,606-km/1,000-mi) are still not feasible for the current technology, duty-cycles like regional haul (characterized by an operational range of 480-km/300-mi), and heavy-duty urban delivery (characterized by an operational range of 160-km/100-mi) are—from the standpoint of range—ready to roll (Zhang et al., 2021).[xxiv] While a duty-cycle characterized by a study will never exactly match real world application, the benchmarks provided here give a solid idea of the direction fleets could be moving to reduce the impact of their operations on the environment and public health (Zhang et al., 2021).[xxv]

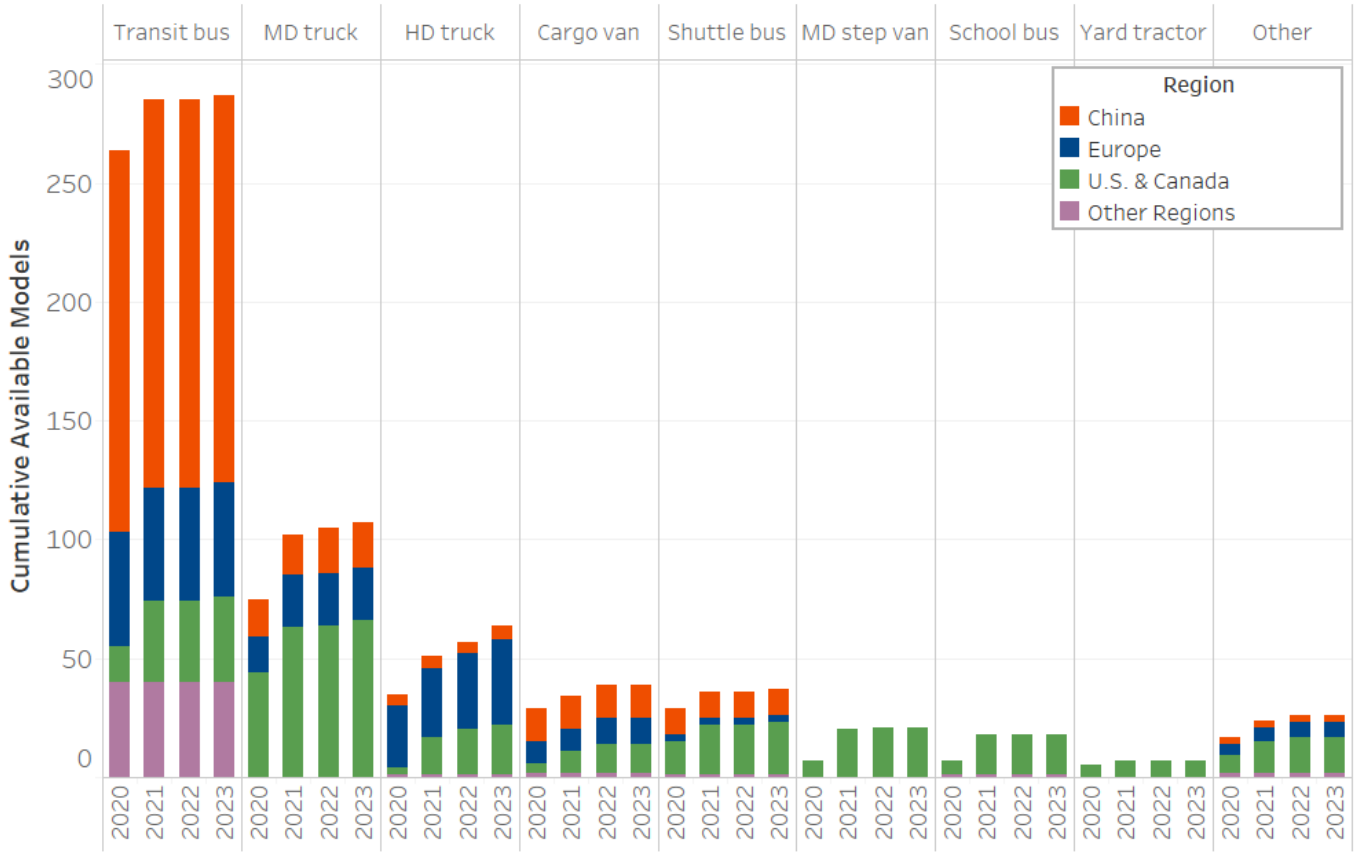
Figure 3. Current and announced ZECV models by year, driving range, platform, fuel type, and region (CALSTART, 2021a)[xxvi]



MODEL AVAILABILITY HEALTHY AND RISING

Drawing from Figure 3, most available zero-emission heavy-duty trucks are able to drive between 160-km and 480-km (100-300 miles) with longer ranges coming in the next few years. Figure 4 below – also drawn from ZETI - shows the availability of current and announced zero-emission heavy-duty trucks among other commercial vehicle types by year. Data from ZETI underscores the rapidly increasing number of available heavy-duty vehicles and provides a one-stop-shop for fleet operators and policymakers to see a snapshot of vehicle specifications and availability. HD offerings like the Volvo VNR (240-km/150-mi), BYD 8T (200-km/125-mi), Lion8 (400-km/250-mi), and the Tesla Semi (480-km/300-mi) are models that are already available or will be available in the next year that can tackle longer distances, with heavier loads (CALSTART, 2021).[xxvii]

Figure 4. Number of ZECV models by year, platform, and region (CALSTART, 2021a)[xxviii]



As ZEHDT technology continues to close in on commercialization status, OEMs have been responding to the changing outlook of transportation and freight. New vehicle offerings from major manufacturers, both new and established, add new momentum to the ZEHDT space and a positive outlook for the future of the technology to take on further distances, faster "refueling" solutions, and price parity.

OEMS ACCELERATING ZERO-EMISSION TRUCK COMMERCIALIZATION

In an unprecedented joint statement from major heavy-duty vehicle OEMs, under the umbrella of the European Automobile Manufacturers Association, the manufacturers announced that by 2040 all new commercial vehicles sold must be fossil-free to ensure carbon neutrality by 2050 (ACEA, 2020).[xxix] The statement was signed by Scania, Daimler, Volvo, Ford, DAF, Iveco and MAN among others and emphasized the need for swift policy action that will enable rapid deployment of vehicles and infrastructure, and achieve price parity with diesel vehicles. Exciting as these goals are, the ambitions of current policy in the European Union and around the world do not reflect the same enthusiasm. To accelerate the rate at which conventional diesel freight technologies are replaced by ZEHDTs, there must be alignment of targets, regulations, and incentives.

Table 3. OEM ZECV Commitments

OEM	COMMITMENT
Scania (Europe)	2030: 50% of total vehicles sales will be ZE 2040: 100% of sales will be "fossil-free" (Scania, 2021)[xxx]
Daimler Truck (Europe, North America, Japan)	2039: Sales will only include CO2-neutral (tank-to-wheel) offerings (Daimler, 2019)[xxxi]
Traton Group	2025: conventional drive vehicles will make up less than 20% of Traton's product development (Trucking Info, 2021)[xxxii]
Volvo Group	2030: 35% of total sales EVs 2040: 100% of sales will be "fossil-free" (Volvo, 2021)[xxxiii]
European Automobile Manufacturers Association- ACEA (Iveco, Ford, DAF Trucks ,MAN Trucks & Bus, CNH Trucks)	2040: Sales will be 100% "fossil-free" (ACEA, 2020)[xxxiv]

OUTLOOK FOR FUTURE ADOPTION

The combination of accelerated battery price reductions, technology readiness, OEM announcements, ZEHDT model availability and supportive policies indicates that ZEHDTs will dominate vehicle fleets in leading markets sooner than expected.

Last Year, California signed the Advanced Clean Truck (ACT) regulation into law, requiring medium- and heavy-duty vehicle manufacturers to sell ZEVs as an increasing share of total sales in the Golden State. The ACT regulation requires that 55% of trucks class 2b-3, 75% of class 4-8, and 40% of tractor trailer sales must be zero emissions by 2035 and by 2045 all vehicles must be ZEVs (CARB, 2021a).[xxxv] This action was followed swiftly by a 15-state memorandum of understanding in the United States, committing to phase out polluting trucks in favor of ZEHDTs (CARB, 2021b).[xxxvi] The MOU calls out for all new MHDVs to be zero emissions by 2050, and 30% of sales being zero emissions by 2030. Legislative action like the ACT rule is also supported with incentive programs like California's HVIP, CORE, and NYTVIP while production volumes scale up to reach cost parity (CALSTART, 2021c)[xxxvii] (CALSTART, 2021d)[xxxviii] (NYSERDA, 2021).[xxxix]

Just like for light- and medium-duty vehicles, if true progress is to be made against climate change and hazardous pollution, the heavy-duty sector must be the target of immediate, impactful action by governments, fleets, and manufacturers in a coordinated effort to accelerate the transition of all fleets to cleaner technology. With more and more manufacturers supporting the vision of a zero-emission future, the message has never been clearer: Zero-emission heavy trucks are already here, and technology is advancing fast to deliver a cleaner future for all. This message must be heard by nations who are already willing to commit to ambitious emissions goals in advance of COP26. Strong targets for ZEHDTs,

together with supportive policies and incentives, are needed to drive the market forward alongside OEMs' commitments. With government and industry aligning climate ambition with the reality of the technology, ZEHDTs can soon become an integral part of a zero-emission future.

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