WHITE PAPER

MOVING ZERO-EMISSION FREIGHT TOWARD COMMERCIALIZATION

Prepared For: International ZEV Alliance

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GLOBAL COMMERCIAL VEHICLE
DRIVE TO ZERO
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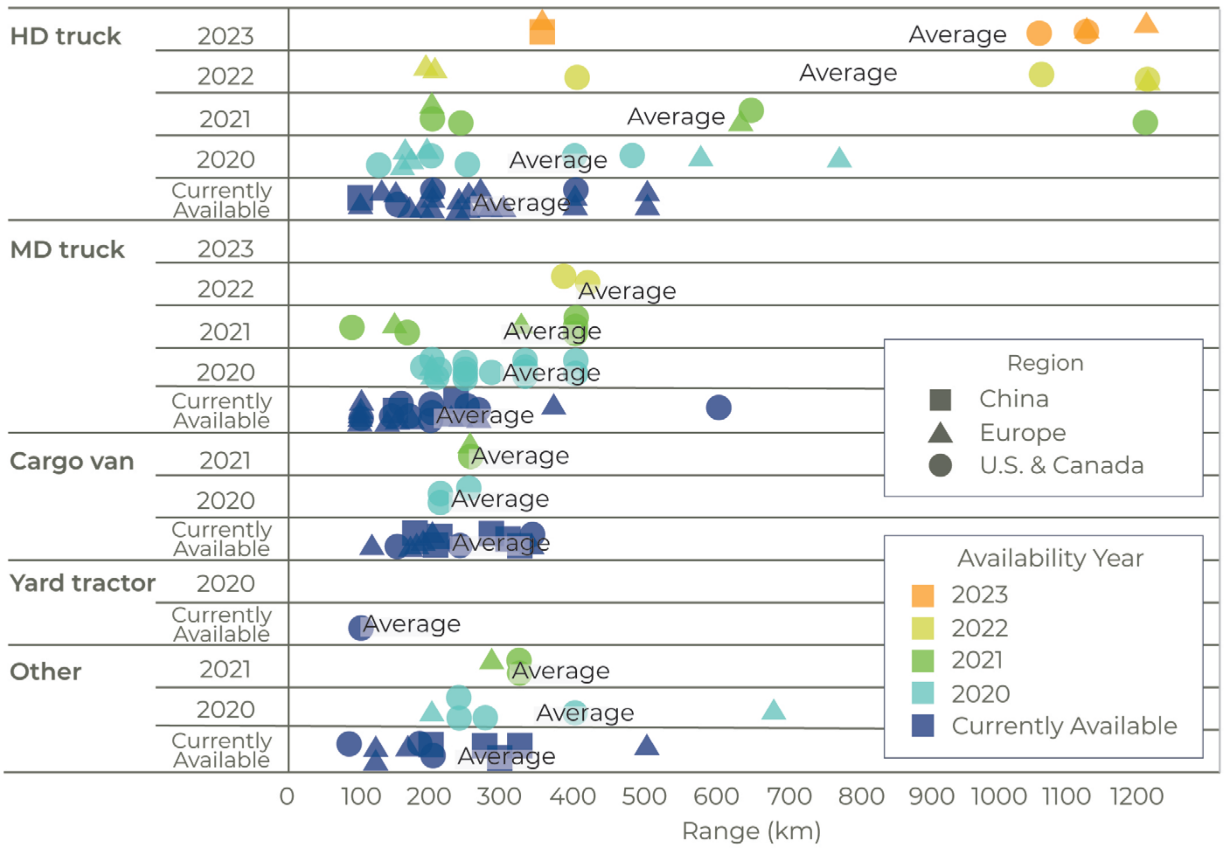
EXECUTIVE SUMMARY

Global transportation systems have begun a shift to newer, cleaner technologies that will meet greenhouse gas (GHG) emission reduction and air quality improvement goals that governments have developed or fleets have adopted for themselves. Though freight vehicles represent a relatively small percentage of on-road vehicles, emissions from freight account for a disproportionately high percentage of GHGs, harmful air pollutants, and noise. Zero-emission freight vehicles (ZEFVs) can match the current transportation system's capabilities while creating hidden societal benefits by reducing the negative outcomes associated with diesel and gasoline consumption.

ZEFVs, defined in this report as vehicles with maximum weight ratings above 3.5 metric tons (t) with drivetrains that cannot produce GHGs or air pollutants and primarily transport cargo instead of passengers, are already commercially available in leading markets. They are grouped in this report into vehicle "platforms," or vehicles with common features such as weight, function, and other design functions. Lighter medium-heavy duty vehicle (MHDV) ZEFV platforms, such as electric cargo vans, have been deployed in China, the European Union, and the United States. These lighter platforms can operate with smaller batteries relative to heavier-duty platforms, thereby reducing costs by limiting the size of batteries that considerably raise ZEFVs' purchase costs. Though ZEFV purchase costs may currently typically exceed those of diesel-powered vehicles, managed charging techniques and lower operating costs are expected to bring the total cost of ownership (TCO) for ZEFVs lower than diesel-powered vehicles as zero-emission technologies reach scale. Each of the modeled ZEFV segments is expected to achieve cost parity with diesel-powered vehicles by 2030.

As manufacturers scale up production and battery technologies improve, heavier-duty vehicle applications with larger battery capacities will expand the ZEFV market. New and diverse models have been announced for the European and North American markets within the next few years (Figure ES.1) (CALSTART, 2020).[i]

Figure ES-1. Current and announced ZEFV models by range, release date, and platform in U.S., Canada, Europe, and China.[1]



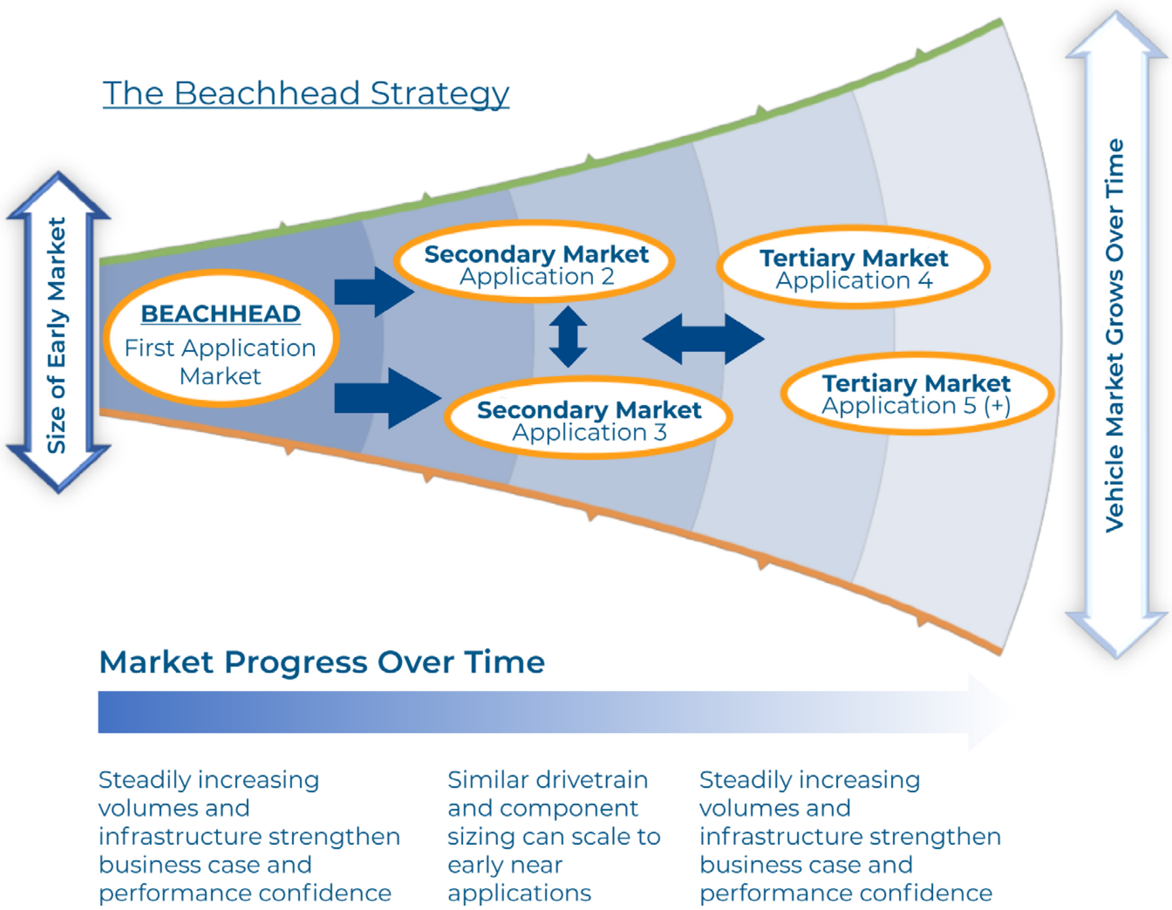
Within each of these ZEFV segments (cargo vans, medium-duty trucks, heavy-duty trucks, and yard tractors), manufacturers or fleets have made early progress or large-scale commitments to producing or purchasing ZEFVs. For example, leading online retailers Amazon (United States) and JD (China) plan to transition at least 100,000 delivery vans and its entire fleet, respectively, to ZEFVs. Industry support for the new technologies has been bolstered by government pledges to restrict diesel-powered vehicle operations or ban their sale, with at least 50 million people living in cities that plan to permit only ZEFV access within a decade, creating a strong market signal for fleets and manufacturers to prepare for large-scale ZEFV deployments. Though no vehicle segment is fully prepared for market commercialization, growth in early segments will support commercialization in the broader market.

By improving on economies of scale and producing components that are transferable and adaptable to new zero-emission vehicle models and segments, manufacturers will advance from first-success

1 The Drive to Zero ZETI tool is regularly updated tool that offers a thorough, yet not completely comprehensive, glimpse of vehicles and markets. The North American and European model inventories have been populated more rapidly than other regions, but additions to other regional markets (most notably in China, Japan, India, and South America) are forthcoming. ZETI data is meant to support fleets and policymakers and should not be construed as representative of the entire vehicle market.

“beachhead”[2] applications to secondary (early near markets) and tertiary markets as technology improves, production volumes increase as market size increases, and costs go down. These successive new market applications will innovate by incorporating clean vehicle technologies in increasingly rigorous duty cycles or in vehicles with demanding operational characteristics. This process of expanding vehicle production capacity leading to a broader market transformation (Figure ES.2) (Drive to Zero, 2020) is integral to the theory of change practiced within the Global Commercial Vehicle Drive to Zero (Drive to Zero) campaign, which was established from learnings with the California Air Resources Board (CARB) to describe and accelerate early market progress for commercial alternate fuel vehicles. The campaign and its framework have earned the support of nine national government pledge partners on four continents, along with more than 70 additional pledge partners from government and industry (CALSTART, 2020f).[ii]

Figure ES-2. The “Beachhead” theory of ZEV market transformation



Infrastructure investments and advancements will be needed to support rapid growth in the ZEFV market. Current deployments of lighter urban delivery vehicles with smaller batteries may be able to

2 The commercial definition of “beachhead” is “a secure initial position that has been gained and can be used for further advancement; foothold.” The term derives from military usage and connotes beginning a new advance by securing a small strip of influence to expand opportunities in less accessible regions. The associated World War II reference is particularly germane to the beachhead model because the Allied advance parlayed their initial landing points into accessing an entire continent.

charge overnight in depots at lower charging rates or opportunistically use publicly available slower or more expensive high-powered charging stations. As the size and quantity of vehicles grow, charging and hydrogen fueling stations will need to become more numerous and robust to meet refueling needs, with charging stations capable of charging vehicles at rates of at least hundreds of kilowatts (hydrogen refueling is typically conducted at higher speeds closer to diesel refueling). The high rates of charge needed to fuel large ZEFV fleets will create challenges both for electric utilities to cost-effectively balance energy supply and for fleets to cost-effectively manage their vehicles' charging needs. Vehicle manufacturers and charging equipment suppliers may ensure that charging investments can be used by the highest number of vehicles possible by agreeing upon common, standardized connection standards. Innovative newer charging solutions, such as overhead catenary technologies that increase range, may also help overcome range limitations.

The challenges of operating and financing ZEFVs create opportunities for transformative technologies and operational and financial approaches. Autonomous driving technologies and drones may reduce operating costs (labor cost reductions up to 20 percent) and improve efficiencies (up to 10 percent savings), improving fleets' TCOs, and advanced battery technologies that enable longer ranges may also reduce upfront vehicle costs because fleets can purchase battery packs with fewer battery cells. Innovation in business models may offer fleets greater flexibility to shift higher upfront capital expenses to operating expenses, where costs are often lower for ZEFVs. Leasing batteries independently of the vehicles, renting ZEFVs rather than purchasing, and collaborating with manufacturers and third parties to install charging and fueling infrastructure are examples of strategies for fleets to limit risk and reduce costs.

Governments can develop the ZEFV market with targeted eco-systems of supportive policies and incentives. MHDV fuel economy and GHG emission standards are common across China, the European Union, and North America, and though these standards provide incentives for incorporating ZEFVs into manufacturers' fleet sales, they do not explicitly advance the ZEFV market. Alternately, CARB followed the success of passenger ZEV programs in California and China by approving the Advanced Clean Truck rule that requires manufacturers to sell increasing shares of ZEFVs as a percentage of fleet-wide vehicle sales. Financial incentives have also been implemented in leading markets to encourage ZEFV uptake. Programs that lower the upfront costs of ZEFVs and the cost of electricity reduce operators' TCO, and regulations that increase costs for diesel-powered vehicle operations (e.g. CO2-based road charges) make the ZEFV TCO more attractive relative to diesel-powered vehicles. Government investments in charging and fueling infrastructure will also help fleets lower their capital expenses and support their operations.

Because truck manufacturers use similar technologies and components across different global markets, with component suppliers and vehicle manufacturers producing parts and models for individual and common markets around the world, aligning ZEFV deployment and supportive systems across leading markets will accelerate economies of scale in ZEFV production. The parallel implementation of supportive eco-systems in leading regions worldwide will send stronger signals to manufacturers to accelerate production volumes, which in turn will lower vehicle costs while technologies improve, encouraging fleets to speed ZEFV uptake. This will ultimately facilitate the large-scale transition to a zero-emission commercial transportation sector. Though the ZEFV market is young, manufacturers have indicated that they are prepared to design and develop vehicles to meet expected demand growth.

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CHAPTER 1

BACKGROUND AND MOTIVATION

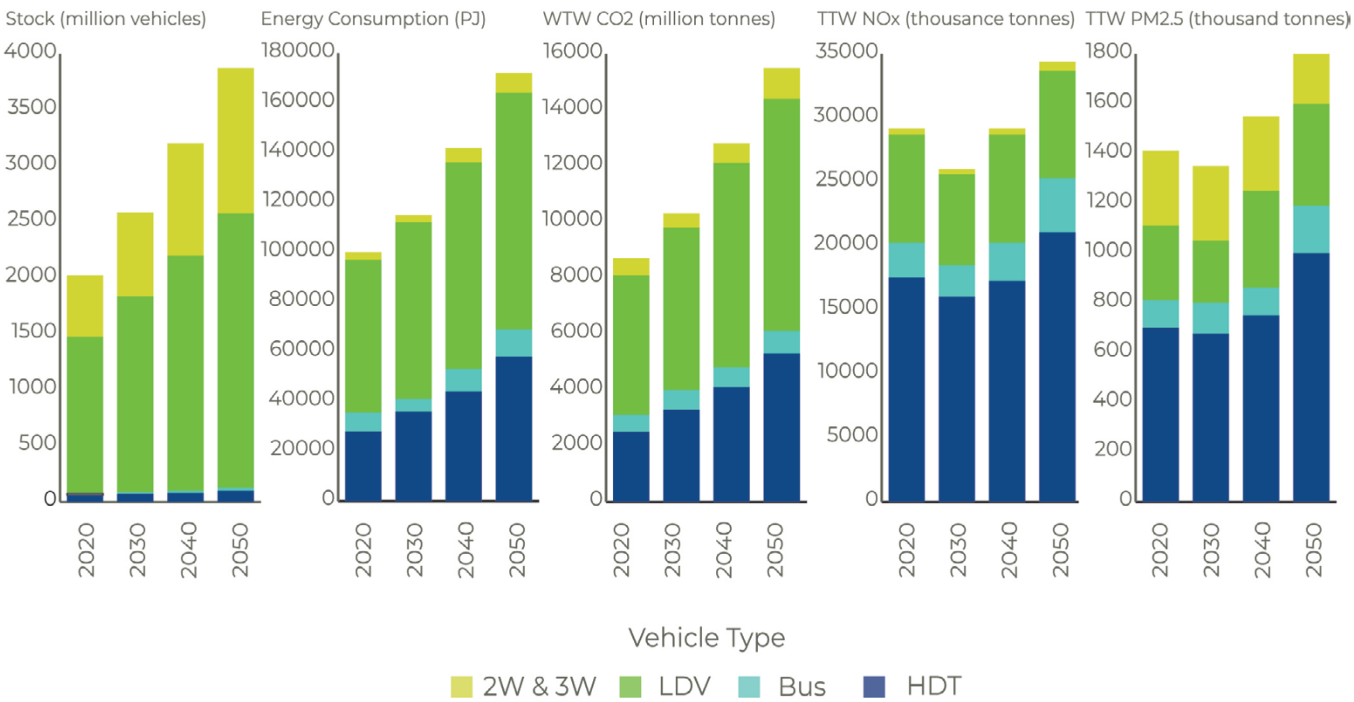
Global freight and goods movement and its associated emissions are expected to increase in the coming decades. Freight activities produce a disproportionately high percentage of transportation emissions, with greenhouse gases contributing to irreversible climate change and air pollutants that harm vulnerable populations living near roadways and freight hubs. Zero-emission freight vehicles (ZEFVs) provide a technological solution that can replace and improve upon the current system that relies predominantly on diesel-powered trucks. These vehicles are defined in this report as vehicles with maximum weight ratings above 3.5 metric tons (t) with drivetrains that cannot produce greenhouse gases (GHGs) or air pollutants and primarily transport cargo instead of passengers (see Appendix 1.A for more on vehicle classifications).

The ZEFV market has already progressed out of its infancy, with some vehicle segments approaching commercialization stages, though uptake and model availability of larger ZEFVs has been limited to date. The outlook for ZEFV uptake has been bolstered with supportive, large-scale pledges from fleets and manufacturers. Governments are also supporting the transition by placing limitations on diesel use, establishing ZEFV sales requirements, and forming multi-state coalitions to develop and implement market-enabling policies, thereby creating opportunities for ZEFVs to fill the spaced vacated by diesel consumption.

1.1 EMISSIONS ESTIMATES

Global freight emissions are forecast to increase substantially, compounding their climate and health impacts. From 2020 to 2050, energy consumption and GHG emissions from trucking are expected to more than double and small particulate matter (PM2.5) emissions to grow by more than 40 percent in a business as usual scenario that does not leverage the use of zero-emission technologies for trucks (Figure 1.1) (ICCT, 2019a) (ICCT, 2019b).[iii,iv] One of the main drivers behind the increase in trucking emissions is the increase in global domestic and international freight demand, estimated to triple between 2015 and 2050 (ITF, 2019)[v], highlighting the need to accelerate the deployment of zero-emission techologies for trucks to meet climate goals and improve urban air quality.

Figure 1-1. "Business as usual" projections in global truck stock, energy consumption and tailpipe emissions



Despite representing a relatively small share of on-road fleets, trucks have a disproportionate impact on energy consumption, climate, and air pollutant emissions. Globally, freight trucks currently represent less than 4 percent of the on-road fleet but contribute to about 27 percent of on-road fuel consumption and GHG emissions, and emit more than 60 percent of on-road nitrogen oxides (NO_x) emissions and more than half of PM2.5 emissions, which result in air pollution and human health impacts (Figure 1.1). Therefore, trucks represent an effective target for emissions control. This trend is even more pronounced in emerging regions such as China and India, with trucks currently representing an even smaller share of the fleet and a higher share of fuel consumption and emissions (Kodjak, 2015).[vi] And because disadvantaged populations tend to live along major freight corridors and facilities (e.g., ports, warehouses), reducing truck emissions will result in substantial air quality and health benefits for disadvantaged communities (American Lung Association, 2020).[vii]

Zero-emission technologies for trucks can lead to substantial energy, climate, and health benefits. While these technologies eliminate tailpipe emissions leading to lower urban air pollution, it is important to acknowledge emissions from brake and tire wear, as well as upstream emissions from the production and distribution of electricity and hydrogen. Recent research has indicated that electric-drive technologies for trucks can reduce lifecycle carbon dioxide (CO2) emissions by more than 60 percent for hydrogen trucks and more than 70 percent for electric trucks, with even higher savings as the share of renewables for hydrogen and electricity production increases (Moultak et al, 2017).[viii] Previous research has also highlighted the health impacts from vehicle noise (T&E, 2020),[ix] indicating another health benefit from quieter ZEFVs.

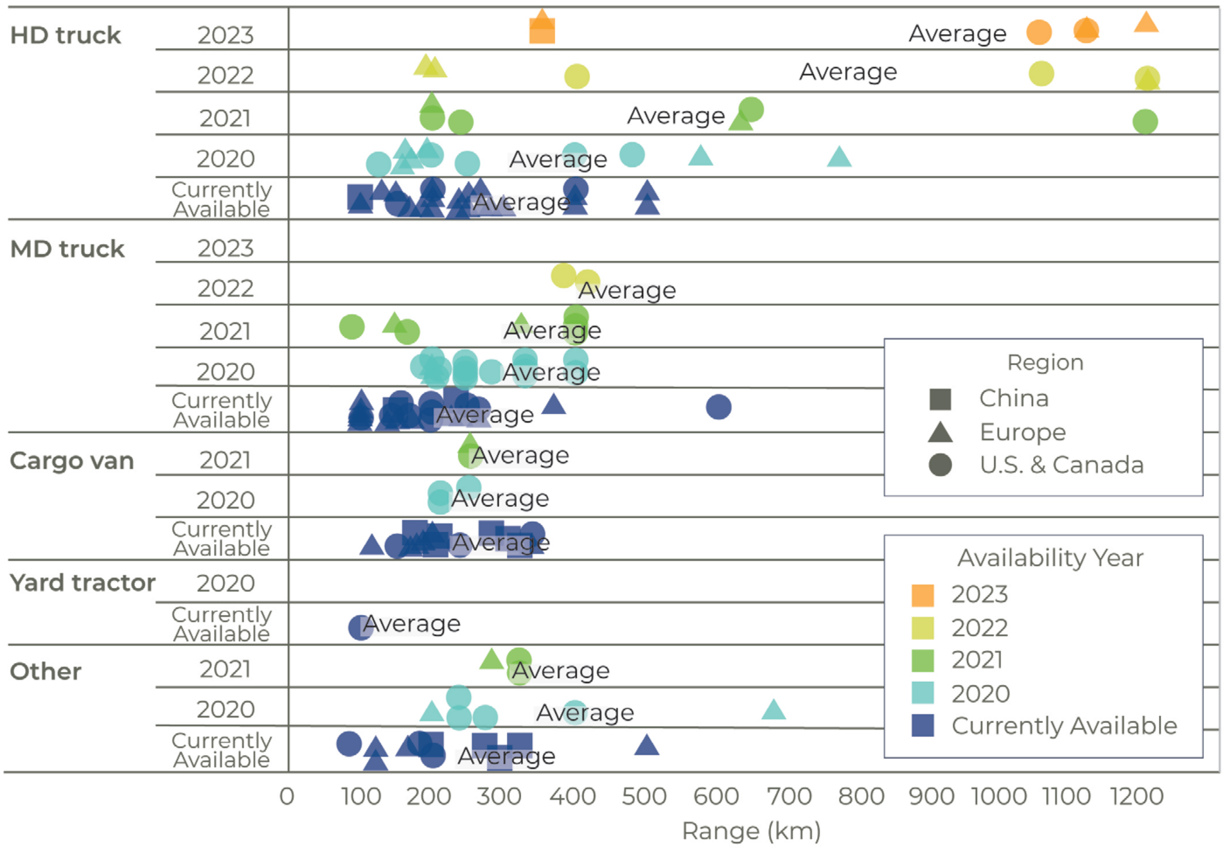
1.2 MODEL AVAILABILITY

1.2.1 MARKET SEGMENTATION

Currently, different segments of the ZEFV market are at different stages in the commercialization curve. Within the lighter truck segment, original equipment manufacturers (OEMs) are already deploying vehicles into an early commercial vehicle market. In the medium segment, U.S. and European OEMs have tested a number of vehicle technologies that are progressively moving from pilots to small-scale implementation with progressive fleets. Chinese OEMs are further along in the commercialization curve and have deployed the vast majority of ZEFVs worldwide, supported by manufacturing plants built in overseas markets such as BYD's facilities in California (Clean Technica, 2017)[x] and a Canadian plant that currently focuses on electric bus production (BYD, 2019).[xi]

Currently available vehicle ranges tend to be designed for shorter distances, particularly for smaller vehicles. Yard tractors are not inhibited by range and can perform their functions as currently constructed, and cargo vans are also able to manage with smaller ranges due to their smaller loads and lower speeds with regular regenerative braking. For larger, long-distance trucks, vehicle ranges are expected to increase as manufacturers develop longer-range batteries and configurations for trucks, with several planned BEV models expecting to exceed 1,000 km by 2023. Fuel cell electric vehicles (FCEVs) will also compete for long-distance truck market share, with several FCEV models emerging within the next few years. Figure 1.2 shows ranges of announced commercial ZEFV ranges, separated by vehicle platforms (CALSTART, 2020).[xii]

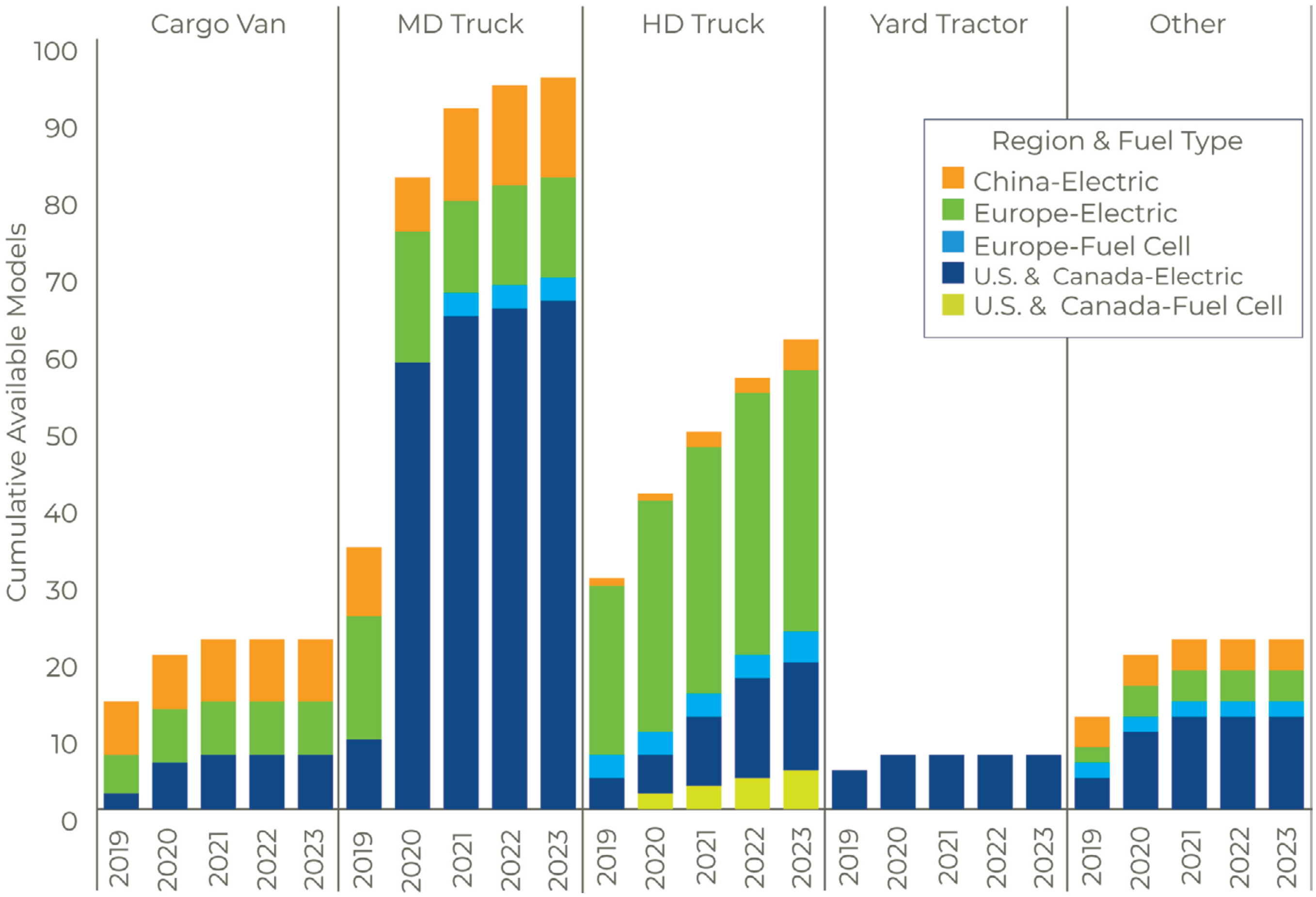
Figure 1-2. Current and announced ZEFV models by range, release date, and platform in U.S., Canada, China, and Europe[3]



By the end of 2020, manufacturers for each on-road vehicle segment will offer at least 10 distinct commercially available vehicle models (Figure 1.3). The number of available models will roughly double in each segment within the next three years, indicating expected market growth. These offerings show maturation, but the ZEFV market will remain far smaller than the comparable diesel vehicle market. Greater parity will develop in the near future as governments and industry progressively push legislation or fleets commit to adopting ZEFVs, creating greater market signals for OEMs.

3 The Drive to Zero ZETI tool is regularly updated tool that offers a thorough, yet not completely comprehensive, glimpse of vehicles and markets. The North American and European model inventories have been populated more rapidly than other regions, but additions to other regional markets (most notably in China, Japan, India, and South America) are forthcoming. ZETI data is meant to support fleets and policymakers and should not be construed as representative of the entire vehicle market.

Figure 1-3. Number of commercial ZEFV models by year, platform, and drivetrain in U.S., Canada, Europe, and China[4]



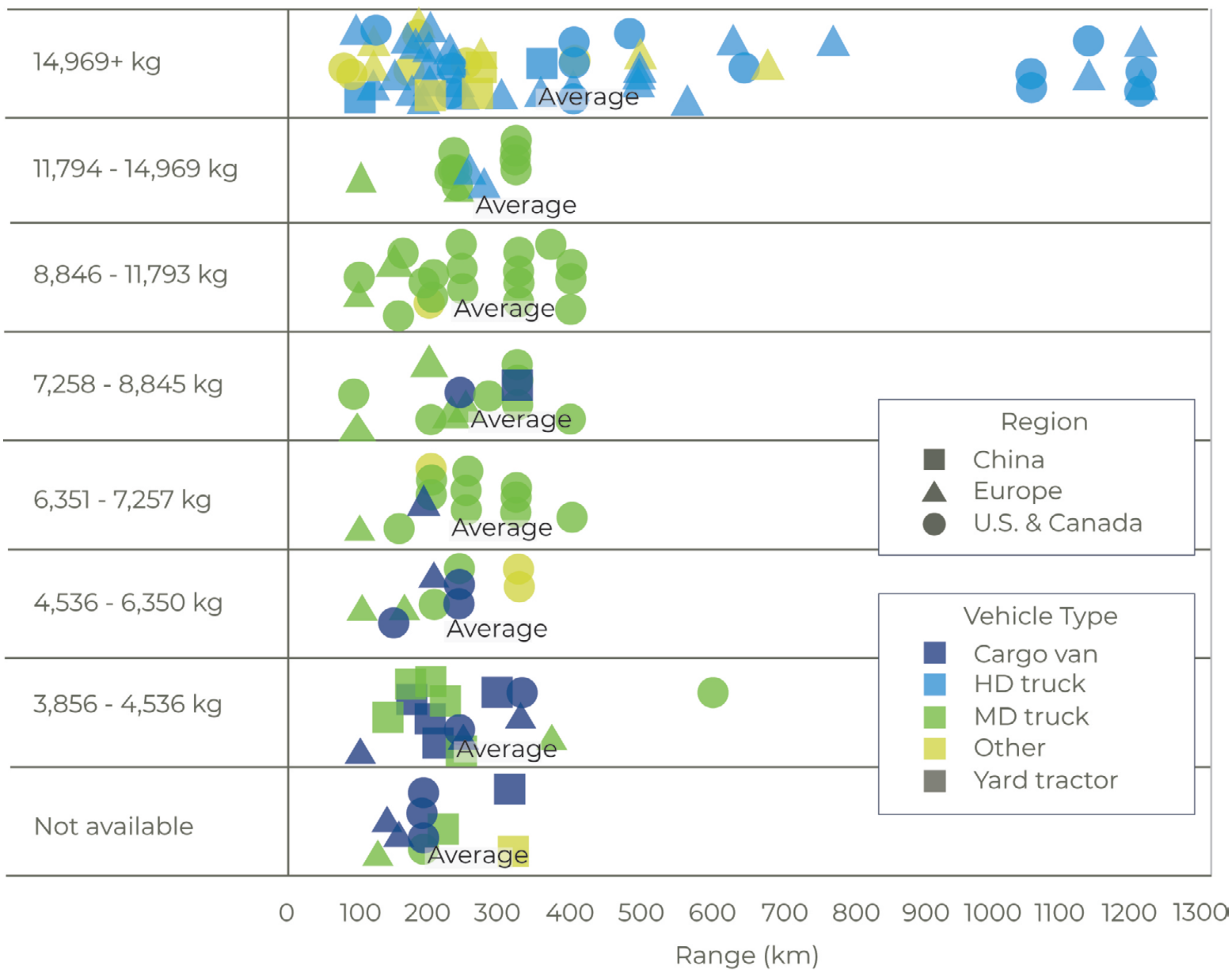
1.2.2 IMPROVING DUTY CYCLES

Duty cycle and vocational applications are becoming more robust in all segments (see Figure 1.4). Vehicle battery sizes and ranges are increasing, opening greater use possibilities and encouraging sales of these vehicles. Most of the trucks tracked in the Zero-Emission Technology Inventory, an online publicly-available tool aimed at cataloging models of current and upcoming zero-emission commercial trucks, buses and off-road equipment designed by CALSTART (further abbreviated as ZETI), have a range of at least 200 km, with some examples exceeding 700 or 800 kms. Current vehicle ranges are likely adequate to meet most fleets' operational characteristics, as for example 60 percent of European trucks' daily driving distances fall below 400 km (T&E, 2020), though distances may vary significantly by region or

4 The Drive to Zero ZETI tool offers a thorough, yet not completely comprehensive, glimpse of vehicles and markets and should not be construed as representative of the entire vehicle market.

platform. Though most currently available ZEFV models serve lighter-duty applications, manufacturers will bring vehicles to market that will be able to meet rigorous new duty cycles and travel longer routes.

Figure 1-4. Vehicle models by GVRW, driving range, and platform in U.S., Canada, Europe, and China[5]

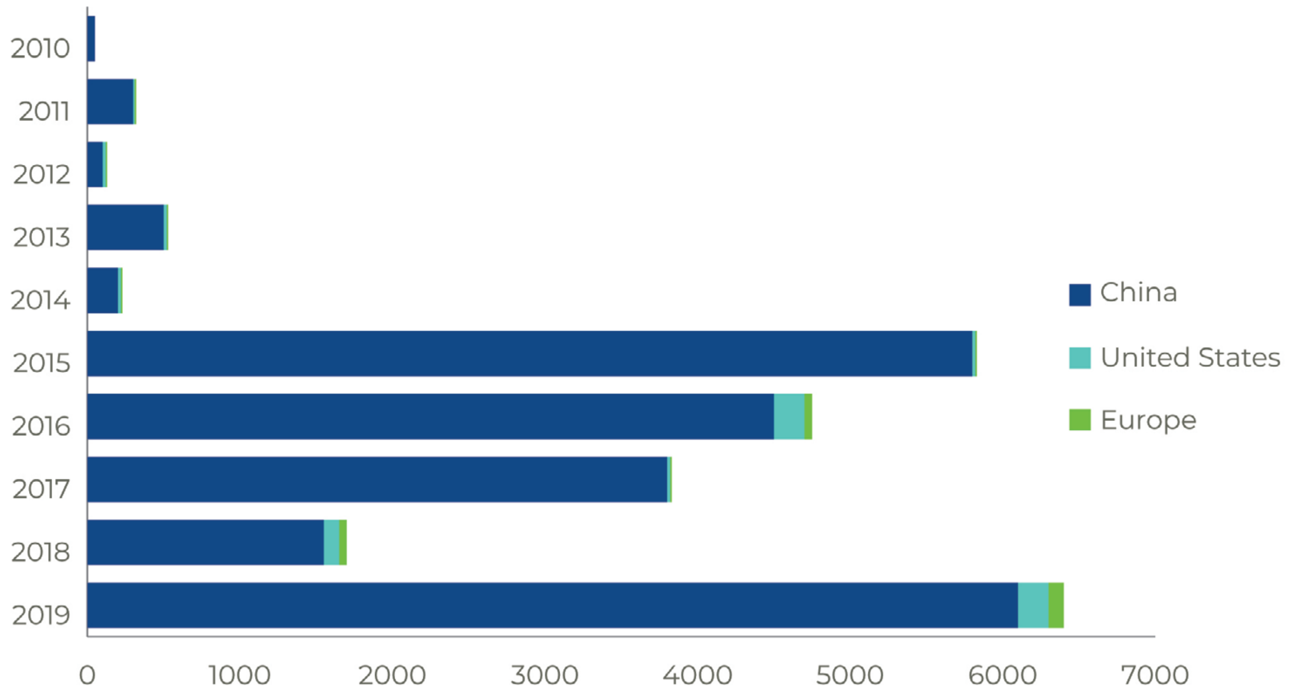


1.2.3 MARKET IMPACTS

Current ZEFV sales are relatively low compared to other successful early applications, such as transit buses. Global stocks of battery-electric (BEV) transit buses total approximately 500,000 from 2015-2019 compared to approximately 16,000 BEV trucks during the same period (IEA, 2020). Global sales of medium- and heavy-duty (MHDV) ZEVs have been largely driven by China, where the vast majority of all vehicle sales have taken place (Figure 1.5) (IEA, 2020).[xiii]

5 The Drive to Zero ZETI tool offers a thorough, yet not completely comprehensive, glimpse of vehicles and markets and should not be construed as representative of the entire vehicle market.

Figure 1-5. Global Sales of MHDV electric trucks by region and year



The early heavy-duty ZEV market has illustrated the extent to which clean vehicles are an international commodity. The current heavy-duty ZEV market is based predominantly in China, with 82 percent of global 2018 sales conducted by companies located in the country (EV-Volumes, 2019). Global manufacturing of all heavy-duty market has been more diverse – 27 percent of all heavy-duty ZEV sales were produced in China, 24 percent were produced in North America, and 19 percent were produced in Europe (ACEA, 2018).[xiv] Where demand exists, suppliers from around the globe will innovate and produce vehicles to fill gaps.

1.3 MAJOR ANNOUNCEMENTS SUMMARY

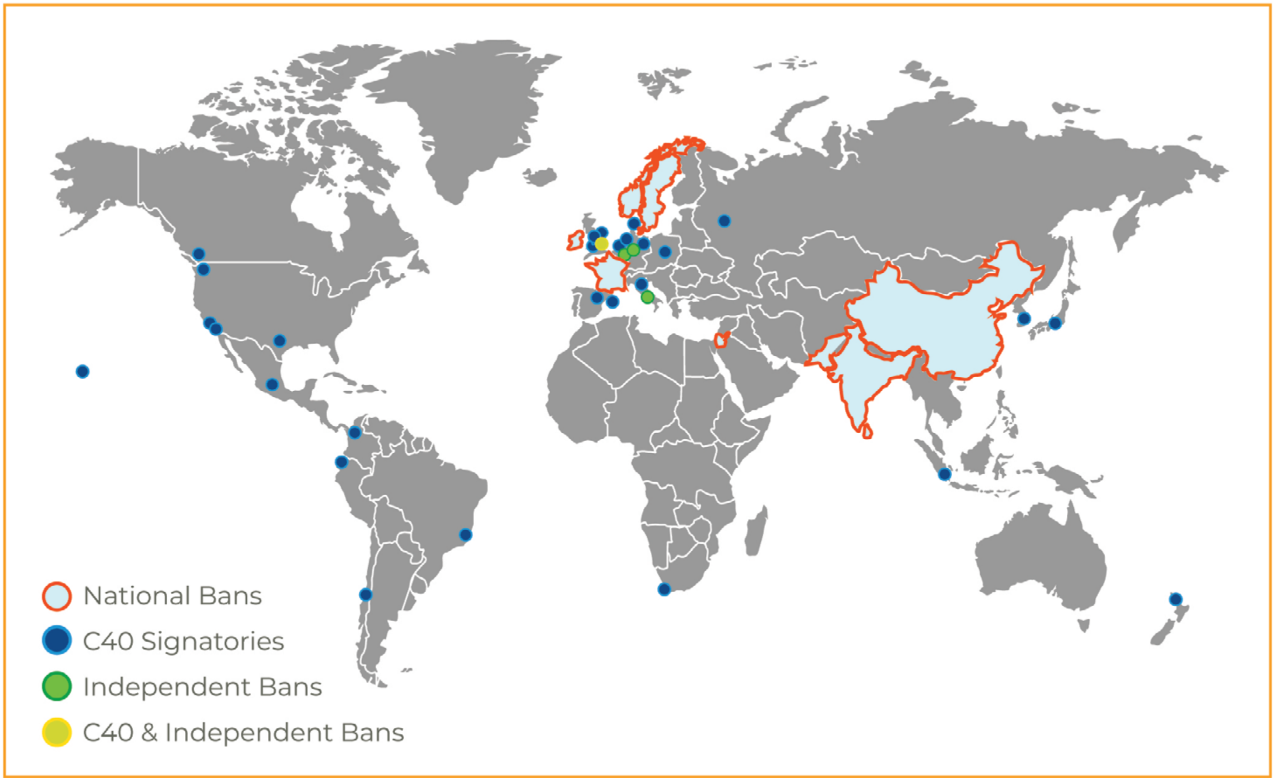
Fast progress in ZEFV technology development has enabled leading firms in the package and urban delivery segment to make major announcements to deploy BEV vehicles in coming years. Although urban delivery vehicles (see Chapter 2.1 for vehicle segment and application definitions) represent a relatively small share of freight truck emissions, they are an important segment for which zero-emission technologies are ready and which can serve as a launching pad for other heavier truck segments.

1.3.1 GOVERNMENTS

In addition to increasing vehicle demand from fleets and vehicle supply from manufacturers, governmental backing is essential in the form of targets, regulations, incentives, and investments. Government commitments to low-polluting vehicles are unprecedented in their scale and ambition.

Cities have announced their intentions to prohibit or restrict operations of any vehicle using fossil fuels within their boundaries, creating enormous population centers that can only be served by ZEFVs. Cities that signed on to C40 Fossil Fuel Free Streets Declaration (C40, 2020)[xv] will create zero-emission zones in significant sections of central business districts with populations of 4.7 million people in North America and 22.25 million people in Europe (City Mayors, 2020).[xvi] Separately, in the wake of the scandal created by the discovery of Volkswagen's defeat devices for emissions testing, many nations have expressed their plans to restrict or eliminate the use of vehicles powered by fossil fuels. Figure 1.6 shows many noteworthy announcements at both city and federal levels that will limit use of fossil fuel powered vehicles. European cities are leaders in restricting diesel vehicle use, creating opportunities for ZEFVs to take over market share. In the Netherlands, the legislature advanced a National Climate Agreement that requires at least 30 of the nation's largest cities to implement zero-emission freight zones (Climate Council, 2020).[xvii]

Figure 1-6. Map of national and city restrictions on diesel-powered vehicle operations



1.3.2 FLEETS

Delivery and logistics companies have been early adopters and champions of ZEFVs. Companies such as DHL and UPS are enormous operations that are highly visible and drive countless miles along residential roads to deliver and pick up packages; Amazon is newer to delivering its own packages, but has significantly increased its operations with plans to rapidly expand, and Chinese retailers and logistics companies such as JD and SF Express have large operations in across the region. These companies announced commitments to ZEFVs and have given the young market a boost and lent the technology a level of sophistication and readiness that will encourage other fleets to commit to zero-emissions technologies. Though large fleet investments will help buoy the market, creating visibility and sustaining the new technologies, smaller fleets will be needed to reach majority ZEFV uptake. Operators with fleets between one and 20 vehicles may account for between 50-65 percent of fleet vehicles (Roland Berger, 2018).[xviii]

Between the announcements and trends by individual fleets in Table 1.1, including logistics companies and major municipal fleet purchases, new ZEFV orders will exceed 130,000 vehicles.[6] The scale of fleets' purchasing commitments, both by companies and municipal fleets, will rapidly mature the ZEFV market and create enormous demand relative to current market conditions.

Table 1-1. Fleet announcements for ZEFV Adoption

YEAR	GEOGRAPHY	LEADER	DESCRIPTION
2017	China	JD	Leading Chinese online retailer JD plans to replace its entire fleet of tens of thousands of vehicles with new energy vehicles (near or zero-emission vehicles) by 2022
2018	China	SF Express	Logistics company SF Express plans to launch nearly 10,000 BEV logistics vehicles in more than 30 cities across the country
2018	California	FedEx	Logistics company FedEx announces purchase of 1,000 BEV Chanje vans for California market
2018	Global	Ikea	Ikea commits to zero-emission deliveries in leading cities by 2020 and in all cities by 2025
2018	Global	Industry	Walmart, Pepsi, Anheuser-Busch, FedEx, Sysco, and other large multi-national corporations pre-order 2,000 Tesla Semis within 6 months of truck's debut
2018	China	Suning	Independent retailer's Qingcheng Plan will deploy 5,000 new energy logistics vehicles in 100 cities across the country
2019	Switzerland	H2 Mobility Association	19 of Switzerland's largest retailers are investing in Hyundai hydrogen trucking services that will deploy up to 1,600 heavy-duty zero-emission trucks
2019	United States	Anheuser-Busch	Anheuser-Busch orders up to 800 hydrogen-powered Nikola heavy-duty trucks
2019	North America	UPS	Logistics company UPS orders 10,000 BEV vans for use in North America with potential for a second order
2020	California	Los Angeles	Municipal fleet will purchase only ZEVs by 2021 where applicable for all vehicles

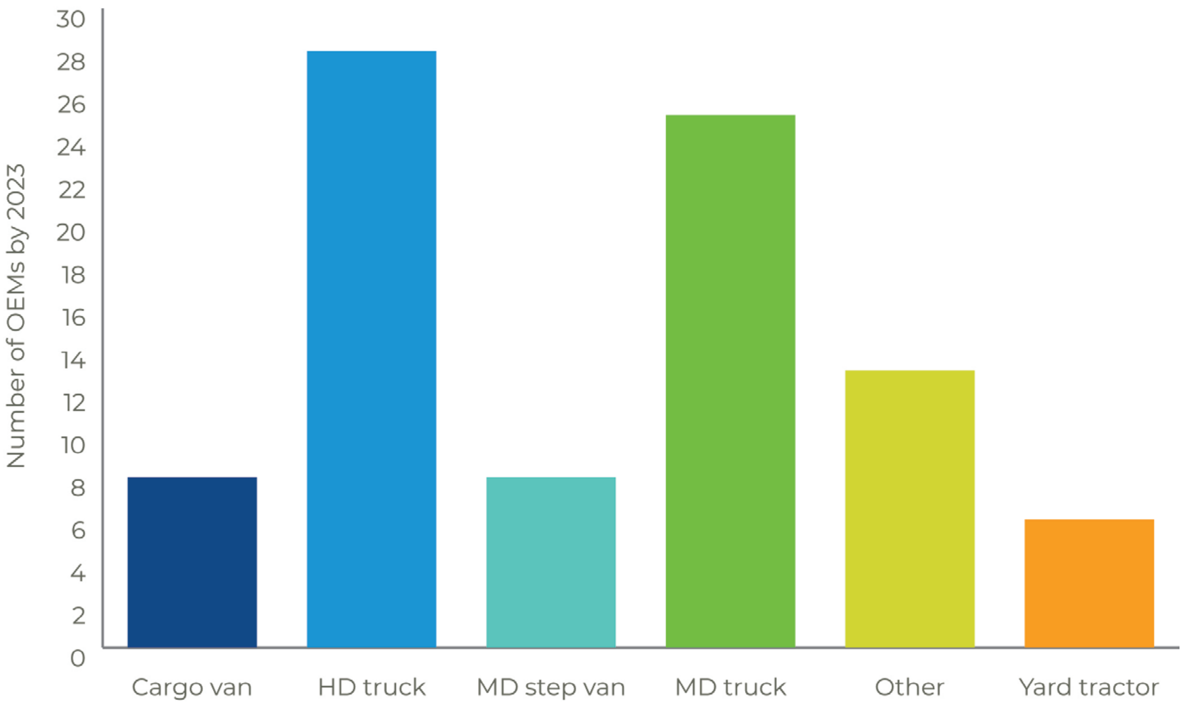
6 This figure does not include DHL's last mile deliveries, since the company's definition of "clean transport" does not differentiate between alternative fuel types, such as compressed natural gas or electric hybrid vehicles.

YEAR	GEOGRAPHY	LEADER	DESCRIPTION
2020	New York	New York City	More than 20,000 municipal vehicles, from school buses to refuse trucks, will be zero-emission by 2040
2020	Global	DHL	Will use clean transportation for 70% of first and last mile deliveries by 2025
2020	Global	Amazon	Online retailer Amazon orders 100,000 BEV vans from startup Rivian

1.3.3 MANUFACTURERS

Manufacturers from traditional truck and engine manufacturers to startup companies have entered the ZEFV market with strong commitments to developing new technologies at large scales in coming years. These companies are joining existing retrofitters, upfitters, and vehicle modifiers that have helped advance the early ZEFV market. Figure 1.7 (CALSTART, 2020) shows the number of truck manufacturers with ZEFV models available or announced through 2023, indicating a level of competition in this market.

Figure 1-7. OEMs with available ZEFV models through 2023 in U.S., Canada, Europe, and China[7]



The growth in ZEFV manufacturing and the number of vehicle producers is expected to continue, as

7 The Drive to Zero ZETI tool offers a thorough, yet not completely comprehensive, glimpse of vehicles and markets and should not be construed as representative of the entire vehicle market.

industry experts have identified the development of "highly efficient, emission-free and silent trucks" as one of the most influential trends in the commercial vehicle industry through 2030 (Roland Berger, 2012)[xix], (Roland Berger, 2018)[xx]. Large-scale vehicle manufacturer commitments to ZEFVs will boost fleet confidence that vehicles will be produced with the right technologies to meet fleets' needs (Table 1.2).

Table 1-2. Select manufacturer announcements for ZEFV production

YEAR	GEOGRAPHY	LEADER	DESCRIPTION
2016	Global	Nikola	Nikola releases heavy-duty hydrogen-powered tractor truck
2017	Global	Tesla	Tesla debuts the BEV Semi truck
2018	Global	Daimler	Daimler debuts its two BEV truck designs for global markets
2019	Europe	IVECO, FPT Industrial, Nikola	IVECO, FPT Industrial and Nikola Corporation unveil Nikola TRE battery-electric truck for European markets
2019	North America	Lion Electric	Lion launches its versatile Class 8 electric truck that is adopted for use in waste fleets and for goods movement by leading railway company Canadian National
2020	Global	UPS, Hyundai, Kia	Automakers and logistics company invest $100 million in UK electric van startup
2020	Europe	Daimler, Volvo	Volvo Group and Daimler Truck AG are planning to form a joint venture in the development, production, and commercialization of fuel cell systems for heavy-duty vehicle applications
2020	Europe	Daimler	Daimler Trucks Launches Global Electric-Truck Charging Initiative
2020	Global	Mitsubishi Fuso	Mitsubishi Fuso to begin series production of fuel-cell trucks by late 2020s; concept eCanter F-CELL
2019	Europe	Hyundai	Hyundai plans hydrogen ecosystem with fuel cell trucks across Europe
2020	Global	Scania	Scania announces market launch of a BEV city-delivery truck

CHAPTER 2

ASSESSMENT OF TECHNOLOGICAL COMMERCIALIZATION PROGRESS

The ZEFV market may be subdivided into four distinct vehicle segments: cargo vans, medium-duty trucks, heavy-duty trucks (BEV and FCEV), and yard tractors. Lighter vehicle applications are currently more technologically advanced than heavier applications, but this early growth in more technologically advanced segments will support broader ZEV growth in the broader commercial vehicle market. By improving on economies of scale and producing components that are transferable and adaptable to new zero-emission vehicle models and segments, manufacturers will advance from "beachhead" applications of first success to expanding their vehicle manufacturing model options and production capabilities (CALSTART, 2020g).[xxi] Manufacturing and process improvements will be important to reducing fleets' total cost of ownership of ZEFVs, which are currently more expensive to purchase, but may be less expensive to operate. TCOs must be competitive with diesel-powered vehicles, but do not encapsulate the entire value of zero-emission technologies, such as the societal benefits of reduced air pollutants, GHGs, and noise.

2.1 REPRESENTATIVE SEGMENTS

Four distinct segments have emerged in various stages of commercialization that represent the early, but rapidly developing ZEF vehicle and technology market. The vehicle segments identified consist of BEV cargo vans, BEV medium-duty delivery trucks, heavy-duty regional and long-haul trucks (including FCEV and BEV), and BEV yard tractors.

These vehicles accurately represent the ZEFV market most directly because they comprise most of the major freight vehicle categories. Commercially available MHDV ZEFV models are tracked and categorized in the Drive to Zero program's ZETI tool by platform, region, and release date (CALSTART, 2020). Six of these platforms can be categorized as pertaining to ZEFVs, including the four selected vehicle segments. The two omitted platforms are less representative of the ZEFV market. The category titled "Other" is overly broad and may contain vehicles that do not haul freight, such as refuse trucks, and are currently in very early market stages. "Step vans" were not included because they nearly exclusively serve the U.S. market as postal couriers, and so do not meet the international scope of this report.

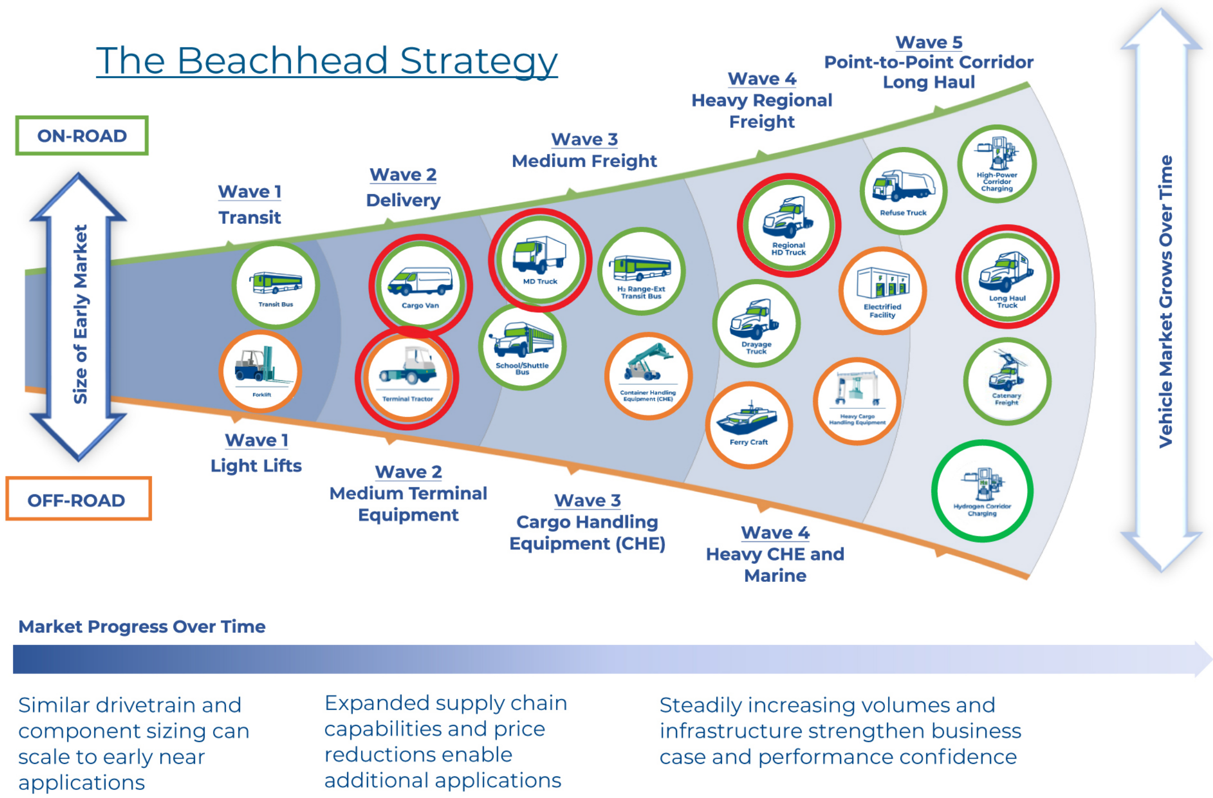
Fleets and manufacturers have demonstrated demand or large-scale investments in the MHDV ZEFV market through commitments to vehicle deployments and rapid growth in available vehicle models. These developments support the representativeness for the following segments, which may be seen as bellwethers for the broader ZEFV market.

- **Cargo Vans**: Weigh at least 3.5t with connected cabs and cargo compartments, used predominantly for regional delivery. The announcements by logistics companies listed in Chapter 1.3 point to an enormous consumer appetite for lighter ZEFVs over the next decade.
- **Medium-Duty Trucks**: Weigh between 4.5t and 12t, used primarily for regional delivery. Manufacturers are investing in vehicle models sufficiently to project market growth in the segment.
- **Heavy-Duty Trucks**: Weigh at least 12t and may be used for regional or long-haul delivery and drayage. Heavier ZEFVs take longer to come to market, but several companies have demonstrated the commercial interest in heavy-duty applications.
- **Yard Tractors**: Off-road MHD trucks designed to move cargo and freight equipment. BEV tractors are less visible to the public view, but they have become a popular zero-emission technology for moving and supporting off-road freight.

The four selected vehicle segments also represent various growth stages in a connected ZEFV market. The Global Drive to Zero program identifies successful ZEV initial applications that will support the growth and development of other ZEV applications. These successful applications are referred to as "beachheads" that develop in waves and contribute to a continuously expanding ZEV market (CARB, 2019).[xxii] The strategy of successive commercial vehicle applications was developed with CARB and has been recognized as a fundamental approach to ZEFV deployment by Drive to Zero partners, including nine national governments and dozens of state agencies, utilities, and industry partners (CALSTART, 2020f).[xxiii]

The beachhead model's projections for ZEFVs start with smaller vehicles, such as cargo vans and yard tractors, as first-success applications in receptive markets around the world. The components and supply chains for these vehicles can be transferred and fashioned into new applications that will meet more rigorous duty cycles in heavier vehicles. The progression from lighter to heavier freight vehicles in an expanding market is shown in Figure 2.1, with the targeted vehicle segments highlighted in red.

Figure 2-1. The “Beachhead” theory of ZEV market transformation



2.2 KEY TECHNOLOGY READINESS

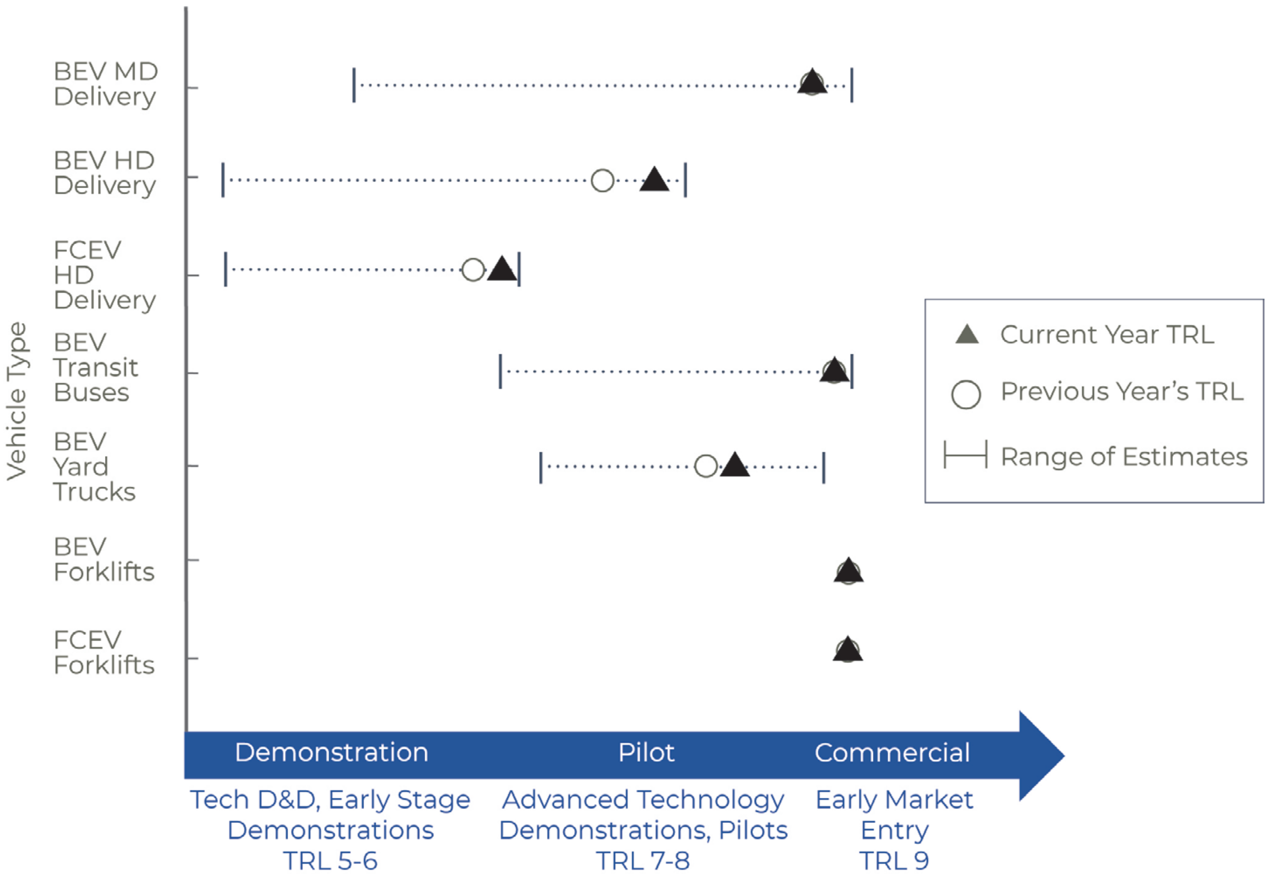
ZEFV segments have advanced toward commercialization at different rates. Accurately assessing how close each ZEFV segment is to commercialization is important for identifying policies and actions that will help develop supportive eco-systems for specific vehicle types. CALSTART has collaborated with the California Air Resources Board to assess the “Technology Readiness Level” (“TRL” on a scale from 1-9, with 9 being ready to enter broad commercial sales (Figure 2.2)) for multiple ZEV platforms (CALSTART, 2020b).[xxiv]

Figure 2-2. Stages of technology readiness

The TRL scores are meant as snapshots of a vehicle platform’s current progress, providing an aggregated score for each vehicle platform technology rather than for one vehicle model. The scoring process combines vehicle models and sales with survey results from industry partners, with weighting applied for how developed vehicle manufacturing and manufacturers are within each segment. These scores are placed into a chart that combines the current status of each ZEFV segment with recent progress toward commercialization.

In the technology status charts shown in Figure 2.3, the x-axis represents how far the technology has advanced toward readiness for production, with those in the early demonstration stages shown on the left. ZEFV technologies that are closer to commercialization sit farther to the right on the x-axis (CALSTART, 2020b). The figure shows a range of TRLs and indicates progress in each ZEFV segment over time. To show the commercialization progress of the earliest successful beachhead applications, the chart also includes TRLs for zero-emission transit buses and forklifts. In the technology status charts shown in Figure 2.3, the x-axis represents how far the technology has advanced toward readiness for production, with those in the early demonstration stages shown on the left. ZEFV technologies that are closer to commercialization sit farther to the right on the x-axis (CALSTART, 2020b). The table shows a range of TRLs and indicates progress in each ZEFV segment over time, as shown by current (2020) and previous year (2019) scores. To show the commercialization progress of the earliest successful beachhead applications, the chart also includes TRLs for zero-emission transit buses and forklifts.

Figure 2-3. Technology readiness level (TRL) by vehicle platform



The TRLs reflect the real-world deployment of ZEFVs between different vehicle segments. In Shenzhen, China, alone, nearly 60,000 BEV cargo vans are operating smoothly and completing urban deliveries (RMI, 2019).[xxv] Similarly, all-electric tractors are commonplace in many of the most sustainable ports and off-road facilities. By contrast, heavy-duty FCEVs and BEV trucks are still progressing through their demonstration phases, and while they hold tremendous promise, their TRL scores reflect their longer path toward commercialization than other platforms.

The advancement of each vehicle segment will support the market acceleration of the broader ZEFV sector due to the relative simplicity of ZEFV vehicle designs that use fewer and more typically interchangeable parts than their diesel-powered equivalents. A basic chassis can be scaled up or down and customized to meet multiple end-uses, such as Canadian manufacturer The Lion Electric Co.'s vehicle catalogue that uses the same core components to that are modified and optimized to produce vehicles ranging from buses to refuse trucks (Lion, 2020).[xxvi] As supply chains and component technologies improve, advances in one vehicle segment can rapidly spread to other segments, accelerating the entire ZEFV market and their respective TRLs.

Notably, current TRL assessments do not necessarily describe every scenario or situation in which a ZEFV may be deployed. For instance, a heavy-duty all-electric truck may have adequate battery range for regional haul, but corridor long-haul operations may be limited by infrastructure or electricity availability. The TRL scores provide a range of assessments and attempt to provide an aggregated understanding of each platform's commercialization progress, but they cannot provide a complete picture for the entire market. Any remaining barriers should be addressed separately from the vehicle technology, and policymakers should decide how best to create a supportive ecosystem for a vehicle that is technologically viable.

TRL scoring is assisted by market research for each vehicle type. The following are examples that speak to the readiness and the representativeness of the four chosen vehicle types.

- **Cargo Vans**: FedEx will purchase 10,000 vans, and Amazon plans to purchase 100,000 vans for its global fleet. These large-scale orders demonstrate the demand for all-electric cargo vans that is not reflected in high numbers of available vehicle models, as the large orders may consist of only one model.
- **Medium-Duty Trucks**: Most notably, the number of medium-duty ZEFV models shown in Figure 1.3 grows rapidly and will exceed the number of models in any other segment by at least 100 percent. This growth underscores an expected demand for differentiated vehicle models that can meet specific needs and diverse duty cycles.
- **Heavy-Duty Trucks**: Traditional truck and engine manufacturers, including Daimler, Volvo, and Cummins, have all developed ZEF vehicles or technologies that have at least entered demonstration phases. Tesla, which has rapidly grown to become a leading global automaker, expects to bring its all-electric Semi truck to market by 2021. Nikola, a startup hydrogen fuel cell truck manufacturer, has secured commitments from major fleets such as InBev and was valued at more than $12 billion after its Initial Public Offering, though its first production model has not yet been manufactured (Forbes, 2020).[xxvii]
- **Yard Tractors**: Yard tractors have become a leading technology in several incentive programs that CALSTART manages, particularly under the newly initiated California Clean Off-Road Equipment (CORE) program. Applications for yard tractor sales met the program's funding limit within the first

day of the program's launch, with 92 approved vouchers and a wait list of more than 120 additional yard tractors (CALSTART, 2020a).[xxviii]

Most of these vehicle types are BEVs, which have gained an early market advantage and are particularly suitable in light-duty applications. As vehicles get larger and have longer ranges, larger batteries may add costs and weight, creating opportunities for FCEVs to carry a greater load since their hydrogen equipment weighs less than batteries that may approach 300 kWh.[xxix] Innovative dynamic infrastructure approaches, such as catenary or in-road charging, may also improve ZEFV efficiency by reducing battery sizes (see Chapter 3 for Infrastructure and Chapter 4 for Breakthrough Innovations).

2.3 TOTAL COST OF OWNERSHIP

2.3.1 ZEFV TOTAL COST OF OWNERSHIP

When planning a ZEFV transition, commercial fleet operators will need to consider the total cost of ownership of a zero-emissions fleet versus a diesel-powered fleet in order to remain competitive. TCO considerations will determine how quickly and thoroughly ZEFVs advance in the freight marketplace in two distinct areas: capital costs and operating costs. Capital costs in vehicle TCO calculations typically include the purchase price and depreciated value of vehicles (excluding infrastructure), along with financing considerations like cost of capital. Operating costs typically include fuel and maintenance costs. The section below provides current and future estimates for targeted vehicle segments, including the following examples:[8]

- Cargo vans (12t– 180 kWh battery)
- Medium-duty regional-haul trucks (19t– 220 kWh battery)
- Heavy-duty long-haul trucks (40-44t– 300 kWh battery)
- Yard tractors (40t towing capacity – 150 kWh battery)

According to TCO estimates in this analysis, most ZEFV segments will reach cost parity with diesel freight vehicles before 2030 (see Appendix 2.A and 2.B for graphs of each segment's break-even point). The zero-emissions cargo van provides the most promising TCO estimate that will reach cost parity in 2026, due partly to smaller battery size (Figure 2.5). The heavier ZEFVs are estimated to achieve cost parity in the ensuing years, aided by battery and component efficiency improvements that will enable longer-distance driving (up to 100,000 km annually) without additional battery or technology costs.

Reasoning for assumptions and example values are explained in Appendix 2.C. Notably, each of the example vehicles is a BEV because determining reliable market and operating costs for FCEVs may be too inaccurate during the early hydrogen-powered ZEFV market. Costs for hydrogen are briefly addressed where applicable, but is not included in a direct TCO comparison. Additionally, this analysis does not include myriad "soft costs," which are highly variable and difficult to capture in a high-level analysis.

8 These examples are chosen to illustrate TCO within each vehicle segment. For a full breakdown of vehicle class ranges, consult Appendix 1.A.

These costs are not strictly defined but may include the costs of training drivers and technicians, revising operations to better suit ZEFV capabilities, or permitting any needed infrastructure or facility upgrades. With proper planning, fleet operators can minimize these hidden costs.

2.3.2 PURCHASE COSTS AND RESIDUAL VALUE

BATTERY AND COMPONENT COSTS

ZEFV purchase prices are currently significantly higher than equivalent diesel-powered freight vehicles, due largely to the additional costs of vehicle batteries. Falling battery costs and improved efficiency, then, will create tremendous opportunities to reduce the purchase price of ZEFVs. The price of batteries has already significantly decreased in the past decade with estimates predicting further price decreases in coming years. Several studies forecast the average prices of battery packs to reach $94/kWh by 2024 and $62/kWh by 2030, such as the Bloomberg New Energy Finance estimate shown in the figure below (Bloomberg, 2019).

Figure 2-4. Development of lithium-ion battery pack price per kWh

Other component costs, such as electric motors, heating and cooling systems, and other control systems are expected to decrease over the same time frame as manufacturing processes improve and components are transferred between models and segments. ZEFV component costs are also less expensive than those of diesel trucks because ZEFVs use fewer components in their design.

RESIDUAL VALUE ESTIMATES

Residual value is an important TCO factor. At the end of their service lives in a fleet, trucks may retain value for resale to other fleets or for their parts. ZEFVs' residual values are uncertain because there is not an established used electric truck market yet. Uncertainty over residual value may benefit or reduce TCO. The following factors weigh in ZEFV TCO estimates:

- Secondary fleets may hold concerns over the functional life or reduced capacity of used vehicle batteries, which would reduce the residual value and the TCO for the original vehicle owner;
- A secondary market for used ZEV batteries, for recycled materials or as stationary storage, may emerge to create additional residual value outside of vehicles;
- Since ZEFVs use fewer components, secondary fleets may save on maintenance, creating additional residual value; and
- ZEFVs will be permitted to operate in cities or countries that will restrict diesel-powered truck access, which creates an extremely strong residual value based on the geographic location of secondary fleets.

2.3.3 OPERATING COSTS

Operating costs impact TCO consistently over the lifetime of a vehicle, which vary by platform due to differentiated usage patterns. For the estimates in this report, the average utilization of cargo vans lasts 8.5 years; medium-duty truck utilization lasts 9 years; heavy-duty truck utilization lasts 5.5 years; and yard tractors lasts 10 years (TTM, 2015),[xxx] (ING, 2019),[xxxi] (Öko-Institut, 2018),[xxxii] (CALSTART, 2011).[xxxiii]

MAINTENANCE COSTS

ZEFV designs require fewer components than diesel-powered vehicles and do not generate as much friction due to their regenerative braking capabilities. Maintenance costs, therefore, are expected to be lower than diesel-powered vehicles over time. However, a Dutch industry association study finds that fleet inexperience with ZEFVs and newly designed components that may experience heightened failure rates could increase maintenance costs through 2025 (BOVAG, 2019).[xxxiv] After the first five years of ZEFV operation, maintenance costs are expected to fall to one-third of diesel-powered trucks.

COSTS OF CHARGING OR FUELING

Fuel consumption is a significant cost over the lifetime of a freight vehicle. Fuel cost estimates heavily rely on energy price predictions over several years, so some uncertainty is inherent in TCO calculations. Over the next decade, both electricity and diesel prices are expected to rise, though diesel prices are expected to rise higher as a percentage of current diesel costs to reflect the volatility of the oil market. Fuel prices may vary significantly by region, electric utility, or even time of day and are difficult to predict for a global market. The cost of charging ZEFVs is generally expected to be lower than fueling diesel-powered trucks, though fleets' charging management strategies and the rate of their vehicles' electricity consumption will significantly impact real-world charging costs.

Electricity consumption estimates are also a function of vehicle efficiency, or how many kilowatt-hours are needed to drive a kilometer. This report's estimates are based on a study that provides vehicle efficiency values starting at 1.6 kWh/km in 2020 and improving to 1.25 kWh/km by 2030 (Moultak, Lutsey, & Hall, 2017)[xxxv]. These values are confirmed by FIERs recent work on the eGLM project, a pilot project that incorporated seven 40T FRAMO e-trucks at multiple transport companies with different logistic operations in Germany and the Netherlands. Vehicle efficiencies were adjusted to match each platform. Final TCO estimates are displayed in Figures 2.5 – 2.6 and used overnight AC Level 2 charging in depots as the base-charging scenario. More information about charging infrastructure can be found in Chapter 3.

Figure 2-5. TCO for cargo vans (12T) and medium-duty trucks (19T)

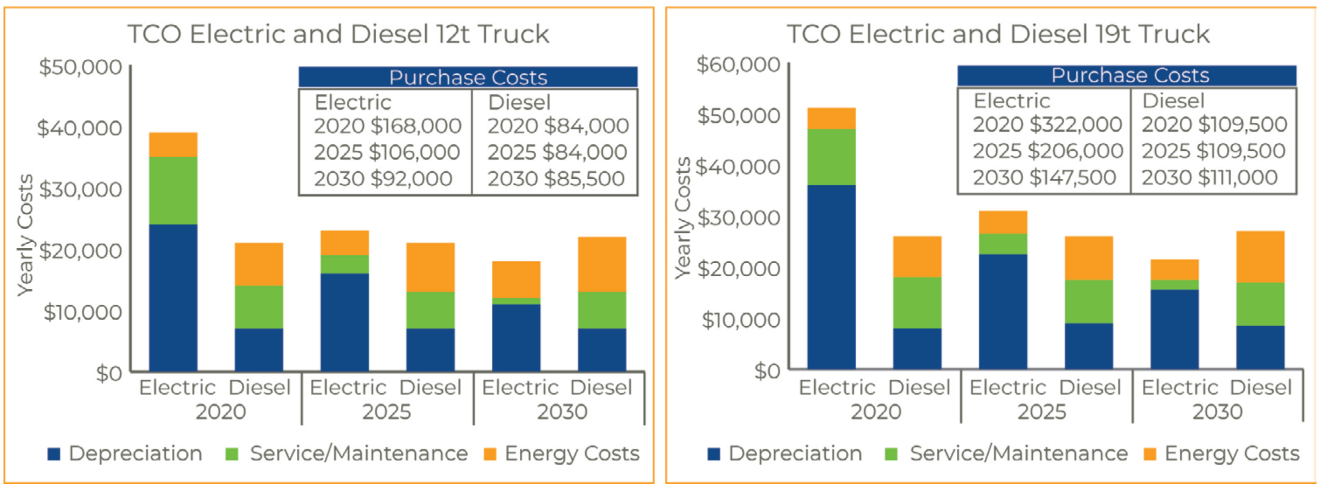
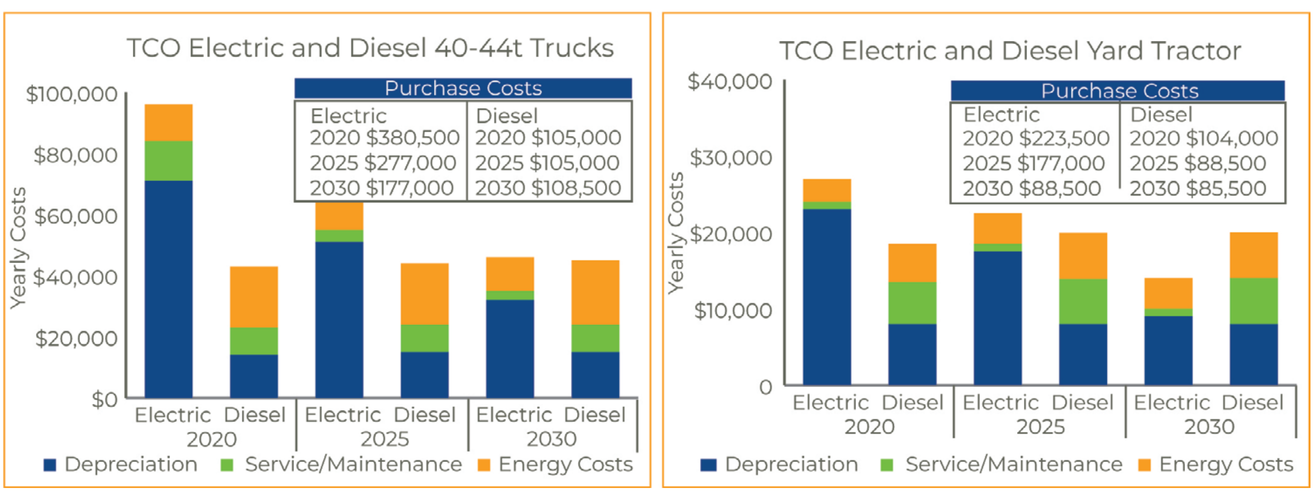


Figure 2-6. TCO for heavy-trucks (40-44T) and yard tractors



2.3.4 TCO CONCLUSIONS

The competitiveness of companies in the logistics market is largely determined by transport costs. A central requirement for the vehicles used, and thus for the market success, is therefore competitive overall costs of ZEFV applications. A competitive TCO largely determines the success and uptake of ZEFVs in the broader market.

Due to ZEFVs' higher purchase costs and uncertain residual value, their capital costs are higher than diesel vehicles' costs with a more rapid rate of depreciation. With managed charging practices and growing maintenance expertise, ZEFV operating costs should be lower than those of diesel vehicles. Therefore, supportive policies should target reductions in ZEFV upfront purchase costs and improved residual values, which could potentially be accomplished by realigning business models to distribute savings from operations to capital expenditures.

Each of the ZEFV types will reach cost parity with diesel freight vehicles before 2030. The ZEFV in the 12t range will reach a cost equivalence in 2026. The heavier ZEFVs, in this case in the 19t and 40-44t categories, will respectively achieve cost parity by 2028 and 2029. Hydrogen fuel cell vehicles were not explicitly addressed in the TCO analysis because the market is relatively young and small, still firmly in pilot stages. The cost of hydrogen will likely differ significantly as economies of scale improve, a secondary market for used fuel cell vehicles has not yet emerged, and maintenance on pilot vehicles may be more expensive because spare parts may not yet exist.

The variations between vehicle segments' TCO performances are caused by different purchases costs, battery capacities, drivetrain efficiencies, years of ownership, and annual mileage driven. Purchase costs, for instance, are significantly impacted by the size of the vehicle batteries, ranging in our calculations from 150 kWh for yard tractor to 300 kWh for a heavy-duty truck. Expected technological developments include the expectation that the battery price will further decrease. Calculations do not include vehicles' expanded service ranges due to increased fast charging availability, which would positively impact ZEFVs' TCOs.

The TCO analysis conducted in this section primarily focuses on the capital and operational costs during the lifetime of the trucks and relies upon many different factors, including the price of the vehicle, fuel and maintenance costs, projected residual value, and other estimates. Fuel-price estimates, for example, used industry averages that were considered representative of real-world market conditions, accepting that prices of electricity and diesel also vary significantly by country, region, or utility provider. Additional factors may apply that significantly impact a vehicle's TCO that were not directly included in the analysis, which was purposefully meant as a high-level, illustrative exercise.

When factoring in additional, highly-specific values such as the impacts of taxes or subsidies on vehicle and fuel prices and operations, TCOs will be markedly affected. For instance, a California fleet can use the California Air Resources Board TCO calculator to apply incentives such as a state-managed purchase voucher or clean fuel credits that both reduce ZEFV TCOs. For a brief analysis of how current policies may impact TCO, see the call-out box "TCO Sensitivity Examples" on how a tax (and corresponding ZEFV exemption) found in some European nations impacts TCO estimates and Appendix 2.D for further information on the specific policies described.

TCO Sensitivity Examples: European Road Taxes and Tolls

Across Europe, taxes on diesel consumption for on-road freight applications are relatively common. Because these taxes aim at improving environmental outcomes, some countries provide exemptions for ZEFVs. The following examples demonstrate the TCO impact of these real-world policies and are not meant as a comprehensive review of all existing and potential policies that affect diesel-powered trucks and ZEFVs.

- In Switzerland, for example, a 40t heavy-duty diesel-powered truck with annual mileage of 60,000 km would be taxed at $60,000 per year. The exemption to this road-use tax creates a potential TCO advantage for strategic ZEFV deployments.
- The German government requires diesel-powered trucks to pay highway tolls (Maut) that, for the 40t truck traveling 60,000 km annually, may add up to $13,200 per year. Exempting ZEFVs from this road tax would help the example fleet reach cost parity sooner (from 2029 to 2027). The cost parity of ZEFVs weighing 19t and 12 tons12t would also come sooner (from 2028 to 2024 and from 2026 to 2023, respectively).
- In the Norwegian city of Oslo, diesel-powered trucks are required to pay road tolls, but ZEFVs are exempt. A 12-tonA 12t diesel-powered freight vehicle that makes two deliveries to the city center six days per week all year pays $8,200 a year in tolls to enter the central business district. If these costs are included in this TCO, a 12-ton12t ZEFV will reach cost parity in 2023, three years earlier than the broad-use TCO estimates.

CHAPTER 3

INFRASTRUCTURE

Charging and fueling infrastructure availability is critically important to accelerate ZEFV deployment and is a significant barrier to market expansion (C2ES, 2020).[xxxvi] The number and capacity of charging or hydrogen stations must progress rapidly to support the growing ZEFV market. Current deployments of lighter freight vehicles with smaller batteries may be able to charge at depots or low-power public charge points overnight with lower charging rates or opportunistically use more expensive high-powered charging stations. Larger trucks that are expected within the next few years will require dedicated higher-powered DC charging stations or hydrogen fueling stations along travel corridors or at freight hubs to complete extended or long-distance routes.

The high rates of charge needed to fuel large ZEFV fleets will create challenges both for electric utilities to cost-effectively balance energy supply and for fleets to cost-effectively manage their vehicles' charging needs.

Innovative technological solutions may alleviate some of the concerns that fleets or energy systems operators may have. Examples of alternative infrastructure technologies include:

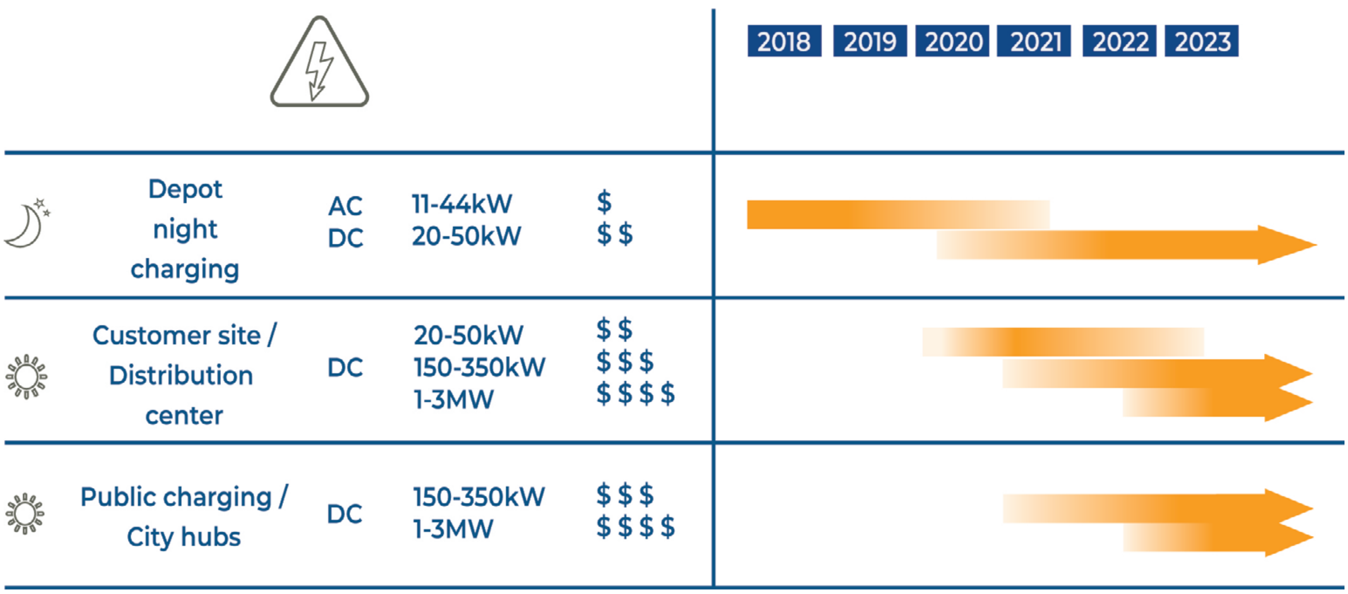
- Battery swapping has been incorporated in projects located in Israel,[xxxvii] and NIO has made recent progress with the practice for passenger vehicles in China,[xxxviii] but the practice has not spread in a large or influential way, particularly for larger batteries needed in ZEFVs (GTM, 2013) (Car and Driver, 2020).
- Roads electrified by overhead catenary charges or in-road cables may be able to extend ZEFV ranges, but the infrastructure investment can be expensive and is limited to the specific roadways where the dynamic charging technologies are installed (Oeko Insititute, 2018).[xxxix]
- Hydrogen stations are currently fewer and more expensive relative to high-powered charging stations. As more manufacturers bring production quantities of heavy-duty FCEVs to leading markets, OEMs and hydrogen suppliers will need to rapidly scale up infrastructure availability while limiting costs. Additionally, hydrogen suppliers must develop cost-effective "green" hydrogen to deliver on the promise of ZEFVs to significantly reduce operating expenses and GHGs.

Standardized charging connections and operations will be needed to support efficient investments in shared infrastructure to increase utilization rates and reduce infrastructure costs. Infrastructure investments for ZEFVs in the near term should avoid "lock-in," or restricted access to charging stations by charging network or connection type, because most charging will take place at depots where each fleet manages its own charging. As private and public high-power charging expands, interoperability of hardware and software will be critical to ensure that fleets can efficiently and conveniently recharge.

3.1 CHARGING INFRASTRUCTURE OVERVIEW

The ZEFV charging infrastructure market is rapidly maturing in terms of hardware and software. Standard solutions are currently available across charging use cases and power supplies and are expected to evolve with increasing demand for faster charging (Figure 3.1) (FIER, 2020). Adopted ZEFV charging technologies will shift toward higher DC fast charging as vehicle weights increase and ranges expand. The shift toward DC charging will increase charging rates and costs and shift some costs away from vehicles toward infrastructure, since higher charging power rates are typically more expensive and vehicles charging solely by DC fast charging will not need to the added costs of installed AC/DC inverters . As part of this high-speed evolution, charging stations are being built to provide greater charge capabilities. Current advanced charging technologies supply electricity at rates up to 350 kW, and faster standards are being developed that approach and exceed 1MW. (CharIN, 2019).[xl]

Figure 3-1. Availability and costs of charging solutions for electric trucks



Charging services need to be right-sized for fleet uses by location and time needed to charge. Level 2 charging stations may be adequate for fleets that have ample time to charge over long periods, either overnight or during operational hours at depots, and DC fast-charging may be appropriate for fleets that must charge rapidly at dedicated facilities or along travel corridors. The level of charging needed will also vary by vehicle type or platform. Smaller vehicles, such as delivery vans, may be able to reliably use Level 2 charging at depots to recharge, but Level 2 charging may be insufficient for larger vehicle applications, such as heavy-duty regional haul trucks, to fully recharge overnight

Whereas Level 2 stations may be installed directly by fleet operators, the higher costs of fast-charging installations may require significant support through government or industry investments, such as OEM charging or hydrogen fueling networks. Coordinated efforts to ensure the placement of charging stations in high-value corridors may lead to higher utilization rates and improved returns on investments. Combining the use of strategically placed, high-power chargers serving multiple ZEFVs is important to distribute the costs of charging.

Abundantly available high-power infrastructure can have the co-benefit of reducing the need for unnecessarily large battery capacities, reducing vehicle purchase costs and improving vehicle efficiency by reducing weight. Reduced battery sizes also help fleets manage penalties for the added weight that batteries put on vehicle axles and relative to class weight limits. Dynamic charging solutions, such as overhead catenary or in-road charging systems, can extend vehicle ranges while reducing needs for heavy and costly batteries..

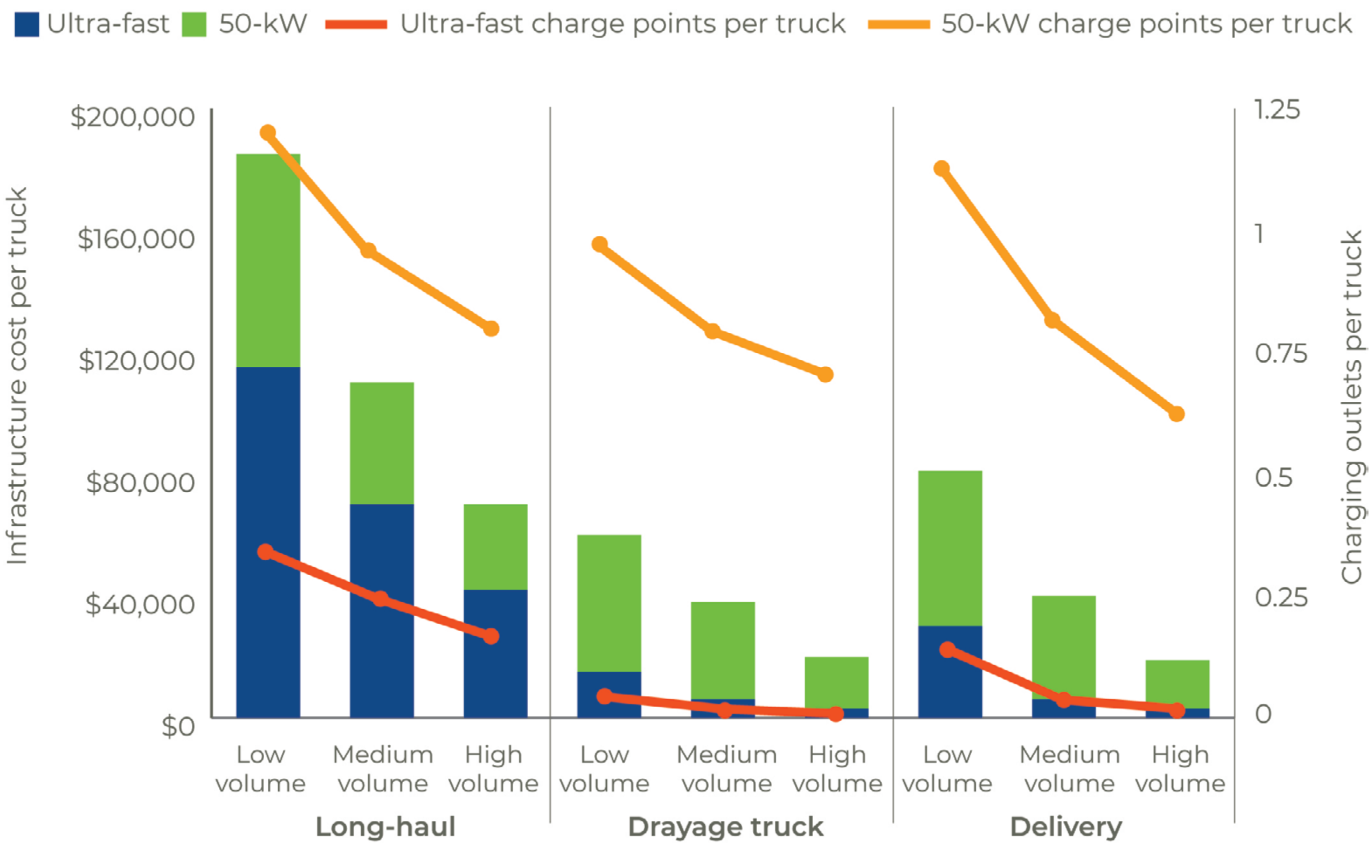
3.2 CHARGING COSTS

Charging costs have a significant impact on TCO parity for ZEFVs and typically drive lower operational costs for an electric truck when compared to a diesel-powered truck. The cost per km with diesel is higher than the cost per km with electricity. In the example calculations in Chapter 2, the diesel cost of a heavy-duty ZEFV are $0.31 (USD) per kilometer and the electricity cost per km is $0.15. This is based on the cost of the energy (diesel and electricity) and the efficiency (l/km or kWh/km) when charging at AC Level 2. Most industrial sites pay a relatively low price per kWh, because the price per kWh drops when the amount consumed per annum rises (EUROSTAT, 2020).[xli]

One of the challenges for TCO parity is that charging and hydrogen infrastructure needs to be financed while diesel fueling infrastructure costs have typically have already been financed and paid for (i.e. a gallon of diesel does not need to be priced to pay for the initial investment of building the station). High-Power Charging (HPC) charging stations are newer and must be purchased, installed, and operated by a freight forwarder or carrier. Therefore, the true cost of a charging station includes the capital expenditures (CAPEX) and operating expenditures (OPEX) of the charger, including grid connection costs on top of the kWh price, that end users may need to pay. The real cost of a charged kWh is therefore higher than only the price per kWh paid to the energy supplier and results in higher electric prices when comparing the equivalent price of diesel, whose vendors do have to maintain and finance their stations, but are not building entirely new infrastructure.

The scale of a financial investment can have a small or large impact on the total cost of charging. For small AC chargers, the effect is small. The costs of a state-of-the-art HPC solution, however, including the costs for new grid connections, a new transformer and an expensive charger, has a significant impact on the cost of charging. The key in optimizing these costs per charged kWh is to increase the utilization of the chargers to spread the installation and depreciation costs. Smart usage of ultrafast charging points, by increasing the fleet size and sharing with third parties, will create better business cases because the costs of the charger and the grid connection can be shared among multiple vehicles. The concept is illustrated in Figure 3.2, though real-world infrastructure costs may vary significantly from those estimated in the figure (Hall et al, 2019).[xlii]

Figure 3-2. Charging infrastructure and associated capital cost required for battery-electric trucks



How the costs of necessary investments in the grid connection are calculated differs per country. These are sometimes invoiced as one-time costs, in other cases as recurring fixed yearly costs based on the peak demand or on the actual energy consumption separately or included in the cost per kWh that is contracted with the energy supplier. Since this has a significant effect on the price of charging, it also has a big impact on the TCO.

3.3 INFRASTRUCTURE STANDARDS

The electric vehicle charging market is rapidly developing and maturing, with new roles still being defined and the integral workings of the market becoming clearer. To create an open, functional, and user-friendly electric vehicle charging market for all actors, one of the most important factors is achieving interoperability and facilitating roaming possibilities, by developing and implementing (open) standards for both the hardware (plugs, sockets, etc.) and the software (data and communication protocols). The market of passenger electric vehicles can provide useful lessons because of its relative maturity in comparison to the electric truck market.

The current plug standards in North America and Europe are CCS1 and CCS2, respectively. Most truck converters and OEMs like Volvo, Mercedes, and MAN use the CCS standard. This plug is currently limited to 350 kW, which means a 300kWh truck battery can be charged nearly empty to 80 percent in about 50 minutes. Improvements beyond the current kW limit are expected to enabling charging up to 3 MW.[xliii] In Asia, CEC and CHAdeMO have joined forces to develop the new 'ChaoJi' standard[xliv] that is backwards compatible with GB/T, CHAdeMO and possibly CCS, and may enable charging rates up to 900 kW. Besides plug charging, other technologies under development and applied in pilot projects include pantograph (catenary)[xlv] and inductive charging,[xlvi] both of which can charge a vehicle dynamically while it is in motion (Siemens & Scania, 2017)[xlvii] (Panchal et al., 2018).[xlviii] See Appendix 3.A for greater detail on charging connector types.

There are a few reasons why interoperability is important.[xlix] Most simply, charging should be hassle-free and as simple as filling a tank to encourage ZEFV uptake (EPRI, 2019). Ensuring that station access is not restricted to particular networks or providers (sometimes referred to as "vendor lock-in") allows truck drivers to charge in numerous locations and not be confronted with different plugs, sockets, or payment contracts. Consistent, compatible hardware and software are also important for user comfort and safety while encouraging greater market competition, driving down prices. Moreover, shared standards and protocols for emerging technologies such as vehicle-to-grid (V2G) supports a more rapid pace of technological development and innovation (IRENA, 2019).[l]

Prerequisites for an interoperable, competitive, and efficient market include hardware standards on the connections between vehicles and chargers, as well as open standards and protocols on communication (such as through European interoperability protocols OCPP[li] and OCPI[lii]) between vehicles, charging hardware, and software operators. Early market developments for passenger electric vehicles have shown that regulations may also be needed to support roaming on the free exchange of data (Open Charge Alliance, 2020) (EVRoaming, 2018). California requires all charging stations to offer OCPI and allows for other additional billing standards (CARB, 2019b).[liii]

3.4 POWER SECTOR CHALLENGES

The electricity market is going to be significantly affected by the shift toward sustainable energy and the added demand from vehicle electrification. The national power supply (generation) will have to increase the amount of energy produced in order to fulfill the demand for electrified transportation (see Appendix 3.B for graphic). The power sector is also facing an enormous challenge to develop a greener energy mix on the grid, while meeting demands of a stable energy supply at a growing demand. Since solar and wind power are intermittent, it influences the stability of the energy supply and the grid balance. Transmission operators are capable of supplying the energy demand for the upcoming years without mayor changes to high-voltage networks.

According to a Rocky Mountain Institute study on U.S. fleet behavior (RMI, 2019),[liv] fleet operators prefer preference to use high power chargers to optimize the implementation of electric trucks. Combining this tendency with the growth of fleets vehicle numbers, peak effects of vehicle electrification on the grids will increase. The impact will be even bigger without smart charging, energy storage or other balancing technologies. A grid that is unable to handle these peak demands will slow down future growth. Therefore, load management (demand side response) will be critical for realizing peak shaving to prevent enormous investments in grid upgrades (see Appendix 3.C for a graphic on demand shifting).

The location of the power delivery and power demand is also crucial. Electric trucks will be charged mainly on commercial sites. These industrial locations are typically already equipped with medium-voltage grids, allowing systems operators to meet growing power demand at these sites in upcoming years. However, the energy demand from (multiple) high-powered chargers at a site can be so high that new medium-voltage connections with new transformers are needed. New power generators, such as wind and solar production sites, may also need transformer upgrades, causing an enormous workload on systems operators and potentially causing long delays in charging infrastructure projects. Combining increasing renewable supply and greater ZEFV demand on grid connections may optimize the workload and make the best use of investments. Systems operators could play an active role in planning and bringing the right parties together to anticipate load and demand growth and support power generators and fleet investment rollouts accordingly.

3.5 SMART CHARGING AND V2G

Enabling and standardizing “smart charging” and “bi-directional charging” (also known as vehicle-to-grid, or V2G) is important to preserve and support charging system operations as potential grid drains loom. For instance, the peak amount of energy needed to simultaneously charge many ZEFVs might exceed grid capacity or available supply. Even if overall supply and demand is balanced, peak supply of renewable energies on the grid will most often not coincide with peak vehicle charging demand, leading to imbalances and inefficiencies. Addressing these problems through grid upgrades may add additional costs and produce surplus energy that is not captured, whereas deducing shifting ZEFV charging schedules can efficiently capture power and potential reduce the total amount of power needed. This time-shifting practice is called “demand-shift” and is part of a broader suite of demand management practices titled “smart charging.” V2G goes a step further by using bi-directionally enabled charging stations that allow vehicles to deliver energy from the battery of the vehicle back to the grid or directly to other electric vehicles or buildings, lowering congestion on local grids and thereby preventing high investments in grid upgrades.

Utilities and grid operators have started to reward vehicle operators for being able to control charging times and speed as well as for supplying energy back onto the grid, helping smooth and balance loads while creating incentives for fleets to operate in a grid-efficient manner. Fleet operators interested in smart charging or V2G may prefer, or be required, to allow utilities or service operators to participate in fleet charging. Access to the charging infrastructure and availability of charging data are extremely important to enable electric utilities, authorities, and service providers to control the charging and preventing congestion on the grid.

3.6 HYDROGEN FUEL PRODUCTION AND INFRASTRUCTURE

FCEVs may help fleet operators avoid costly demand charges, reduce weight, and increase range. However, the FCEV market will require significant progress in hydrogen station installation and the production of low-carbon hydrogen itself.

The material costs of hydrogen stations typically exceeded $1.6 million in early California installations (CARB, 2019a).[lv] When adding labor and other soft costs, the "all-in" costs of a hydrogen station can often exceed $2 million-$3 million. These costs may exceed a high-powered corridor charging station by an order of magnitude, creating uncertainty in a market that is not mass-producing vehicles yet. The assessment of technologies and costs also predicts that station material costs will fall by at least 40 percent from the early market costs while also recommending financial support for expanding a hydrogen station network (CARB, 2019a).[lvi] These cost estimates are supported by other international hydrogen station projects, which may range between $1 million and $2 million in Europe and from $2.4 million to $3 million in Japan (Wards Auto, 2020).[lvii]

Hydrogen can be produced in many ways, but 'green' hydrogen is mainly produced with wind, solar and hydropower[lviii] energy through electrolysis (Hyundai, 2019). However, with the cost of producing 'green' hydrogen through electrolysis still being relatively high,[lix] fuel that is both readily available and highly affordable will not likely support early market growth. New forms of low-carbon[lx] hydrogen may be needed to reduce GHGs rapidly and support the development of a viable market (Muhammet et al., 2019) (Power Technology, 2020). With the growth of renewable energy, substantial amounts of surplus electricity may occur during the course of a year, causing very low (or even negative[lxi]) prices for energy and thereby improving the business case for dedicating surplus energy to inexpensive, green hydrogen production[lxii] (CLEW, 2020)[lxiii] (Ball & Weeda, 2016),[lxiv] supported by advancements in electrolysis technologies and hydrogen distribution networks. Current estimates for renewable energy production of hydrogen, which do vary somewhat, indicate that this practice is nearly always more expensive than hydrogen derived from fossil fuels, and in some cases may be up to nine times more expensive (EIA, 2019a).[lxv] The California Fuel Cell Partnership estimates that the dispensed cost of hydrogen produced by electrolysis is approximately $16/kilogram, which is approximately twice the cost that would be needed to achieve parity with the cost of fueling of gasoline- and diesel-powered trucks (based on California average prices). The study estimates that with continued learning improvements and increases in electricity availability and economies of scale, the dispensed cost of electrolysis-produced hydrogen could drop to $10 per kilogram by 2025 and $8 per kilogram by 2030 (CA Fuel Cell Partnership, 2020).[lxvi]

CHAPTER 4

POTENTIAL FOR BREAKTHROUGH AND DISRUPTIVE FREIGHT TECHNOLOGIES

Advancements in technologies and financing models may help rapidly overcome the challenges facing a sector-wide transition to ZEFVs. Developing breakthrough and disruptive technologies, such as autonomous vehicle operation and drones, have the potential to greatly improve efficiencies and reduce operating costs, making ZEFVs more financially viable. Innovative business models may also improve TCO by restructuring the higher upfront costs or by reducing risks to fleet operators.

4.1 AUTONOMOUS TRUCKS

As with passenger vehicles, autonomous driving for trucks will be implemented in phases. There are different levels of autonomy, where all stages up to and including Level 3 require some degree of driver engagement. At Level 4 the driver has no responsibility on certain roads (mostly highways), while Level 5 autonomy absolves driver responsibility on all roads and conditions and could remove the driver from the vehicle entirely. In the near future both partially autonomous truck platooning (Level 4) and fully automated driving (Level 5) may begin impacting freight efficiency as early as 2020 and 2025, respectively (EIA, 2018).[lxvii] Industry studies estimate that platooning and other eco-driving techniques enabled by autonomous technologies may reduce fuel consumption by as much as 10 percent (Schoettle & Sivak, 2017).[lxviii] Real-world efficiency will be impacted by vehicle size, speed, the space between vehicles, road and temperature conditions, and the platoon-able miles for a given vehicle or fleet.

The same studies also estimate that these technologies may reduce labor costs by as much as 20 percent because fewer drivers will be needed. The immediate financial gain for fleet operators could lead to severe economic uncertainty for large segments of the working population, however. In the United States, driving trucks is one of the largest industries and has shown resiliency amid uncertain financial times, growing faster than the broad economy over the past decade and employing millions of workers (U.S. Census, 2019).[lxix] Efficiency gains and lower labor costs may also have a human cost in the short term through worker displacement, though the concern over automation impacting job availability is shared by other industries (BBC, 2019).[lxx]

Various levels of autonomous driving are being tested by major truck OEMs, on public roads like highways, as well as for dedicated purposes like off-road use (mining) and in port areas. For the near future, autonomous yard trucks, truck-trailers for short transport on dedicated tracks, and maneuvering at terminals, private terrain and loading docks, offer potential for increasing transport efficiency. Pilot projects that are exploring these areas of improvement are underway in Shanghai[lxxi] and Thailand,[lxxii] with freight operator NFI in negotiations to begin testing autonomous yard truck applications in California (Robotics and Automation News, 2019) (Port Technology, 2020) (Transport Topics, 2020).[lxxiii] In parallel to autonomous driving, automated charging solutions are being developed, ranging from conductive and inductive solutions to robotizing plug charging.

4.2 DRONES AND OTHER AUTOMATED LOGISTICS SOLUTIONS

Vehicle manufacturers, technology companies and logistics providers are developing and experimenting with a broad range of robotization, automation and autonomous driving solutions to supplement advances on electric-drive powertrains, aiming at increasing the efficiency of transport and distribution.

Tailored logistics solutions might require fit-for-purpose vehicles with the capacity to power auxiliary systems for in-vehicle cargo handling and drones. For example, fully automated cargo loading and unloading of delivery trucks could shorten the turn-around time at logistics centers. Automated parcel handling could also be conducted inside the delivery vehicle to save handling time for the driver. Multiple drones and droids could deliver goods from a centrally located delivery truck, while the driver could focus on those deliveries that still require human handling. Whereas an integrated implementation of such solutions might take a while, some elements will likely be deployed sooner. For example, Amazon, Just Eat, Domino's and Valeo are developing droids that deliver parcels and food to households fully autonomously (see Appendix 4.A for examples of current autonomous freight innovations).

City regulations such as zero-emission zones, bans on internal combustion engine vehicles, curbside management, and road pricing might affect urban deliveries in cities. Heavy-duty trucks could transport cargo from regional distribution centers to city hubs, from where cargo could be distributed by smaller trucks or vans to its final destinations such as stores and households with the support of automated devices. This would enable retail and logistics companies to efficiently use shorter-range zero-emission vehicles with dedicated autonomous capabilities (like follow-me functionalities) for last-mile deliveries while the performance and cost of electric-drive technologies for larger vehicles improve.

Automated technologies could also become more predominant in ports, logistics and intermodal terminals depending on labor law issues. In addition to increasing order-picking automation within warehouses, autonomous vehicles that maximize logistics and energy efficiency can move cargo within terminals. This is in many ways easier to implement than city logistics because routes are predictable and charging stations for different vehicle types could be co-located. Software systems could optimize routes and charging times to minimize costs and equipment downtime.

Although 3D printing is still in its infancy and has had very little impact on cross-border trade, it could become a disruptive technology in specific niche markets. 3D printing could become an attractive manufacturing model for non-bulk products that require heavy assembly, that involve high labor costs, transportation, and inventory, or that create much waste. The most ambitious forecasts for 3D printing predict a reduction in global trade by 40 percent between 2040 and 2060 (ING, 2017).[lxxiv]

4.3 BATTERY BREAKTHROUGHS

Battery price and performance is a critical precursor on how affordable ZEFVs can become and how well they will meet increasingly rigorous duty cycles in larger vehicles with longer ranges. Investors in battery research and development include vehicle and battery manufacturers, governments, and academia. Though battery prices have fallen while performance has improved, continued technological breakthroughs may enable a rapid shift in TCO performance, making ZEFVs much more competitive against diesel trucks in the short term.

Projections for breakthrough technologies have recently been announced, but replication of projected or laboratory results have not been achieved in production volumes. If successful, examples like Tesla's[lxxv] or Toyota's[lxxvi] next-generation batteries could create immediate ZEFV price parity with diesel-powered trucks and ensure a long battery life for a ZEFV's most expensive component (Reuters, 2020) (Car and Driver, 2020). BYD claims that its newest Blade battery combines safe, extremely reliable performance with 50 percent more storage capacity (Sohu, 2020).[lxxvii] Nevertheless, Bloomberg New Energy Finance predicts that next-generation technologies such as solid-state batteries will not impact the market until the late 2020s or later (Bloomberg 2019).[lxxviii]

4.4 FINANCING MODELS

The higher upfront costs for ZEFVs and charging infrastructure act as a significant barrier to fleet electrification. In addition, lack of experience with ZEFVs, coupled with the current uncertainties around vehicle uptime, the lifetime of the drivetrain and battery and maintenance costs create significant investment risks for transport companies. Innovative financing models could help to address these challenges.

4.4.1 TRUCKS

Transport companies will welcome financial support and certainty when investing in a newer and more expensive technology such as ZEFVs. Alternative financing strategies will facilitate the uptake of these vehicles. Battery costs represent a significant portion of the vehicle purchase price and investment risk (as discussed in 2.3 "Technology Costs and Benefits"). One solution to reduce the financial risk for transport companies that is being tested with transit buses is the decoupling of battery and vehicle ownership through battery leasing or guaranteed second-life uses. Truck manufacturers may also choose to explore the opportunity for battery leasing to lower upfront costs and support ZEFV deployments, as transit bus manufacturers have attempted.

- Proterra currently offers a battery leasing option to transit agency customers (Proterra, 2020).[lxxix]
- Volvo offered a Bogota, Colombia transit agency a monthly payment plan for the bus batteries of a fleet of hybrid electric transit buses (Automotive World, 2013).[lxxx]

This financial model could also apply to the ownership and operation of the entire vehicle, not just the batteries. ZEFVs can be provided as a service that is paid for per use (in time, and/or in mileage), just as light-duty vehicles can be rented. Manufacturers or third parties would lease and manage the vehicles that are made available for rent or lease. This innovation makes ZEFV adoption simpler to manage and reduces the risk for transport organizations. Management companies, under this scenario, may financially support fleet adoption by taking on some risk and leasing or renting vehicles at a rate with projected residual value, rather than shifting a large depreciation to fleet operators through extensive lease or use payments.

Third-party ZEFV management has already gained some traction in China. A Shanghai logistics company executive points to a comprehensive service package that includes sourcing vehicles, goods management, networking platforms, and financial services as the future of ZEFV integration (Gaogong Electric, 2017).[lxxxi] A new collective integration "E-Logistics" model has emerged in China, where OEMs, logistics companies, leasing companies, and other cooperative operators build terminal programs, manage online payments, and track vehicle functions and performance to create a monitoring platform that integrates collected resources into a collaborative operation system (Sohu, 2016).[lxxxii]

4.4.2 CHARGING INFRASTRUCTURE AND GRID

Finding a second life for used batteries could reduce the up-front or depreciation costs of ZEFVs.[lxxxiii] The use of repurposed EV batteries as on-site distributed energy resources co-located with charging stations to avoid on-peak charging would lower costs for charging companies and energy users. On-site energy storage systems allow high power charging at more affordable off-peak rates by using the batteries as intermediaries to slowly charge (for example, during nighttime) and rapidly discharge electricity to ZEFVs. Battery systems may also store locally produced clean energy and may sell electricity back to the energy market during periods of peak demand, if the energy is not immediately needed for charging, smoothing charging patterns and lowering peak demand charges while also reducing transmission costs.[lxxxiv] Though the practice of used EV batteries as stationary storage is relatively new, Electrify America has installed 60 high-speed charging stations with new Tesla battery storage at approximately 60 EV charging stations,[lxxxv] demonstrating the real-world ZEFV applications for EV batteries that may be expanded to used EV batteries.

CHAPTER 5

EXISTING POLICIES, LIMITATIONS, AND POTENTIAL FURTHER DEVELOPMENT

Government support is critical to helping the early ZEFV market reach viability and compete against diesel-powered vehicles. Government interventions include:

- Vehicle regulations, which may provide varying levels of support, from fuel economy standards that reward ZEFV sales to requirements that explicitly require ZEFV sales;
- Financial incentives such as direct vehicle subsidies or vehicle vouchers, which have been implemented in leading Chinese, European, and North American markets; and
- Government investments in charging and fueling infrastructure, which will also help fleets lower their capital expenses and will support their operations.

These government efforts may be augmented by industry and non-profit initiatives that span regions and borders, creating a connected network of ZEFV supporters and policies.

5.1 VEHICLE AND FUEL REGULATIONS

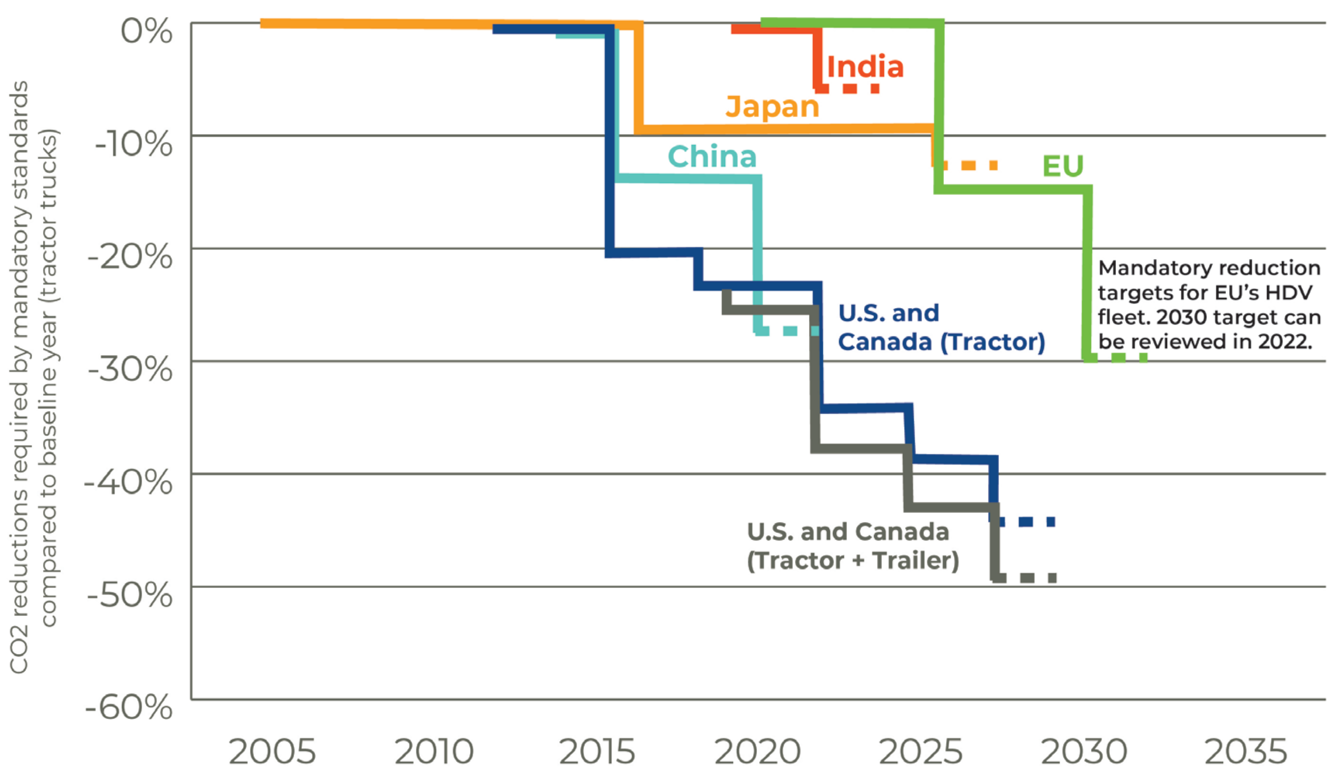
5.1.1 POLLUTANT EMISSIONS AND FUEL ECONOMY STANDARDS

Regulations on the amount of fuel consumed or pollutants emitted by each truck sold are a direct strategy to improving environmental outcomes. Such regulations are typically technology-neutral and allow manufacturers the option to use any technologies that meet the minimum (in the case of local pollutant standards) or average limits (in the case of fuel economy and GHG emissions standards). No such regulations require zero-emission technologies, even though ZEFVs can help manufacturers meet fleet-average limits, in particular with multiplier credits where ZEFVs count as more than one in the fleet average.

All major vehicle markets worldwide have regulations limiting emissions of local pollutants such as particulate matter and nitrogen oxides. The countries with the most stringent standards (i.e., equivalent to Euro VI standards) include the U.S., Canada, Europe and Japan, but major markets such as China, India, Mexico and Brazil have already adopted standards equivalent to Euro VI to be implemented in coming years (ICCT 2019b).[lxxxvi] Because such standards establish minimum emission limits for every vehicle produced, increasingly tighter limits increase the cost of emission after treatment systems, thus improving the relative cost parity of zero-emission technologies. Only the Euro VI standards provide an additional incentive for zero-emissions technologies (super-credits), which will reward manufacturers for up to twice the credit allocation of a diesel-powered vehicle through 2024 (ICCT, 2016).[lxxxvii] This system will be replaced by a benchmarking system through 2030.

China, the EU, the U.S., and Canada are among the only countries and regions with fuel economy or GHG emission regulations for MHDVs sold within their jurisdictions (see Figure 5.1) (ICCT, 2019c).[lxxxviii] Though these standards will require substantial technological and efficiency improvements, such regulations will only force zero-emissions technologies to the extent that their stringency is sufficient to require the additional investment. Some countries provide additional credits for zero-emissions technologies. For example, the U.S. Phase 2 standards for heavy-duty vehicles assign ZEVs a zero score for their total emissions (assuming no upstream emissions or fuel consumption).

Figure 5-1. National and regional MHDV fuel economy standard targets



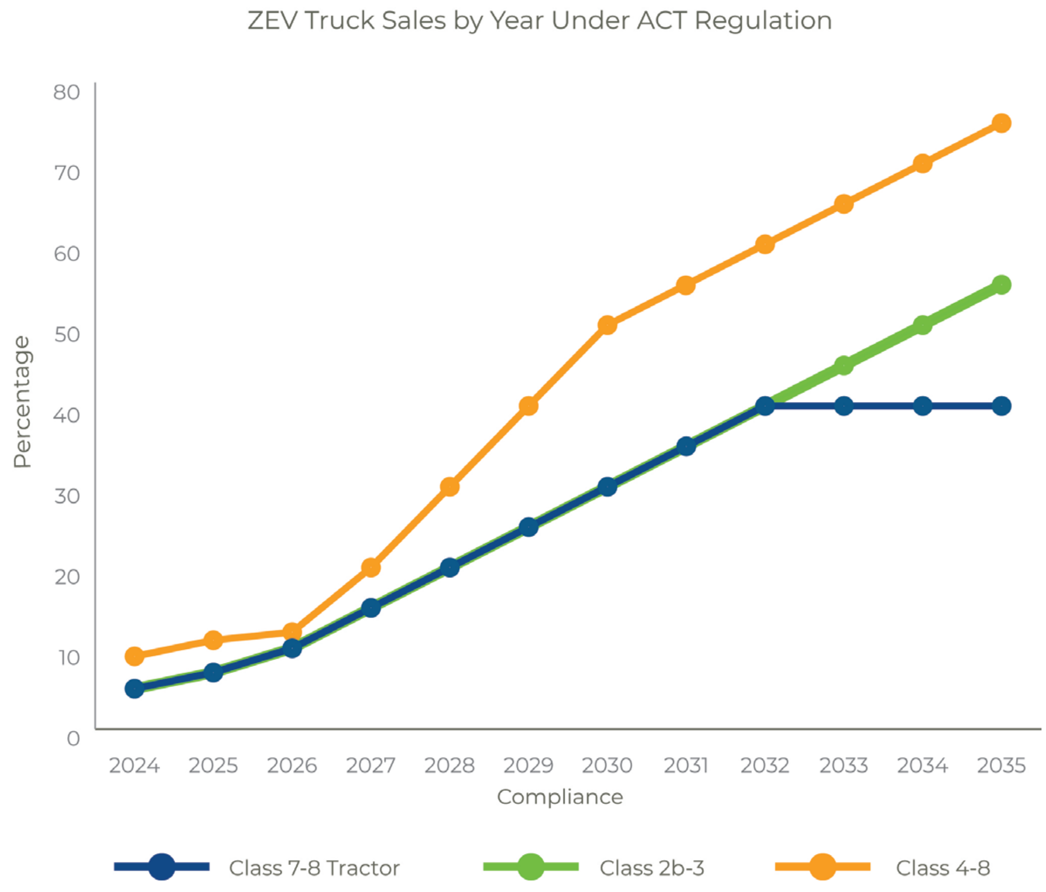
5.1.2 REGULATED SALES PROGRAMS

Programs that require ZEFV sales may logically be more effective at developing a ZEFV market. Canada, China, and the United States have demonstrated the concept by implementing light-duty ZEV sales requirements. California's program for light-duty ZEVs requires automakers to sell ZEVs as a rising percentage of total sales over time;[lxxxix] and has been adopted by 10 other U.S. states. The Chinese government adapted California's regulatory structure for its own ZEV program (CARB, 2020a), and the Canadian provinces of Québec (Environment Québec, 2020)[xc] and British Columbia (BC Clean Transport, 2020)[xci] both operate similarly structured programs. Additionally, the European Union oversees a voluntary program for ZEV manufacturers that count ZEV sales as offsets against future fuel economy obligations beginning in 2021. These programs all create incentives for vehicle manufacturers to produce and create market demand for ZEVs. Failure to generate enough credits through ZEV sales (or in the EU, to meet fuel economy improvement targets) will result in a financial penalty for non-compliant manufacturers.

California's Advanced Clean Truck (ACT) rule builds upon the success of light-duty ZEV programs by applying sales requirements to MHD ZEFV manufacturers. The program design reflects the purpose stated within the regulation: "to accelerate the market for on-road zero-emission vehicles and to reduce emissions of oxides of nitrogen (NOx), fine particulate matter (PM), other air pollutants, toxic air contaminants, and greenhouse gases (GHG) from medium- and heavy-duty on-road vehicles" (CARB, 2020b).[xcii]

ZEFV sales are categorized within three distinct on-road vehicle classes and types, for which vehicle manufacturers must generate sufficient credits to meet regulation for each model year (Figure 5.2).

Figure 5-2. Share of ZEV truck sales in California required through 2035



The ACT rule sets a clear zero-emission market signal for vehicle manufacturers in the California market.

Sales of Class 4-8 trucks must rise from 9 percent when regulations begin in 2024 to 75 percent by 2035, which constitutes an eight-fold increase in ZEFV sales within 11 years. Manufacturers have established ZEFV targets to meet and must expand their production capacities and sales strategies to comply with the ACT rules.

The California Air Resources Board (CARB), which oversees the ACT rule, provides guidance and flexibilities for manufacturers and fleets. CARB identifies truck operations that "operate in urban centers, have stop and go driving cycles, and are centrally maintained and fueled" as the most opportune early ZEFV adopters (CARB, 2020c).[xciii] Manufacturers can focus their initial sales efforts on fleets with the geographic and operational characteristics that CARB recommends. Fleets and manufacturers are also provided technological flexibility under the ACT rule with provisions for Near Zero Emissions Vehicles (NZEVs). CARB defines NZEVs as hybrid-electric vehicles that can be charged from external sources, such as plugs or inductive charging. NZEV sales may generate credits based on their battery ranges, up to 0.75 of a full ZEV credit, up to model year 2035.

5.1.3 OTHER REGULATIONS

In addition to the vehicle technology-forcing regulations mentioned above, other policies can accelerate zero-emissions technologies by limiting number of vehicles sold, controlling vehicle access, and reducing the carbon content of fuels.

- **Vehicle Registration Limits and Exemptions**: In areas with high levels of pollution and congestion, cities have restricted new vehicle license plate registrations, thereby limiting the number of polluting vehicles on roads. Old vehicles may be able to transfer plates to new vehicles, encouraging the uptake of new, cleaner vehicles. Prioritizing or waiving limits on ZEFVs creates a strong incentive for fleets to adopt ZEFVs for immediate deployment. These practices have been particularly effective in China, where the cities of Beijing and Shanghai restrict new vehicle registrations through a lottery or auction while exempting new energy vehicles that include ZEFVs.
- **Controlled Access Zones**: As the mileage that vehicles travel increases in many nations, the health impacts of on-road vehicle emissions are better understood, and pedestrians aim to reclaim public roadways to make cities more livable, local governments are considering excluding all vehicles that produce air pollution that exceed a given threshold from operating in the most populated or polluted parts of cities. Allowing exceptions for ZEFVs may permit cities to meet congestion goals while allowing for clean transportation and goods deliveries by reducing vehicle diesel-powered miles traveled and prioritizing ZEVs. These zones may be applied at any level from on- or off-road freight facilities to city centers and up to national access. Thresholds for vehicle emissions may range from low-emission zones, which allow a restricted level of emissions and charge non-compliant vehicle operators, to zero-emission zones. Early actions indicate that these programs may be having an impact on vehicle purchasing and operating decisions.
  - In London's Ultra Low Emission Zone, delivery companies have experimented with hybridized technologies that switch their vehicles to electric-only mode when operating within the regulated area.
  - In Chinese cities with restrictions on new vehicle registrations, fleet management companies have invested in ZEFVs to rent out to fleets that are meeting zero-emission delivery goals.
  - Oslo, Norway, has restricted parking availability in its city center, leading logistics company

DB Schenker to develop a new freight hub that completes last-mile deliveries by battery-electric vans and cargo bikes (CALSTART, 2020d).[xciv]

- **Low Carbon Fuel Standard or Renewable Fuel Standard**: These regulations may work in different ways – a low-carbon fuel standard (LCFS) creates a cap on carbon intensity and credits low-carbon fuels production below that cap, whereas a renewable fuel standard identifies low-carbon fuels and establishes a volumetric requirement for their use – but they both create incentives to produce low-carbon fuels. Generators and refiners of renewable natural gas, electricity, and low-carbon biofuels used for transportation earn credits for producing or selling their fuels, making low-carbon fuels less expensive and more abundant. These savings can be passed along to fleets, to reduce their fuel costs. The California Air Resources Board has estimated that all-electric transit buses can generate enough credits to reduce fuel costs to $7,000 annually, saving more than 50 percent on electricity costs without the LCFS and more than 70 percent on annual diesel costs.[xcv]
- **Infrastructure Directives**: To support the uptake of clean vehicles, governments can require and set targets for the development of alternative fuels infrastructures, such as public recharging points and hydrogen filling stations. As an example, the European Commission has instituted the Alternative Fuels Infrastructure Directive (AFID 2014/94/EU)[xcvi] that requires EU Member States to develop national policy frameworks. Each nation must plan for market development of alternative fuels and related infrastructure while supporting the development of common technical specifications for recharging and refueling stations.
- **Vehicle Weight Exemptions**: Batteries add weight to ZEFVs relative to diesel-powered vehicles. Added weight can incur financial penalties for exceeding maximums within a particular class or for pressure on each axle, creating a perverse incentive for fleets to avoid ZEFV adoption. Fleet operators may be forced to choose between paying penalties or reducing cargo, creating a financial loss in either scenario. Exemptions for ZEFVs' maximum gross vehicle weight and maximum axle pressure can mitigate the impacts of heavier ZEFV vehicle operations and support the transition to zero-emission trucking. The California legislature has enacted such an exemption, allowing alternative fuel vehicles (including zero-emissions technologies) a 2,000-pound exemption to vehicle class weight limits (U.S. Dept. of Energy, 2020).[xcvii] The European Union has implemented a 2t exemption for ZEV technologies to exceed class limits,[xcviii] though interpretations of current regulations may not permit any truck to exceed 40t regardless of drivetrain type (Publications Office of the E.U., 2019) (Transport and Environment, 2020).[xcix]
- **Fleet Purchase Requirements**: Municipal fleets operate a range of different ZEFVs, from smaller work trucks to heavy-duty sanitation trucks. These vehicles typically operate in residential areas that are vulnerable to diesel pollutants. Cities are positioned to positively impact their residents and meet their GHG reduction goals by requiring their agencies to purchase ZECVs. The two largest cities in the United States have both issued requirements for their municipal fleets to transition to ZECVs, creating strong market signals for vehicle manufacturers and enabling smaller cities to follow with their own ZECV purchases or procurement requirements. The European Union's Clean Vehicle Directive aggregates municipal purchases to national levels and establishes procurement targets for each member state. This process of aggregating municipal purchases provides member states with flexibility for how to efficiently allocate procurements between fleets (European Commission, 2020).[c]

5.2 FINANCIAL INCENTIVES

One of the most direct methods of promoting ZEFVs is creating a financial incentive that makes manufacturing, owning, or fueling less expensive. Reducing the up-front cost of a ZEFV, which typically costs more than an internal combustion engine vehicle, has been used in some of the regions with the highest rates of ZEFV adoption. In addition to reducing the cost of a vehicle, financial incentives may include differentiated fee structures for accessing roadways or regions, improved prices for fuels and infrastructure, and large-scale investments in battery production or purchases.

- **Fleet-Friendly Purchase Incentives**: Vouchers and direct subsidies allow fleet operators to earn point-of-purchase savings on ZEFVs. These programs are typically preferable to tax credits or rebates because they don't require fleets to provide a capital outlay and they provide accessibility to a greater number of fleets (CALSTART 2019).[ci] Zero-emission trucks have been eligible for up to $15,000 in China through direct subsidies (ICCT, 2020)[cii] and up to $150,000 in New York state (NYSERDA, 2020)[ciii] and California (CALSTART, 2020c)[civ] through vouchers that pay most of the incremental cost between on-road ZEVs and diesel-powered vehicle purchase costs. CARB provides vouchers worth up to $200,000 for off-road ZEFVs through the CORE[cv] program (CARB, 2020d) (CORE, 2020). China's direct subsidies are standardized as a purchase price reduction valued per kWh of battery capacity, with a cap set around ¥2 million. Additional examples of standard purchase incentives are found in Table 5.1.
- **Access or Use Fee Exemptions**: Access or use fees place a price on diesel-powered vehicles that operate within a particular area, functionally requiring fleets to pay for their diesel emissions. These fees are similar to congestion fee prices, but are differentiated by their intent to reduce air pollutant or GHG emissions rather than vehicle traffic. In a more targeted manner, fees for accessing roads or restricted areas (such as city centers or port facilities) can create a strong market signal for fleets to switch to ZEFVs. The Swiss government charges an annual use fee for diesel-powered freight trucks to use its roads with exemptions for ZEFVs; retailers in Switzerland are adopting a program of hydrogen fuel cell trucks to reduce costs and increase performance. The Ports of Los Angeles and Long Beach have created a ZEFV-exempt access fee[cvi] that may rise over time, making ZEFVs more financially advantageous with each use (Port of Long Beach & LA, 2017).
- **Direct Technology Investments**: Batteries are typically the most expensive component of a ZEFV and represent the highest cost of adopting the new technologies. Governments can reduce the costs of battery production, thereby reducing the costs to fleets of purchasing ZEFVs and their batteries, by providing incentives for battery production or the purchase of vehicles with domestically-produced batteries. The Chinese government supported the early growth of the Chinese battery production market by exclusively subsidizing vehicles that use domestically-produced batteries (this program has since been eliminated) (Reuters, 2019).[cvii] The U.S. state of Nevada provided tax incentives for Tesla to manufacture batteries in its state,[cviii] which enabled the automaker to more cost-effectively produce batteries (Scientific American, 2014). The European Investment Bank (EIB) approved a $350 million loan agreement to support the financing of Europe's first home-grown gigafactory for lithium-ion battery cells, Northvolt Ett, in Sweden (EIB, 2020).[cix] The European Fund supports the financing for Strategic Investments (EFSI), the main pillar of the Investment Plan for Europe.
- **Direct Project Investments**: Early market projects may not be cost-effective due to economies of scale and expensive new technologies, but they are valuable for proving the technologies and refining project operations. Governments can support these early pilot projects with direct investments. The Dutch government supports dozens of living labs that are each exploring novel

strategies and technologies for zero-emission vehicle deployments, such as its DKTI vehicle subsidy targeted at near- or zero-emission MHDVs (Netherlands Enterprise Agency, 2020).[cx] The state of California strategically invests cap- and-trade proceeds from the power sector to support the growth of a clean vehicle economy that reduces GHGs and helped demonstrate that ZEFVs are viable enough to enact the ACT regulation.

Table 5-1. Examples of vehicle purchase incentives

GEOGRAPHY	DESCRIPTION
Germany (Federal Government)	2018: Federal subsidy scheme for electric trucks in Germany. Grants ranging from €12,000 to €40,000 depending on the trucks' weight. 2020: Federal government doubles electric vehicle subsidies, no more diesel support. Private and municipal operators will receive €1.2 billion through a bus and truck fleet modernization program to switch to alternative.
The Netherlands (Amsterdam / County of Gelderland)	2019: City of Amsterdam subsidies for electric commercial vehicles. 20% subsidy for electric trucks of the purchase value (up to a maximum of €40,000). 2019: County of Gelderland subsidizes delivery vans and trucks. Companies receive a subsidy of €4,000 for the purchase or lease of an electric delivery van or electric truck.
Spain (Federal Government)	2019: Federal government subsidizes electric mobility with €45 million, up to €15,000 subsidy for eTrucks.
United Kingdom (Federal Government)	2012: United Kingdom extends electric vehicle subsidies (Plug-In Van Grant). Up to 20,000 pounds sterling subsidy for large vans and trucks extended until 2023.
France (Federal Government / Province Ile-de-France)	2017: Province Ile-de-France provides €9000 subsidy for electric trucks in the 3.5 – 7.5t weight range. 2020: French government subsidy up to € 7000 for the purchase of electric trucks.
Italy (Federal Government)	2019: Ministry for Sustainable Transport approves €25 million incentives for clean trucks. Subsidies of up to €20,000 for the purchase of green trucks and semi trailers.
Poland (Federal Government)	2020: Subsidized purchase of alternative fuel trucks. Companies will receive a subsidy up to €45,000 for both medium- and heavy-duty trucks with alternative drivelines.

GEOGRAPHY	DESCRIPTION
China (Federal Government and Localities)	2020: Four ministries and commissions issued the "Notice on Improving the Promotion and Application of Financial Subsidy Policies for New Energy Vehicles." As urban logistics distribution vehicles, the subsidy standard will not decline in 2020. In 2021-2022, the subsidy standards are reduced by 10% and 20%, respectively, from the previous year. China's direct subsidies are standardized as a purchase price reduction valued per kWh of battery capacity, with a cap set around ¥2 million. Local governments often enhance the kWh subsidy rate by an established percentage.
Canada (Ontario, Québec, and British Columbia provinces)	2017: The Ontario government launched a program to fund up to CA$150,000 of the incremental cost from diesel equivalent trucks for ZEFVs (funding not currently available) (Ontario Ministry of Transportation, 2018).[cxi] 2017: The Québec government established the Écocamionnage program for eligible commercial freight vehicles. The program offers operators 50 percent off the incremental price of a new BEV or PHEV truck up to CA$75,000 (Québec Transportation, 2020).[cxii] 2020: The Fraser Basin Council Society's CleanBC program provides up to CA$50,000 for ZEFVs and other qualifying vehicles for individuals and businesses (Plug-in BC, 2020).[cxiii]
United States (California and New York)	2020: CARB launched the CORE program to fund the incremental cost of qualifying off-road vehicles. This program is based off the innovative HVIP program that provides point-of-sale vouchers for the purchase or lease of qualifying commercial vehicle technologies. The maximum voucher amount for these programs is $200,000 and $150,000, respectively. 2020: The New York State Energy Research & Development Authority runs the NYTVIP program that follows the same voucher design as HVIP, but has been restructured for New York's distinct needs. This program also offers a maximum voucher amount of $150,000.

5.3 INFRASTRUCTURE AND INDUSTRY INVESTMENTS

Infrastructure availability is a critically important component to making ZEFV operations easier and will require separate investments apart from public (light-duty) stations to meet the large energy needs of electrified fleets, most notably at large charging depots, at high-speed charging stations built along travel corridors, or at hydrogen stations. Electric utilities and systems operators should be strong partners in the effort to expand ZEFV charging access because they are already involved in preparing electric grids for load growth and spikes, they benefit from increased load or downward pressure on rates, and in some cases may be able to make direct investments in infrastructure and vehicles. Industry actors are also helping to create a more opportune ZEFV ecosystem by investing directly in high-speed charging stations, charging hubs, and hydrogen stations.

- **Government Infrastructure Investments**: Direct investments may support a variety of ZEFV use cases. Corridor charging may benefit vehicles with longer ranges and less predictable routes; hub charging may benefit vehicles with predictable, urban routes that do not have access to or cannot afford to wait and charge when idle; and depot charging may benefit vehicles with predictable routes and parking behaviors that can charge for longer periods of time. In Shenzhen, China, transit operators demonstrated a best charging practice by installing extra depot charging power capacity for its all-electric fleet, allowing its vehicles to charge regularly without incurring high demand charges. The United Kingdom's Department for Transport is working with local and private stakeholders to identify ways to improve charging access and hydrogen station installations in towns and localities across the nation. The government will provide 500 million pounds sterling to support installations through 2025, including funding for Rapid Charge (UK Department for Business, Energy and Industrial Strategy, 2020).[cxiv] The state of New York has support ZEFVs and other charging applications through its EVolveNY program that invests $250 million in targeted high-speed corridor charging projects (NYPA, 2020).[cxv]
- **Utility Investments**: Electric utilities are knowledgeable industry partners with an interest in expanding ZEFV uptake; however, they may be restricted from participating in charging markets due to regulations on competition or how utility funds can be invested. If states or utility commissions see a need for electric utilities to fill in charging infrastructure gaps and to participate in competitive charging markets, utilities may provide ZEFV charging at a large and rapid scale. California's SB 350 directed electric utilities to propose electric vehicle charging investments, which has led to more than $1 billion in proposed activities to help accelerate the state's charging market. As a direct result, Southern California Edison's has proposed to spend more than $300 million to install truck and bus charging stations at sites within its service territory within the next five years (GTM, 2020).[cxvi] More broadly along the U.S. West Coast, a coalition of utilities known as The West Coast Transit Corridor Initiative has mapped out promising sites for MHDV ZEV high-speed charging and has proposed investments totaling $850 million over the next decade (San Diego Union Tribune, 2020).[cxvii] In Canada, the Québec National Assembly authorized utility Hydro-Québec to use new revenues to invest in public charging infrastructure. The utility's charging network, the Electric Circuit, is aiming to install 1,600 fast-charging stations by 2029 (Hydro-Québec, 2019).[cxviii]
- **Industry Investments**: Automakers, charging service providers, or other stakeholders may look to concurrently develop the light-duty and commercial electric vehicle market by developing high-speed charging infrastructure, typically in excess of 100 kilowatts. Industry investments in high-visibility charging locations can create greater confidence in the technology and the availability of charging for light-duty customers, and the higher wattage will allow ZEFVs to use these stations as opportunity chargers. Ionity and Electrify America are building out high-speed corridor charging networks in Europe and the United States, respectively. In Switzerland, automakers including Hyundai, Nikola, and Toyota are investing in a network of hydrogen fueling stations[cxix] to support the fuel cell trucks that will complete deliveries for several of the nation's largest retailers (Trucks, 2019).

5.4 REGIONAL AND MULTI-COUNTRY INITIATIVES

The combined efforts of government and industry to promote ZEFVs are being supported across regional and national boundaries by a growing number of initiatives that help create a more unified momentum toward ZEFV uptake.

Table 5-2. Multi-national initiatives that impact international ZEFV uptake

GROUP NAME	GROUP LEADER	FOCUS	GOAL	NOTABLE PARTICIPANTS
ZEV Alliance	ICCT (Secretariat)	Government	Overcome any barriers, achieve ZEV deployment targets, and continue to increase ZEV adoption to meet climate change goals by acting together, sharing experiences and best ideas.	National, state, and provincial governments in Europe and North America
Global Commercial Vehicle Drive to Zero	CALSTART	Government; fleets; OEMs	Accelerate the growth of ZEV technologies by developing partnerships of governments and industry to create initial successful ZEV applications	Canadian Government; Global coalition of city and state / provincial governments, electric utilities, fleets, OEMs
EV100	The Climate Group	Fleets	Organize commercial fleets around the world to commit to purchasing zero-emission fleet vehicles	Ikea, DHL, Heathrow Airport, DB Schenker, Unilever
Electric Vehicle Initiative	Clean Energy Ministerial	Government (national)	Bolstering supportive policies, mobilizing action, and accelerating geographical coverage of ZEV mobility	National governments of Canada, France, Japan, Norway, Chile, Germany, the Netherlands, Sweden, China, India, New Zealand, United Kingdom, and Finland
ZE Freight Vehicle Action Group	Transportat-ion Decarb-onization Alliance and CALSTART	Government; fleets; OEMs	Support the creation of a mass market for ZEFV by increasing their global demand through commitments made by governments, cities and private companies	Combined coalitions of international industry and government partners

GROUP NAME	GROUP LEADER	FOCUS	GOAL	NOTABLE PARTICIPANTS
Green and Healthy Streets Members	C40 Cities	Government (cities)	Transition to ZEV transit buses by 2025 and major area of a city is zero-emission by 2030	More than 20 major North American and European cities with populations exceeding 30 million people
Corporate Electric Vehicle Alliance	Ceres	Fleets	Set corporate targets and aggregate demand for ZEVs by sharing information and adopting supportive policies	Amazon, Exelon, DHL, Ikea, Edison International, National Grid, American Airlines
Multi-State Memorandum of Understanding ZEV Initiative (NESCAUM, 2020).[cxx]	NESCAUM	Government (states)	Ensure that 100% of all new MHDV sales be ZEVs by 2050 with an interim target of 30% ZEV sales by 2030.	States of California, Connecticut, Colorado, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington (and District of Columbia)

The scale of international efforts shown in Table 5.2 demonstrates the interest and investment in the growing ZEFV market. These initiatives will harness the policy and industry potential of some of the world's largest governments and fleets. With major OEMs and ZEFV startups diversifying and expanding their lineups to meet expected zero-emission growth, ZEFV demand should meet an increasing supply.

CHAPTER 6

RECOMMENDATIONS FOR MOVING ZEFVS TO WIDE-SCALE COMMERCIALIZATION

Consistent with CALSTART's Drive to Zero theory of change, accelerating the commercialization of ZEFVs relies on (1) a commercialization strategy that targets vehicle and infrastructure deployment in first-success segments where zero-emission technologies are most readily available, (2) building eco-systems of supportive policies and incentives, and (3) aligning deployment and ecosystems across leading markets. This will enable the ZEFV market to reach economies of scale faster as technologies implemented in earlier applications can be transferred to other on-road, off-road, and marine sectors as components mature, volumes grow, and costs decrease.

6.1 COMMERCIALIZATION STRATEGY

Drive to Zero's theory of change is to target first-success applications where zero-emissions technologies work today. Because multiple vehicle platforms and applications use similar components, such as powertrains, batteries, and power electronics technology, progress in first-success applications will lead to further technology development and transfer to other on-road, off-road, and marine sectors as components mature, volumes grow, and costs decrease.

As illustrated in Figure 2.1, the beachhead model of vehicle innovation establishes zero-emission transit buses as the earliest technological foothold. While relatively small in initial production volumes, they form the basis for a successful first market where core component technologies and architecture take place. Fuel cell electric buses use the same electric powertrain as a battery-electric bus, which itself is built on the hybrid transit bus architecture, and over time expanded the use of core electric drive components. The development of these components has had wider applicability than initially expected, and has now led to several other applications in different stages of development including battery-electric shuttle and school buses, battery-electric delivery vans, and fuel cell electric buses. As component volumes increase and technology improves, secondary markets will develop including battery-electric medium- and heavy-duty delivery trucks (sometimes operating with plug-in range extender systems) and battery-electric yard hostlers. Eventually these innovations will lay the foundation to yet more applications with higher distance and payload requirements, including electric and hydrogen fuel cell drayage trucks and regional heavy-duty trucks.

However, rapid ZEFV deployment will only happen if existing barriers – higher upfront cost, lack of model availability, enabling policies, infrastructure, and fleet awareness – are tackled through supportive ecosystems of aligned policies and incentives.

6.2 ECOSYSTEMS OF SUPPORTIVE POLICIES AND INCENTIVES

Governments play an important role in developing new technologies by establishing and enforcing supportive policies and incentives. It is already evident that the markets with the largest numbers of ZEFVs already deployed are those with the strongest ecosystems including instruments such as regulated sales targets, vehicle purchase incentives, infrastructure investments, congestion pricing, preferred access or exclusion lanes and zones, and procurement requirements. China leads the world in ZEFV registrations, driven by tight restrictions on new petroleum-powered vehicle registrations and robust financial incentives that have supported the rapid growth of ZEFV manufacturing and made vehicles more affordable. These policies have been effective for the Chinese market, but other policies and actions may be more effective or appropriate for other markets and jurisdictions. Achieving 100 percent ZEFV deployments in a region or nation will likely need a combination of market-enabling policies that help fleets and manufacturers develop and adopt new clean vehicle technologies, regulations that require ZEFV adoption over time, and support to hasten targeted infrastructure investments and clean energy to power the vehicles and stations. Governments can set decisive targets that create strong market signals for fleets and manufacturers to adjust their operations and plan for a transition to ZEFVs.

This section includes recommendations for ZEFVs and associated infrastructure with the appropriate level of policy support, from city (including city centers, ports, and other freight hubs) and regional (including states or provinces) to national or multi-national efforts. Electric utility opportunities are also identified.

6.2.1. VEHICLE POLICY AND INCENTIVE RECOMMENDATIONS

ADOPT ZEFV SALES REGULATIONS (REGIONAL, NATIONAL, MULTI-NATIONAL)

Requirements for truck makers to sell ZEFVs as a percentage of total vehicle sales will lead directly to higher ZEFV sales in a regulated market. OEMs will be impelled to innovate and create vehicles that operate efficiently and meet fleet needs and will prioritize manufacturing and sales in markets with vehicle regulations. This effect can be seen in higher model availability in U.S. markets that follow the light-duty California ZEV program. As with any regulation, the robustness of vehicle regulations may depend upon enforcement and setting a strong market signal. The only adopted ZEFV sales requirement currently adopted is the California ACT rule. The Chinese government adapted California's light-duty ZEV sales regulations for its own passenger vehicle market, requiring average manufacturer fleet sales of new energy vehicles to reach 4 percent of total vehicle sales by 2020 (IEA, 2019).[cxxi]

ADOPT FLEET PURCHASE REQUIREMENTS THAT MIRROR REGULATED SALES TARGETS (CITY, REGIONAL, NATIONAL, MULTI-NATIONAL)

Because zero-emission technologies for medium- and heavy-duty applications are relatively new and production volumes are still too small to enable cost parity with internal combustion engine technologies, fleet purchase requirements send strong signals to OEMs that there will be demand for ZEFVs. Fleet rules should have timelines consistent with sales requirements for OEMs. The European Union's Clean Vehicle Directive is an example of a fleet purchase requirement that provides clear targets over time while providing some flexibility for regulated parties (European Commission, 2020b).[cxxii]

PROVIDE VEHICLE PURCHASE INCENTIVES (REGIONAL, NATIONAL, MULTI-NATIONAL, ELECTRIC UTILITY)

Reducing the costs of purchasing or leasing a ZEFV is critical to influencing fleet managers to justify the investment in a new technology. Even the largest fleets may not have the capital to purchase ZEFVs despite the long-term savings on fuels and operations, and some publicly operated fleets may not be eligible for tax credits. Voucher programs and direct manufacturer subsidies are two examples of fleet-friendly vehicle purchase incentives. California's HVIP voucher program was developed in collaboration with fleets and manufacturers and makes the process of reducing vehicle purchase or lease costs more effective. China's government provides direct subsidies to manufacturers that domestically sell their vehicles. Both programs provide point-of-sale reductions in vehicle costs that have enabled ZEFV adoption in these, two of the world's largest markets. Incentives are typically scalable to conform to market conditions; both the California[cxxiii] and China[cxxiv] incentive programs have been reduced for specific technologies that are deemed approaching market-ready (Reuters, 2020). The goal of these programs is to create industry investments that develop a viable early vehicle market that can sustain itself without ongoing incentives.

IMPLEMENT ACCESS RESTRICTIONS TO INTERNAL COMBUSTION ENGINE TECHNOLOGIES (CITY, NATIONAL)

Limiting or banning the use of diesel-powered vehicles in densely populated areas helps to reduce exposure to harmful pollutants, creates a strong incentive for vehicle operators to adopt ZEFVs, and sends strong signals to OEMs to invest and scale up ZEFV manufacturing. Early actions indicate that these programs may be having an impact on vehicle purchase and operating decisions. In London's Ultra Low Emission Zone, delivery companies have experimented with hybridized technologies that switch their vehicles to electric-only mode when operating within the regulated area. In Chinese cities with restrictions on new vehicle registrations, fleet management companies have invested in ZEFVs to rent out to fleets that are meeting zero-emission delivery goals. Beijing recently restricted access to delivery vehicles less than 4.5t, setting a ZEFV target of 90 percent of all qualifying vehicles that enter the Fifth Ring Road (Baidu, 2019).[cxxv]

ADOPT FUEL AND ROAD PRICING (CITY, REGIONAL, NATIONAL, MULTI-NATIONAL)

Adequately pricing fossil fuels to incorporate environmental externalities while reducing or waiving fees on zero-emission technologies can help ZEFVs achieve cost parity sooner. In addition to increasing fossil fuel taxes, a carbon tax or a cap-and-trade system would provide the greatest economy-wide approach to reducing emissions, but they may be politically infeasible. In a more targeted manner, fees for accessing roads or restricted areas (such as city centers or port facilities) can create a strong market signal for fleets to switch to ZEFVs. For example, the annual Swiss road tax has been set at a high enough level that a coalition of large Swiss retailers are heavily investing in hydrogen trucks. The Ports of Los Angeles and Long Beach have created a ZEFV-exempt access fee that may rise over time, making ZEFVs more financially advantageous with each use (Port of Los Angeles, 2018).[cxxvi]

ENSURE ADEQUATE VEHICLE SEGMENTATION IN POLICIES AND INCENTIVES (CITY, REGIONAL, NATIONAL)

As previously mentioned, some applications are better suited for near-term implementation of zero-emission technologies in freight vehicles, in particular urban applications where vehicles travel along relatively short distances over known routes and return to the depots for charging overnight. As a result, the ecosystem of policies and incentives should adequately segment vehicles in such a way that ZEFV implementation is phased based on technology readiness for given technology platforms and duty cycles. This enables those applications for which zero-emission technologies are most readily available to have more ambitious targets sooner while technology improves for those with more demanding payloads and duty cycles. For instance, smaller zero-emission (and sometimes autonomous) vehicles are ready and currently meeting intra-city delivery demands. Policies that promote ZEFV deliveries in the short term would allow smaller ZEFVs to fill urban niches as ZEFV technology matures to meet more rigorous duty cycles.

6.2.2 INFRASTRUCTURE RECOMMENDATIONS

Infrastructure is commonly being recognized as a growing and sometimes leading barrier to ZEFV deployment. The recommendations below are intended to resolve the challenges described in Chapter 3 and provide an actionable policy agenda to expand charging and fueling infrastructure in a strategic manner.

INTRODUCE REGULATIONS OR PROGRAMS TO SUPPORT CHARGING AVAILABILITY AND INTEROPERABILITY

A national or international program could establish the minimum available public charging infrastructure for adequate charging accessibility. An accompanying regulation to set charging standards would support the smooth expansion of interoperable charging infrastructure. Efforts are underway to catalog current standards and establish collective standards, such as through OECD forums (ITF, 2020).[cxxvii]

Programs and regulations that require interoperable charging infrastructure deployments should address at minimum:

- Defined standards for AC and DC connections between charging stations and vehicles;
- Communication protocols to allow for open data accessibility, including station availability, pricing, payment, and roaming;
- A range of smart charging practices that electric utilities and charging service providers can use to manage load; and
- Binding targets for charging infrastructure to identify and enforce adequate charging coverage, which could be benchmarked against any pertinent vehicle sales regulations.

The program to require infrastructure investments may place the regulatory burden on manufacturers, but governments could provide some degree of financial support for station installations. To ensure that the stations are located in high-use areas of need, regional stakeholder networks could be established to identify common travel and freight corridors. Regional stakeholder infrastructure networks have recent precedent – the U.S.-based West Coast Collaborative convened an Alternative Fuel Infrastructure Corridor Coalition to develop an alternative fuel MHDV investment strategy (CALSTART, 2020e).[cxxviii]

CREATE A REGULATORY BASIS TO WORK TOGETHER FOR BETTER EFFICIENCY IN ENERGY GRID UPGRADES

Electric utility interconnections and grid upgrades to accommodate ZEFV deployments will become major investments over time. Absorbing grid upgrades for freight and heavy-duty transportation into planned investments may be a cost-effective strategy for updating electric grids. Strategic reviews and incorporation of planned industrial, building, and energy generation sites to likely high-use freight corridors would allow for an efficient, system-wide process of modernizing utility-grade electric infrastructure. Electric utilities will reduce costs with a coordinated investment strategy, and targeted investments along freight routes will reduce any behind-the-meter upgrade costs that may fall to ZEFV fleet operators. Systems operators and utility commissions may be able to provide early support to manage and forecast load growth.

INTRODUCE INCENTIVES THAT STIMULATE SMART CHARGING SOLUTIONS

Managed charging programs support grid efficiency and create positive financial outcomes for fleets. Programs that offer lower rates for charging during times that avoid peak energy usage are currently offered by some regions or electric utilities, but ZEFV fleet managers may need heightened incentives to adjust their operating schedules. Governments could stimulate solutions that prevent high load peaks and congestion on the grid by introducing or raising incentives for smart charging and load balancing solutions.

Some fleets must maintain continuous operations and may not be able to shift their loads by time of day. Smart charging may also make use of technological solutions, such as co-siting with renewable energy production or energy storage that provide dedicated energy streams while reducing grid impacts. These technologies typically add significant capital costs that may inhibit investments. Incentives that reduce the costs of new clean or managed charging technologies will help improve grid performance and make charging more affordable for ZEFV operators. California utility Pacific Gas and Electric has developed a commercial vehicle subscription service that allows fleet operators to pay a monthly fee to avoid costly demand charges, reducing exorbitant vehicle operation costs for charging at high rates while creating a steady revenue stream for the utility (PG&E, 2020).[cxxix]

INCORPORATING HYDROGEN AS A COMPLEMENTARY FUELING STRATEGY

Investments in green hydrogen and in hydrogen stations are important to supporting the growth of a technology that may support ZEFV adoption for some of the most rigorous duty cycles, such as long haul and heavy off-road equipment. A low-carbon fuel standard will financially support the growth of green hydrogen, or hydrogen produced with a low GHG output. Targeted government investments in hydrogen fueling stations along freight corridors will create opportunities for fleets to take advantage of a potentially complementary technology to battery-electric trucks while avoiding the potentially prohibitive costs of investing in privately owned hydrogen stations.

In July 2020, the European Commission adopted the EU Strategy for Energy System Integration[cxxx] and Hydrogen[cxxxi] (European Commission, 2020) (European Commission, 2020a). The Hydrogen Strategy focuses on long-haul and heavy-duty vehicles and hydrogen infrastructure, providing strategic guidance for the advancement of FCEVs. In addition to longer-term opportunities enabled by fuel and corridor station investments, the European Commission explains that the use of hydrogen in transport should target immediate opportunities "where electrification is not feasible," though feasibility may depend upon many factors and the definition may shift over time.

6.3 CROSS-REGIONAL ALIGNMENT OF DEPLOYMENT AND ECOSYSTEMS

Because truck manufacturing is a global market, aligning ZEFV deployment and supportive ecosystems across leading markets will accelerate economies of scale in ZEFV production.

Aligning ZEFV deployment across leading markets is essential to achieve sufficient economies of scale to secure a stronger foothold in those urban applications for which zero-emissions technologies are most readily available. After initial deployment in urban applications, zero-emissions technologies can expand with other applications demanding more aggressive payloads and duty cycles, less predictable routes, and longer distances. Because many components and technologies can be transferred across applications (e.g., batteries and drivetrains that support transit buses can also support delivery vans), the ability to produce components that can support multiple applications will lead to increased production volumes that reduce costs over time. Additional process improvements that support technology transfer and expansion include improved manufacturing capability and operational practices. Innovation in all of these categories will allow vehicle manufacturers to create diverse ZEFV fleets that can meet a growing number of applications.

The parallel implementation of supportive ecosystems of policies and incentives in multiple leading regions worldwide will send stronger signals to manufacturers to accelerate production volumes, which in turn will lower vehicle costs while technologies improve, encouraging fleets to speed ZEFV adoption. This supportive, iterative process of successive clean ZEV applications and deployments will ultimately facilitate the large-scale transition to a zero-emission commercial transportation sector.

LIST OF ACRONYMS

$	United States dollar
ACT	Advanced Clean Truck regulation
BEV	Battery electric vehicle
CO2	Carbon dioxide
FCEV	Fuel cell electric vehicle powered by hydrogen
GHG	Greenhouse gas
GTW	Gross train weight
GVWR	Gross vehicle weight rating
HPC	High-power charging
ICCT	International Council on Clean Transportation
km	Kilometer
kW	Kilowatt
kWh	Kilowatt-hour
LCFS	Low-carbon fuel standard
MHDV	Medium-heavy duty vehicle
NOx	Nitrogen oxides
NZEV	Near-zero emission vehicle
OEM	Original equipment manufacturer
PM2.5	Particulate matter with a diameter of 2.5 micrometers or less
t	Metric ton
TCO	Total cost of ownership
TRL	Technology readiness level
V2G	Vehicle-to-grid
ZEFV	Zero-emission freight vehicle
ZEV	Zero-emission vehicle

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SECTION 1

1.A TRUCK CLASSIFICATIONS IN UNITED STATES AND CANADA; EUROPEAN UNION; CHINA; AND JAPAN

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<tr><td>25 - 30</td><td rowspan="3">8b</td><td rowspan="3">> 27.2</td><td>25.0 - 31.0</td><td rowspan="2">27.0 - 35.0</td></tr>
<tr><td>30 - 35</td><td rowspan="2">>31.0</td></tr>
<tr><td>35 - 40</td><td>35.0 - 40.0</td></tr>
</table>

* The weights shown are the gross vehicle weight (GVW) (the weight of the vehicle plus the maximum intended payload) for the European Union and Japan, the maximum design weight for the People's

Republic of China, and the gross vehicle weight rating (GVWR) (the maximum recommended operating weight of a vehicle as specified by the manufacturer) for the United States and Canada. These all refer to the same end goal: the maximum designed weight of the vehicle plus its payload. The sole exception is the tractor category, which may carry trailers that exceed maximum weights.

** The weight classes for the United States and Canada are rounded to the nearest tenth of a ton (t). In the United States and Canada, classifications for all trucks are independent of vehicle design (though trailers will be classified and regulated separately through MHDV Phase II Regulations). In the European Union, trucks and trailers / semitrailers are classified and regulated separately. In China and Japan, (single unit) trucks and tractors are classified and regulated separately. Classification structures in other countries and global regions will differ from those shown in the table.

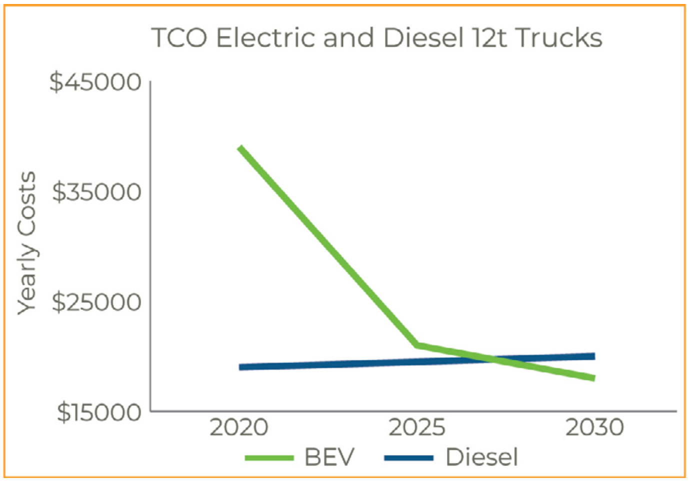
*** In the European Union, vehicle categories N1 and N2 are defined in Annex II of Directive 2007/46/EC as vehicles for goods transport with a reference mass (i.e. without payload) exceeding 2,610 kg.

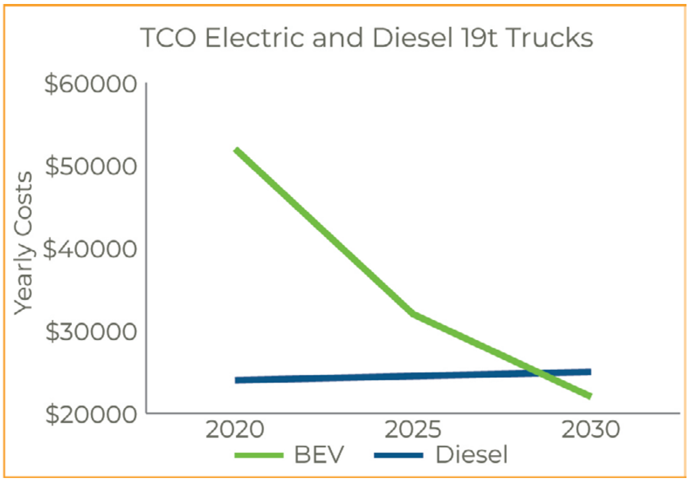
**** In China, tractor categories continue in 3-ton increments up to 49 tons, with the heaviest category defined as tractors exceeding 49 tons.

This graphic reinterprets an existing graphic developed for the International Energy Agency (IEA, 2020).[i]

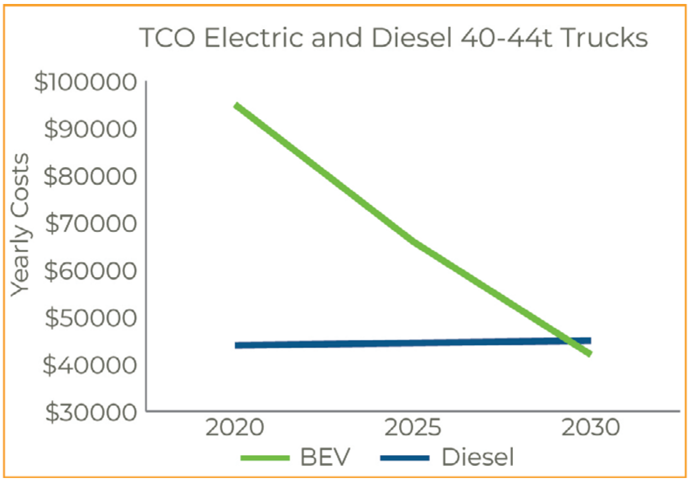
SECTION 2

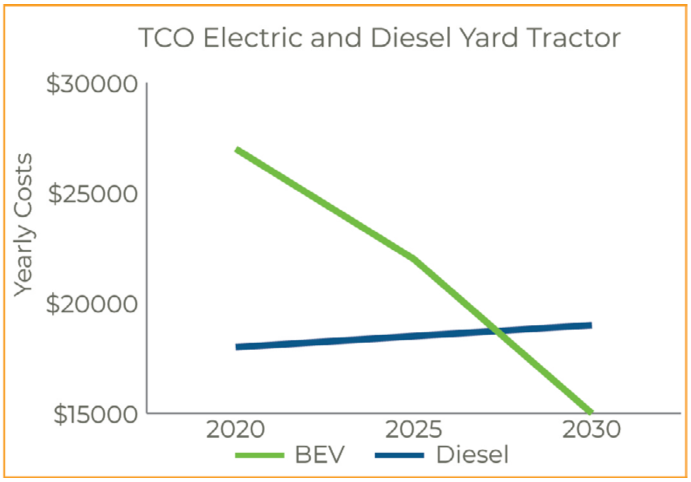
2.A BREAK-EVEN POINT FOR CARGO VANS AND MEDIUM-DUTY TRUCKS





2.B BREAK-EVEN POINT FOR HEAVY-DUTY TRUCKS AND YARD TRACTOR





2.C TCO EXPLANATION ON ESTIMATES

PURCHASE PRICE FREIGHT VEHICLES

The purchase prices of the electric trucks are partly determined by CALSTART's ZETI tool and on FIER's own research obtained through projects in the field of electric trucks. For each segment, purchase prices have been collected for the most relevant models. This has been done for both diesel and electric powered freight vehicles. In summary, a basket has been determined per segment from which the average purchase prices have been obtained. The purchase prices of the ZEFVs range from 167.500USD to 380.000USD. For the diesel freight vehicles respectively between 83.000USD and 107.500USD.

PURCHASE PRICE CHARGER

In this TCO the purchase price of the charger is based on a fleet of 5 electric trucks. The exact purchase value of the charger is partly determined by the practical experience and knowledge of FIER in the field of projects aimed at electric trucks. Relevant reports have also further substantiated the purchase price of 15.000USD 24kW DC ABB charger used in this TCO.

DEPRECIATION

The depreciation of diesel trucks per segment is easy to determine, it concerns information that is well available. This information has been obtained through knowledge of the market and also relevant reports. Due to the small number of electric trucks in use by companies, the depreciation has been determined by reports from reputable banks and institutes, like ING and Bloomberg NEF, focusing on the future and use of electric trucks. To support these reports, the depreciation has also been determined by a very extensive investigation by FIER focused on the introduction of heavy-duty electric trucks for local logistics. The depreciation years used are as follows; yard tractor 10 years, cargo van 8,5 years, medium duty truck 9,3 years, heavy duty truck 5,5 years. These depreciation years are also applied to the ZEFVs in the TCO.

CONSUMPTION

Consumption is determined per segment. By using a comparison between 3 trucks in the same category (Diesel and electric) an average consumption has been calculated. For the diesel trucks, this information can be found in technical journals aimed at practical testing of trucks. To determine the consumption of the electric trucks, a mix was chosen between FIER's practical consumption experience and the data provided by the manufacturers (both OEM and retrofit). For the energy costs, the most current and representative diesel and electricity prices were taken s input for the TCO. These data are derived from Eurostat[ii] and the site Global Petrol Prices (Global Petrol Prices, 2020) (EUROSTAT, 2020).[iii]

SERVICE AND MAINTENANCE COSTS

ZEFV designs require fewer components than diesel-powered vehicles and do not generate as much friction due to their regenerative braking capabilities. Maintenance costs, therefore, are expected to be lower than diesel-powered vehicles over time. However, a Dutch industry association study finds that fleet inexperience with ZEFVs and newly designed components that may experience heightened failure rates could increase maintenance costs through 2025 (BOVAG, 2019).[iv] After the first five years of ZEFV operation, maintenance costs are expected to fall to one third of diesel-powered trucks.

2.D INCENTIVE IMPACT ON ZEFVS IN EUROPE

TAX ON TRUCKS IN SWITZERLAND

The performance-based tax on heavy duty vehicles is a federal tax which depends on the total weight, the level of emissions and the kilometers driven in Switzerland and the Principality of Liechtenstein (Federal Customs Administration, 2020).[v] The tax is payable on all motor vehicles and trailers which have a total permissible weight of more than 3.5 Tons, serve to transport goods and are registered in Switzerland and abroad and use the public road network in Switzerland. Electric freight vehicles are exempt from the tax. For example; a 40 Ton diesel freight vehicle with a Euro 6 diesel engine pays 2.28 Swiss francs cents per kilometer driven. In the TCO is taken into account a maximum day distance of 200km and a maximum year mileage of 60.000km. Assuming the maximum yearly mileage, a transport company with a 40 Ton Euro 6 diesel truck pays 54.720 Swiss Francs which equals 60.000 US Dollar a year. This positively influences the TCO of the Electric Freight vehicles. If the annual toll costs for the diesel freight vehicles are included in the TCO calculation, all the segments directly benefit from cost parity from now on.

TOLL ROADS GERMANY

In Germany all vehicles and vehicle combinations with a gross vehicle weight of 7.5 Tons or more are subject to toll (Toll Collect, 2020).[vi] The freight vehicle toll will be calculated on the basis of emission class, weight class and, for vehicles or vehicle combinations with a gross vehicle weight over 18 Tons, it will also be calculated based on the number of axles. In addition, the costs of noise pollution will be taken into account. For example; a 40 Ton diesel freight vehicle with a Euro 6 diesel engine pays 18.7 Euro cents per kilometer driven. The transport company with a 40 Tons Euro 6 diesel freight vehicle pays on yearly base 11.220 Euros which equals 13.200 US Dollar. In Germany, battery powered electric vehicles, hybrid electric vehicles that are charged from the outside or fuel cell vehicles are exempt from toll. If the annual toll costs for the diesel freight vehicles are included in the TCO calculation the 40 Ton ZEFV will reach cost parity as early as 2027. The 19tons and 12tons categories, will respectively achieve cost parity by 2024 and 2023.

CITY OF OSLO (NORWAY)

Since October 1st 2017, congestion charge and environmental differentiation rates are introduced at the toll points in Oslo (Fjellinjen, 2020).[vii] The toll also applies to diesel powered freight vehicles above 3.5Tons. Electric and hydrogen freight vehicles are exempt from this toll. In this calculation we assume a Euro 6, 12 Tons diesel powered truck for inner city distribution. The truck has 2 deliveries and uses 4 toll gates. The total cost is 244 Norwegian crowns per day, which equals 26 dollars. Based on 6 days a week, 52 weeks a year, the cost rises to 8200 US dollars. (76128 Norwegian crowns). If these costs are included in this TCO, a 12 Ton ZEFV will reach cost parity in 2023.

SECTION 3

3.A OVERVIEW OF ELECTRIC FREIGHT VEHICLES CHARGING SYSTEMS

TECHNICAL STANDARDS - VEHICLE TO CHARGE POINT CONNECTION

Since the emergence of the electric trucks, on each continent a different charging connector standard was developed. Now that the market is maturing worldwide, some working groups active on different continents have been converging their standards, or like Tesla, been adapting their vehicles to the local standards. North-America and Europe have combined their efforts in the CCS standard, which is being developed by CharIn. In the table below, a condensed overview is shown for the most common types of charging technologies (form factors) used for electric trucks, that cover the standard technologies being used now and/or in the nearby future.

TYPE OF CHARGE SYSTEM	EUROPEAN TECHNOLOGY STANDARDS	POWER RANGE	COMMENT/REMARKS
Plug-connector	AC: Type-1	Up to 19.2 kW	Mainly used in North-America and Japan. Allows for 1-phase AC charging at 120 to 240 Volt and a maximum of 80 Amps.
	AC: Type-2 "Mennekes"	3.7 kW to 43 kW	Most of the AC chargers allow for 1 and 3-Phase charging at 230V and up to 63A. The speed of charging is highly influenced by the vehicle and dependent on the type of AC/DC converter it had on-board. For e-Trucks, most AC Type-2 chargers will deliver at least 22 kW.
	DC: CCS1 (Combo 1)	Theoretically up to 500 kW	North-American version of the CCS standard, which stands for Combined Charging System. In this version Type-1 AC and CCS1 DC are combined in one socket and it's being used mainly in North and Central America, Korea and Taiwan.

TYPE OF CHARGE SYSTEM	EUROPEAN TECHNOLOGY STANDARDS	POWER RANGE	COMMENT/REMARKS
	DC: CCS2 (Combo 2	Theoretically up to 500 kW	CCS stands for Combined Charging System. Combined refers to the fact that part of the plug is the same as the AC Type-2 plug. The EU AFI Directive 2014/94/EU,[1] states public DC recharging points shall be equipped with at least CCS Combo 2, therefor making CCS2 the de-facto standard in the EU. CCS2 is mainly used in Europe, South America, South Africa, Arabia, India, Oceania and Australia.
	CHAdeMO	Up to 400 kW (ver. 2.0)	Mainly used for passenger cars worldwide, mostly in Japan. Since the US has chosen CCS1 and Europe CCS2 as the de-facto standards and GB/T is more popular in China, it remains to be seen how long CHAdeMO will stay. In August 2018, the CHAdeMO Association has announced co-development of the next-generation ultra-high-power plug with CEC (China Electricity Council), with which CHAdeMO will harmonise. This project with the code name ChaoJi aims to enable 900 kW (600A x 1.5kV), all the while ensuring backward compatibility with the current CHAdeMO and GB/T chargers.
	GB/T	Up to 185 kW	Mainly used in China with over 300.000 connectors. Development started in 2013 and will be followed up by ChaoJi (like CHAdeMO, see above).
Pantograph / Overhead	DC; Pantograph-up	DC, ≈ 600 kW	Pantograph charging allows for very high power charging, which doesn't need to cope with the restricted capabilities of a cable, plug and socket, making it highly suitable for bigger, heavier vehicles that carry big battery packs. Pantograph-up better allows for possible in-motion charging, which can already be found on trolley-buses but also in experiments, like from Siemens and Scania.[2]

1 https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32014L0094&from=en

2 https://press.siemens.com/global/en/feature/ehighway-solutions-electrified-road-freight-transport

TYPE OF CHARGE SYSTEM	EUROPEAN TECHNOLOGY STANDARDS	POWER RANGE	COMMENT/REMARKS
	DC; Pantograph-down	DC, Very high	Pantograph-down technology is only suitable for stationary charging, because the connecting pantograph is attached to an over-head chargepoint, which moves down to connect with the vehicle below it. However, the plus side of it, is that the vehicles don't need to carry the whole pantograph system on their roof, which makes implementation cheaper and less susceptible for technical malfunctions. Less pantographs are needed for the same amount of vehicles being operated and the vehicle height can remain lower. The most common protocols in use for pantograph-down charging are the DC connection standards IEC 61851 and ISO15118. For instance, OppCharge[3] is a solution that can be used, which is an adaption of these protocols.
Inductive	Future: CCS 3.0	(Pilots being deployed)	Inductive charging has been implemented in pilots and is (slowly) maturing towards implementations in real world operations. The biggest challenges to overcome are the efficiency of the power transfer and safety. In theory inductive charging can be used as a stationary solution or as in-motion, but given the fact that with the current status of the technique the line-up between the sending and receiving coils has to be very precise to allow for higher power transfer and high efficiency, in-motion charging still seems to be far away.

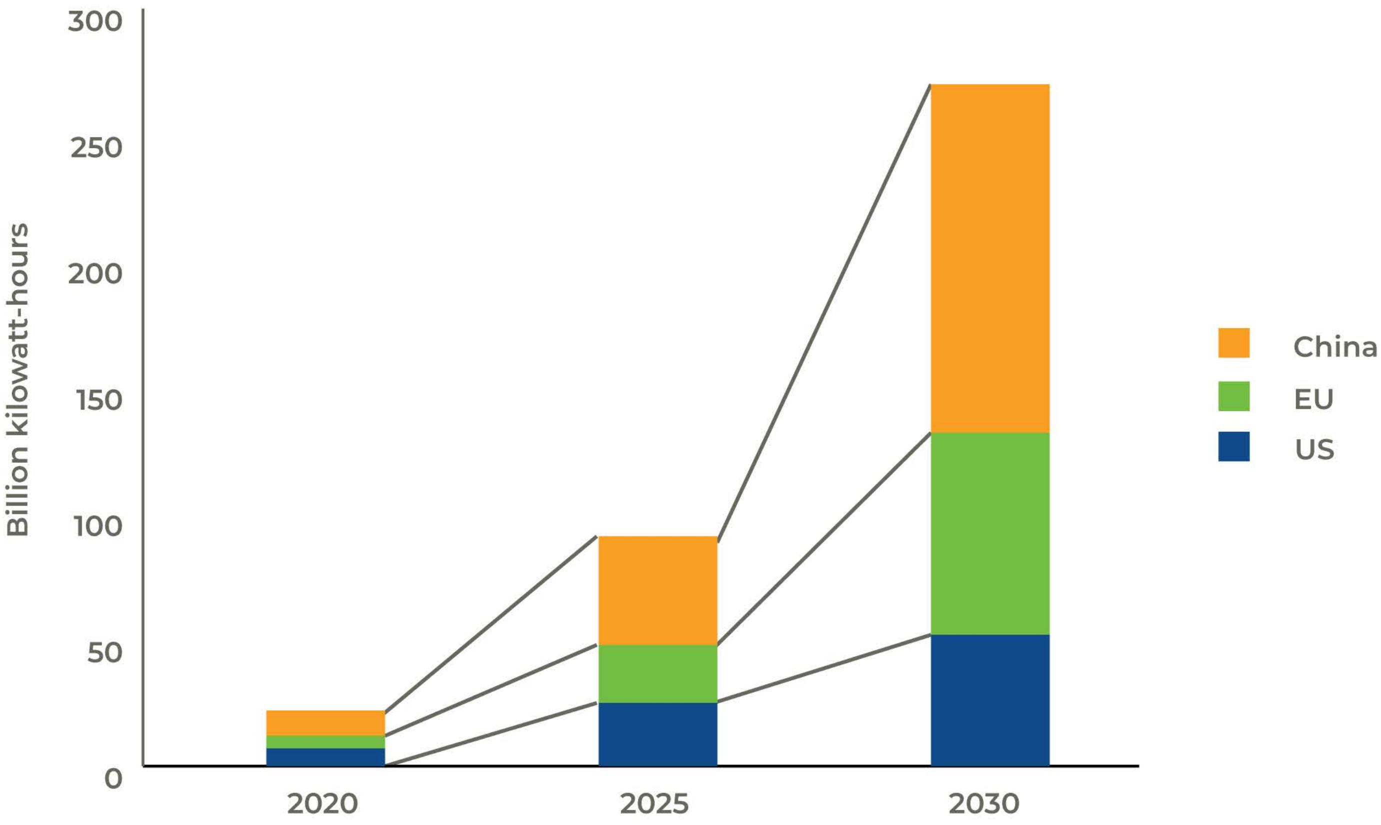
TECHNICAL STANDARDS - ACTORS AND STANDARD COMMUNICATION PROTOCOLS

For an EV driver to be able to charge at a (public) charging point, the two most important market parties involved in making sure the user can charge, are the Charge Point Operator (CPO) and the e-Mobility Service Provider (eMSP). The CPO is responsible for the correct operation of the charge point, and is in many cases also the owner of the charge point. Communication of data and operations between the charge point and the charge point management system of the CPO (often referred to as the CPMS) are handled by the Open Charge Point Protocol (OCPP). If the EV-driver is using a payment method provided by an eMSP (i.e. through a smartphone app or an RFID card), the CPO then communicates with the eMSP by making use of the Open Charge Point Interface (OCPI) protocol. The standardization

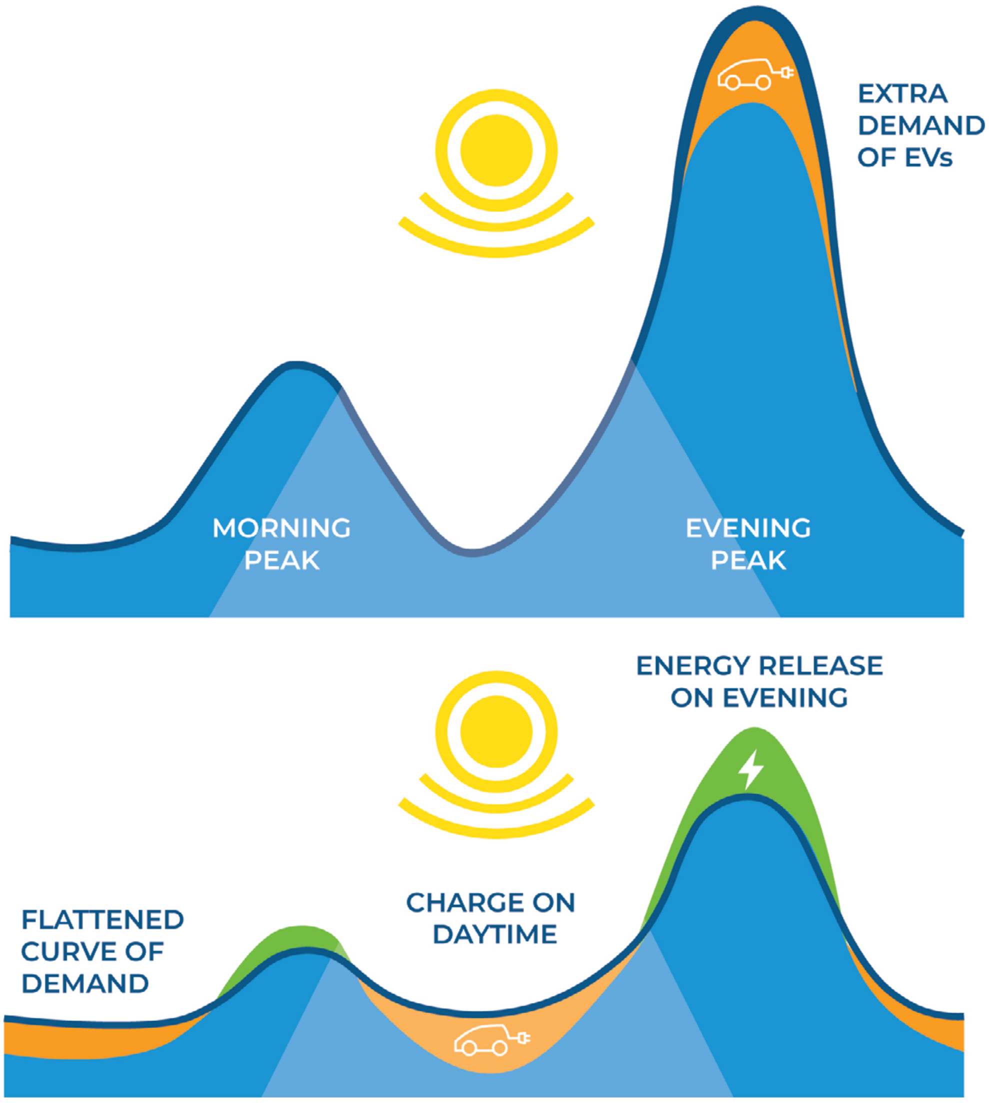
3 https://www.oppcharge.org

of these communication protocols has resulted in a charging landscape that is interoperable among many different market roles and suppliers, preventing vendor lock-in for the EV-driver and contributing to hassle-free national and international roaming, which is mandatory for a great user experience and therefore stimulating the EV uptake.

3.B CHARGING ENERGY DEMAND FOR ELECTRIC VEHICLES[VIII]



3.C ENERGY PEAK DURING THE DAY AND DEMAND SHIFTING[IX]



SECTION 4

4.A EXAMPLES OF AUTOMATED TRUCKS

TYPE OF CHARGE SYSTEM	EUROPEAN TECHNOLOGY STANDARDS	POWER RANGE	COMMENT/REMARKS
2020	North America	Amazon	Amazon aims at self-driving trucks
2019	North America	Daimler	Daimler tests self-driving truck on public road
2020	North America	DOT	DOT gives $4.4 million for self-driving truck project on I-70
2019	Europe	MAN	MAN convinced of future for platooning
2020	Europe	UPS, Gaussin Electric	UPS Testing Electric/Autonomous Yard Tractors in England
2020	Asia	Quomolo	Hutchison Ports first to introduce autonomous tractors to Thailand
2019	Rotterdam	Port of Rotterdam	Autonomous trucks for Maasvlaktes' internal Container Exchange Route
2020	North America	FedEx	FedEx Unveils Autonomous Delivery Robot
2020	North America	Buffalo Wild Wings	Buffalo Wild Wings take to the skies with drone delivery trial
2019	North America	UPS, Amazon, Alphabet	3 Companies Looking to Dominate Drone Delivery
2020	Europe	Starship	Delivery robots thrive in the coronavirus lockdown
2020	Asia	Korea Post	Robots to Replace Mail Carriers for Parcel Delivery
2020	North America	NURO	Nuro Gets a Permit to Test Its Delivery Robot on Public Roads
2020	North America	Amazon	Amazon starts deploying 'cute' delivery robots in US, calls them 'adora-bots'
2020	Europe	Several brands	Delivery droids coming to London pavements as soon as next month
2020	Europe	VALEO	Autonomous, electric vehicle delivery prototype to be unveiled at CES 2020

i International Energy Agency (IEA, 2020). Global Electric Vehicle Outlook. Available online at https://www.iea.org/reports/global-ev-outlook-2020

ii EUROSTAT (EUROSTAT, 2020). Electricity Price Statistics. Available online at https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics

iii Global Petrol Prices (Global Petrol Prices, 2020). Diesel prices, liter, 28-Sep-2020 Available online at https://www.globalpetrolprices.com/diesel_prices

iv BOVAG (BOVAG, 2019). The effect of electric powered trucks and buses on the after sales business model. Available online at https://mijn.bovag.nl/downloads/onderzoek-cijfers/samenvatting-bovag-onderzoek-effect-ev-op-aftersal/bovag_ev_trucks-en-bussen_highlights_15-april-2019

v Federal Customs Administration (Federal Customs Administration, 2020). HVF- General/Tariffs. Available online at https://www.ezv.admin.ch/ezv/de/home/information-firmen/transport--reisedokument--strassenabgaben/schwerverkehrsabgaben--lsva-und-psva-/lsva---allgemeines---tarife.html

vi Toll Collect (Toll Collect, 2020). Current Toll Rates. Available online at https://www.toll-collect.de/en/toll_collect/bezahlen/maut_tarife/maut_tarife.html

vii Fjellinjen (Fjellinjen, 2020). Toll Calculator. Available online at https://www.fjellinjen.no/private/toll-calculator

viii Mckinsey & Company (McKinsey 2018). Charging ahead: Electric-vehicle infrastructure demand. Available online at: https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/charging-ahead-electric-vehicle-infrastructure-demand

iv SEEV4-City (SEEV4-City 2019). Flexpower. Available online at: https://www.elaad.nl/uploads/files/SEEV4_city_OP_Amsterdam_Flexpower_1.pdf