WHITE PAPER

GLOBAL COMMERCIAL VEHICLE DRIVE TO ZERO

A PROGRAM OF CALSTART

THE BEACHHEAD MODEL

CATALYZING MASS-MARKET OPPORTUNITIES FOR ZERO-EMISSION COMMERCIAL VEHICLES

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Definitions of Acronyms

$	United States dollar
AC	Alternating current
BEV	Battery electric vehicle
CARB	California Air Resources Board
DC	Direct current
CEM	Clean Energy Ministerial
FCEV	Fuel cell electric vehicle powered by hydrogen
GHG	Greenhouse gas
GSE	Ground support equipment
GTW	Gross train weight
GVWR	Gross vehicle weight rating
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program
kW	Kilowatt
LCFS	Low-carbon fuel standard
MHD	Medium-heavy duty
NZEV	Near-zero emission vehicle
OCPI	Open charge point interface
TRL	Technology readiness level
ZECV	Zero-emission commercial vehicle
ZETI	Zero-Emission Technology Inventory

Introduction

The global market for medium- and heavy-duty commercial vehicles is poised for a complete transformation with the rapid development and deployment of zero-emission commercial vehicle (ZECV) technologies. These electric- and hydrogen-powered technologies will help improve urban air quality, mitigate climate change, spur industrial innovation, and create new clean tech jobs.[1][2] China leads the early global ZECV market by a wide margin, but other regions across the globe are introducing supportive policies that will expand and encourage ZECV market growth (IEA, 2020) (McKinsey, 2018) (GTM, 2019). To accelerate these trends, CALSTART's Global Commercial Drive to Zero program (Drive to Zero) aims to enable and speed the growth of near-zero[3] and ZECVs—beginning with applications where they are most likely to succeed, referred to as first-success or "beachhead" applications, in first-mover regions with supportive policies and incentives. Once these initial footholds have been established, the Drive to Zero program supports their scaling and expansion with the vision that ZECVs will be commercially viable for beachhead applications in first-mover regions by 2025 and dominate new vehicle sales by 2040. This vision for successive vehicle applications that is central to the Drive to Zero program, which is an official campaign of the Clean Energy Ministerial's (CEM) Electric Vehicles Initiative (see text box for an introduction to CEM).

Drive to Zero's theory of change is predicated on targeting first-success applications where electric- and hydrogen-powered vehicles are currently viable (Chapter 1). These ZECV technologies support and accelerate the development of subsequent follow-on, or "near early" markets This theory of change is referred to as the "beachhead model" (Figure 1).

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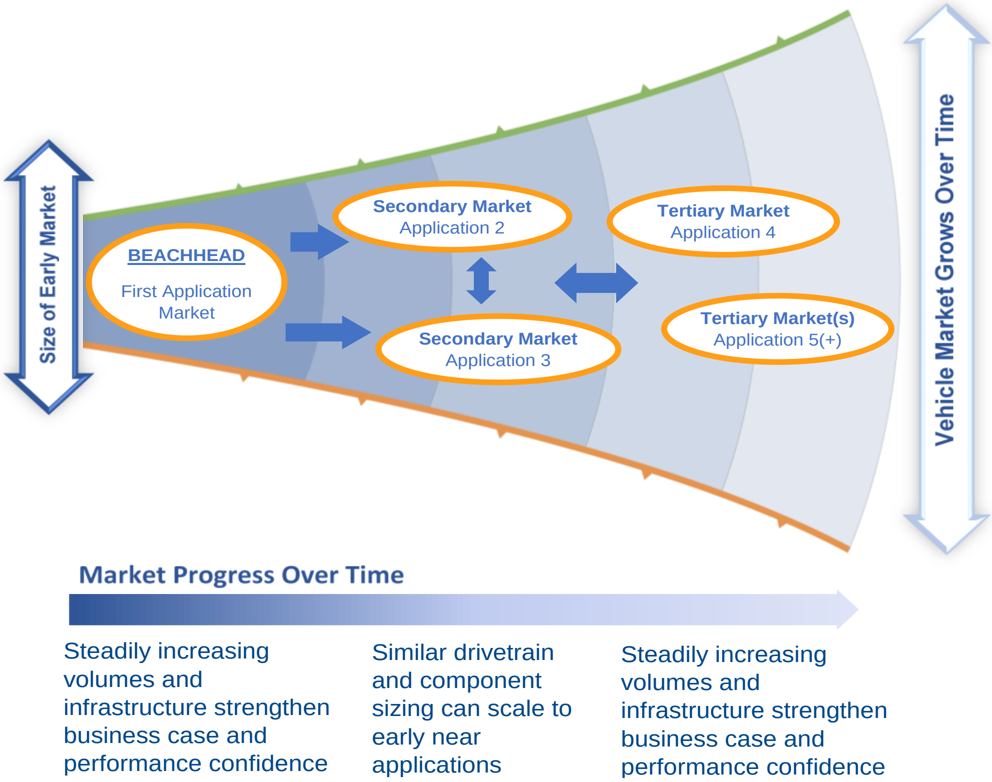
[1] The definition of "zero-emission" includes vehicles with drivetrains that cannot produce greenhouse gases or air pollutants, indicating vehicles powered solely by electricity or hydrogen.

[2] The definition of a "commercial vehicle" varies by region based on weight and cargo or passenger capacity. For a comparison of international commercial vehicle standards, see the Appendix.

[3] See text box in Chapter 1 for distinctions on near-zero emissions vehicles in this brief.

Figure 1: The "Beachhead Model" of Successive Vehicle Applications



Because multiple vehicle applications use similar components such as powertrains, batteries, and power electronics, progress in first-success applications will lead to further technological development and transfer to other on-road, off-road, and marine sectors as components mature, volumes grow, and costs decrease (Chapter 2). However, rapid ZECV deployment will only happen if existing barriers – such as higher upfront cost and a lack of model availability, enabling policies, infrastructure, and fleet awareness - are tackled through supportive ecosystems of aligned policies, incentives, infrastructure investments, and pilot projects (Chapter 3). With these steps taken together, the ZECV market will mature rapidly and expand geographically to become commercially viable, dependable, and competitive for a large range of applications.

Recognition by the Clean Energy Ministerial (CEM)

The Clean Energy Ministerial is a global forum for top energy ministers designed to drive forward policies and programs that advance clean energy technology. CEM includes 25 countries and the European Commission representing roughly 90 percent of global clean energy investments and 75 percent of global greenhouse gas emissions. CEM campaigns are noted efforts designed to raise visibility and target global resources to those campaigns that have a strong potential for transformative impact in the clean technology sector.

Drive to Zero was recognized at the 2020 CEM event hosted virtually in Riyadh. The program is part of the Electric Vehicles Initiative, CEM's campaign to accelerate the introduction and adoption of electric vehicles.

Chapter 1. First-Success "Beachhead" Applications

Drive to Zero is grounded in establishing and broadening first-success "beachhead"[4] ZECV applications for vehicles that are already available in receptive markets around the world. The initial success of these applications is typically attributable to matching vehicle availability with suitable duty cycles, industrial capacity, and vehicle performance. The combination of these factors leads to better total ownership cost parity between ZECVs and their conventional counterparts, especially when financial incentives are in place. These early applications typically meet urban needs (and therefore modest daily distances) along established routes where vehicles return to base to charge overnight. Initial beachhead applications include transit buses and forklifts, vehicles with operational characteristics that make for an easier transition to zero-emissions. Through subsequent "waves" of technology transfer and vehicle deployment, follow-on beachhead applications include return-to-base operations such as urban delivery vans, drayage trucks, yard tractors, garbage trucks, and medium- and heavy-duty regional trucks, eventually including long-haul freight trucks that are not limited to return-to-base operations.

Targeting areas of first success and enabling industry to use these beachheads as staging grounds to deploy and improve their vehicles, supply chains, and business practices will quickly create traction for further ZECV deployments. By focusing technological and business model innovation within beachhead applications, vehicle manufacturers will be able to leverage similar powertrains and components while fleets could benefit from expanded fueling/charging infrastructure. As supply chain volumes for common components grow and drive down costs, the confidence in vehicle performance and business case also grows.

In addition to targeting ZECV deployment in beachhead applications, key regional markets are also more primed for accelerated deployment. The costs and the challenges of simultaneously manufacturing, deploying, and servicing zero-emission trucks and buses at large scales around the world are prohibitive. By focusing on first-mover regions and filling in regional gaps as global demand increases, the beachhead model creates opportunity for manufacturers to streamline and innovate their products in a receptive commercial market while expanding their capacity to reach new markets.

Near-Zero Emission Vehicle Definition and Distinction

The definition of near-zero emission vehicles (NZEVs) can be construed to apply to many technologies, from vehicles that operate with much greater efficiency due to hybrid capabilities to conventionally-powered vehicles fueled by renewable liquid fuels. For the purposes of the beachhead model, near-zero emission vehicles are defined as having the capability for zero-emission operations at least in part of their duty cycles. This definition would include electric power takeoff systems and plug-in hybrid technologies. In addition, the beachhead model also considers the use of renewable natural gas or renewable liquid fuels on more aggressive duty cycles while zero emission technologies are not yet ready for implementation.

Near-zero emission vehicle technology can be an important component of achieving improvements in air quality and greenhouse gas portfolios. The flexibility provided by these technologies will allow

[4] 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.

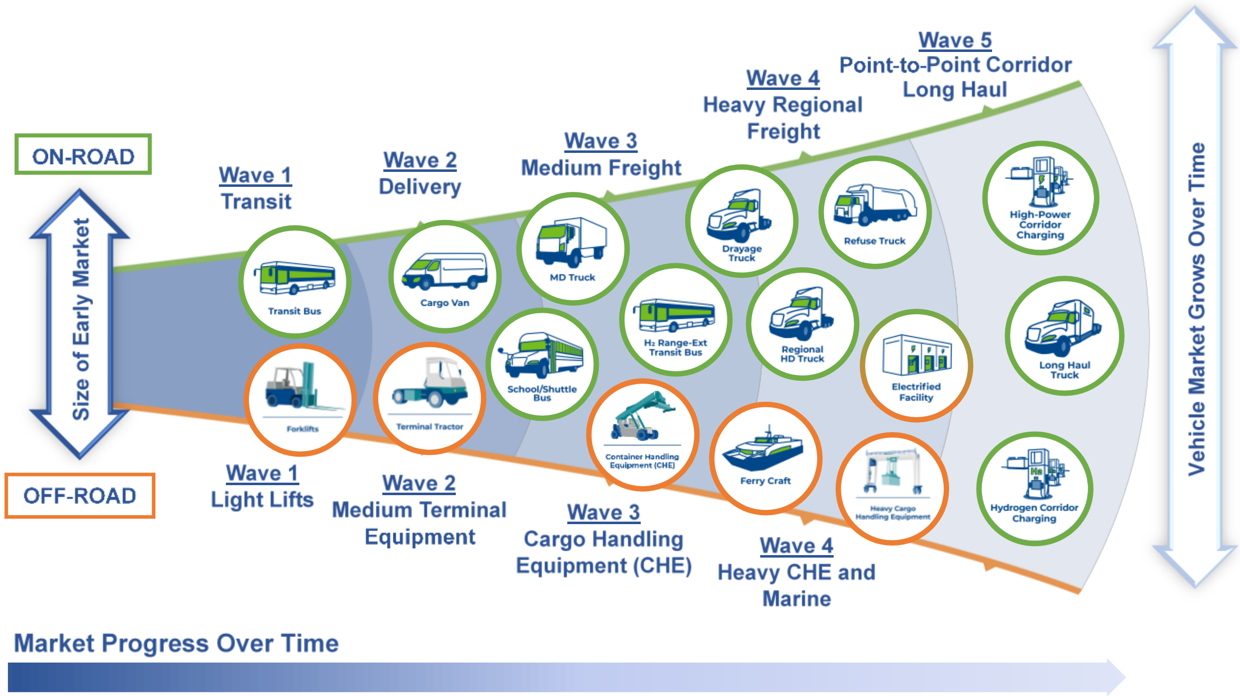
a greater number of fleets to operate efficiently, particularly in areas that require zero-emission operations, while meeting challenging routes and duty cycles. Several innovative and impactful pilot projects around the world use near zero-emission vehicles to advance their sustainability efforts and test new clean vehicle technologies.

Though near-zero emission technologies will be relied upon to some degree in the near and medium term, and investing in near zero-emission vehicles will support the development of zero-emission pathways, near-zero technologies need to be ultimately replaced by zero-emission technologies even on the most aggressive duty cycles to achieve the air quality and greenhouse gas emissions reductions needed to establish a safer, more prosperous future. Therefore, this briefing focuses on zero-emission pathways only.

Successive Vehicle and Technology Applications

The flow of innovation follows the transition from first-success beachhead applications, expanding to larger-volume, longer-distance, and more demanding applications that can make use of core ZECV powertrain components and supply chains (Figure 2). The beachhead model establishes zero-emission transit buses as the earliest on-road technological foothold. While relatively small in initial production volumes, they form the basis for a successful first market where core component technologies and architecture are shaped. Fuel cell electric buses utilize the same electric powertrain as a battery electric bus, itself built on the hybrid transit bus architecture, which over time expanded the use of core electric drive components. The development of these components has had wider applicability than initially expected and has 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 (MHD) delivery trucks (sometimes operating with plug-in range extender systems) and battery-electric yard trucks. 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 (sometimes also operating with plug-in or hydrogen fuel cell range extenders).

Figure 2: "Beachhead Pathways" for Zero-Emission Vehicle Commercialization



Another pathway illustrated in Figure 2 shows off-road applications beginning with electric and hydrogen fuel cell forklifts, which operate in controlled systems of limited access where operators can install and improve the functionality of advanced vehicle and charging systems. These closed systems may include ports, warehouses and other freight facilities. This pathway lays the foundation for zero-emission technologies of multiple types of cargo handling equipment, especially those operating higher payloads.

Heavy-duty applications with longer ranges and rigorous duty cycles will require larger and more powerful fueling supplies. Shared large-scale charging facilities for on-road and off-road applications will allow fleet operators to cost-effectively charge vehicles on-site. High-power charging and hydrogen fueling stations located along travel and freight corridors will enable long-haul freight and buses to expand the ZECV market.

A summary of ZECV beachhead applications is provided in Table 1 for on-road vehicles and Table 2 for off-road vehicles.

Table 1: On-Road ZECV Applications and Market Timing

Application	Operational Characteristics	Tech Wave	Avg Daily Distances[5]	Typical Designation or Class[6] [7]	GVWR[8] Range[9]	Charging Method
Transit Bus 	Passenger vehicle with predictable, often fixed routes	First	93 miles / 150 km	Class 4-8	16,000 - 61,730 lbs / 7,255-28,000 kg	Depot, On-Route
Shuttle Bus 	Passenger vehicle with highly variable routes	Second	62 miles / 100 km	Class 3-6	10,360 – 30,000 lbs / 4,700 – 13,607 kg	Depot, Opportunity
School Bus 	Passenger vehicle with typically predictable, but not fixed routes	Second	67 miles[10] / 108 km	Types[11] A, B, C, D	10,000 – 32,000 lbs / 4,500 – 14,400 kg	Depot, Opportunity
Delivery Van 	Cargo vehicle to complete last-mile deliveries over variable routes	Second	33 miles / 53 km	Class 3-5	4,630 -10,535 lbs / 2,100 - 4,778 kg	Depot, Opportunity

[5] Calculation derived from U.S. Department of Energy annual mileage divided by number of days in a year
[6] Vehicle classes are designated by the U.S. Federal Highway Administration
[7] Due to variables (vehicle length, axle configuration) involved in vehicle classification outside of North America, only U.S. classifications by weight are provided in this table. See Appendix for additional information on vehicle classification systems in China, the European Union, Japan, and India.
[8] GVWR: Gross Vehicle Weight Rating is the maximum operating weight of a vehicle as specified by the vehicle manufacturer
[9] Range is derived from the Global Drive to Zero program's Zero Emission Transportation Inventory (ZETI), a tool that catalogues worldwide commercially available offerings of zero-emission medium- and heavy-duty vehicles. The tool aims to provide fleets and governments with comprehensive information including regions where zero-emission brands are available for purchase, and the timeline over which additional models are expected to become available. School bus daily value is derived from the average number of miles driven annually divided by 180, the minimum number of school days in a U.S. school year. The number shown here may be higher than a typical route if the school buses are regularly used when not transporting pupils.
[10] School bus daily value is derived from the average number of miles driven annually divided by 180, the minimum number of school days in a U.S. school year. The number shown here may be higher than a typical route if the school buses are regularly used when not transporting pupils.
[11] School bus types are categorized by GVWR and by platform design, such as by California code MS 169.011 sub. 71.

Application	Operational Characteristics	Tech Wave	Avg Daily Distances[5]	Typical Designation or Class[6] [7]	GVWR[8] Range[9]	Charging Method
MHD Regional Delivery 	Cargo vehicle to deliver retail goods over variable routes	Third	36 miles / 58 km	Class 4-7	9,910 -39,683 lbs / 4,495 - 18,000 kg	Depot, Opportunity
FCEV Extended Range Transit Bus 	Passenger vehicle capable of routes longer than typical EV routes	Third	N/A	Class 4-8	26,000 - 61,730 lbs / 11,800 - 28,000 kg	Depot
Drayage Truck 	Cargo vehicle with predictable routes that transports goods between ports to warehouses	Fourth	238 miles / 383 km	Class 7-8	44,000-110,000 lbs / 19,960 - 49,895 kg	Depot, Opportunity, On-Route
HD Regional Truck 	Cargo vehicle with open, unpredictable routes that operates within one geographic region	Fourth	172 miles / 277 km	Class 7-8	30,864 – 97,000 lbs / 14,000 – 44,000 kg	Depot, Opportunity, On-Route
Refuse Truck 	Work truck that operates on fixed routes to collect waste	Fourth	68 miles / 109 km	Class 7-8	26,000 – 97,000 lbs / 11,800 – 44,000 kg	Depot
HD Long-Haul Truck 	Cargo vehicle to move goods long distances over variable routes	Fifth	172 miles / 277 km	Class 7-8	44,000-110,000 lbs / 19,960 - 49,895 kg	Depot, Opportunity, On-Route

Table 2: Off-Road ZECV Applications and Readiness

Application	Operational Characteristics	Tech Wave	Typical Designation or Class	GVWR Range	Charging Method
Light Lifts  Forklifts	Small specialized vehicle to move light cargo within ports or other freight facilities	First	N/A	N/A	Depot
Hostler / Yard Tractor  Terminal Tractor	Truck tractor that operates strictly within a port or other freight facilities	Second	Light - Heavy Duty / Class 3-8	8,600-102,000 lbs / 3,900-46,266 kg	Depot
Cargo Handling Equipment  Cargo Handling Equipment (CHE)	Specialized vehicle to move cargo within ports or other freight facilities	Third	N/A	N/A	Depot
Marine Harbor Craft  Ferry Harbor Craft	Marine vehicles that operate short distances and return to base (e.g. ferries and tugs)	Fourth	N/A	N/A	Depot
Heavy Cargo Handling Equipment  Heavy Cargo Handling Equipment	Large specialized vehicle to move heavy cargo within ports or other freight facilities	Fourth	N/A	N/A	Depot

Infrastructure Needs and Strategies for Emerging Technologies

Charging and fueling infrastructure availability is a critical component to the successful commercialization of ZECVs. As shown in Tables 1 and 2, different vehicle types may have distinct and varying methods of charging or refueling. Nearly all vehicles should be able to charge in a depot when idle, which makes efficient use of vehicle operator time and may reduce costs due to charging at low speeds. Vehicles with longer operational routes or smaller battery capacities may also need to charge during operation. Those vehicles operating on predictable routes such as transit buses or drayage trucks may use on-route chargers or stations reserved for their use, whereas vehicles with highly variable routes such as delivery trucks and vans may take advantage of publicly available chargers or stations as opportunities provide. Long-haul trucks will rely predominantly on hydrogen stations or high-powered direct current (DC) charging stations capable of rapid charging located along major travel corridors, while making selective use of depot charging.

Some unique beachhead applications can potentially use shared depot infrastructure. For example, marine harbor craft, cargo handling equipment, yard tractors, and drayage trucks operate at shipping terminals and warehouses and may be able to leverage shared infrastructure investments. On-road vehicles, such as regional haul trucks, yard tractors, and other ZECV applications may also be able to use common charging spaces. The potential for shared-use facilities is being demonstrated through the Volvo LIGHTS project, a pilot project in Northern California that combines zero-emission regional haul truck applications with dozens of zero-emission electric forklifts and yard trucks that operate at the shared freight facility (CARB, 2020). These shared-use scenarios are represented in Figure 2 as electrified facilities, serving both on- and off-road vehicles at common facilities.

Infrastructure investments in sites that host multiple operations, such as shipping terminals and shared freight facilities, may yield greater benefits beyond high utilization rates. The expected co-benefits that would accompany infrastructure include labor and maintenance training and high visibility for on-site fleets to become accustomed to zero-emission technology, increasing the likelihood that new fleets will adopt zero-emission vehicles. Multiple-operation sites may also host a range of technologies that would both be tested and on display for captive fleets. Investing in infrastructure at large sites with multiple operations, therefore, makes financial sense for fleet utilization while marketing toward a built-in captive fleet market and testing new zero-emission technologies to expand to secondary and tertiary markets (CARB, 2020).

Practical Examples of Beachhead Progress

The beachhead model is being examined and adopted by regions around the world as a useful framework for accelerating technology transformation in medium- and heavy-duty vehicles. In the United States, this concept has helped the California Air Resources Board (CARB) target most funding to those applications that have the strongest potential for technology transfer to broader applications (CARB, 2020). Evidence of strategically advancing beachhead applications is also seen in other regions in the United States and in Europe, Asia, India and South America as investments in zero-emission buses and lifts can lay the foundation for faster ZECV adoption in other vehicle categories. For example, the following Drive to Zero pledge partners have invested in zero-emission buses and infrastructure:

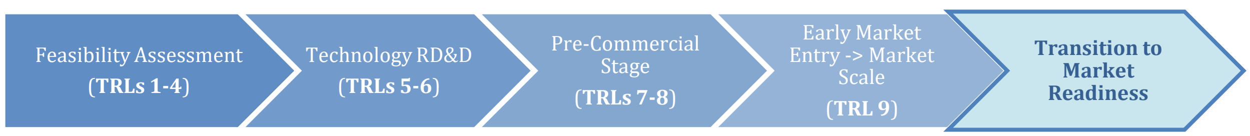
- The federal government of Canada is investing CA$1.5 billion in zero-emission buses and associated charging or fueling infrastructure loans as part of a national infrastructure package. As the first national government signatory to the Drive to Zero program in early 2019, the focus on zero-emission buses reflects an understanding and commitment to the beachhead model (Canada Infrastructure Bank, 2020).
- China is the world leader in ZEVCs by a vast margin, due partly to aggressive financial and policy support for "new energy vehicles" that produce nearly or no tailpipe emissions. The

southern city of Shenzhen first adopted electric transit buses in 2009, growing to an electrified fleet of more than 16,000 transit buses by 2018 (Bloomberg, 2018). Shenzhen subsequently become a global leader in zero-emission delivery vehicles, with 300 registered vehicles growing to more than 60,000 by 2019 (RMI, 2019). This adaptation and commercialization follows the beachhead model of progressive vehicle application successes.

- The Chilean government has established vehicle electrification goals that initially prioritize transit buses to support broader zero-emission vehicle deployments. The City of Santiago is an early regional leader that operates hundreds of electric transit buses (World Bank, 2020).

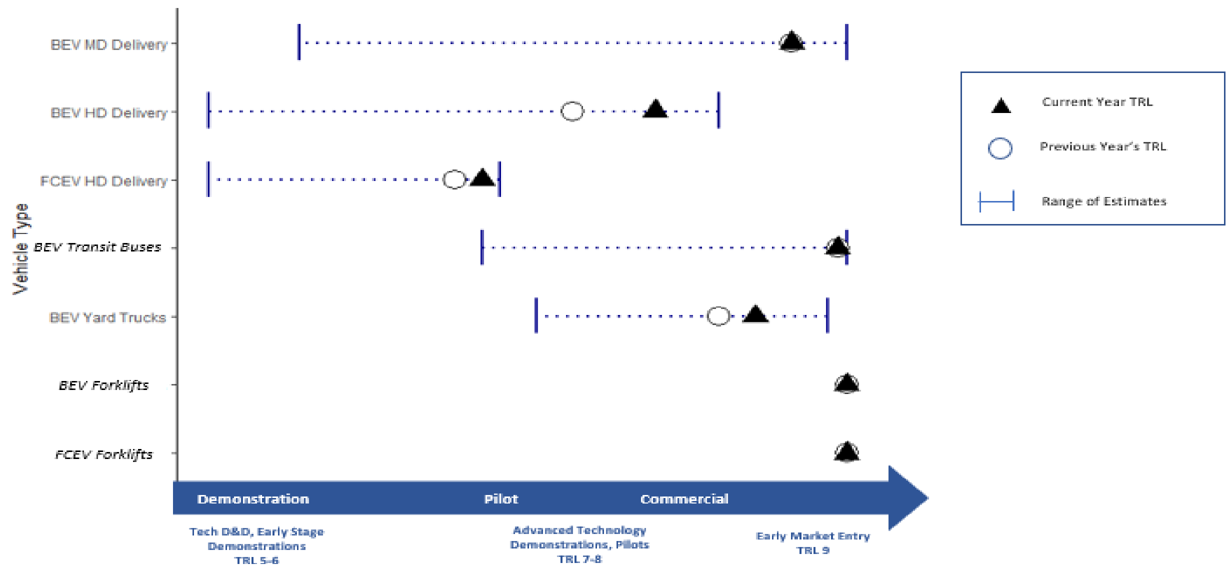
The ZECV market has steadily progressed from a focus on initial applications delivered by zero-emission transit buses and forklifts. CARB annually evaluates the commercially viability of different ZECV technologies (CARB, 2020), described through "Technology Readiness Levels (TRLs)." Each vehicle platform is assigned a score on a scale from 1-9, with 9 being ready to enter broad commercial sales (illustrated in Figure 3).

Figure 3: Stages of Technology Readiness



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 chart shown in Figure 4, 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. The figure shows a range of TRLs and indicates progress in each ZECV segment over time as shown by current (2020) and previous year (2019) scores. Initial applications such as battery-electric (BEV) transit buses and BEV and fuel cell electric (FCEV) forklifts rate at the highest TRL, but vehicle segments with increasingly rigorous duty cycles and ranges show progress toward commercialization as well.

Figure 4: Technology Readiness Levels by Vehicle Platform



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 model availability and sales with survey results from industry partners, with weighting applied for how developed vehicle manufacturing and manufacturers are within each segment. Tracking model availability, for example, demonstrates how and when the vehicle model grows. Figure 5, developed using the Drive to Zero "Zero-Emission Technology Inventory (ZETI)" tool,[12] indicates model availability for on-road vehicle segments and yard tractors beyond the initial applications of transit buses and light lifts. The trends evident in the figure indicate that great currently available vehicle models tend to be designed for shorter distances, particularly for smaller vehicles, but that vehicle ranges will grow over time, particularly for heavier vehicles with long-distance applications. Yard tractors are not inhibited by range and can perform their functions as currently constructed.

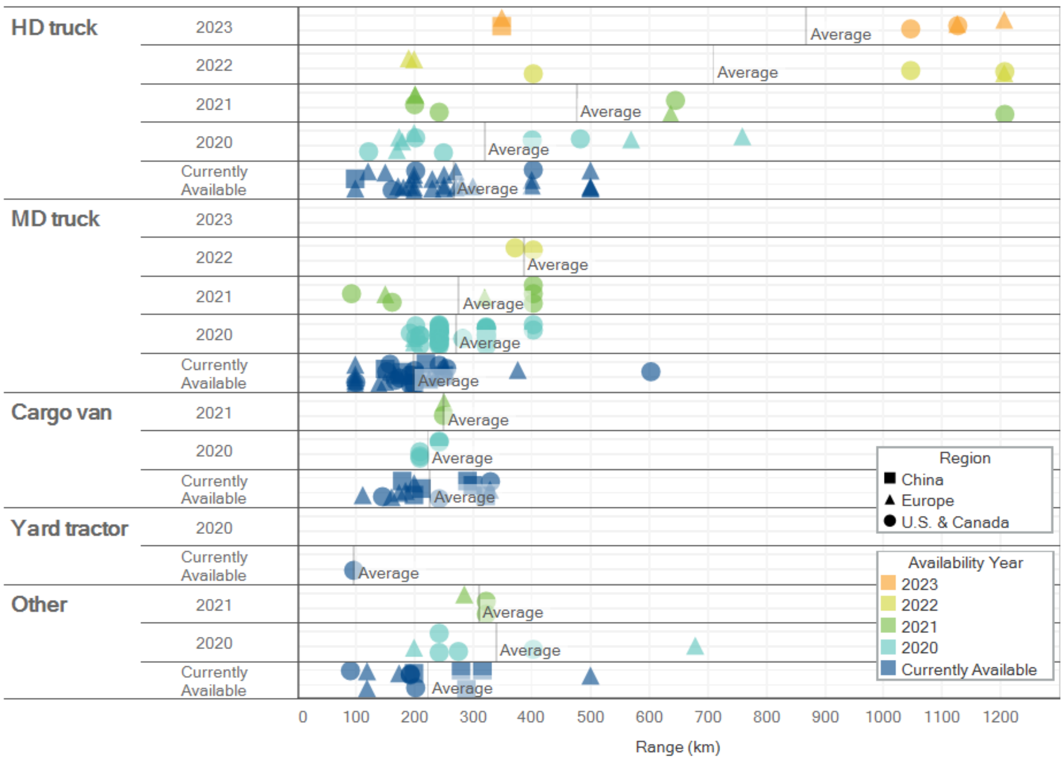
A New Tool to Find the Right Vehicle Model

CALSTART developed a new tool to help Drive to Zero stakeholders assess if and when vehicles are available for their needs. The Zero Emissions Technology Inventory (ZETI) is an interactive online tool that allows users to search for commercially available medium- and heavy-duty vehicles by platform, geography, manufacturer, and release date. Explore available vehicles here:

https://globaldrivetozero.org/resources/zero-emission-technology-inventory/

[12] 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 5: Current and Announced ZECV Models by Range, Release Date, and Platform for U.S., Canada, Europe, and China Markets



Chapter 2. Technology Transfer

As pathways proceed beyond initial beachhead applications in urban environments, zero-emission technologies will expand to applications with heavier duty cycles, often along longer and less predictable routes. Such expansions are supported by component transfers from one vehicle application to another, as ZECVs share many technologies that can be transferred or applied from an initial beachhead technology to a secondary application (e.g. batteries and drivetrains that support transit buses can also support delivery vans). This component and technology transfer is a critical step in the beachhead model: production of components that can support many applications will lead to increased production volumes that reduce cost over time (CARB, 2020).

Supply chain and component streamlining is implemented at both regional and global scales. The advantages of using interchangeable components is immediately experienced through local supply chains. Vehicle operators and servicers will have a steady supply of components that meet multiple vehicle types, ensuring that new vehicle technologies can reliably operate and are not constrained by a shortage of unique and expensive components. Transferrable components also benefit manufacturers by making platforms and parts less expensive to develop and produce at scale, providing a competitive advantage and allowing for flexible production in markets around the world (CARB, 2020).

Component and technology transfer is perhaps the most essential element to creating a ZECV market that meets increasingly rigorous duty cycles while expanding production capacities and simultaneously reducing costs. Additional process improvements that support beachhead technology expansion include improved manufacturing capability and operational practices. Innovation in all of these categories will allow vehicle manufacturers to create diverse ZECV fleets that can meet a growing number of applications.

Component Transfer and Manufacturing Innovation within Open and Closed System Applications

Because the zero-emission components that drive a transit bus are similar to the components that will drive vans, delivery trucks, and work trucks, manufacturers will be able to produce new vehicles using their existing and modified components to meet new duty cycles at low cost and with limited resources. Common powertrains and components (e.g. motors, power electronics, energy storage) can be transferred to other applications with similar power and torque needs, or can be modified to suit other applications (CARB, 2020). Consequently, ZECV manufacturers will be able to, and indeed already are beginning to, pivot to produce new vehicle platforms. Table 3 includes a list of common ZEV components that are transferable between ZEV models and applications.

Table 3: ZEV Systems and Common Transferable Components

Vehicle System	Component Class	Description
Energy Storage	Main Battery	Primary battery system that powers the electric motor(s)

Propulsion	Electric Motor	Converts the energy stored in the main battery to propel the vehicle
	Regenerative Braking	Recaptures kinetic energy when slowing a vehicle to store in the main battery system
	Transmission	Transfers mechanical power from the electric motor to turn the vehicle's wheels
	Power Electronics Controller	Acts as the brain, managing the flow of electricity from the main batteries and controlling the speed and torque produced by the motor
Control	Auxiliary Batteries	Some manufacturers will add an additional battery to power electronics systems separately from propulsion
	Thermal Cooling Systems	Maintains a proper operating temperature of motor, batteries, and other electrical components
	Heating Systems	Optional for vehicles depending upon type of vehicle or location of deployment, this component may use traction energy, fuel-fired heaters, or heat pump technologies to provide warmth for passengers in vehicle cabins
	DC Converter	Converts high-voltage DC power from main battery to lower-voltage DC power to run vehicle accessories and recharge auxiliary battery
	Vehicle Controls	Category that includes electronics that manage vehicle operations, such as onboard computers, steering systems, and basics like window and wiper movement
Charging	Charge Port	Allows the vehicle to physically connect to a wired external power source and power the main battery
	Receiving Plate	Allows the vehicle to connect with a wireless overhead or inductive charging system (*may not apply to all vehicles*)
	Onboard Charger	Converts an AC charge to DC for charging the main battery while monitoring the temperature and state of charge (*may not apply to all vehicles*)
Hydrogen	Fuel Cell Stack	An assembly of membranes that converts stored hydrogen to electricity to power the electric motor
	H_2 Filler and Tank	Enables a vehicle to accept and hold hydrogen fuel to power the hydrogen fuel cell stack
	Balance of Plant	Draws in and compresses air to optimize fuel mix with hydrogen

Across the full ZECV market, vehicle applications can be divided into "open" system deployments, in which vehicles operate along open routes, and closed or "controlled" systems, in which vehicles operate within a facility, typically in off-road applications. Following the beachhead model, technologies and operating strategies that have successfully been used in transit bus and forklift deployments will be applied to ZECV innovations in subsequent open and controlled systems.

On-Road / Open System Innovations

Transit buses remain an important first success zero-emission technology application in cities and regions around the world. The city of Shenzhen, China has famously converted its entire 16,000-vehicle transit bus fleet to all-electric by 2018. Zero-emission transit buses have also made early inroads in other regions, from an order of 200 in Santiago, Chile to early adopters in Los Angeles and Seattle that have now committed to completely electrifying their transit fleets by 2025. The zero-emission transit bus represents a proven, scalable application with a global stock estimated at greater than 500,000 vehicles that is helping to prove ZECV technology (IEA, 2020) In fact, the market for zero-emission transit buses is already sufficiently developed that California enacted the Innovative Clean Transit Regulation in 2018, requiring public transit fleets to procure progressively greater numbers of zero-emission buses until all new bus purchases are zero-emission from 2029.

Several vehicle manufacturers are already demonstrating the pivot from zero-emission transit buses to innovations for other ZECV applications. BYD has offered several iterations of medium- and heavy-duty zero emission trucks (including yard trucks) for years (BYD, 2020). This shift to take components from its transit bus operations to develop other ZECVs, including off-road applications, was part of the company's business plan dating back to 2013 (BYD, 2020a). Proterra recently announced the development of partnerships with Daimler Trucks and Thomas Built Buses that will install its electric drivetrains in zero-emission trucks, buses, and other applications (Forbes, 2019). These companies were pioneers of zero-emission transit buses that have taken components from their successful beachhead applications and innovated to reach new markets and duty cycles.

The ZECV market is growing quickly through additional commitments by companies that have not strictly developed all-electric transit buses. The diverse group that is innovating to meet growing demand in beachhead markets includes:

- Newer manufacturers that have shown flexible approaches to ZECV markets and designs. For example, Lion Electric, a Canadian company that has split out of a traditional school bus manufacturer, produces all-electric school buses that have been deployed across Canada and the United States. The range of products expanded in 2019 to include a flexible class 8 chassis that can be adapted to serve multiple heavy-duty trucking functions, from regional haul to refuse trucks (Lion, 2020).
- Traditional automakers that have also demonstrated flexible ZECV manufacturing designs. For example, global heavy-duty truck and bus manufacturer Volvo developed an all-electric powertrain for transit buses, then adapted the platform for applications that have similar performance needs. Variants of Volvo's 185 kW and 370kW powertrain have been used in a long-body transit bus, class 8 tractors, and refuse trucks.
- Vehicle upfitters and modifiers that have developed and are continuously improving zero-emission drivetrains in a range of vehicles, from small shuttles to medium-duty delivery trucks and heavy-duty drayage trucks. The number of upfitters and modifiers and their diversity of models is growing to meet fleet demands. Individual companies such as Motiv, Lightning, Phoenix, and SEA Electric incorporate parts from Roush and other large vehicle component manufacturers with innovative vehicle redesigns to existing vehicles to create custom-designed trucks, buses, and shuttles.

Off-Road / Closed System Innovations

Zero-emission technologies are already common for some off-road equipment including forklifts and airport ground support equipment (GSE). CARB describes zero-emission forklifts as "ubiquitous" in the state and suggests that several other technologies, including but not limited to yard trucks, heavy lifts, and transportation refrigeration units, are primed for expansion beyond initial applications. For example, JetBlue operates entirely zero-emission airport GSE at Long Beach Airport in California and at JFK Airport in New York (Bloomberg, 2019). These technologies fit the evolution of beachhead markets in Figure 1, where the application of zero-emission technologies in initial applications such as forklifts and ground service equipment branch out to subsequent applications.

Additional zero-emission technologies are currently being tested within California. For example, the Port of Long Beach and Toyota have been operating a custom-built heavy-duty zero-emission fuel cell drayage truck that uses core components from its light-duty Mirai (Trucks, 2019). The Ports of Long Beach and Los Angeles will also test the following ZECV technologies at their facilities (Port of LA, 2020):

- Fuel cell drayage trucks that operate on freight corridors between ports;
- Converted existing fossil-fueled equipment to zero- or near-zero emissions, including nine all-electric cranes, 12 all-electric yard tractors, and four plug-in hybrid electric drayage trucks;
- Demonstrations of new zero-emissions vehicles, including three all-electric top handlers, one all-electric yard tractor, and one fuel cell yard tractor; and
- Four all-electric retrofitted tugboats.

Though the numbers of vehicles being tested are relatively small, the diversity of ZECV applications demonstrates the real-world value of innovating with existing ZECV components to reach new vehicle markets. Off-road technologies are expected to have significantly longer life expectancies but much lower volumes than their on-road counterparts. Users purchase railcar switchers, cranes, cargo loaders and construction equipment at prices easily exceeding one million dollars and with an expected life of twenty or more years (EPA, 2005). Within this context the need to develop zero-emission components for higher volume on-road applications that can support and reduce the costs of off-road vehicles is even more critical.

Technology Transfer Between Systems

Certain ZECV technologies have been developed and incorporated in parallel between systems, providing new applications in vehicle systems. As Figure 1 illustrates, many technologies from closed systems with industrial purposes may be applied to improve on-road vehicle technologies. CARB describes the transfer of fuel cells from industrial lifts to range extenders that can be used in on-road trucks and buses, which are currently in pilot phases, as "enabling, if not in all cases directly leading to, additional applications" that include heavy-duty applications such as GSE and transportation refrigeration units. This technology transfer is also underway in commercial harbor craft, including ferries, excursion vessels, crew and supply vessels, and barges (CARB, 2020a).

Innovation between systems goes both ways; on-road technologies can also be used to provide zero-emission solutions for port and off-road equipment. Zero-emission bus and other on-road technology has been applied in marine equipment and in heavy-duty truck applications around the world:

- A hybrid-electric excursion vessel based in the San Francisco Bay area used a system that component supplier BAE Systems traces directly to the powertrain developed for a 60-foot hybrid electric articulated transit bus (CARB, 2020);
- In northern European ports, such as the ports around Copenhagen, demonstration projects are testing all-electric applications of passenger and vehicle ferries (E-Ferry, 2020);
- The Port of Stockton, California is testing 18 of the first commercially available all-electric large-capacity forklifts, which can lift from 30,000 to 70,000 pounds (CARB, 2020); and
- The world's largest all-electric vehicle is a dump truck in Switzerland that transports 60 tons of materials downhill, regenerating while laden to power its return trips uphill (Popular Mechanics, 2019).

Technological Evolution on Schedule

Innovation to new beachhead applications is a natural, orderly, and productive process that industry and government entities should prepare for and facilitate. The California Air Resources Board describes progress toward new applications: "The success of this [beachhead] strategy has been extremely valuable as a framework for planning the introduction timelines of medium- and heavy-duty electrification. Rather than expecting market launches randomly, there is a clear and sequenced cadence to the growth of zero-emission capabilities. Utilities, cities, fleets, and government agencies can better plan the phased timing of infrastructure deployments, supporting policies, incentives, and development of funding and use regulations based on this steady expansion and progression." (CARB, 2020).

Manufacturing Improvements

Refining vehicle component production and distribution is a critical step to reducing costs and improving performance. As production scales up to meet growing demand, process improvements and falling component costs will make vehicles more affordable in the initial markets of first success. McKinsey estimates that electric vehicle production costs in the light-duty segment will fall by over 20 percent by 2025 owing to falling battery manufacturing costs and process improvements (McKinsey, 2019). Within a beachhead market, where production volumes are expected to increase and supply chain management will become more streamlined, production costs are also expected to fall. Similarly, the cost of hydrogen for fuel cell vehicles is currently expensive relative to diesel, but fuel costs are expected to decrease as fuel cell technology and the scale of hydrogen production and fueling sites increases.

Zero-emission vehicles are known for needing fewer major components for their operations, but those components are specialized and relatively new to the vehicle market, particularly in the commercial space. Each of these components must be manufactured and installed in an efficient, cost-effective manner that reduces battery weight and space requirements, emphasizes reliable performance, and can be produced quickly to assemble new vehicles or to provide replacement parts. Because the market is new and manufacturing volumes are low, many components (particularly the main batteries) are expensive. A robust ZECV market will require reduced costs and readily available component parts.

The ZECV market may benefit from the efficiency technologies that have been developed for diesel- and gasoline-powered vehicles. The supply chains that produce components for hybrid-electric engines and idle reduction technologies may apply and support ZECVs. Manufacturers (and ultimately, fleets) benefit not only from production improvements specific to the ZECV market but to the vehicle market broadly. Efficiency standards in nations across the world will support the reduced costs to build ZECVs through lower shared component costs.

Process Improvements

By concentrating component production and servicing in regions that follow the beachhead model, vehicle manufacturers and dealers can streamline their processes, generate consumer confidence, and improve the total cost of ownership for fleets. Concentrating production and deployment in beachhead regions may yield the following process improvements:

- Production Expertise: Knowledge of local regulations and needs may help companies find inroads and innovate to new market opportunities. A New York City regulation, for example, requires school buses to not exceed 102 inches, which is narrower than a typical Type C or D school bus (NYC DOT, 2020). Vehicle manufacturers active in the New York City market with local knowledge of vehicle requirements have an advantage because they can tailor their products for specific fleets, and they also develop expertise in modifying and adapting their technologies. Similarly, vehicle modifiers and upfitters that alter existing chassis may develop a relationship with a regional client that increases the efficiency of producing a custom-built ZECV.
- Enhanced Customer Service: Many of the ZECVs on the roads across the globe are all-electric transit buses. These buses may have been built by traditional manufacturers that have added electrified variants of their products (e.g. New Flyer) or by companies that are newer to widespread commercial vehicle operation and only produce zero-emission products (e.g. Proterra). In either case, the companies would be either new to servicing zero-emission components or to providing vehicle services that are unrelated to electric drivetrains. The beachhead model allows companies to improve their customer service in concentrated areas with workforces hired for these specific tasks than can respond immediately.
- Workforce Training: Fleets that operate traditionally fueled vehicles will require training on how to charge, maintain, and safely operate ZECVs. As leading ZECV knowledge centers, manufacturers may be called upon to provide training for fleet operators. Providing training within a concentrated beachhead market will allow manufacturers or fleets to consolidate the workforce to train and to limit the amount of travel and training required.
- Infrastructure Improvements: ZECVs often require extensive infrastructure investments to operate. A single transit bus charging at a depot can draw from 60 – 100 kW, or from 300 – 450 kW if charging at a fast charging station or on-route overhead charger.[13] A single, large transit bus fleet simultaneously charging at the lower end of DC fast charging can exceed the power demand of a very large commercial building (CALSTART, 2015). Charging ZECVs will require a new paradigm of managed charging, thoughtfully and cost-effectively siting and upgrading infrastructure and utility interconnections, ensuring interoperability between stations to maximize the efficiency of infrastructure investments, and improving infrastructure

[13] From CALSTART collaborative research at transit agencies in Minnesota and Utah

design to meet future demands. Being mindful to right-size infrastructure needed for ZECV fleets will economize on upfront cost (such as reduced electrical infrastructure upgrade costs from additional distribution facilities) as well as on operating cost (from lower demand charges incurred by charging that is controlled to reduce coincidence across vehicles and with system peaks). Even in the case of fuel cell electric vehicles, installing hydrogen stations will likely require navigating unique regulations and technological barriers to deployment (NYSERDA, 2006). Beachhead markets enable manufacturers and fleets to revise and refine these infrastructure challenges as they expand their ZECV operations.

Combining the overall manufacturing and process improvements with efficient component transfers within a supply chain will greatly reduce the total cost of production and support the rapid growth of new vehicle applications and markets. These techniques and improvements will demonstrate the maturity and suitability of zero-emission vehicles to the commercial vehicle space and will prime industry to take the next steps to innovate and expand beyond initial markets of first success.

Chapter 3. Supportive Policy Ecosystems

Following beachhead pathways toward successful ZECV deployments, first-mover industrialized regions with significant commercial vehicle markets may serve as bellwethers for subsequent regional success. These vital first-mover regions include China, the European Union, the United States led by California, Canada, Japan, and South America. If vehicles in beachhead applications are commercially viable in these beachhead regions, the global ZECV market will benefit from zero-emission vehicle technology reaching economies of scale and cost-competitiveness. These regional beachhead markets can foster advanced, clean technologies in a developing marketplace and will provide transformative examples for the next wave of cities, states, or regions looking to advance their clean vehicle economies.

Conditions for Successful Beachhead Applications

Success in beachhead applications depends on whether ZECVs can overcome key barriers, including higher upfront costs and insufficient model availability, infrastructure, fleet awareness, or user demand. The following conditions are reliable indicators that a beachhead application will be successful:

- **Models are available:** Vehicle models in beachhead segments are a vital and unmistakable first step to achieving initial ZECV adoption. In addition, model diversity creates a more competitive marketplace and allows a greater number of fleets to participate in the new ZECV market. In the light-duty vehicle sector, greater model availability was found to be critical for market growth (ICCT, 2019).
- **Infrastructure is installed or available:** Charging or fueling must be affordable and available in the form most fitting for a beachhead application (i.e. depot, on-route, or opportunity). Fleets must be confident that they will be able to reliably complete their routes. The Netherlands has been a leading market for light-duty and medium- and heavy-duty electric vehicles, owing in large part to national efforts to make charging infrastructure widely available and interoperable, allowing any vehicle to charge at any station and improving the business case of station operators and encouraging investment in infrastructure (McKinsey, 2014). The state of California requires electric utilities to consider public transportation infrastructure investments, expanding infrastructure availability (CEC, 2020).
- **Vehicles achieve cost parity:** In a competitive market, ZECV fleet operators cannot compromise profits for the sake of operating cleaner vehicles. Improvements in manufacturing and servicing vehicles, combined with incentives for ZECV ownership and operation or penalties for diesel-powered vehicle ownership and operation, will make the total cost of ZECV ownership equal or less than a diesel-powered equivalent vehicle. Removing purchase cost as a barrier is one of the most critical steps in promoting alternative fuel vehicles, as has been demonstrated in California through the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP), which has made the state a leading market for hybrid, natural gas, and all-electric commercial vehicles (CALSTART, 2019).
- **Governments adopt enabling policies:** Diesel-powered vehicles will be difficult to initially displace due to their existing built infrastructure, the current low cost of the vehicles and of diesel fuel, fleet familiarity with the technology, and a lack of pricing mechanisms placed on carbon or air pollutants. To balance the equation, governments can support ZECV beachhead

applications by enacting supportive policies and actions that make operating ZECVs more attractive relative to diesel-powered vehicles (including making operating diesel-powered vehicles less attractive). Enabling policies may include financial incentives to improve the total cost of ownership or other actions that support ZECV adoption. Examples of such enabling policies include regulations on manufacturer ZECV sales, clean fuel standards that promote the use of zero-emission fuels, zero-emission zones in city centers, fleet-friendly financial incentives for vehicle purchases, and others (see "Enabling Policies" section for great detail.

- Fleets adopt ZECVs: Fleet managers need certainty in their operations and therefore must be familiar and comfortable with new ZECV applications before adopting them. The California Air Resources Board recommends that captive fleets in sites with multiple operations, such as at freight facilities or large depots, make optimal targets for familiarizing new fleets with ZECV technologies (CARB, 2020). Alternately, fleet management company DST rented and operated zero-emission deliveries for IKEA in Shanghai, thereby meeting demand for ZECVs while avoiding any uncertainty about new technologies and their operations (Fast Company, 2019).
- Freight users demand new zero-emission technologies: Demonstrated demand for new ZECV applications is a prerequisite for manufacturers to build those vehicles. As beachhead applications expand beyond initial transit bus deployments, freight carriers must signal their intent to purchase zero emission cargo vans and trucks. EV100 and the Corporate Electric Vehicle Alliance are examples of consortia of global fleets aimed at promoting zero-emission technology adoption (Climate Group, 2020) (Ceres, 2020). Several large logistics companies, notably Amazon and the United Postal Service, have taken the step to invest billions of dollars in new vehicle models and technologies that will directly support their services (Forbes, 2020) (UPS, 2020).

Cities and urban areas will serve as the frontline for ZECV beachhead applications; not only does their density offer more suitable duty-cycles and makes managing vehicle fleets more opportune, but cities are frequently the drivers in addressing the contribution of mobile source emissions to local air pollution. Established beachhead technology applications already serve cities (e.g. transit buses) and the nearby large ports that are typically situated around cities and urban regions (e.g. forklifts). Cities have demonstrated commitment to supporting ZECV beachhead technologies, such as the dozens of cities that have signed the C40 Green and Healthy Streets Declaration that signals the intent to create zero-emission areas and convert transit bus fleets entirely to zero emissions (C40, 2020). With the right supportive policies and actions, cities and urban regions can be extremely influential in catalyzing local and widespread ZECV adoption (ICCT, 2020a).

Cities and regions that financially and operationally support ZECV adoption are more likely to entice manufacturers and vehicle upfitters and modifiers to develop and release new vehicle models. In California, for example, the Air Resources Board has funded a clean bus and truck voucher incentive program (HVIP) that has provided incentive funding for a variety of powertrain and vocation options for nearly a decade. With an early focus on conventional hybrids, the program has supported progressively cleaner and more advanced technology over time, with funding currently reserved only for near- and zero-emission technologies. The available funding and open technology format has resulted in nearly 150 unique near-and zero-emission commercial vehicle models registered under the program (CARB, 2020b). Additional policies and actions that either support or compel the transition to ZECVs will create greater opportunities for manufacturers and fleets to innovate with new vehicle models and platforms.

Enabling Policies

To support global action and progress in ZECV development and adoption, policymakers, manufacturers, fleets, utilities, NGOs, and others will need to understand which policies and actions can remove adoption barriers and accelerate ZECV uptake. Examples of these policies and actions include:

Policies and Actions Toolkit

CALSTART's "Policies and Actions Toolkit" catalogues and categorizes examples of enabling policies from around the world. This free online tool defines these policies actions, where they are being used, case studies of their successes, additional resources for in-depth research, and a matrix that allows for comparison between strategies:

http://toolkit.globaldrivetozero.org/

Manufacturer Sales Requirements: ZECVs may become more commonplace or even ubiquitous at state or federal levels through the support of regulations that require automakers to sell ZEVs as a rising percentage of total sales over time. California has approved the Advanced Clean Truck (ACT) rule to support the growth of medium- and heavy-duty freight vehicles by setting a minimum percentage of ZE truck sales for each obligated manufacturer and providing those automakers with flexibilities to meet requirements through a crediting system (CARB, 2020e). The ACT rule builds upon the success of California's light-duty ZEV program that the Chinese government adapted for its own ZEV program (CARB, 2020f) (ICCT, 2019a).

Fleet Procurement Requirements: Zero-emission transit buses are at the leading edge of the beachhead model. Regulations requiring transit operators to plan for and purchase ZECVs offer the dual benefits of familiarizing and integrating beachhead technologies within a city or region and helping that city or region to improve local air quality, meet GHG reduction goals, and eventually improve the total cost of ZECV ownership. For example, California's Innovative Clean Transit regulation requires all public transit operators to gradually shift procurements toward zero-emission transit buses until all new bus purchases must be zero-emission beginning in 2029 (CARB, 2020d). As other heavy-duty fleet vehicles become commercially available, municipal fleets may also be obligated to purchase ZECVs. The two largest cities in the United States have both issued requirements for their municipal fleets to transition to ZECVs (Drive to Zero, 2020), 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 (European Commission, 2020). This process of aggregating municipal purchases provides member states with flexibility for how to efficiently allocate procurements between fleets.

Fleet-Friendly Purchase Incentives: One of the most direct methods of promoting ZECVs is creating a financial incentive that makes manufacturing, owning, or operating a vehicle less expensive. Reducing the up-front cost of a ZECV, typically higher than that of a petroleum-powered vehicle, has been a common tactic in some of the regions with the highest rates of ZECV adoption. For example, voucher incentive programs in California and New York help reduce the purchase price of low- and zero-emission commercial vehicles through an innovative voucher system that provides a point-of-sale discount to fleets (CARB, 2020c) (NYSERDA, 2020). 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, 2019a).

Congestion Zones and Pricing[14]**:** Cities may require payment for vehicles to enter a restricted zone to ease urban congestion and improve urban air quality. Reducing or eliminating payment for ZECVs to enter a congestion zone creates a financial reward for adopting ZECVs, as the cost of doing business in congestion zones is lessened relative to operating conventionally powered trucks or buses. London's Ultra Low Emission Zone requires payment for vehicles that do not meet emissions standards to drive into the central city; as emissions standards for commercial vehicles increase and the regulated zone expands in size, ZECV operators will save on fees to access central London (TFL, 2020). Fleets operating within the zone have already responded by switching to electrified delivery vehicles (UPS, 2018).

Access Fees: ZECVs can become more attractive to fleet operators of they are more cost-effective. Placing taxes or fees on vehicles with tailpipe emissions improves the total cost of ownership for ZECVs relative to diesel-powered vehicles. Some ports or freight facilities are introducing fees on drayage trucks while encouraging air quality and GHG emissions improvements by providing preferential pricing or access for ZECVs. Over time, the access price for gasoline- and diesel-powered vehicles may climb high enough to practically prohibit these vehicles, leading to an entirely ZECV fleet. For example, the Ports of Los Angeles and Long Beach are experimenting with steadily rising access fees that may ultimately permit only ZECVs to operate on the premises (San Pedro Bay Ports, 2020). In Europe, some nations assess annual road taxes on diesel-powered vehicles but exempt ZECVs. One such road tax in Switzerland (Swiss Customs, 2020) has led a consortium of the nation's largest retailers to trial a fleet of long-haul FCEV trucks (Reuters, 2020).

Preferred Access Lanes and Zones: Many global ports and urban corridors are experiencing major congestion issues; reserving access to ZECVs reduces congestion while incentivizing clean transportation adoption. A Los Angeles County Metropolitan Transit Authority (Metro) and South Coast Air Quality Management District study found that reserving highway access to large regional ports for a zero-emission corridor is feasible (CALSTART, 2012). Separately, the New York State Energy Research & Development Authority determined that "green loading zones," or reserving curbside spaces for zero-emission trucks, in New York City could cost-effectively promote ZECV adoption and help achieve the city's air quality and GHG goals (NYSERDA, 2014).

Zero-Emission Areas (Cities): Some cities (or sections of cities) may exclude polluting vehicles from entering designated boundaries. By providing a timeline for restricting vehicle access to cities and providing exemptions for ZECVs, these cities are creating a new and guaranteed market for zero-emission vehicle and fuel manufacturers to meet expected demand. Some countries have also announced policies intended to prohibit the sale of gasoline- or diesel-powered vehicles. These zero-emission areas have been implemented in European cities, such as Oslo's growing zero-emission city center (Fjellinjen, 2017) (Urban Access Regulations, 2020) or across the Netherlands, where 30-40 of the largest cities will implement zero-emission freight zones by 2025 (C40a, 2020). Beijing has restricted access to delivery vehicles weight less than 4.5 metric tons, setting a ZEV target of 90 percent of all qualifying vehicles that enter the Fifth Ring Road (Baidu, 2019). As more megacities follow this path, a greater number of mayors will become increasingly aware of the emissions and noise benefits of zero-emission electric trucks and buses.

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[14] This category is differentiated from "Zero-Emission Areas" because congestion pricing programs or low-emission zones permit varying degrees of tailpipe pollution, whereas zero-emission areas explicitly prohibit tailpipe emissions or otherwise define zero-emission vehicles as the only qualifying technology allowed to enter an area.

Fossil Fuel Vehicle Exclusion (State, Province, or Federal): The elevated air quality impacts of diesel vehicles and a growing urgency to find cleaner, equitable transportation solutions with lower greenhouse gas (GHG) emissions has inspired some national governments to declare their intentions to exclude petroleum-powered vehicle sales or operations within their borders. Governments from around the world are considering such bans on internal combustion engine use or sales, which would make ZECV adoption compulsory in some nations as early as 2030. Examples of potential federal exclusion zones include European (France, the Netherlands, Slovenia, Sweden, the United Kingdom) and Asian (China, India) governments, as well as a North American province (British Columbia) (GTM, 2018).

Vehicle Registration Limits and Exemptions: Controlling license plates and vehicle regulations can impact and improve emissions in congested, urban areas with high levels of pollution and congestion. By placing a limit on new diesel-powered truck registrations and exempting or waiving restrictions on ZECVs, cities create a strong incentive for fleets to adopt ZECVs for immediate deployment. The City of Beijing places new gasoline- and diesel-powered vehicle registrations into a lottery, and the City of Shanghai limits such registrations through an auction system (Bloomberg, 2019a) (The Economist, 2018). Both cities exempt "new energy vehicles" that include ZECVs from registration restrictions.

Weight Exemptions: Battery systems typically add weight to vehicles relative to diesel engines and fueling systems. Vehicles are typically regulated with strict weight caps by vehicle type, creating a potential penalty that would require fleet operators to carry less cargo or pay a penalty for exceeding weight limits. Manufacturers are addressing battery weight concerns through vehicle efficiencies but have not yet reached comparable weights to diesel trucks. Exemptions to exceed weight limits will ease fleet ZECV adoption by eliminating the potential weight penalty. The California legislature allows a 2,000 pound weight exemption for all alternative fuel commercial vehicles, including electric and fuel cell vehicles (CA DOT, 2019). The European Union has implemented a two-ton (metric) exemption for zero-emission technologies to exceed class limits (EU Publications, 2019), though the absolute upper weight limit is still enforced (T&E, 2020).

Low-Carbon Fuel Standards: These standards place a cap on the carbon intensity of fuels and require that fuel suppliers sell aggregated fuels below that cap or incur penalties. This regulation creates incentives for clean electricity and hydrogen generation, which either lower a fuel supplier's aggregate carbon intensity or generate credits by third parties that can be sold to fuel suppliers. To make ZECVs more attractive, the European Union, British Columbia, California, and Oregon have low-carbon fuel standards require carbon intensity reductions in fuel content (Drive to Zero, 2020a). The Canadian federal government plans to introduce a low-carbon fuel standard proposal by the end of 2020 (ECCC, 2020).

Direct Infrastructure Investments: Widely available charging and fueling infrastructure remains a critical step toward widespread the adoption of ZECV, which will require separate charging investments from public light-duty stations to meet the large, high-speed needs of electrified fleets (FCEVs refuel more quickly than BEVs, and therefore hydrogen stations may be more commonly shared with light-duty fleets). Whereas diesel stations are already available to service fleets, fleet operators may have to pay to install charging and hydrogen infrastructure where it is not publicly available. To reduce ZEV operational costs, the United Kingdom's Department for Transport will provide 500 million pounds sterling to support public DC fast charging and hydrogen installations through 2025 (UK Low-Emission Vehicles, 2020). The state of New York has support ZECVs and other charging applications through its EVolveNY program that invests $250 million in targeted high-speed corridor charging projects (NYPA, 2020). The California Energy Commission will invest up to $20 million annually to develop up to 100 hydrogen stations that enable FCEVs to travel along freight hubs and corridors (CARB, 2020g).

Utility Regulatory Policy: Electric utilities are knowledgeable industry participants and may be able to accelerate ZECV infrastructure installations to facilitate ZECV adoption, but utility commissions or legislation may inhibit utilities' permission to participate in the market. California legislators and regulators recently combined to enable electric utilities' efforts to electrify transportation. In 2018 the California Public Utilities Commission gave approval for the use of nearly $800 million in ratepayer funds, with $579 million approved to deploy infrastructure primarily to support commercial vehicle fleets using zero-emission vehicles (CPUC, 2018) (CPUC, 2018a). The commission also supported new pricing policies that are favorable to the fleets and enable them to avoid costly demand charges, such as Pacific Gas and Electric's 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).

Aligned Policies: Jurisdictions sharing vehicle emissions targets, deployment goals, and accessible infrastructure standards ease burdens on manufacturers and improve the efficiency of adopting new technologies. In the deliberation over U.S. light-duty fuel economy standards, for instance, automakers have prioritized regulatory certainty across all markets rather than meet "a patchwork" of regulatory standards (Washington Post, 2020). To support the ZECV transition, fifteen leading states across the United States have are developing a shared set of principles to provide financial and non-financial incentives, support utility actions for developing charging infrastructure, develop uniform standards, and other actions (ICCT, 2020). (NESCAUM, 2020). Similarly, governments can set standards for charging and fueling stations that have interoperable hardware and software, ensuring that operators are able to connect their vehicles to the stations, interact with the station, and make easy payments. The state of California requires all charging stations to offer open charge point interface (OCPI) and allows for other additional billing standards (CARB, 2019).

Recommendations

The beachhead model approach to identifying, investing in, and expanding to new ZECV markets has already been demonstrated in first-success markets around the world. Regions that adopt and follow the beachhead theory of change will improve urban air quality and reduce GHG emissions while investing in a clean transportation economy. Policymakers should adopt enabling policies to accelerate the adoption of ZECVs such as regulations, purchase incentives, congestion pricing, preferred access or exclusion lanes and zones, and procurement requirements. The parallel implementation of such policies will send stronger signals to manufacturers to accelerate production volumes, which in turn will lower vehicle costs, encouraging fleets to speed ZECV adoption worldwide, and ultimately facilitating the large-scale transition to a zero-emission commercial transportation sector.

Appendix

Classification of vehicles varies greatly across countries and regions. In the United States vehicles are classified primarily by gross vehicle weight rating, or the estimated maximum curb weight of a vehicle with fuel and payload. In Europe and elsewhere, by contrast, several other factors are used to categorize vehicles: vehicle length, gross vehicle weight (but not rating), axle configuration, payload, and passenger capacity all contribute to classifying vehicles. Table A1, derived from International Energy Agency research, shows how selected countries and regions classify their commercial truck segments (IEA, 2017).

Table A1: Truck Classification in United States and Canada; European Union; China; and Japan

<table>
<tr><th></th><th colspan="2">United States & Canada</th><th colspan="4">European Union</th><th colspan="2">China</th><th colspan="4">Japan</th></tr>
<tr><th>Weight (t)*</th><th>Vehicle Category</th><th>Weight**</th><th>Vehicle Category ***</th><th>Weight</th><th>Trailers & Semitrailers</th><th>Weight</th><th>Trucks (Category by Weight)</th><th>Tractors (Category by Weight)****</th><th>Trucks Category</th><th>Weight</th><th>Tractors Category</th><th>Tractors Weight</th></tr>
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<tr><td>4 - 4.5</td></tr>
<tr><td>4.5 - 5</td><td rowspan="4">3</td><td rowspan="4">4.5 - 6.4</td><td rowspan="2">4.5 - 5.5</td><td rowspan="2">2</td><td rowspan="2">4.5 - 5.5</td></tr>
<tr><td>5 - 5.5</td></tr>
<tr><td>5.5 - 6</td><td rowspan="3">5.5 - 7.0</td><td rowspan="2">3</td><td rowspan="2">5.5 - 6.5</td></tr>
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<tr><td>7- 7.5</td><td rowspan="3">5</td><td rowspan="3">7.3 - 8.9</td><td rowspan="3">7 - 8.5</td></tr>
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<tr><td>8 - 8.5</td><td rowspan="4">6</td><td rowspan="4">8.0 - 10.0</td></tr>
<tr><td>8.5 - 9</td><td rowspan="6">6</td><td rowspan="6">8.9 - 11.8</td><td rowspan="4">8.5 - 10.5</td></tr>
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<tr><td>10 - 10.5</td><td rowspan="17">O4</td><td rowspan="17">> 10.0</td><td rowspan="4">7</td><td rowspan="4">10.0 - 12.0</td></tr>
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<tr><td>12 - 12.5</td><td rowspan="13">N3</td><td rowspan="13">> 12.0</td><td rowspan="3">8</td><td rowspan="3">12.0 - 14.0</td></tr>
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<tr><td>20 - 25</td><td>20.0 - 25.0</td><td rowspan="4">11</td><td rowspan="4">> 20.0</td><td rowspan="4">2</td><td rowspan="4">> 20.0</td></tr>
<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.

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