

# GLOBAL ROADMAP FOR REACHING 100% ZERO-EMISSION MEDIUM- AND HEAVY-DUTY VEHICLES BY 2040

---

Cristiano Façanha, PhD., CALSTART  
Bill Van Amburg, Strategic Advisor to CALSTART  
Peter Jenkins, CALSTART  
Owen MacDonnell, CALSTART

**June 2022**

# ACKNOWLEDGMENTS

This work was conducted with generous support from the ClimateWorks Foundation and the William & Flora Hewlett Foundation. The authors would like to thank key CALSTART staff for their critical review of and contributions to this report, including Jessica Olson, Robyn Marquis, Alycia Gilde, Kevin Walkowicz, and Fred Silver. This document is based on information gathered as of February 2022. Any errors are the authors' own.

No part of this document may be reproduced or transmitted in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission by CALSTART. Requests for permission or further information should be addressed to CALSTART, 48 S. Chester Ave, Pasadena, CA 91106 or [Publications@CALSTART.org](mailto:Publications@CALSTART.org).

All rights reserved.

---

Global Commercial Vehicle Drive to Zero

[www.globaldrivetozero.org](http://www.globaldrivetozero.org)  
**@TeamDriveToZero**

CALSTART

[www.calstart.org](http://www.calstart.org)  
**@calstart**

© Copyright 2022 CALSTART

# TABLE OF CONTENTS

<b>Acknowledgments</b> . . . . .	<b>ii</b>
<b>List of Acronyms</b> . . . . .	<b>iv</b>
<b>Figures and Tables</b> . . . . .	<b>v</b>
<b>Executive Summary</b> . . . . .	<b>vi</b>
<b>Chapter 1. An Implementation Framework for a New Global Standard</b> . . . . .	<b>.1</b>
<b>Chapter 2. Stage 1: Establish Beachheads</b> . . . . .	<b>.10</b>
<b>Chapter 3. Stage 2: Secure Policy Alignment</b> . . . . .	<b>.13</b>
<b>Chapter 4. Stage 3: Launch Long Haul</b> . . . . .	<b>.15</b>
<b>Chapter 5. Stage 4: Saturate Cities</b> . . . . .	<b>.18</b>
<b>Chapter 6. Stage 5: Build the Infrastructure Backbone</b> . . . . .	<b>22</b>
<b>Chapter 7. Stage 6: Complete the Network</b> . . . . .	<b>25</b>
<b>Conclusion: Urgent Action Needed Now</b> . . . . .	<b>.28</b>
<b>References</b> . . . . .	<b>.29</b>

# LIST OF ACRONYMS

ACF	California's Advanced Clean Fleet regulation
ACT	California's Advanced Clean Truck Regulation
BEV	Battery-electric vehicle
CARB	California's Air Resource Board
COP26	The 26th UN Climate Change Conference
GHG	Greenhouse gas
ICT	California's Innovative Clean Transit regulation
IPCC	Intergovernmental Panel on Climate Change
MHDV	Medium- and heavy-duty vehicle
MOU	Memorandum of Understanding
ZE	Zero emission
ZET	Zero-emission truck
ZECV	Zero-emission commercial vehicle
ZE-MHDV	Zero-emission medium- and heavy-duty vehicle
ZETI	Zero-emission Technology Inventory
ZEV	Zero-emission Vehicle

# FIGURES AND TABLES

## FIGURES

- Figure 1.** 6-Stage Strategy to Enable 100% ZE-MHDVs by 2040 (and 30% by 2030)
- Figure 2.** Launch of the Global MOU at COP26
- Figure 3.** Global ZE-MHDV Model Availability
- Figure 4.** Zero-Emission Medium- and Heavy-duty Vehicle range by Segment (CALSTART, 2022a)
- Figure 5.** Framework for ZE-MHDV Market Transformation
- Figure 6.** ZE-MHDV Commercialization Pathways and Sales Targets by Segment
- Figure 7.** Comparison of Global ZE-MHDV Sales Targets with California's ACT and ICT Regulations
- Figure 8.** The Zero-Emission Beachhead
- Figure 9.** Cumulative ZE-MHDV Model Availability (2019-2023)

## TABLES

- Table 1.** Summary of 6 Stage Key Actions and Outcomes

# EXECUTIVE SUMMARY

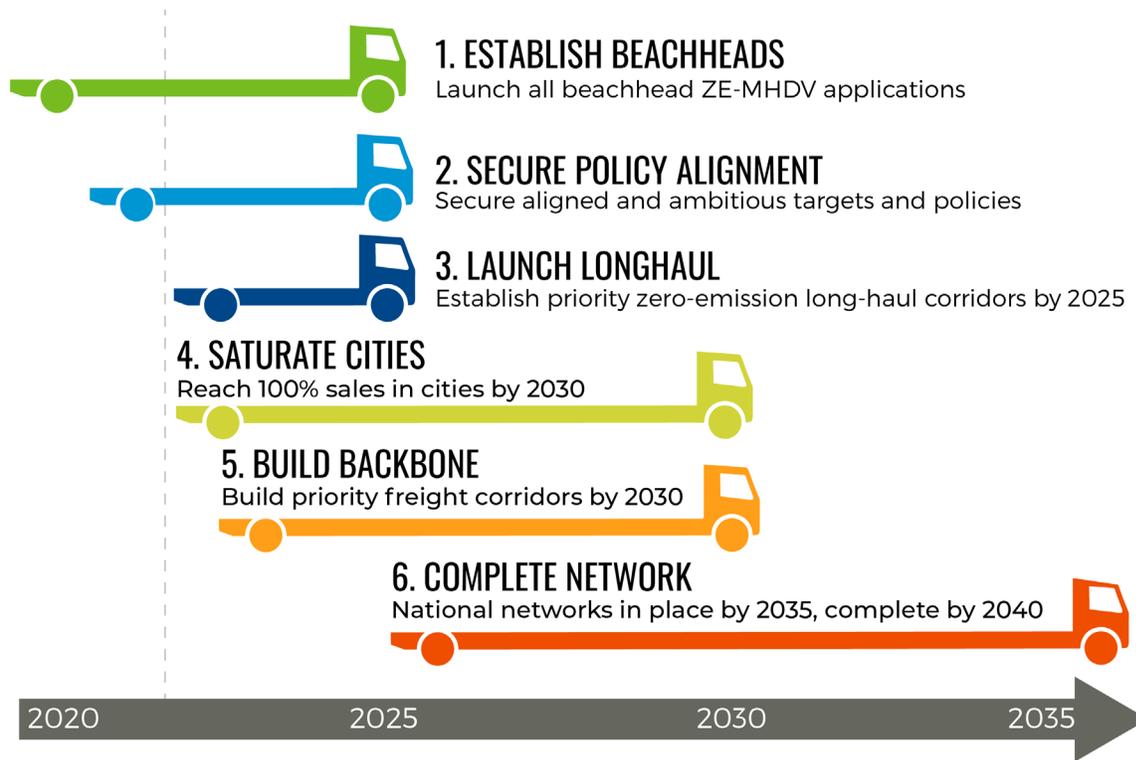
At COP26, an initial group of 15 leading nations signed a Global Memorandum of Understanding (MOU) for Zero-Emission Medium- and Heavy-Duty Vehicles, establishing a clearly defined goal of 30 percent zero-emission commercial vehicle sales by 2030 and 100 percent sales by 2040. Supported by over 40 subnational government and industry endorsements, this Global MOU is the centerpiece of a landmark Global Agreement on Zero-Emission Trucks and Buses establishing a clear pathway for the commercial on-road transportation sector to reach net zero carbon by 2050 in alignment with the Paris Agreement.

## AN IMPLEMENTATION FRAMEWORK FOR A NEW GLOBAL STANDARD

With this standard firmly in place, the focus must now shift to implementation. Successfully achieving the long-term outcomes established by the Global MOU requires a front-loaded implementation framework to guide government and industry partners and align policy and investment decisions. Working backwards from an end state defined by a complete market transformation to ZE-MHDVs, CALSTART's Global Commercial Vehicle Drive to Zero program and campaign of the Clean Energy Ministerial (Drive to Zero) has created a new global roadmap outlining the major steps required to enable 100% of sales of new medium- and heavy duty vehicles to be zero emission by 2040, defining the key elements – including goals, metrics, and timing – within and across each stage of this roadmap.

As a directional document, this six-stage strategy establishes an action plan and timeline for how to achieve Global MOU goals through an aligned set of discrete and actionable elements. Building on an established strategy and early progress in ZE-MHDV technology development and commercialization, this roadmap identifies and defines six discrete yet connected stages culminating with the full infrastructure network build-out, capital investment, and operational capability required for 100 percent of commercial vehicles to be zero-emission:

**Figure 1.** 6-Stage Strategy to Enable 100% ZE-MHDVs by 2040 (and 30% by 2030)



## A LIVING STRATEGY BUILDING ON PROGRESS

With a half-decade of experience accelerating the deployment of ZE-MHDVs globally, progress against this strategy is well underway. This roadmap therefore incorporates early learnings, current progress, and future needs, which continue to evolve and may differ across regions. As a directional document, this must be a living strategy, with input from partners and continued refinement over time. The six stages have been developed to run in parallel, not sequentially; indeed, most of them must run in parallel to meet the timing required. Each of the six stages progressively builds the framework to achieve 2040 outcomes, and each builds off or connects to the stages operating in parallel.

## GROWING AVAILABILITY OF ZE-MHDVS, BUT URGENT NEED TO ACCELERATE MARKET TO MEET TARGETS

Across global regions and commercial vehicle segments, there is robust ZE-MHDV model availability and a strong start to technology commercialization. This progress has been underpinned both by clear regulatory requirements in select markets and a steadily improving business case. However, full

market transformation to achieve 2040 goals will require much more than this. Operational capabilities are improving but current deployed volumes are still very low. Manufacturers need a strong market signal to ramp up supply and fleets and users need assistance to climb the learning curve and bring purchasing cycles ahead of target dates. Governments can help by providing a clear, predictable, and supportive policy ecosystem.

## STRONG POLICY ECOSYSTEMS NEEDED

California's experience provides a framework for early market success. Accelerating the transition to ZE-MHDVs requires strong goals backed by a clear regulatory framework and supported by targeted and timebound incentives and other technology and infrastructure investments. This strategy builds on California's early market transformation framework by taking lessons learned to identify the subsequent technology and policy outcomes required to achieve full market transformation.

## TECHNOLOGY READINESS, TOTAL COST OF OWNERSHIP AND PENETRATION RATE CAN MEET OUTCOMES

Cost parity and Total Cost of Ownership will be a key tipping point in the commercialization and mass adoption of ZE-MHDVs. Already, across several regions and vehicle segments, ZE-MHDVs have a more favorable TCO compared to fossil fuel alternatives, with full, un-incentivized cost parity for all medium- and heavy-duty vehicle classes in the US projected by at least 2035. However, deploying these vehicles at scale and achieving the full transition to ZE-MHDVs requires much greater stakeholder coordination, including global supply chain development, manufacturing capacity, fleet awareness, infrastructure development, and other public and private investment.

To guide this transition, CALSTART developed a "beachhead" strategy identifying first-success ZE-MHDV applications. "Beachhead" applications such as zero-emission transit buses and last-mile urban delivery vehicles serve as market introduction points to build initial volumes and expand supply chains for common components, allowing expansion into additional, more difficult applications as costs come down. Building on this beachhead strategy, and with the clear end-goal established by the Global MOU, CALSTART has evaluated ZE-MHDV technology penetration rates across different vehicle segments. This modelling demonstrates that the Global MOU goals are feasible and achievable and helps to inform this six-stage strategy and roadmap by identifying the major milestones – and their order of precedence – that must be met over the next two decades for full market transformation by 2040.

# CALL TO ACTION

The capability to transform the fastest growing sector for greenhouse gas emissions – transportation – into one of the main contributors to climate reductions is well at hand. It is technically feasible, economically desirable and brings crucially needed co-benefits in the form of cleaner urban air to long suffering communities. What has been lacking is coordinated action: a clear vision and plan to meet the urgent timeline and the political and social will to undertake it.

This document presents a new vision and outlines actions to align stakeholders and regions around shared 2040 outcomes. By setting an aggressive but achievable goal, broken into six discrete stages, this roadmap outlines a strategy for rapidly tackling one of the biggest transformations in human history in manageable and interconnected steps. With global governments and industry pulling together against this plan, on the same timing, its outcomes can be achieved. The key provisions of the six stages are summarized in the following chart.

## SUMMARY OF 6 STAGE KEY ACTIONS AND OUTCOMES

WHY IS THIS STAGE IMPORTANT?	WHAT IS NEEDED TO SUCCEED?	PROVISIONAL INDICATORS OF SUCCESS
<b>STAGE 1: ESTABLISH BEACHHEADS (2018 TO 2025)</b>		
<p>Establishes a common and understandable framework for electrifying complex truck and bus markets rapidly.</p> <p>Enables targeted policies in early segments of success.</p> <p>Helps launch early volumes and builds momentum.</p>	<p>Expand core awareness of ZE-MHDV technology readiness and emerging TCO parity.</p> <p>Assist early market success with targeted incentives and data sharing.</p> <p>Provide policy and implementation planning tools for transformation.</p> <p>Organize and align first-mover stakeholders.</p>	<p>Vehicle product availability in all beachhead applications and targeted regions.</p> <p>Vehicle product diversity in all applications (multiple OEMs providing products in each application and region).</p> <p>Component cost reduction over time.</p>

## STAGE 2: SECURE POLICY ALIGNMENT (2021 TO 2025)

<p>Sets clear and common global targets for ZE-MHDVs.</p>	<p>Countries set ambitious ZE-MHDV targets.</p>	<p>MOU countries represent 10% of global vehicle sales by 2022, 25% by 2023, and 50% by 2025.</p>
<p>Brings heavy transport outcomes in line with Paris agreement and California rules.</p>	<p>Countries establish strong policies to meet ZE-MHDV targets.</p>	<p>All MOU countries complete policy development by 2023.</p>
<p>Sends strong signal to industry and investors providing timeline and certainty of outcome, supply chain confidence.</p>		

## STAGE 3. LAUNCH LONG HAUL (2022 TO 2030)

<p>Launches the early implementation of long haul ZE-MHDVs; critical to reach 2040 goals because this segment takes longer to implement but is a big percentage of GHG emissions.</p>	<p>Identify and prioritize first zero-emission corridors in leading regions.</p>	<p>Zero-emission priority infrastructure phase-in roadmaps are established for all MOU nations by 2023.</p>
<p>Launches early implementation of long haul ZE-MHDVs; critical to reach 2040 goals because this segment takes longer to reach scale.</p>	<p>Organize coalitions of corridor users and secure funding.</p>	<p>Five OEMs are producing low volumes (500+ units/year) of long range capable (300-plus miles between charging/fueling) ZE-MHDV tractors by 2025.</p>
<p>Overcomes perceptions that electric drive technology cannot support longer routes and heavy trucks.</p>	<p>Develop infrastructure deployment roadmaps.</p>	<p>At least six high priority freight corridors are open and in low-volume operation (100+ trucks in each corridor) globally by 2025.</p>
<p>Accelerates the first build out of critical infrastructure connecting cities and freight hubs Develops policies, financial mechanisms, and infrastructure roadmaps to support electrified freight systems.</p>	<p>Align infrastructure providers.</p>	
	<p>Overhaul and streamline utility policies and pricing.</p>	
	<p>Determine best practices for broader sharing.</p>	

#### STAGE 4. SATURATE CITIES (2022 TO 2030)

<p>Focuses accelerated outcomes on urban applications most suitable to early electrification, which are critical to meeting 30% ZE truck goal by 2030</p> <p>Compensates for the longer time needed to scale long haul freight volumes</p> <p>Provides significant and focused air quality benefits to priority communities in locations where diesel performs worst</p>	<p>Implement regulations and supportive policies to ensure 100% of new transit buses, urban delivery vans and commercial trucks operating in cities are zero emissions by 2030.</p> <p>Implement aggressive zero-emission zones and other city-level policies such as curbside management to drive urban delivery electrification.</p> <p>Require utility investment and supportive rate structures to accelerate the build out of ZE-MHDV charging infrastructure.</p> <p>Enable public regional fast charging hubs.</p> <p>Determine best practices for broader sharing.</p>	<p>100% of new transit bus, delivery van and commercial truck sales in cities are zero emissions by 2030.</p> <p>Governments representing 25 percent of global vehicle sales implement fleet rules targeting 100 percent urban delivery electrification by 2030.</p> <p>100 cities implement zero-emission zones to cover all commercial vehicle applications and all portions of the city by 2030.</p>
--	--	---

#### STAGE 5. BUILD THE INFRASTRUCTURE BACKBONE (2025 TO 2035)

<p>Establishes the backbone framework of the zero-emission freight system with sufficient lead time for full build-out by 2040.</p> <p>Enables industry and infrastructure providers to learn lessons and refine systems as early as possible.</p> <p>Refines roadmap and template for the massive 2030-2040 build out.</p>	<p>Expand awareness of ZE-MHDV technology readiness and business case for long-haul.</p> <p>Direct public infrastructure funding to priority corridors and encourage private investment.</p> <p>Accelerate utility interconnection times and establish fuel policy consistency.</p> <p>Refine and expand infrastructure deployment roadmaps.</p>	<p>All OEMs have long haul (300-to-500-mile range with fast charge/fuel capability) ZE-MHDV products available and with enough supply to fulfill demand by 2030.</p> <p>Twenty (20) percent of each targeted region's primary freight routes have zero-emission recharging/ refueling available by 2030.</p>
---	--	--

<p>Provides a clear focus for capital markets and investors.</p> <p>Enables 2040: cannot meet 100 percent sales goals without base infrastructure.</p>	<p>Expand and coordinate coalitions of corridor users.</p>	<p>Zero-emission infrastructure roadmap for reaching 2040 build out is established and being pursued in all regions.</p> <p>Private capital is providing over 75% of infrastructure investment to build corridors.</p>
--	--	--

**STAGE 6. COMPLETE THE NETWORK (2030 TO 2040)**

<p>Fully enables 2040 target by ensuring that no ZE-MHDV is out of reach of the recharging/refueling network.</p> <p>Ensures ability to drive to all areas (95%+) of nations with a ZE-MHDV without risk of being stranded.</p> <p>Ensures the ability to drive to all areas (95%+) of nations with a ZE-MHDV without risk of being stranded.</p> <p>Enables faster fleet turnover by providing certainty; can encourage remaining adoption prior to the 2050 net zero carbon timeframe.</p>	<p>Make the case for complete transformation.</p> <p>Unleash capital investments to reach deployment scale.</p> <p>Integrate commercial vehicle electrification into grid modernization investments.</p> <p>Scale workforce to meet infrastructure expansion needs.</p> <p>Fill rural infrastructure gaps.</p>	<p>All primary freight corridors can support ZE-MHDV charging/refueling; 50 percent of secondary routes have adequate coverage by 2035.</p> <p>100 percent of primary and secondary routes and all rural connecting points have zero-emission infrastructure adequate to demand by 2040.</p> <p>Power/fuel generation, distribution and availability is fully adequate to meet the scale of 100 percent zero-emission commercial vehicle sales by 2040.</p>
--	--	---

# CHAPTER 1

## AN IMPLEMENTATION FRAMEWORK FOR A NEW GLOBAL STANDARD

In 2021 the world moved beyond a critical crossroads. It is now clearly on an accelerated path to full zero emissions for ground transportation.

**Figure 2.** Launch of the Global MOU at COP26



At COP 26, under a Global Memorandum of Understanding (MOU) for Zero-Emission Medium- and Heavy-Duty Vehicles organized by the Government of the Netherlands and CALSTART, fifteen initial countries<sup>1</sup> agreed to set, and develop action plans to achieve the goal of 100 percent zero-emission commercial vehicle sales

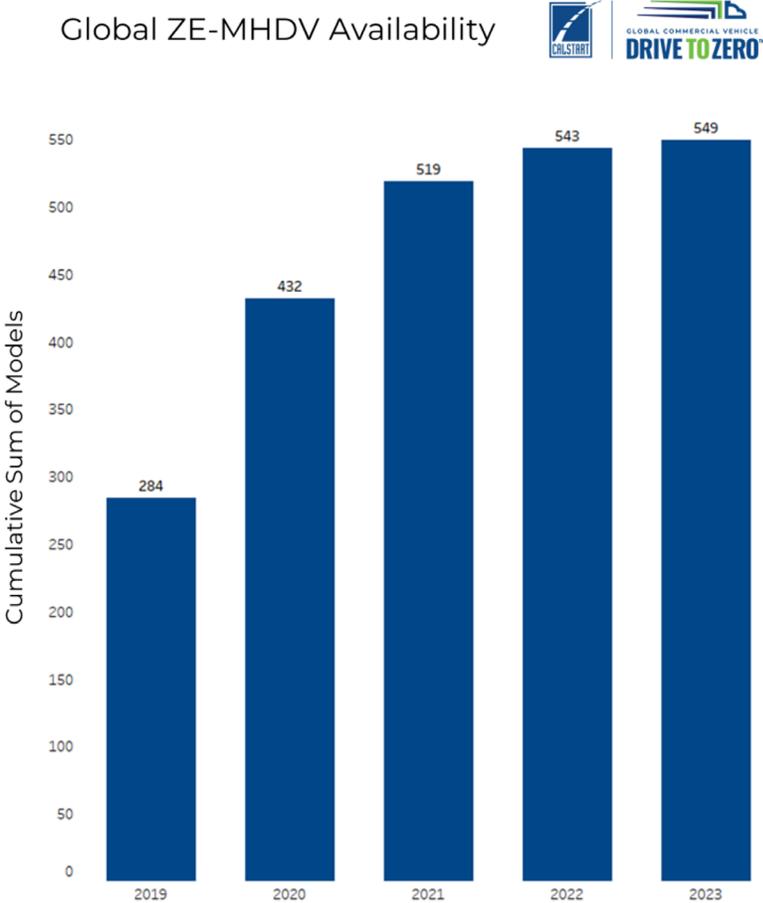
by 2040; and 30 percent by 2030 (CALSTART, 2022). This is the first time a clearly defined sectoral goal has been set for ground transportation and aligns with Paris Agreement to reach net zero carbon by 2050. Additional countries are expected to sign the agreement in 2022 and beyond (CALSTART, 2021).

This MOU – part of a broader Global Agreement on Zero-Emission Trucks and Buses that includes sub-national government, industry and fleet endorsements - has become the de facto new global standard (CALSTART, 2022). This standard is also aligned with the targets announced by most major global OEMs who have set 2040 as the date by when all new truck sales will be zero emissions or fossil free (CALSTART, 2021a). These first mover countries and industry partners are the vanguard of a growing groundswell to now focus on action and implementation and leave debate on targets and technologies behind.

<sup>1</sup> 16 countries as of May 2022 with Portugal signing the MOU

# GROWING ZE-MHDV MODEL AVAILABILITY AND CAPABILITY, BUT URGENT CHALLENGE TO MEET TARGETS

**Figure 3.** Global ZE-MHDV Model Availability



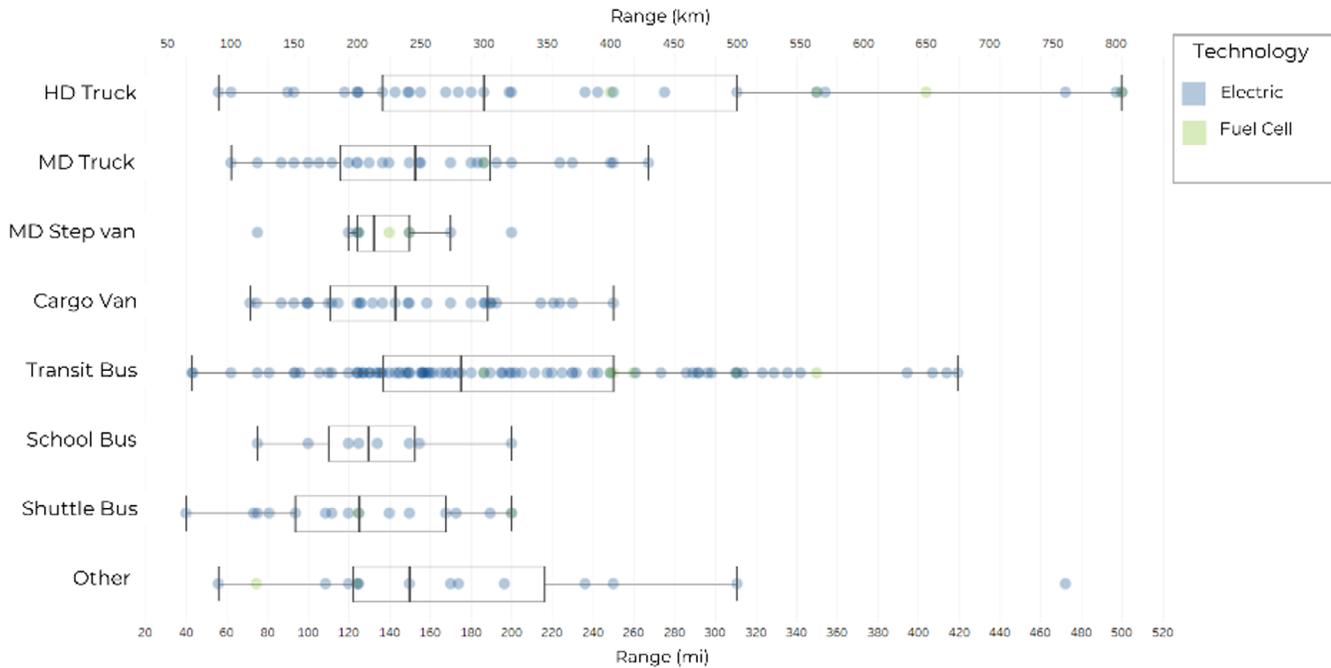
The real capability to manufacture and offer zero-emission medium- and heavy-duty vehicles (ZE-MHDVs) across multiple use applications is well documented by the Zero-Emission Technology Inventory (ZETI) tool and is steadily expanding. The number of ZE-MHDVs will grow by over 26 percent from 2020 to 2023 in all major regions (China, Europe, U.S./Canada) (CALSTART, 2022a). This capability is spurred by regulatory requirements coupled with growing business case benefits.

ZE-MHDVs today have also largely conquered the barrier of operational range in the main beachhead segments. This includes heavy-duty tractor-trailer duty-cycles like regional haul (characterized by an operational range of 480-km/300-mi), and heavy-duty urban operations (characterized by an operational range of 160-km/100-mi) (Zhang et al., 2021). While the most extreme

long-haul duty-cycles are still challenging to meet with current technology, this is rapidly improving.

Drawing from robust ZETI data, most available zero-emission heavy-duty trucks are able to drive between 160-km and 480-km (100-300 miles) with longer ranges coming in the next few years. ZETI data underscores the rapidly increasing number of available heavy-duty vehicles and provides fleet operators and policymakers with a snapshot of vehicle specifications and availability. Heavy-duty offerings such as the Volvo VNRe (442-km/275-miles), BYD 8TT (322-km/200-miles), Lion8T (400-km/250-miles) and the Tesla Semi (480-km/300-miles) are models that are either available or will be available in the next year that can tackle longer distances, with heavier loads. The figure below illustrates the ranges of available ZE-MHDVs tracked in ZETI from manufacturers today.

**Figure 4.** Zero-Emission Medium- and Heavy-duty Vehicle range by Segment (CALSTART, 2022a)



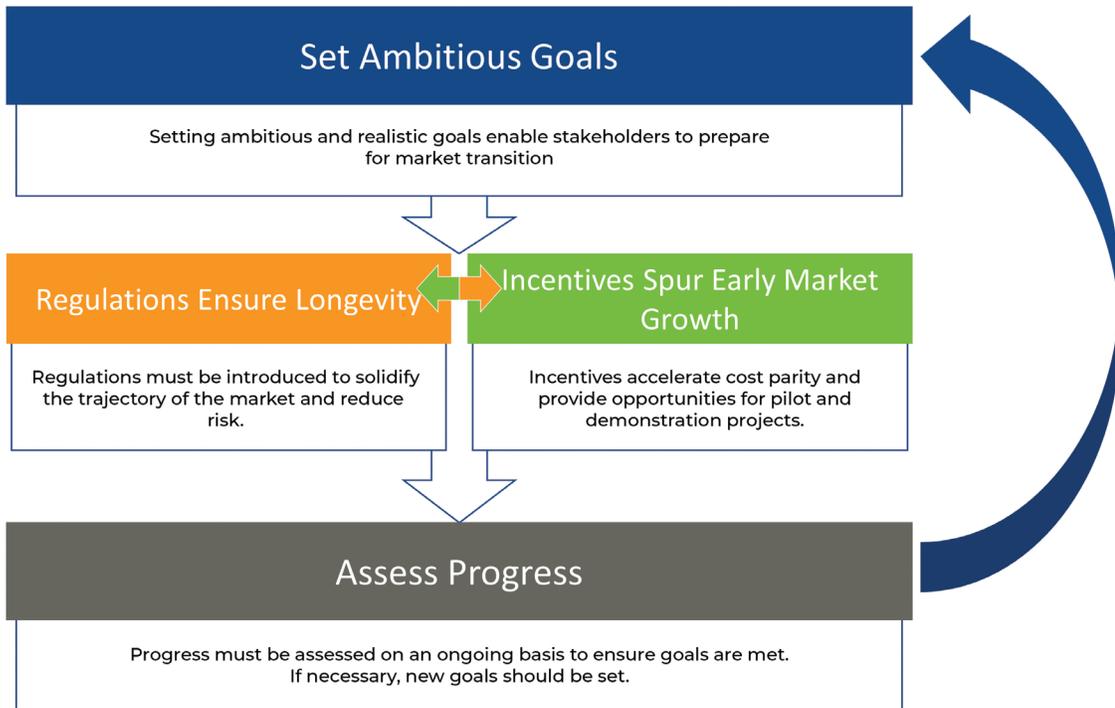
Despite this expanding ZE-MHDV capability, actual deployed volumes of zero-emission trucks and buses are still low and not yet on track to global goals, though industry production and fleet purchase commitments in the next several years are growing significantly (CALSTART, 2022b), (CALSTART, 2021b). OEMs must rapidly ramp up production and governments create supportive policy ecosystems to achieve the pace of ZE-MHDV introductions needed to reach the necessary volumes to meet emissions targets outlined by the Paris Agreement.

The goal is challenging, but with focused action, is achievable. Drive to Zero assessed the achievable sales targets for the primary global commercial vehicle segments (CALSTART, 2021b). It concluded that 2040 MOU outcomes are feasible and can be met. But key conditions, such as regulatory framework, policy support and infrastructure deployment are vital. Governments and industry must act more quickly.

## STRONG POLICY ECOSYSTEMS NEEDED

Setting clear and unified targets is a critical step to transform the market. It will lay the foundation for strong policies and accelerate work already well underway to build and deploy the first wave of zero-emission trucks, vans and buses.

**Figure 5.** Framework for ZE-MHDV Market Transformation



Drive to Zero has analyzed success models from early markets and has adopted a strategy heavily informed by California’s experience, as well as experience from Europe and China. This framework for ZE-MHDV expansion is guided by establishing strong goals, backing up those goals with a regulatory framework, and spurring and supporting achievement of requirements with concurrent incentives, investments and supportive policies. This ecosystem approach to market transformation forms the basis of the aggressive action plan implementation stages that will be required (CALSTART, 2022d). Many more jurisdictions must implement this comprehensive set of policies to drive ZE-MHDV adoption at the scale needed to meet global climate targets. Given the scale of the change and the short timeframe to achieve it, this transformation requires continued, consistent, and significant public and private involvement to establish the goals, set requirements and seed each successive step.

This transformation requires strong regulations. But in parallel, it also requires a portfolio of supportive policies, investments and incentives to meet the time remaining to meet goals. For instance, if legacy subsidies to petroleum and high carbon fuels remain; if supporting regulations and investment to install charging and fueling infrastructure and modernize the grid are not enacted; this transformation cannot happen in time.

# TECHNOLOGY READINESS, TOTAL COST OF OWNERSHIP AND PENETRATION RATE CAN MEET OUTCOMES

Strategies to rapidly transform markets are heavily informed by analyzing the key commercial vehicle segments and their ability to electrify, where they are in technology readiness, production scalability, market viability (based on Total Cost of Ownership – TCO), expected future costs, and projecting to potential sales penetration rates.

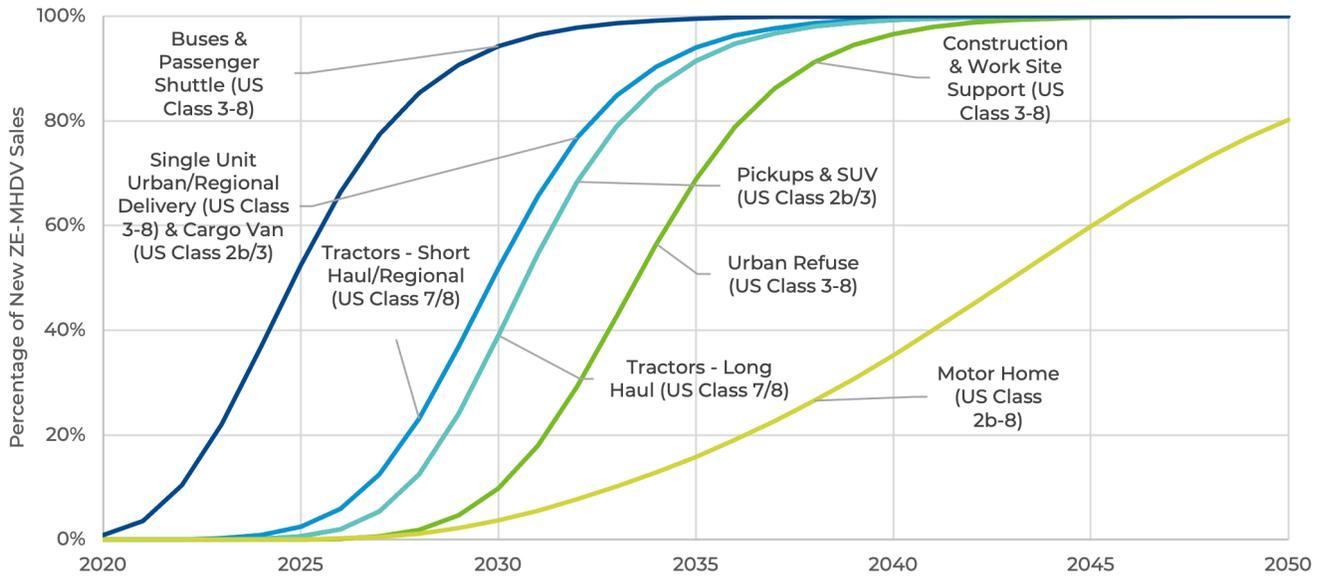
TCO is a key metric impacting penetration rate and mass adoption of ZE-MHDVs. In the absence of other drivers (such as strong sustainability and carbon reduction goals), economic impacts and business cost drive fleet owner choices in their acquisition of vehicles. Importantly, there are now many vehicle segments where ZE-MHDVs will cost less to operate than diesel and, despite higher acquisition costs, lead to positive economic benefits over their life. However, stakeholder understanding of these details is still lagging.

Most cost analyses hinge on the price of the battery pack, which is on a steep cost reduction curve. Batteries can comprise 30% or more of a current ZE-MHDV's price depending on the type, weight, and vocation of the vehicle (Statista, 2022). Lawrence Berkley National Lab researchers determined that a Class 8 BEV truck with a 375-mile range running a route of 300 miles per day can achieve 13% lower cost of ownership compared to an equivalent diesel model. This study showed that the extra costs of acquiring the BEV truck were paid back over 3 years, and over 15 years generated net present savings of \$200,000 (LBNL, 2021).

ZE-MHDV utilization and maintenance also plays a major role in the economics. A Transport and Environment report highlighted that in areas of Europe electric vans are now cheaper to own and operate than diesel equivalents (T&E, 2022). Vehicles operating close to their maximum utilization achieve greater savings on fuel costs and maintenance. The U.S. Department of Energy (DOE) National Renewable Energy Laboratory projects that ZE-MHDVs will achieve cost parity with diesel vehicles by 2035 for all medium- and heavy-duty vehicle classes without incentives (NREL, 2022).

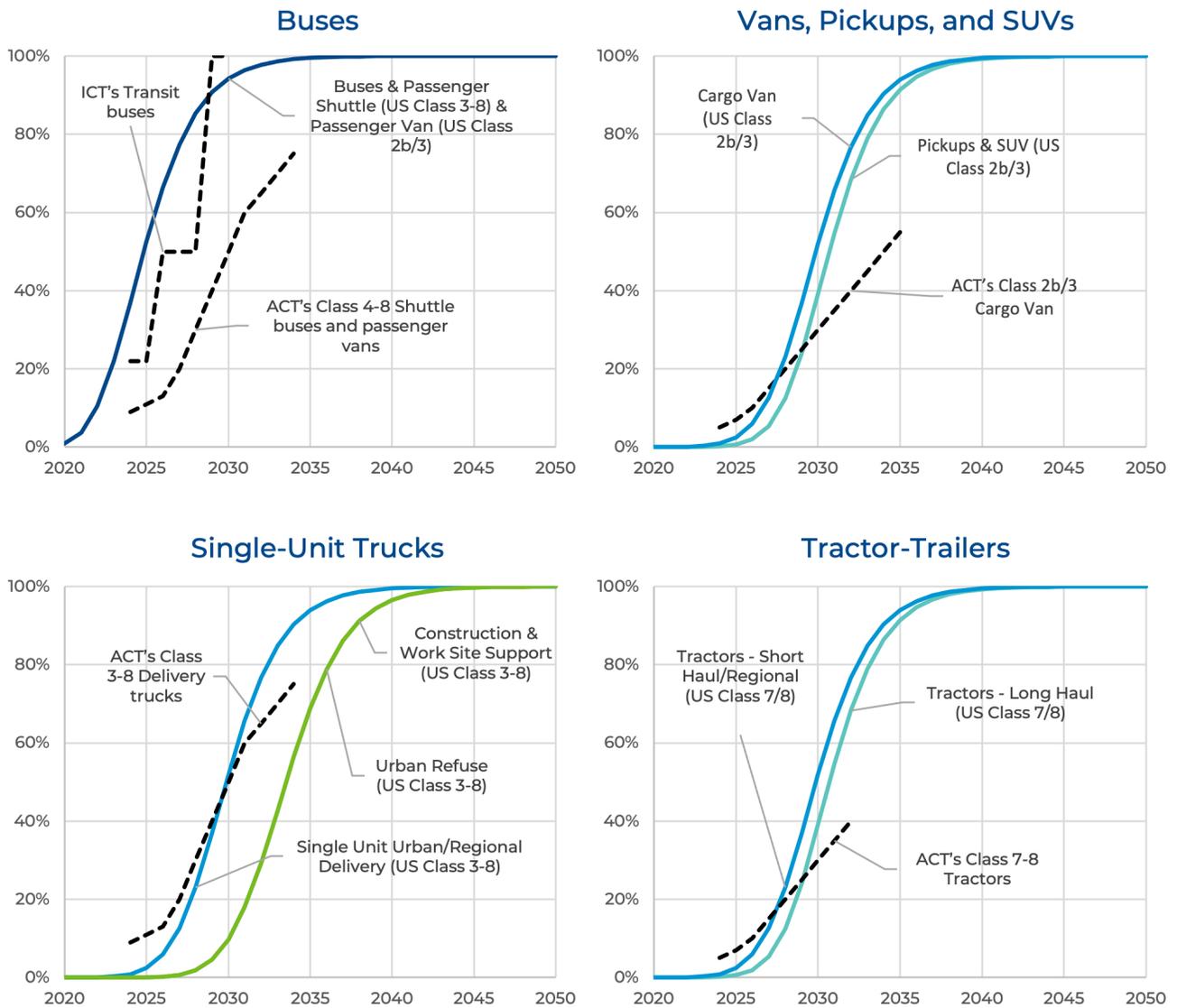
Using technology readiness and viability for key duty cycles, TCO and production scalability inputs, CALSTART has projected global zero-emission technology penetration targets and timing for the primary commercial vehicle categories and found the 2040 MOU goals are achievable (CALSTART, 2022c).

**Figure 6.** ZE-MHDV Commercialization Pathways and Sales Targets by Segment



Importantly, ZE-MHDVs will achieve cost parity even earlier in regions that have expedited policy and action to build a conducive ecosystem for the deployment of ZE-MHDVs. In regions such as Germany, France, and the Netherlands, cost parity of tractor trailers can be achieved by the end of 2022, with the United Kingdom, Italy, Spain, and Poland hitting this benchmark by mid-decade (ICCT, 2021). Analyses from China also indicate that all BEV segments will achieve cost parity by mid-decade, with FCEVs reaching this benchmark closer to 2030 (ICCT, 2021a).

**Figure 7.** Comparison of Global ZE-MHDV Sales Targets with California’s ACT and ICT Regulations



CALSTART has also identified the commercial vehicle segments that can be first-success applications. These “beachheads” serve as market introduction points to build initial volumes and expand supply chains for common components, allowing expansion into additional, more difficult applications as costs come down (CALSTART, 2020). Using this framework, CALSTART assessed zero-emission technology penetration timing for several commercial vehicle categories and compared this rate with the California Advanced Clean Truck (ACT) and Innovative Clean Transit (ICT) rule timing, and the goals of the Global MOU (CALSTART, 2022c). The penetration rates vary by category, as some vehicle platforms are farther along in production readiness and have different market attractiveness based on cost and the expected timing of battery and component cost reductions. This means some applications (such as urban duty cycles, broadly) can achieve faster adoption in the early years and that the pacing of ACT can be exceeded by targeting faster action in applications that can move more quickly sooner.

These adoption curves for different application types deeply informed the six-stage strategy that follows. It highlights the need to assist the early ramp up for longer haul, heavy transport trucks because of their longer lead time to scale and their more significant needs for route and corridor charging/refueling. It also made clear that the scale and rate at which regions can achieve cost parity for ZE-MHDVs is heavily dependent on the investments being made now by governments, OEMs and fleets, and supportive policies.

## REFINED GLOBAL PLAN REQUIRED TO MEET TIMELINE

The concept of “beginning with the end in mind” framed the Drive to Zero assessment of what is required to reach 100 percent ZE-MHDV sales globally by 2040. Given that there is insufficient time to “hunt and peck” a path to this goal, it is critical to prioritize the stages of work based on when technology products will be available, the unique infrastructure requirements of each succeeding application segment and where early volumes must be concentrated.

By assessing the capability and deployment gap between today’s reality and the 2040 outcomes, Drive to Zero has identified and established the major milestones that must be met – and their order of precedence – over the next two decades. These milestones comprise the six primary stages requiring coordinated and focused actions to surmount.

There is sometimes an assumption that with clear goals and regulations alone, manufacturers will develop their own unique and targeted segmentation and sales strategies to bring appropriate vehicles to market. But the actual implementation effort required and time remaining to achieve 2040 goals is significant, if not daunting. What is required is fundamentally transforming the global fleet and fueling infrastructure in less than two decades.

The reality of run-away climate emissions coupled with growing urban air quality impacts on communities requires this action. Public and private actions together must jointly address the biggest steps to achieving 2040 outcomes. Where to start and how to prioritize actions is critical to meeting this timeline. A new structure is required. The six stages will define the work of the next two decades.

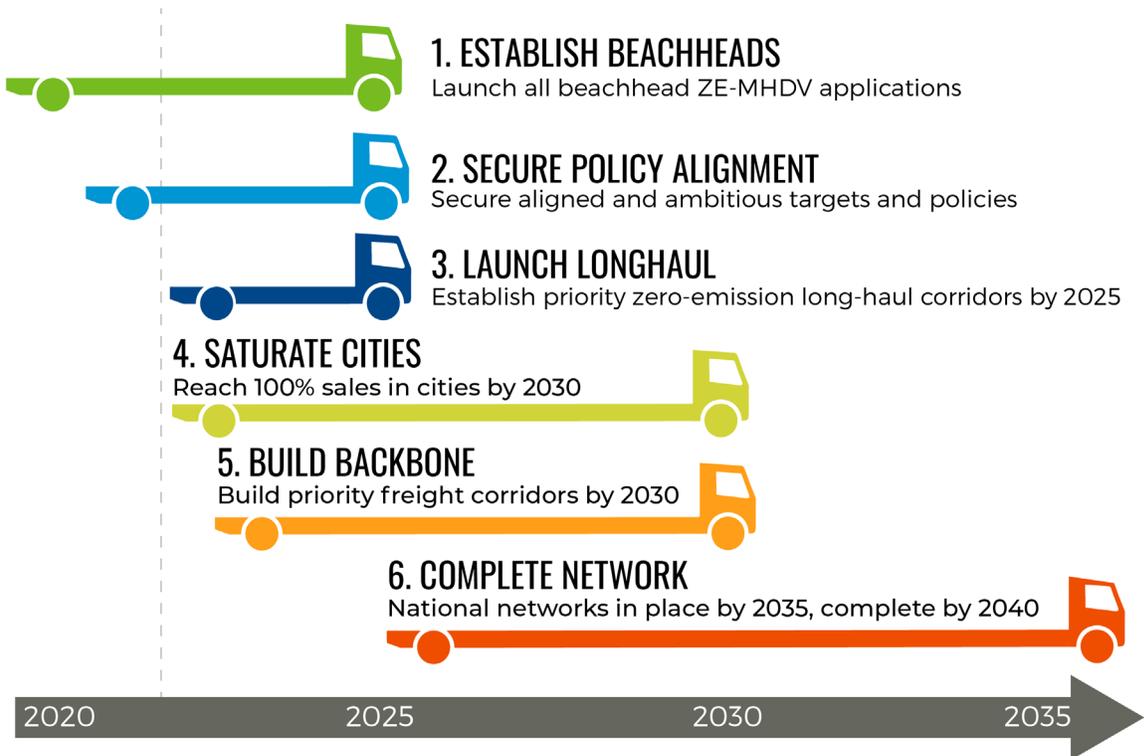
## SIX STAGES TO 100 PERCENT ZE-MHDV SUCCESS

The clear ambition that all new commercial vehicles must be zero emissions by 2040 means that the basic requirements needed to support these vehicles must be in place by then. A dominant part of this involves infrastructure installation and availability. Much of this work in the near term involves policy development and in the later years relies on establishing a broadly available network of fast charging and refueling sites accessible for all primary and secondary routes and duty cycles. This significant build-out can seem overwhelming. It is easier to address when broken down to more actionable and discrete elements.

Creating and then acting against these discrete, actionable stages comprises the core of Drive to Zero's new 2040 strategy plan. This six-stage strategy outlines HOW to achieve the ambition set by the Global MOU and sets in place the action plan and timing for Drive to Zero and its global government and industry partners. The six stages have been developed to run in parallel, not sequentially; indeed, most of them must run in parallel to meet the timing required. Each of the six stages progressively builds the framework to achieve 2040 outcomes, and each builds off or connects to the stages operating in parallel.

These stages are summarized in the section that follows. This strategy represents a living and constantly evolving plan. The initial indicators of success proposed for each stage will be refined yearly based on technology improvements, market dynamics and stakeholder capabilities.

**Figure 1.** 6-Stage Strategy to Enable 100% ZE-MHDVs by 2040 (and 30% by 2030)



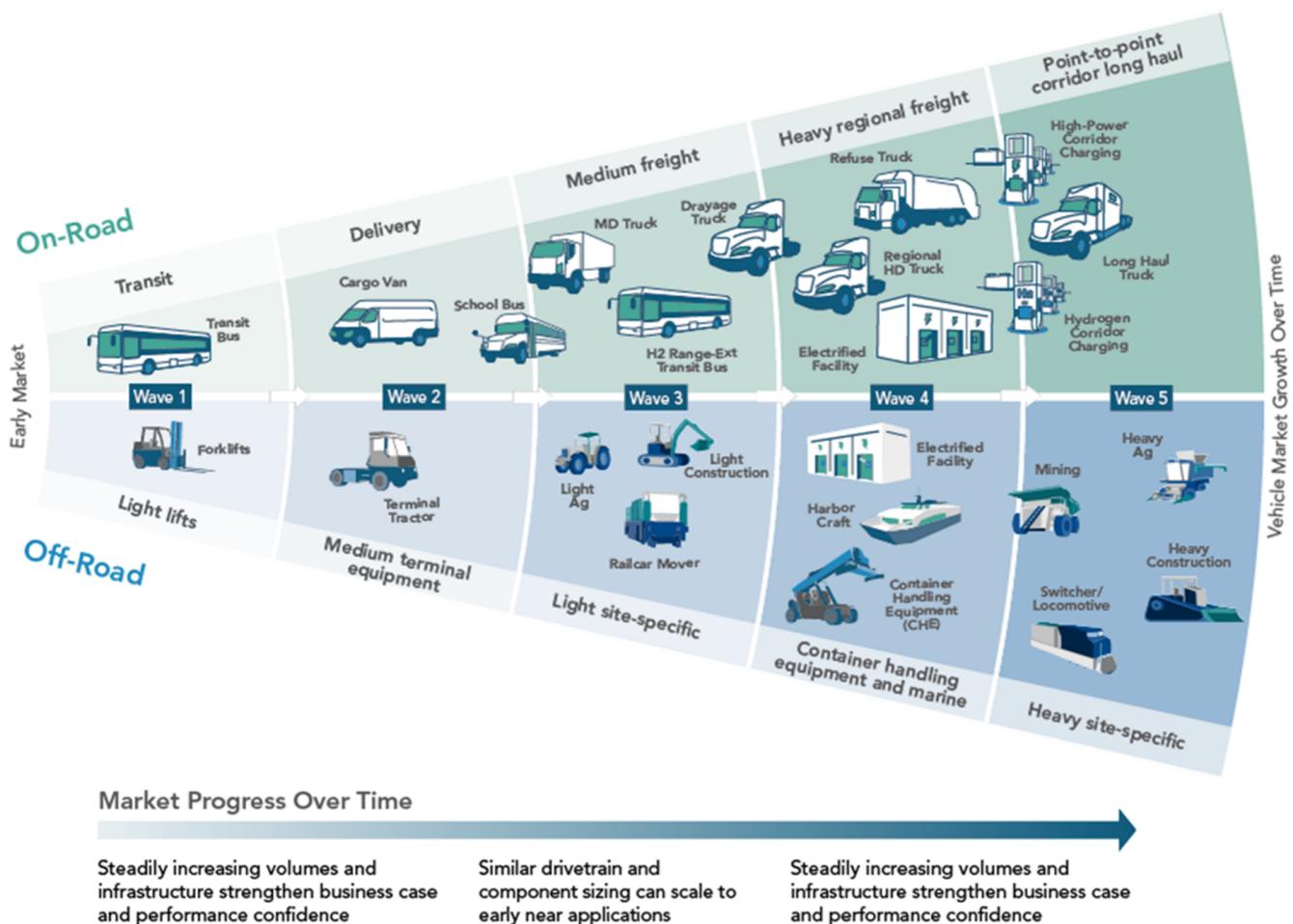
# CHAPTER 2

## STAGE 1: ESTABLISH BEACHHEADS

### Launch All Beachhead ZE-MHDV Applications

This stage formed the initial foundation of the Drive to Zero program and campaign. It focuses on the identification of first success applications – or “beachheads” – and targets action to accelerate deployments in those segments. Work against this stage has been underway for the past half decade.

**Figure 8.** The Zero-Emission Beachhead



It is based on the understanding that zero-emission technology is fully capable of performing multiple initial duty cycles and applications and can rapidly extend to broader use in additional markets as supply chain volumes drive down cost and engineering and technology improvements increase capability. These “beachhead” applications, identified in joint work with the California Air Resources Board (CARB) include transit, delivery, urban services, distribution, regional heavy haul and refuse (CALSTART, 2020).

*Why is this stage important?*

- It establishes a common and understandable framework for electrifying complex truck and bus markets rapidly
- It enables targeted policies in early segments of success
- It helps launch early volumes and builds momentum

*What is needed to succeed?*

**Expand core awareness of ZE-MHDV technology readiness and emerging TCO parity.** Raising the profile of the viability and reality of ZE-MHDVs is a critical element of the work needed in Stage 1. Policy makers are key. They need to be able to see, touch and feel the vehicles and understand the benefits vehicles bring to achieving climate and environmental goals. This can take the form of publications, on-line searchable inventories (such as the Zero-Emission Technology Inventory – ZETI – tool) and physical displays and expositions of the vehicles. As important is to document and showcase the economic and jobs benefits that come with their use. Fleet users need to become acquainted with and more comfortable with ZE-MHDVs and see that they can perform the daily work required. Manufacturers also need to see that real market demand exists and vehicle introductions will be supported and/or required.

**Assist early market success with targeted incentives and data sharing.** Building confidence, experience and momentum is critical to cementing the growth of the first markets. Seeding early successes with public funding reduces risks for manufacturers to build and fleets to deploy ZE-MHDVs which are still more expensive than conventional commercial vehicles. The launch of these first applications coupled with the sharing of lessons and best practices from them, have created a growing global understanding of the reality and viability of ZE commercial vehicles. The early volumes, aggregated across the regions where activity has started first (China, California and Europe) have also helped build initial component volumes and given confidence to expand component supply chains.

Electric transit buses represent a notable example of success. There is now tremendous momentum and confidence for completely transforming urban transit bus fleets to zero-emission operation in the near term based on the early support for and focus on products for this application. Similarly, in North America the electrification of school buses is starting to become a groundswell. Urban delivery has shown tremendous promise for transformation, though until 2022 product availability has been limited. This is changing. There have also been meaningful breakthroughs in zero-emission heavy freight tractors from almost every major original equipment manufacturer (OEM). These products are first aimed at urban heavy goods movement applications (drayage, urban logistics), but by 2023 will be capable of traveling between cities in longer distance corridors. Each of these early markets has been

assisted in its launch.

**Provide policy and implementation planning tools for transformation.** Providing policy makers with a suite of policies and actions that have proven effective in supporting ZE-MHDV deployments in other regions can provide guidance and confidence, along with policy case studies. Policy makers, utilities and manufacturers can also benefit from road-mapping exercises outlining potential vehicle introduction timelines customized to specific regions. This support can help focus demonstration and pilot deployments of ZE-MHDVs and build real-world experience.

Fleet users also need assistance to plan successful procurements and operations. Tools to support this stage include fleet purchase planning guides and Total Cost of Ownership (TCO) calculators, as well as vehicle availability tracking reports by application type, manufacturer and geographical availability and case studies of vehicle use. This provides secondary benefits in showcasing the products of manufacturers with early products. Importantly, infrastructure planning guides and tools are critically important as this is an essentially unknown realm to traditional truck operators.

**Organize and align first-mover stakeholders.** One of the most critical elements of this stage is to organize, build and support a global stakeholder base and to seek to align their actions, policies and investments. This builds momentum for action and leverages economies of scale. There is tremendous power in a shared vision and timeline to establish concurrent demand for common vehicle product architectures (similar components) worldwide to assist with growing supply chains and reducing cost.

#### *Stage 1 Indicators of Success*

- Vehicle product availability in all beachhead applications and targeted regions
- Vehicle product diversity in all applications (multiple OEMs providing products in each application and region)
- Component cost reduction over time

## CHAPTER 3

# STAGE 2: SECURE POLICY ALIGNMENT

### *Secure Aligned and Ambitious Targets and Policies*

Meeting global climate targets requires establishing strong governmental goals and policies that are consistent with needed reduction timelines and consistent worldwide. There is insufficient time remaining to achieve Paris Agreement reductions without this action. While Drive to Zero and other analyses confirm that ZE-MHDVs will have less expensive operational costs and will provide an improved total cost of ownership compared to diesel within this decade, a transformation reliant on market forces alone is not adequate to meet the pace of climate reductions needed.

*Why is this stage important?*

- It develops a clear and common global target for zero-emission trucks and buses
- It brings heavy transport outcomes in line with Paris targets
- It is aligned with the California regulatory model, a key launch market
- It sends a powerful signal to industry and to investors of stages and timelines needed and provides a certainty of outcome
- It encourages confidence that supply chain volumes can be established for higher levels, reducing net costs faster

*What is needed to succeed?*

A key part of the theory of change is to establish strong and clear reduction goals for ZE-MHDVs from multiple countries that are closely aligned globally, and then to secure national backstop regulations and supportive policies to ensure their achievement.

**Countries set ambitious ZE-MHDV targets.** This requires that a cohort of country governments first agree to set ambitious zero-emission commercial vehicle sales targets aligned with those in the Global MOU and California's Advanced Clean Truck (ACT) rule, equivalent to 30 percent zero-emission sales by 2030 and 100 percent by 2040. These goals have been aligned with Paris Agreement outcome pathways and represent the contribution commercial vehicles must make to its achievement.

As previously noted, the first cohort of 16 leading countries has already set these targets through

the Global MOU, committing to the 100 percent goal by 2040 and an interim target of 30% by 2030. The initial agreement was successful because it built on trusted relationships established between countries and key non-governmental organizations, as well as commitments and endorsements from manufacturers, fleets, suppliers and fuel providers that the technology was viable and becoming increasingly available.

**Additional countries sign ZE-MHDV target agreement to increase impact.** To reach the next tier of countries and to have a larger impact on the global vehicle inventory will require a significant communications and recruitment effort, particularly to ensure policy makers in additional countries and regions are aware of the operational and financial viability of ZE-MHDVs and the benefits to their countries. This can be done via sharing access to ZE-MHDV availability trackers, providing direct experiences with ZE-MHDVs, providing case studies and policy toolkits, as well as through direct contact with existing signatory countries as a mentoring group. Developing targeted regional roadmaps for ZE-MHDV deployment potential can be useful to support country decision-making. Hands-on access to and experience with ZE-MHDVs at regional or global events may also be a useful strategy. Industry leaders based in or doing business within targeted countries lending their support to the ZE-MHDV adoption goals will be extremely powerful.

**Countries establish strong policies to meet ZE-MHDV targets.** Once established, ZE-MHDV targets then become the framework for developing an enforceable action plan that includes specific regulations, policies and investment that can meet the targets. The first cohort of countries that signed the Global MOU have started the process of developing action plans to achieve the agreed goals through policies and regulations. For success, these action plans must be enforceable national requirements and ideally become trackable components of the National Determined Contributions (NDCs) from each agreeing country. The first countries who make these agreements and develop action plans can set the new standard and provide a support mechanism to assist additional countries who join the cohort. To have a significant impact on the global supply chain it will be important to secure agreements and policies from countries representing 25 percent of the global on-road commercial vehicle fleet, and ideally greater. Initial representation from countries representing 10 percent or more of the global fleet can have a huge impact on momentum and sales in early markets.

#### *Stage 2 Indicators of Success*

- 15+ countries sign MOU representing 10 percent of global vehicle volumes (by 2022)
- 25 countries sign MOU representing 25 percent of global vehicle volumes (by 2023)
- 10 countries have completed action plan development/policy implementation (by 2023)

# CHAPTER 4

## STAGE 3: LAUNCH LONG HAUL

### *Establish Priority Zero-emission Long Haul Corridors by 2025*

Because long haul freight trucks represent such a large percentage of ZE-MHDV miles driven, and therefore GHG emissions, they are a critical component of reaching 100 percent ZE-MHDV penetration by 2040. Most analyses – though not all – project this as the most difficult segment to become fully zero emissions because of the need to haul heavy loads over long distances, and the need for high-rate charging or high-capacity hydrogen fueling along freight corridors. Drive to Zero’s assessment is that short haul regional tractors will reach scale faster than long haul, which will lag behind urban applications in penetration rate in the early years.

#### *Context*

Despite current range limits, the long-haul segment shows some of the most compelling business case paybacks (due to the amount of expensive diesel fuel replaced) of all applications. Extended ZE-MHDV driving ranges and fast charging/fueling infrastructure expansion will enable higher utilization rates, greatly benefiting the business case. As of 2022, this capability is emerging with heavy freight tractors achieving ranges of 250-300 miles and longer ranges projected by 2023. Examples of these vehicles and their high-level specifications can be found in the Zero-Emission Technology Inventory (ZETI), where they are tracked globally. Examples include: Freightliner’s class 8 eCascadia (230+ miles), Volvo’s Class 8 VNRe (275 miles), Mercedes-Benz’s class 8 eActros (250 miles) Hyzon’s class 8 FCEV Tractor (up to 500 miles), Hyundai’s class 8 FCEV Xcient (250 miles). It is critical that the long-range transport of freight start the zero-emission transition process earlier than many observers anticipate because of the long leads times to build out infrastructure, the long lives of these vehicles and to overcome resistance and build understanding that ZE-MHDVs can perform this critical economic role.

#### *Why is this stage important?*

- It launches the early implementation of long haul ZE-MHDVs; this is critical to reach 2040 goals because this segment takes longer to reach scale but is a big percentage of GHG emissions
- It helps to overcome perceptions that electric drive technology cannot support longer routes and heavy trucks
- It helps to accelerate the first build out of critical infrastructure connecting cities and freight hubs

- It develops the policies, financial mechanisms, and infrastructure roadmaps upon which the future electrified freight system will be based

*What is needed to succeed?*

To successfully achieve 100% ZE-MHDV sales penetration by 2040, 2025 is a vital milestone. By that time, to meet ramp up timing, it will be important to have multiple long haul truck routes, or corridors, operating in at least demonstration mode in several different regions of leading countries. There are several key strategies needed to successfully implement this stage. They involve electricity charging rate structure, infrastructure funding and other supportive policy work. They also involve early mover partner mobilization, initial actionable freight corridor identification and prioritization, and project development and best practice sharing.

**Identify and prioritize the first zero-emission corridors in leading regions.** Given their status as early launch markets, the most promising regions for establishing the first zero-emission corridor segments will be Europe, China and California and key parts of the US and Canada. India may also offer a strong potential because of how freight trucks operate in that region. In each of these regions, it will be extremely useful to identify high priority freight routes with the strongest suitability for early zero-emission freight operation. These parameters can include length of driving segments between freight facilities, high volume of predictable freight traffic, siting locations for high-rate charging or hydrogen refueling facilities, willing first-mover fleet partners, capable manufacturers and products, funding for infrastructure installation, and other considerations.

**Organize coalitions of corridor users and secure funding.** An important effort involves identifying, organizing and helping coordinate first-mover goods movement shippers and fleets to identify their high priority and high success corridors for first development, and then to fund them. It will include obtaining commitments from fleets to purchase and operate ZE-MHDVs for zero-emission freight operation and to expand those purchases based on lessons learned. Truck manufacturers able to build and support longer range trucks on this timeline that can accommodate higher rate charging or refueling must also be identified and recruited. Coalitions can compete to secure public and private financing on highest priority first corridor segments.

**Develop infrastructure deployment roadmaps.** As the first corridors are identified and prioritized for deployment, the next tier of important corridors should be identified for phased implementation over the next five to ten years. These corridors can either extend the reach of these first segments or can be added to create a more complete network. The result of this work will be to create a regional or national location and timing roadmap for building out the primary, and then the secondary, freight routes by 2040. Such a plan can become the basis of national planning for infrastructure investments. In parallel with this is the work to capture the learnings from the first deployments and turn them into implementation templates that can be built into roadmap guidelines. This process will help speed follow-on deployments and build out these first corridors into a national freight system (Stage 5). The commitment to take first lessons learned and translate that into infrastructure roadmaps for selecting, financing, and building out a corridor network will be a key metric and important outcome of this stage.

**Align infrastructure providers.** Concurrent with this, infrastructure providers and site operators must be recruited who will invest in, maintain and operate the infrastructure for a successful zero-emission corridor with guaranteed performance, high reliability and backup contingencies. Similarly, fuel providers will be needed along the priority routes who can provide electricity and/or hydrogen at competitive and guaranteed pricing to support a successful business case. This will include, but is not limited to, regional electric utilities.

**Overhaul and streamline utility policies and pricing.** An important component of this stage, and to set the framework for the following stages to succeed, is the policy work needed to refine investment decisions and fuel pricing. In most regions of the world, electricity pricing is overseen at the sub-national level, often by states or provinces, leading to a patch work of pricing structures and policies. These long-haul zero-emission corridors can provide a recommended pricing and policy best practices tool kit to regional oversight bodies that uses lessons from first success markets, such as California, or low fuel cost regions, such as Texas. Policy work may be required with key regulators on electricity rate case structure; hydrogen pricing as a transportation fuel; policies to encourage or backstop infrastructure financing as well as targeted public co-investment/funding; and possibly policies to support use of public highway right-of-way for recharging/refueling siting.

**Determine best practices for broader sharing.** Finally, the lessons from these first corridors, and the resulting best practices and processes that can lead to their faster installation, need to be captured and documented to create templates for other regions and corridor segments to follow and upon which they can build. In parallel with this, an actionable roadmap for the build out of national zero-emission freight networks must be developed and in place (supporting Stage 6).

### *Stage 3 Indicators of Success*

- Zero-emission priority infrastructure phase-in roadmaps are established for all MOU nations by 2023
- Five OEMs are in producing low volumes (500+ units/year) of long range capable (300-plus miles between charging/fueling) ZE-MHDV tractors by 2025
- At least six high priority freight corridors are open and in low-volume operation globally by 2025

## CHAPTER 5

### STAGE 4: SATURATE CITIES

#### *Reach 100% ZE-MHDV Sales in Cities by 2030*

To reach the goals of full zero emissions by 2040, the beachhead applications must be firmly established well in advance. The earliest applications are primarily city or urban-based with known routes and depot-based charging/refueling requirements. These city applications, which represent anywhere between 40 and 60 percent of the vehicle inventory (though not the mileage) will likely need to represent the bulk of vehicles deployed needed to reach the 2030 goal of 30 percent of all sales, as longer haul trucks will take more time to reach deep penetration. In other words, reaching 30% ZE-MHDV sales by 2030 means reaching close to 100% ZE-MHDV sales in cities (combined with other approaches to providing zero emissions goods delivery and services, such as cargo bikes, mode shifting, etc.).

This is a fact that is too often overlooked by city, state and national policy makers and planners and the urgency around this stage needs to be greatly elevated. Without significantly increased policy action to deploy vehicles, through regulations, targeted vehicle incentives, and infrastructure investments, the 2030 sales goals, so critical to staying on track for 2040, will be difficult to reach. Importantly, several global commercial vehicle makers are committing to produce zero-emission products at rates that can exceed the 2030 targets (CALSTART, 2021b). The open question is whether the impacted fleets and needed infrastructure installations will be ready and can keep pace.

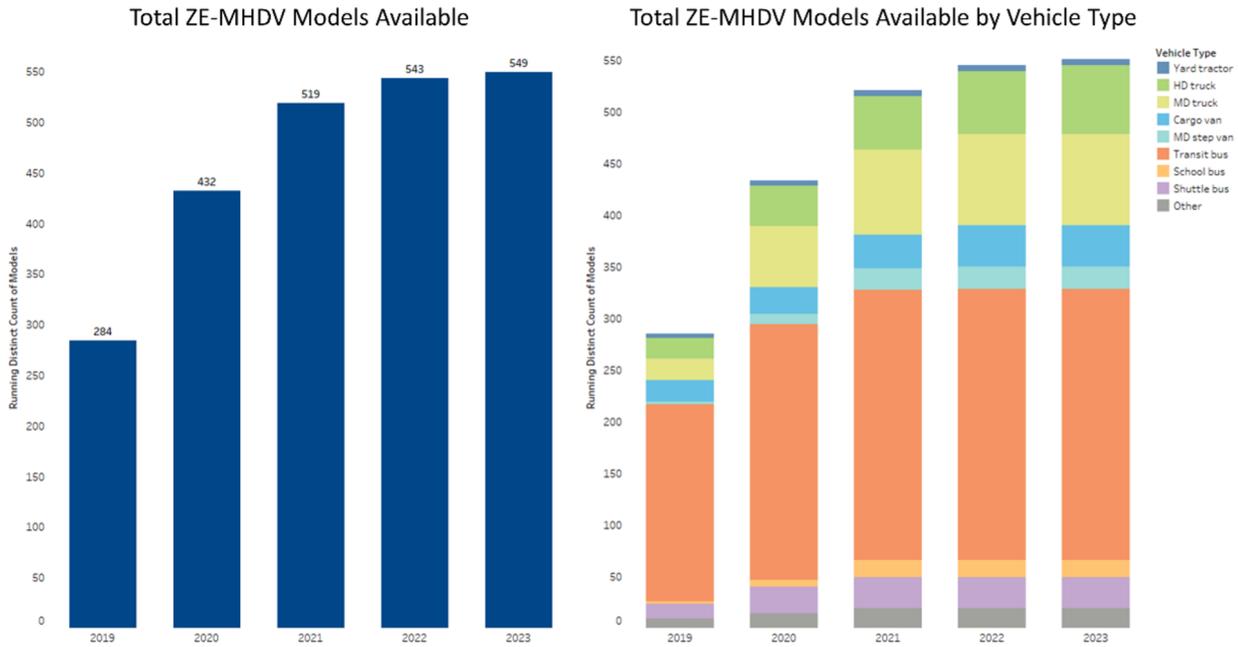
#### *Context*

Data drawn from the Zero-Emission Technology Inventory (ZETI) indicates that transit buses are the most developed segment in the zero emissions market.

**Figure 9.** Cumulative ZE-MHDV Model Availability (2019-2023)



**Global ZE-MHDV Model Availability Total & by Vehicle Type**



Globally there are over 262 zero emission (ZE) transit bus models with a median range of 180 miles. Beyond transit buses, the ZETI tool tracks 40 ZE cargo vans, and 89 ZE medium-duty trucks globally with average ranges well within and beyond what equivalent diesel vehicles travel daily. The vehicle models are either available today or becoming available by 2023 in most first-mover regions of the world with rapid transfer to other regions.

*Why is this stage important?*

- It focuses accelerated outcomes on urban duty cycles which are critical to meeting overall 30% ZE truck goal by 2030; requires nearly 100% penetration of ZE in cities
- It compensates for the longer time needed to scale long haul freight volumes
- It focuses on city applications and duty cycles most conducive to early electrification
- It provides significant early action air quality benefits to priority communities by electrifying applications early in these locations where diesel performs worst

*What is needed to succeed?*

Policies that reward, prioritize and require zero-emission operations in urban regions will be critical enablers of Stage 4 success. However, these tools are not always within the purview of city authority and may need to be instituted at regional, state/provincial or federal levels.

**Implement regulations and supportive policies to ensure 100% of new transit bus, urban delivery van and commercial truck sales in cities are zero emissions by 2030.** Given the operational data and production capacity already developed, all new urban transit buses can and should be zero emissions by 2030. As of late 2021, seven countries and California had committed to 100% transit bus sales, many of which before 2030 (ICCT, 2021b). All urban transit systems should have goals or regulations that require full zero-emission bus purchases no later than 2030. There are few technical obstacles remaining for this to happen: most remaining issues are upfront cost, infrastructure cost and installation timing. The greater use of new financial models that off-set higher purchase price with lower operating costs can be an important part of managing this transition. City/urban use of commercial vehicles can similarly become fully zero emission on this timeline since they share many electric-drive components with transit buses.

Another key policy component would be to implement, in all nations and regions with ZE-MHDV requirements (such as an ACT regulation), an equivalent fleet rule (e.g., California’s proposed Advanced Clean Fleet rule) that targets higher purchase requirements – reaching 100 percent by 2030 - for those applications and fleets with city and urban drive cycles.

**Implement aggressive zero-emission zones and other city-level policies such as curbside management to drive urban delivery electrification.** For cities with the jurisdictional ability to set zero-emission zones, a rapid transition to full city coverage with such zones, and an implementation date of 2030 (as in the Dutch model) would be a massive lever on the market (Electrify, 2021). Absent complete coverage of a city, large zones targeting not just city centers but those communities most impacted by pollution (and therefore justified for health-based reasons) would also set a strong barrier to combustion vehicle operation. Non-European cities have struggled finding the authority to implement these zones but they still have control over local registration fees and curb management, which can drive urban delivery electrification through a combination of preferential access rights given to ZE-MHDVs, time-of-day restrictions to non-ZE-MHDVs, and pricing mechanisms based on vehicle technology.

**Require utility investment and accelerate the build out of ZE-MHDV charging infrastructure.** Of parallel importance is the time and cost needed to permit, build and connect charging infrastructure for urban fleets. Electrical infrastructure in city locations is often older and capacity to support commercial vehicle loads is not always available where fleet locations are situated. Utilities and city planners must accelerate the permitting and construction/inter-connect process for bus and commercial vehicle depots and fleet facilities. Inducements, directives and guidance needs to be developed requiring utilities to prioritize, invest in and speed installation and interconnection of charging infrastructure and supporting systems (Distributed Energy Resources, microgrids, control software) in vehicle depots and facilities. This will sometimes involve city-owned utilities but more likely will involve rate case activities at the utility oversight level, often at the sub-national level. Encouragement of private investment is also needed; this could take the form of loan guarantees and or use of public land for fueling/charging sites.

**Enable public regional fast charging hubs.** Beyond depots and fleet facilities, a nominal network of regional fast charging hubs should be developed to give fleet operators confidence they can perform their work and to accommodate smaller users without fixed parking facilities. Cities themselves, together with regional governmental partners, can identify possible locations for commercial fast

charging hubs, open to all, and may be able to provide or donate excess or open public land to reduce the time and cost of installation (such as at Dundee, Scotland for commercial taxis and ride sharing) (DDE, 2022).

**Determine best practices for broader sharing.** Assembling these steps into a more effective package of best practices and actions, and then providing this new toolkit and training, would be extremely useful for government agencies on all levels. Currently there is no good template for this transition in practice.

#### *Stage 4 Indicators of Success*

- 100% of new transit bus, urban delivery van and commercial truck sales in cities are zero emissions by 2030
- Governments representing 25 percent of global vehicle sales implement fleet rules targeting 100 percent urban delivery electrification by 2030
- 100 cities implement zero-emission zones to cover all commercial vehicle applications and all portions of the city by 2030

## STAGE 5: BUILD THE INFRASTRUCTURE BACKBONE

### *Build Priority Freight Corridors by 2030*

On the heels of validating and developing the infrastructure roadmaps for corridors in Stage 3, Stage 5 would prioritize the primary freight corridors globally and drive implementation of infrastructure installation in all locations. Ports and multi-modal freight facilities would serve as critical hub points for connecting this backbone. Given the long lead times – often 3-5 years – currently needed to install high rate (such as megawatt scale) charging facilities and large-scale hydrogen refueling sites, there is a strong urgency to start this process as soon as possible. Hence, this stage is mostly concurrent with and extends and builds on the roadmaps developed in Stage 3. The period from 2023-2027 will be an especially critical period for making the case for, identifying, and beginning the planning, financing, siting and installation of these prime route corridor systems that will define the backbone of national zero-emission distribution systems.

#### *Context*

Several major truck makers will within the next three years begin deploying longer range trucks that can operate on long range corridor systems. The three largest global heavy-duty vehicle OEMs, Daimler, Volvo, and Traton recently signed a joint venture to create a European high-performance fast-charging network that will enable the acceleration of zero-emission long haul trucking (Volvo, 2021). As examples, Volvo's VNRe (275 mile range), available in 2022, Daimler's eActros (250 miles) and eCascadia (230+ miles), Scania's announced 2023 long range tractor (240+ miles) and the delayed Tesla Semi (300+ miles) would all benefit heavily from this infrastructure deployment. The joint venture would unlock a combined 500-million Euro investment towards high-powered charging infrastructure and result in over 1,700 green-energy powered charging points situated near highways and other logistical sites.

#### *Why is this stage important?*

- It establishes the backbone framework of the zero-emission freight corridor and hub system with sufficient lead time for full build-out by 2040
- It enables industry and infrastructure providers to learn lessons and refine systems as early as possible
- It provides a roadmap and template for the massive 2030-2040 build out

- It provides a clear focus for capital markets and investors
- It enables 2040: cannot meet 100 percent sales goals without base infrastructure

*What is needed to succeed?*

**Expand awareness of ZE-MHDV technology readiness and business case for long-haul.** There are several critical elements required to make Stage 5 successful. Primary among these is expanding the awareness and understanding, particularly among policy makers, government agencies and investors, that ZE-MHDVs are ready for long distance goods movement operations. There remains a knowledge gap, fueled by old assumptions and fossil fuel interest disinformation, that zero-emission technologies cannot carry heavy loads and travel longer distances, or that they will remain cost prohibitive beyond this decade (LBNL, 2021).

This must be aggressively countered through a communications campaign that can reach policy makers, key transportation agency decision makers and investors about the reality of ZE-MHDV long haul capabilities and the timing urgency of establishing a recharging/refueling corridor framework. This work logical builds off Stage 3 early actions. Analyses of total cost of ownership (TCO) in Europe, for instance, indicate that all ZE-MHDV applications will achieve TCO parity without incentives by 2030 (ICCT, 2021). A master campaign could develop the core information for use globally, but targeted sub campaigns will be needed in key regions and for the different stakeholders to be reached.

**Direct public infrastructure funding to priority corridors and encourage private investment.** A second critical element involves policy. It includes prioritizing public infrastructure funding to building out these corridors and putting in place inducements and clear signals to private sector investors that these are needed and valuable investments to make. While national ZE-MHDV goals and regulations will send an important signal, to accelerate the timing of action will require policy and finance mechanisms to spur faster infrastructure installation. This might include provisions to allow the use of public right-of-way for charging/refueling facilities to reduce their cost, or loan guarantees for sufficient facilities to fully complete a corridor. Successful strategies and learnings from Stage 3 can be leveraged for Stage 5.

**Accelerate utility interconnection times and establish fuel policy consistency.** One additional important policy activity, building on Stage 3, involves continuing the work to speed utility interconnection time (where it is needed – some facilities may be grid independent) and establish national networks of consistent and competitive electricity rates and regulations that support heavy-duty ZE-MHDVs, as well as hydrogen. ZE-MHDV freight corridors cross multiple jurisdictional and geographical boundaries and need consistency of pricing and fuel availability to ensure a dependable business case and experience. An expanded campaign aimed at utilities and their oversight bodies should develop and share the recommended policy structures and best practices to emulate from Stage 3 successes and first-success regions.

**Refine and expand infrastructure deployment roadmaps.** An essential element is to continue to refine and fully develop infrastructure roadmaps developed in Stage 3. These implementation roadmaps, by nation or region, will identify all primary priority freight routes (by truck and freight volumes, willing users and contribution to a connected network) that need to be built out during this period. Expanding

and improving initial roadmaps will require input and support from shippers, fleets, manufacturers, utilities and fuel providers, infrastructure providers and public agency stakeholders (such as national and sub-national highway authorities). The roadmaps will include a scalable framework for siting and operating recharging/refueling facilities based on Stage 3 learnings. They will provide clear and regularly updated guidance on the recommended mix of charging levels and fueling combinations required per mile of corridor and volume of ZE-MHDVs

**Expand and coordinate coalitions of corridor users.** Expanding and coordinating stakeholder coalitions of committed corridor users, building on but broader than those in Stage 3, is needed to build out the elements of a prioritized national/regional roadmap. It also assembles the critical advocate base to convince the public and private sector investments of the viability and timing need of these corridors. All these strategies must begin by 2023 and proceed in parallel with and extend Stage 3.

#### *Stage 5 Indicators of Success*

- All OEMs have long haul (300-to-500-mile range, fast charge/fuel capable) ZE-MHDV products available and with enough supply to fulfill demand by 2030
- Twenty (20) percent of each targeted region's corridors – but the primary freight routes –have zero-emission recharging/refueling available
- Zero-emission infrastructure roadmap for reaching 2040 build out is established and being pursued in all regions
- Private capital is providing over 75% of infrastructure investment to build corridors

## STAGE 6: COMPLETE THE NETWORK

### *National Recharging/Refueling Networks in Place by 2035; Complete by 2040*

Meeting the goal of all medium- and heavy-duty vehicle sales being zero emissions by 2040 requires a supporting network of recharging/refueling available or within access of all primary and secondary freight routes and applications in a country or region (with some possible small exceptions, such as Arctic pipeline support or timber roads in extremely remote areas).

Stage 6 is clearly an extension of the strategies and learnings from Stages 3 and 5 but with the intention of filling in all remaining gaps in the travel network not just in the heaviest freight corridors but between and in all cities, towns and communities. It relies on the fact that the backbone framework of the network and the policies and investments for it are in place (including linking nations and states across state and national boundaries).

Stage 6 requires strong policies are in place that envision the build out required and commit a nation's infrastructure resources to that goal. This commitment must be set in motion early enough (between 2025 and 2030) that there is time for its full implementation by 2040, which is a significant endeavor. It will require an urgency to maintain an aggressive schedule of deployment and likely requires a further refinement of the infrastructure implementation roadmap developed in Stage 3 and fleshed out in Stage 5. It must focus on the most strategic missing pieces and the willingness of market forces (with inducements) to invest and meet the timing.

*Why is this stage important?*

- It fully enables the 2040 target to be met by ensuring that no ZE-MHDV is out of reach of the recharging/refueling network
- It can ensure the ability to drive to all areas (95%+) of nations with a ZE-MHDV without risk of being stranded
- It can enable faster fleet turn-over by providing certainty; a sales target of 100 percent does not yet mean 100 percent ZE-MHDV operation. This network can encourage remaining adoption prior to the 2050 net zero carbon timeframe, likely with some degree of accelerated fleet turnover to retire the oldest vehicles

*What is needed to succeed?*

The financial tools, utility learnings and infrastructure installation templates from Stage 5 will need to be implemented at scale and on a faster timeline for Stage 6 to succeed. Beyond full zero-emission infrastructure coverage along all primary freight routes, all secondary highway systems will also need adequate coverage for expected demand with an ability to scale as the remainder of the existing vehicle fleet transitions to ZE-MHDVs.

**Make the case for complete transformation.** While Stage 6 is the final stage of this plan, it requires a front-loaded public policy framework to be successful. This framework needs to be established during the earlier stages but clearly envisioning the end state represented by Stage 6: complete transformation. It will be critical before the middle of the 2020 decade to target advocacy and policy work on making the core case for fully building out zero-emission commercial vehicle infrastructure and developing the scale of investments and coverage required. This campaign work will take place initially in parallel with Stages 3 and 5 by providing the context and the longer-term vision of what's needed and helping to set the expectations in place for the eventual scale, coverage and duration needed. This policy and advocacy activity needs to help put in place the regulatory, structural and financial framework that will be required for the eventual buildout.

**Unleash capital investments to reach deployment scale.** Financing will be key. This can include steering early public funding into commercial vehicle infrastructure, with its much more predictable driving patterns and potential for extremely high and predictable infrastructure utilization rates. But the scale will require that private capital be the primary driver, and this will potentially mean the creation of supporting or backstopping policy mechanisms to reward or encourage investments, at least in the early years. Earlier stages will be creating best practices to encourage private investment; Stage 6 needs to ensure those tools are in place by no later than the years 2025-2030.

**Integrate commercial vehicle electrification into grid modernization investments.** The investment required to complete this transformation is extremely large, but not at all unknown nor without precedent. It represents a fraction of the investment already underway in electrical grid modernization and expansion. To succeed, the transport component of grid modernization must be fully integrated with grid planning and investments. This represents some of the policy and advocacy work needed early in this stage by mid-decade in the 2020s. A critical part of this work is to inform, educate and convince private and institutional capital investments to target this transportation infrastructure build out. Supporting policies and mechanisms such as usage guarantees, off-take agreements for transportation use, operational support funding in early years and possibly access to public right-of-way land may be some of the frameworks required to meet the pace.

Utilities will also need to be convinced, or directed through strong policies, to ensure that transportation infrastructure and the ability to produce and distribute renewable electricity (possibly in concert with renewable hydrogen generation and storage) is scaled adequately and on pace with the transportation sector's needs. Most studies confirm that sufficient generation of renewable electricity will not be the biggest limiting factor for transportation; rather, it will be adequate and timely storage and delivery of power from the utility grid provided to adequate infrastructure where needed in the transport "grid."

**Scale workforce to meet infrastructure expansion needs.** An expanded and highly skilled workforce will be required to meet this infrastructure ramp-up pace and scale. While existing construction industry assets might suffice for some of the installation process, additional training and added staffing will be needed for electrical interconnect capabilities, electrical equipment maintenance, and support functions, in addition to additional engineering design, permitting and siting functions. A global job training campaign, implemented in each country and region, will be critical. Since the skilled workforce does not exist today to build what is needed by 2040, the time to set in place, fund and implement job training programs in electrical design, installation and maintenance is critical to set in place by 2025 and steadily expand through the mid 2030 decade. This will include skill improvement and enhancement for existing electrical workers; skill transfer to existing construction and maintenance workers; and ground level training in an expanding field for new workers, especially in traditionally underserved and rural communities that will need skills directly in their region.

**Fill rural infrastructure gaps.** Stage 6 must include rural infrastructure installation in all regions to ensure that no parts of the goods and services network, nor segments of society, are left out of the transition. The benefits of providing highly localized job benefits in rural regions to install and maintain infrastructure, and support vehicles, can be a component of encouraging faster adoption.

#### *Stage 6 Indicators of Success*

- All primary freight corridors can support ZE-MHDV charging/refueling and 50 percent of secondary routes have adequate coverage by 2035
- 100 percent of primary and secondary routes and all rural connecting points have zero-emission infrastructure adequate to demand by 2040
- Power/fuel generation, distribution and availability is fully adequate to meet the scale of 100 percent zero-emission commercial vehicle sales by 2040

# CONCLUSION

## URGENT ACTION NEEDED NOW

The February 2022 Intergovernmental Panel on Climate Change (IPCC) report makes clear that the world is not on course to avoid the worst impacts of climate change, much less meet Paris Agreement outcomes of staying under 1.5 degrees Celsius of temperature increase (IPCC, 2022). It concludes that urgent action in both adaptation and emissions reductions are desperately needed and can still be effective. ZE-MHDVs are a prime part of that action.

The capability to transform the fastest growing sector for greenhouse emissions – transportation – into one of the main contributors to climate reductions is well at hand. It is technically feasible, economically desirable and brings crucially needed co-benefits in the form of much cleaner urban air quality to long suffering communities. Market penetration models show that based on technology readiness and suitability, business case and production scalability the 2040 goals are feasible and achievable. Achieving their pace does require a coordinated portfolio of regulations, policies and investments, particularly for infrastructure. And what has been lacking is action: a clear vision and plan to meet the urgent timeline and the political and social will to undertake it.

That action plan at its highest level is outlined here. It is intended to be directional, not prescriptive nor fully comprehensive. Detailed work plans for each of these stages will be required. Yet while still a work in progress and in need of continual refinement over time, it does represent a clear and actionable framework against which the world can act. By setting an aggressive but achievable goal, broken into six discrete stages, it outlines a strategy for rapidly tackling one of the biggest transformations in human history in manageable and interconnected steps. With global governments and industry pulling together against this plan and its timing, its outcomes can be achieved. 16-plus countries have already embarked on this path. The world can no longer afford to wait.

# REFERENCES

- CALSTART (CALSTART, 2020). The Beachhead Model Catalyzing Mass-Market Opportunities For Zero-Emission Commercial Vehicles. Retrieved from: <https://globaldrivetozero.org/publication/thebeachhead-model>
- CALSTART (CALSTART, 2021). Landmark commitment at COP26: countries, subnational governments, vehicle manufacturers and fleets target 100% zero-emission new truck and bus sales by 2040. Retrieved from: <https://globaldrivetozero.org/2021/11/09/landmark-commitment-at-cop26-countries-subnational-governments-vehicle-manufacturers-and-fleets-target-100-zero-emission-new-truck-and-bus-sales-by-2040-10-nov-2021>
- CALSTART (CALSTART, 2021a). Analysis of Public Sales Commitments Of Medium- And Heavy-Duty Vehicle Manufacturers And Expected Volumes. Retrieved from: <https://globaldrivetozero.org/publication/analysis-of-public-sales-commitments-of-medium-and-heavy-duty-vehicle-manufacturers-and-expected-volumes>
- CALSTART (CALSTART, 2021b). Analysis of public sales commitments of medium- and heavy-duty vehicle manufacturers and expected volumes. Retrieved from: <https://globaldrivetozero.org/publication/analysis-of-public-sales-commitments-of-medium-and-heavy-duty-vehicle-manufacturers-and-expected-volumes>
- CALSTART (CALSTART, 2022). Global Memorandum Of Understanding On Zero-Emission Medium- And Heavy-Duty Vehicles. Retrieved from: <https://globaldrivetozero.org/mou-nations>
- CALSTART (CALSTART, 2022a). ZETI Analytics v7.0. Retrieved from: <https://globaldrivetozero.org/tools/zeti-analytics>
- CALSTART (CALSTART, 2022b). Zeroing in on Zero-emission Trucks. Retrieved from: <https://calstart.org/zeroing-in-on-zero-emission-trucks>
- CALSTART (CALSTART, 2022c). Global Sales Targets For Zero-Emission Medium- And Heavy-Duty Vehicles – Methods And Application. Retrieved from: <https://globaldrivetozero.org/publication/global-sales-targets-zemhdvs>
- CALSTART (CALSTART, 2022d). Building a beachhead: California's path to accelerating zero-emission commercial vehicles. Retrieved from: <https://globaldrivetozero.org/publication/building-a-beachhead-californias-path-to-accelerating-zero-emission-vehicles>
- Chen Zhang, Andrew Kotz, Kenneth Kelly, Luke Rippelmeyer (Zhang et al., 2021). Development of heavy-duty vehicle representative driving cycles via decision tree regression. Retrieved from: <https://www.sciencedirect.com/science/article/pii/S1361920921001462#b0105>
- Drive Dundee Electric (DDE, 2022). Princes Street charging hub. Retrieved from: <https://www.drivedundeeelectric.co.uk/princes-street>

- Electrify (Electrify, 2021). Dutch municipalities to set-up zero-emission zones by 2025. Retrieved from: <https://www.electrify.com/2021/02/15/dutch-municipalities-to-set-up-zero-emission-zones-by-2025>
- Intergovernmental Panel on Climate Change (IPCC, 2022). IPCC Sixth Assessment Report: Climate Change 2022: Impacts, Adaptation and Vulnerability. Retrieved from: <https://www.ipcc.ch/report/ar6/wg2>
- Lawrence Berkeley National Laboratory (LBNL, 2021). Why Regional and Long-Haul Trucks are Primed for Electrification Now. Retrieved from: [https://eta-publications.lbl.gov/sites/default/files/updated\\_5\\_final\\_ehdv\\_report\\_033121.pdf](https://eta-publications.lbl.gov/sites/default/files/updated_5_final_ehdv_report_033121.pdf)
- National renewable energy lab (NREL, 2022). Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis. Retrieved from: <https://www.nrel.gov/docs/fy22osti/82081.pdf>
- Statista (Statista, 2022). Projected battery costs as a share of large battery electric vehicle costs from 2016 to 2030. Retrieved from: <https://www.statista.com/statistics/797638/battery-share-of-large-electric-vehicle-cost>
- The International Council on Clean Transportation (ICCT, 2021). Total Cost of Ownership For Tractor-Trailers In Europe: Battery Electric Versus Diesel. Retrieved from: <https://theicct.org/sites/default/files/publications/TCO-BETs-Europe-white-paper-v4-nov21.pdf>
- The International Council on Clean Transportation (ICCT, 2021a). Total Cost Of Ownership For Heavy Trucks In China: Battery-Electric, Fuel Cell Electric, And Diesel Trucks. Retrieved from: <https://theicct.org/sites/default/files/publications/ze-hdvs-china-tco-EN-nov21.pdf>
- The International Council on Clean Transportation (ICCT, 2021b). Decarbonizing Bus Fleets: Global Overview Of Targets For Phasing Out Combustion Engine Vehicles. Retrieved from: <https://theicct.org/decarbonizing-bus-fleets-global-overview-of-targets-for-phasing-out-combustion-engine-vehicles>
- Transport and Environment (T&E, 2022). Why the future of long-haul trucking is battery electric. Retrieved from: [https://www.transportenvironment.org/wp-content/uploads/2022/02/2022\\_02\\_battery\\_electric\\_trucks\\_HDV\\_factsheet.pdf](https://www.transportenvironment.org/wp-content/uploads/2022/02/2022_02_battery_electric_trucks_HDV_factsheet.pdf)
- Volvo Group (Volvo, 2021). Volvo Group, Daimler Truck and the TRATON GROUP plan to pioneer a European high-performance charging network for heavy-duty trucks. Retrieved from: <https://www.volvogroup.com/en/news-and-media/news/2021/jul/news-4017125.html>