WHITE PAPER

MULTI-COUNTRY ACTION PLAN FOR THE GLOBAL MEMORANDUM OF UNDERSTANDING ON ZERO-EMISSION MEDIUM- AND HEAVY-DUTY VEHICLES

Owen MacDonnell, CALSTART
Cristiano Façanha, PhD., CALSTART

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Global Commercial Vehicle Drive to Zero

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LIST OF ACRONYMS

ACT	California's Advanced Clean Truck Regulation
BEVs	Battery Electric Vehicles
CARB	California's Air Resource Board
CEC	California Energy Commission
CI	Carbon Intensity
CO_2	Carbon Dioxide
COP26	The 26th UN Climate Change Conference
CPUC	California Public Utilities Commission
DEVC	Dynamic Electric Vehicle Charging
ERS	Electric Road Systems
ERSV	Electric Road System Vehicle
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
ePTO	Electric Power Take Off
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse gas
HDV	Heavy Duty Vehicle
HVIP	Hybrid and Zero-emission Truck and Bus Voucher Incentive Project
ICE	Internal combustion engine
iMHZEV	Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles
MCAP	Multi Country Action Plan
MCS	Megawatt Charging System
MHDV	Medium- and heavy-duty vehicle
MOU	Memorandum of Understanding
MSRP	Manufacturer Suggested Retail Price
NGO	Non-Governmental Organization

LIST OF ACRONYMS

NO_x	Nitrogen oxides
OEM	Original Equipment Manufacturers
PEM	Polymer Electrolyte (Proton Exchange) Membrane
TCO	Total Cost of Ownership
TEN-T	Trans-European Transport Network
ZE	Zero-emission
ZE-MHDV	Zero-emission medium- and heavy-duty vehicle
ZEB	Zero-Emission Bus
ZET	Zero-Emission Truck
ZETI	Zero-emission Technology Inventory
ZEV	Zero-emission Vehicle
ZEZ	Zero-Emission Zone

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CALL TO ACTION

The call to action below is issued on behalf of the national governments who have already signed the Global Memorandum of Understanding on Zero-Emission Medium-and Heavy-Duty Vehicles. The Global MOU is the world's most ambitious multi-national agreement to cut climate emissions from transport and accelerate the global zero-emission truck and bus segment.

CALL TO ACTION ON ZERO-EMISSION MEDIUM- AND HEAVY-DUTY VEHICLES

We strongly invite and encourage nations worldwide to join and sign the Global Memorandum of Understanding (MOU) on zero-emission medium- and heavy-duty vehicles (ZE-MHDVs), aiming for 30% new MHDVs being zero emissions by 2030, and a full transition to ZE-MHDVs in new fleets by 2040, to facilitate the achievement of net-zero carbon emissions by 2050.

Transport is a large and fast-growing source of greenhouse gas (GHG) and local air pollutant emissions globally, and MHDVs are a large source of transport sector emissions that negatively impact the climate, air quality, and human health, disproportionally affecting disadvantaged communities located near freight corridors, ports, and distribution centers. ZE- MHDVs are essential to reducing transport emissions, mitigating climate change, improving air quality, and reducing the use of fossil fuels and energy costs.

Commercial deployment of ZE-MHDVs remains limited, and further advancements in the state of technology and deployment stand to benefit from global collaboration and coordination, which can also result in accelerated private sector investment in the ZE-MHDV sector. Investments in ZE-MHDVs could help to stimulate economic growth by creating new jobs in the zero- emission vehicle and charging/ fueling equipment manufacturing, supply chain, energy and service sectors.

ZE-MHDVs offer a viable pathway to decarbonize the road transport sector. Technology has advanced greatly over the last decade. A growing number of OEMs voice strong ambition to produce zero-emission commercial vehicles. Many studies show the cost competitiveness of these vehicles in many parts of the world and for many parts of the fleet by the end of this decade or early next decade at the latest. This makes ZE-MHDV deployment a much needed and viable proposition, but it will only deliver its full potential through aligned global ambition.

The MOU aligns around a common ambition but recognizes that the adoption of ZE-MDHVs might require different approaches and enabling conditions in different parts of the world. As a result, the targets in the MOU are non-binding and the MOU implementation is within the discretion of each country participant. In addition, the MOU includes a forum for coordination, collaboration and information sharing on ZE-MHDVs, which is meant to support countries to achieve their ambition, share implementation lessons learned, and monitor collective progress.

CALL TO ACTION

Given long fleet turn-over times, it is important to urgently begin the adoption of ZE-MHDVs. Our aim is to have the MOU signed by the largest possible group of country signatories to maximize our collective market share and impact. In addition to the 16 countries who have already signed the MOU, over 50 sub-national governments and businesses endorsed the MOU, recognizing their important role in the market transformation towards ZE-MHDVs. We plan to announce new MOU country signatories at COP27 in November/2022 in Egypt, and we sincerely hope that you will join us in this important effort.

On behalf of the 16 country signatories (Austria, Canada, Chile, Denmark, Finland, Luxembourg, Portugal, Netherlands, New Zealand, Norway, Scotland, Switzerland, Turkey, United Kingdom, Uruguay and Wales), you are invited to sign the Global MOU this year. Your contribution will be pivotal to scale up the ZEV uptake, align transport with the Paris agreement ambition and fully reap the multiple benefits of accelerated ZEV deployment.

The Global MOU is co-led by the Netherlands and CALSTART/Drive to Zero. For more information, please contact Herman Sips (herman.sips@minienw.nl) and/or Cristiano Façanha (cfacanha@calstart.org).

Viviane Heijen
Minister for the Environment, Netherlands

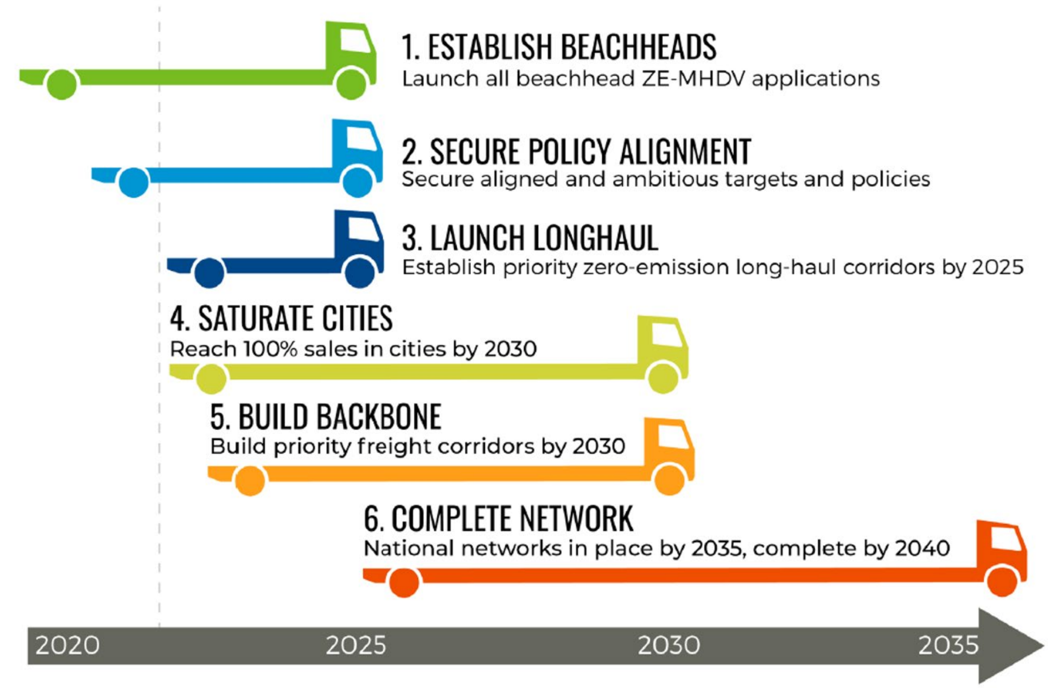
John Boesel
President and CEO, CALSTART

EXECUTIVE SUMMARY

Sixteen leading nations—Austria, Canada, Chile, Denmark, Finland, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Scotland, Switzerland, Turkey, United Kingdom, Uruguay, and Wales—have become the first wave of countries to sign the Global Memorandum of Understanding (MOU), agreeing to work together toward a full transition to new medium- and heavy-duty vehicles (MHDVs) being zero-emission by 2040, and an interim target of 30% new vehicle sales by 2030, as to enable net-zero carbon emissions by 2050. MHDVs are a compelling target for emissions control. Constituting only 4% of the global on-road vehicle fleet, MHDVs are responsible for roughly 36% of on-road fuel consumption, and upwards of 73% of NOx emissions (CALSTART, 2020). The disproportionate impact that these vehicles have on greenhouse gas (GHG) emissions and other harmful pollutants makes them a threat to both climate and air quality.

The clear ambition that all new commercial vehicles must be zero-emission by 2040 means that the production capacity and infrastructure must be in place well before then. Many of these efforts in the near term involve 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 but becomes easier to address when broken down to more actionable and discrete elements. A six-stage strategy outlines how to achieve the ambition established by the Global MOU (Figure ES-1).

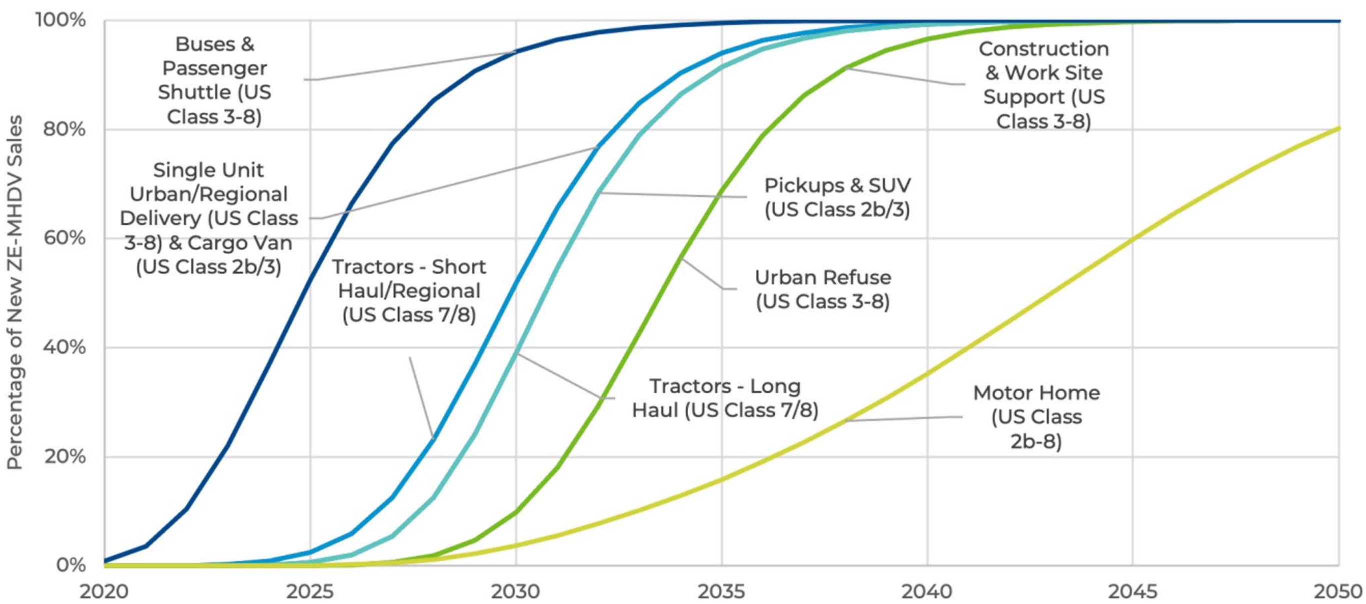
Figure ES-1. Six-Stage Strategy for ZE-MHDV Market Acceleration (CALSTART, 2022)



The Global MOU aims for a full transition toward new zero-emission medium- and heavy-duty vehicles (ZE-MHDVs) by 2040. Recognizing the great diversity across MHDV segments, it is important to understand how zero-emission technologies can enter the fleet for specific vehicle segments, considering technology readiness (i.e., operational capacity), supply scalability (i.e., how fast manufacturers can scale up production), and fleet demand (i.e., likelihood that fleets will select a "novel" technology assuming cost parity and infrastructure availability).

Figure ES-2 illustrates such disaggregated adoption curves which collectively illustrate the path to a full transition toward ZE-MHDV sales by 2040. While not all eight segments can reach 30% zero-emission (ZE) sales by 2030, their aggregate sales will reach or surpass that threshold in any country that adopts the policies recommended in this action plan (See Appendix for regional weight conversion table).

Figure ES-2. Global ZE-MHDV Sales Targets by Segment (CALSTART, 2022b)



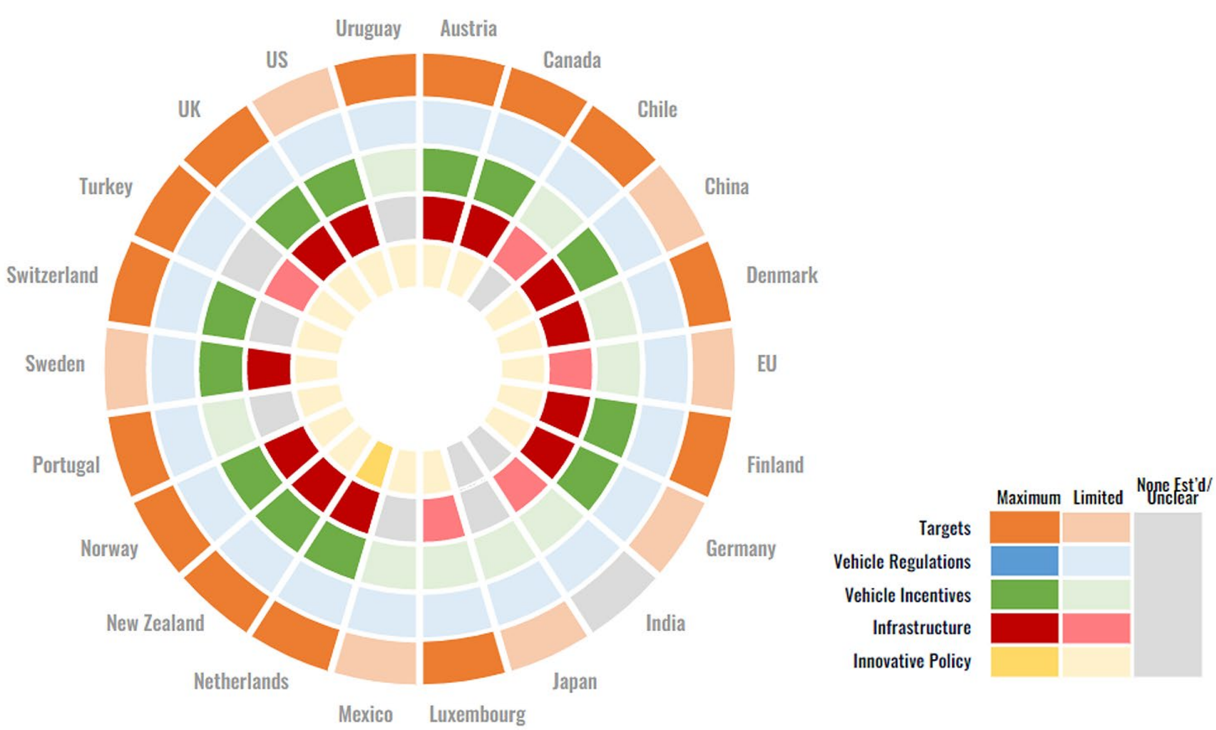
Note: E.U. Class N2 = U.S. Classes 2b-7 & E.U. Class N3 = U.S. Class 8

Figure ES-2 indicates that buses and passenger shuttles and then single-unit urban/regional delivery trucks and short-haul/regional trucks must be an early focus to lay the groundwork for vehicle segments with more demanding operational requirements. Vehicles that are rolled out in these early segments will be deployed in local and regional settings and most frequently return to base for charging overnight without the need for public infrastructure. Early deployments also necessitate the development of associated private infrastructure, increasing the volume of chargers and ensuring grid electrical upgrades, make-ready programs, and utility charging rates can be established and fine-tuned as the share of ZE-MHDVs increases in the leading segments of the market. Further along the adoption timeline are long-haul tractor trucks and pickups/SUVs. This ordering reflects the timing for technology readiness of ZE technologies for different vehicle vocations, types, and weights, and recognizes that ZE technologies can be transferred across vehicle types as technologies evolve and costs decrease. Further along in the adoption timeline are more specialized vehicles like refuse and construction trucks, as well as mobile homes, all of which represent a relatively small, specialized share of MHDVs, often having other power demands such as from an ePTO unit.

The Multi-Country Action Plan for the Global Memorandum of Understanding on Zero-Emission Medium- and Heavy-Duty Vehicles (MCAP) summarizes policies and actions taken by Global MOU signatory countries to date that support the MOU's target of 30% sales of new ZE-MHDVs by 2030 and a full transition to new ZE-MHDVs by 2040. Preliminary data indicates that MOU countries fall somewhere on a continuum of implemented policy, from aggressive to little action taken. Offering policy recommendations to the Global MOU signatories based on objective realities of the technology and successful sequencing and combination of key policy elements is one of the goals of the MCAP. Elevating the ambitions of the signatory countries through these resources is key to accelerating the market for ZE-MHDVs. To effectively achieve this, it is important to summarize the successful actions already taken by countries. Figure ES-3 provides a visual representation of the current policies adopted by MOU countries and a few additional select global markets. Policies are grouped into five dimensions:

1. **Targets**: Setting clear and ambitious yet achievable ZE-MHDV targets allows fleet operators, manufacturers, utility providers, local authorities, and other stakeholders to better plan for a major technology transition, make the needed supply chain investments, explore innovative financing mechanisms, and educate their workforce.
2. **Regulations**: It is also imperative to back ZE-MHDV targets with **regulations** to provide market certainty and give industry the confidence to invest heavily in ZE technologies.
3. **Vehicle Incentives**: Because most ZE-MHDVs in the market today still have much higher upfront costs, targeted and timebound vehicle financial incentives can accelerate cost parity, encourage early investment by fleets, and enable the early introduction of regulations.
4. **Infrastructure Investments**: Infrastructure availability is one of the most prevalent barriers for the transition to zero-emission technologies today. Governments must enable, encourage, and require utilities to plan for, invest in, and take an active role installing ZE-MHDV infrastructure at the pace required to meet rapid market growth.
5. **Other Innovative Policies**: Other policies that cannot be easily categorized as one of the previous four can also be critical to accelerate ZE-MHDVs. For example, zero-emission zones (ZEZs) can be an effective approach to decarbonize cities and urban regions. Other key measures with widespread success are vehicle weight exemptions for ZE-MHDVs to account for heavier vehicle weight because of batteries and not penalize ZE-MHDVs with lower payloads.

Figure ES-3. ZE-MHDV Policies Adopted by Leading Countries



The importance of each policy dimension is elaborated in its respective section and is followed by relevant examples of successful implementation across the MOU countries. There are numerous routes forward and there is not one "right" approach. Providing policymakers with a suite of policies and actions that have proven effective in supporting ZE-MHDV deployments in other regions can provide guidance and confidence. Beyond helping partners take away a greater understanding of what other MOU countries are implementing, the following sections also provide a set of recommendations, also summarized in Table ES-1, to countries that may be unsure of where to begin.

Table ES-1. Summary of Multi- Country Action Plan Policy Recommendations

Policy Dimension	Recommendations
Targets	• Align and establish targets for specific MHDV segments with technology readiness and operational capability. • Establish target for 100% sales of zero-emission transit buses and urban delivery vehicles. • Support targets through roadmaps and planning that will ensure global climate agreements are met on time.
Regulations	• Regulations must be specific and include strategic timelines and phase-in plans. • Countries should strengthen GHG and criteria pollutant standards for MHDVs. • Countries should consider adoption of complementary sales requirements for ZE-MHDVs.
Incentives	• Incentives must be targeted and timebound and align with regulatory frameworks. • Incentives should be implemented alongside regulations to ensure maximum impact. • Incentives should target small fleets.
Infrastructure Investments	• Create roadmaps to forecast infrastructure demand and identify priority deployment locations. • Create regulatory structure directing utility investment in ZE-MHDV infrastructure. • Encourage interoperability standards and reliability metrics in the infrastructure system. • Direct utility and government action toward beneficial rate structure for fleet charging. • Jumpstart early markets with incentives, investments, industry engagement, user education, and workforce training. • Explore low-carbon fuel standards to spur innovation.
Other Innovative Policies	• Implement zero-emission zones for urban distribution in cities. • Implement weight exemptions to ensure ZE-MHDV are not penalized by lower payloads. • Implement vehicle and road user charges that provide relative economic benefits to ZE-MHDVs. • Implement carbon pricing schemes for MHDVs.

ZE-MHDVs offer the primary and critical pathway to decarbonize the road transportation sector. Technology has advanced greatly over the last decade and is ready for large-scale deployment, and a growing number of OEMs have voiced strong ambitions to produce zero-emission commercial vehicles. Many studies show the cost competitiveness of these vehicles in many parts of the world and for many segments of the fleet by the end of this decade or early next decade at the latest. For certain lighter, urban segments the timeline for achieving cost parity will be even sooner.¬¬¬ This makes ZE-MHDV deployment a much-needed and viable proposition.

The MCAP provides the policy framework for countries to adopt by showcasing current policies adopted to date and providing guidance to leading nations on next steps to establishing their own strong plans. The Global MOU is the first global agreement aligning the goals of national governments to decarbonize trucks and buses, a segment of the market that contributes disproportionately to CO_2 emissions and air pollution. The document that follows establishes the policy status of the Global MOU countries—and several countries not yet signatories—and outlines the major policy developments to date. The MCAP highlights the importance of nurturing the development of all aspects of a country's policy ecosystem and lays out recommendations for each dimension for governments to adapt into their own planning and rulemaking processes. Achieving harmony between national governments driving innovation is critical to scaling supply, reducing costs, encouraging interoperable infrastructure, and ultimately achieving the proliferation of ZE-MHDVs, clean air and a brighter future for all.

CHAPTER 1

BACKGROUND AND MOTIVATION

1.1. GLOBAL ALIGNMENT OF ZE-MHDV TARGETS

Sixteen leading nations—Austria, Canada, Chile, Denmark, Finland, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Scotland, Switzerland, Turkey, United Kingdom, Uruguay, and Wales—signed a Global MOU, agreeing to work together toward a full transition to new MHDVs being zero-emission by 2040, and an interim target of 30% new vehicle sales by 2030, as to enable net-zero carbon emissions by 2050 (CALSTART, 2022c).[1]

This ambition is also aligned with targets announced by most major global original equipment manufacturers (OEMs) who have set 2040 as the date by when all new truck sales will be zero-emission or fossil free (CALSTART, 2021). Over 60 sub-national governments and industry partners—manufacturers, fleets, infrastructure providers, and investors—have also endorsed the Global MOU goals, recognizing their strong role alongside national governments to enable such market transformation (CALSTART, 2022d).

The Global MOU is the first step of this market transformation. This MCAP provides guidance to leading nations on the policies and actions needed next to implement their Global MOU ambition and summarizes their progress to date. While each country will adopt a policy package best suited to its own market, these recommendations will be crucial to fully decarbonize all new MHDVs by 2040, and ultimately achieve carbon neutrality by 2050.

1.2. IMPORTANCE OF A FULL TRANSITION TOWARD ZE-MHDVS

MHDVs are a compelling target for emissions control. Constituting only 4% of the global on-road vehicle fleet, MHDVs are responsible for roughly 36% of on-road fuel consumption, and upwards of 73% of NO_x emissions (CALSTART, 2020). The disproportionate impact that these vehicles have on GHG emissions

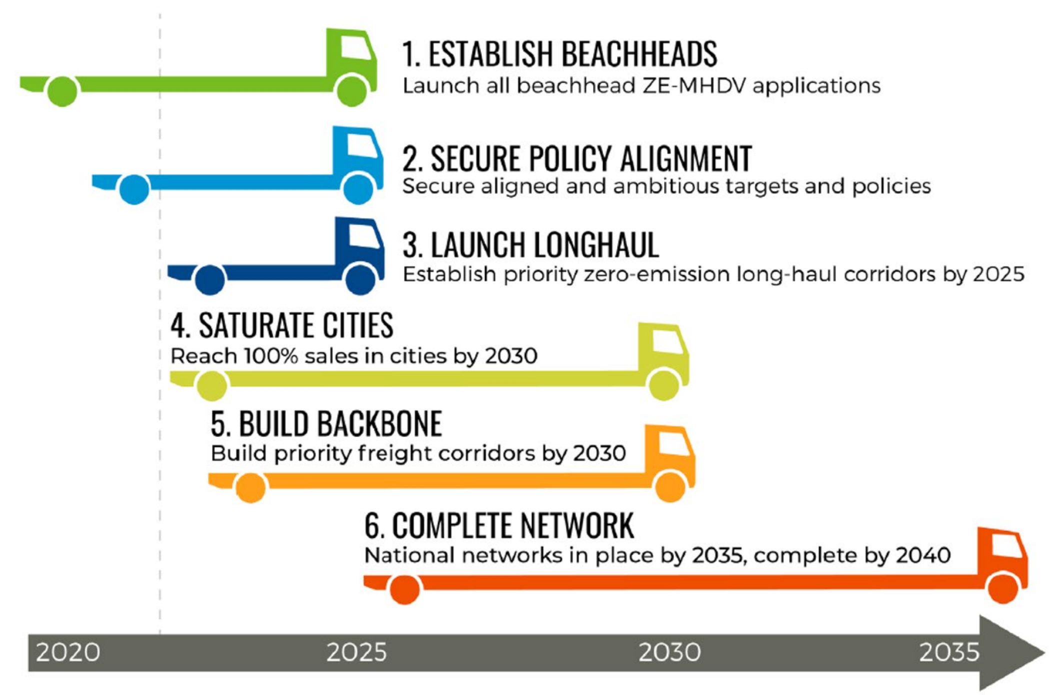
1 For purposes of this MOU, MHDVs are vehicles with gross vehicle weight above 3,500 kilograms used for freight and passenger transport. ZE-MHDVs are MHDVs with zero tailpipe emissions

and other harmful pollutants makes them a threat to both climate and air quality. Emissions from commercial vehicles, in particular freight vehicles, are also forecast to increase. From 2020 to 2050, GHG emissions from freight are expected to double and harmful particulate matter ($PM_{2.5}$) associated with combusting diesel is predicted to increase by more than 40% in this time frame (CALSTART, 2020). Alongside rising emissions, truck and bus fleet turnover also remains challenging to navigate. Average fleet age varies by country and vehicle type but can span anywhere from 10 to 25 years, further highlighting the importance of accelerating the transition as soon as possible. If meaningful action is to be taken against climate change and air pollution, there must be a coordinated global undertaking to reduce the impact of MHDVs and ensure that the future of transportation and goods movement does not have an adverse impact on the environment and public health. Facing these combined challenges, zero-emission technologies offer the only complete path forward.

1.3. ROADMAP TO 100% NEW ZE-MHDVS BY 2040

The clear ambition that all new commercial vehicles must be zero-emission by 2040 means that the production capacity and infrastructure must be in place well before then. Many of these efforts in the near term involve 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 but becomes easier to address when broken down to more actionable and discrete elements. This six-stage strategy outlines how to achieve the ambition established by the Global MOU (CALSTART, 2022a).

Figure 1. Six-Stage Strategy for ZE-MHDV Market Acceleration (CALSTART, 2022a)



The six stages have been developed to run in parallel. **Stage 1** highlights the need to leverage those vehicle applications (i.e., beachheads) for which zero-emission technologies are most readily available, namely transit and urban delivery applications, where vehicles travel for known and relatively shorter routes before returning to depots for overnight charging. Because zero-emission technologies are transferable across vehicle applications, these early successes can enable technology to mature before transferring to heavier vehicles traveling for longer distances. This leads neatly into **Stage 2** where, for effective scaling on both vehicle supply and demand, policy must be aligned across regions to provide the private sector with certainty and confidence. **Stage 3** highlights the need for beginning immediately to establish well-planned and developed infrastructure along major trucking corridors. While the strategy remains zero-emission technology-neutral, leading research indicates that in the near-term battery-electric vehicles will dominate deployments (CALSTART, 2022e). Revolutions in charging equipment have brought charge times down significantly, enough for some studies to suggest that battery-electric trucks will be able to tackle long-haul routes in the near future, given appropriate network buildout (Transport & Environment, 2021). Regardless, frontloading long-haul corridor buildout now will significantly alleviate friction as volumes increase across markets. At the same time as these corridors are being developed, cities (**Stage 4**) must continue to be a major target for ZE-MHDV technology as it has been proven to be the best option for intracity delivery and people movement. This is where ZE-MHDV technology immediately flourishes, with the ability to take advantage of regenerative breaking through stop-and-go operations, relatively shorter driving distances, and depot charging. Finally, **Stages 5 and 6** focus on completing the network. Government must establish specific and clear targets, OEMs must continue to scale their capacity, utility operators must agree on favorable rate structure and commit to hardware upgrades, and the supporting workforce and working industry knowledge must grow. None of the six stages above can be achieved in isolation or by one actor alone. The key to success is collaboration and constructive partnerships that will result in lower costs, cleaner air, and a sustainable environment for all.

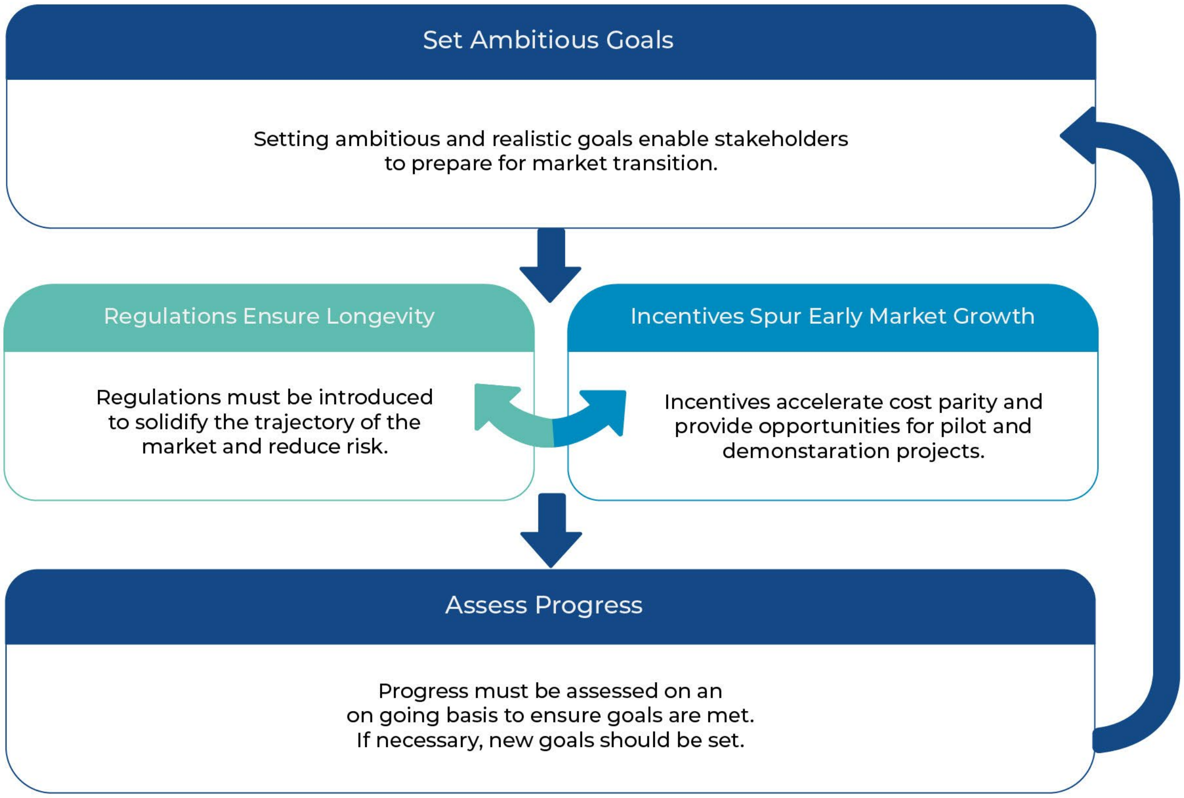
1.4. SMART POLICY FRAMEWORK

Despite their technological progress and increasing commercial readiness, ZE-MHDVs have faced several barriers to commercial competitiveness and widespread deployment, including higher upfront costs, the need for new charging and fueling infrastructure, and limited (though growing) model availability for specialized and long-distance duty cycles. Likewise, no single stakeholder—whether government, fleet owners, or vehicle manufacturers—can address these challenges alone. Rapid ZE-MHDV deployment will happen only if these barriers are tackled through a multi-pronged strategy to market transformation that is: (1) guided by clear goals and targets; (2) supported and accelerated by incentives; (3) institutionalized through regulations; and (4) driven continuously through pilot projects, infrastructure investments, and multi-stakeholder implementation.

This strategy has been deployed by California, an innovator and driver of impactful policies that has established itself as a leading global region in the deployment of zero-emission vehicle (ZEV) technology. Through successive and increasingly ambitious policies, short- and long-term planning, public- and private-sector coordination, and a mix of financial incentive "carrots" and regulatory "sticks," California has developed and demonstrated the necessary components for a supportive policy framework for ZE-

MHDV market transformation, as conceptually represented in Figure 2 below:

Figure 2. California's Strategy for Market Transformation (CALSTART, 2022f)

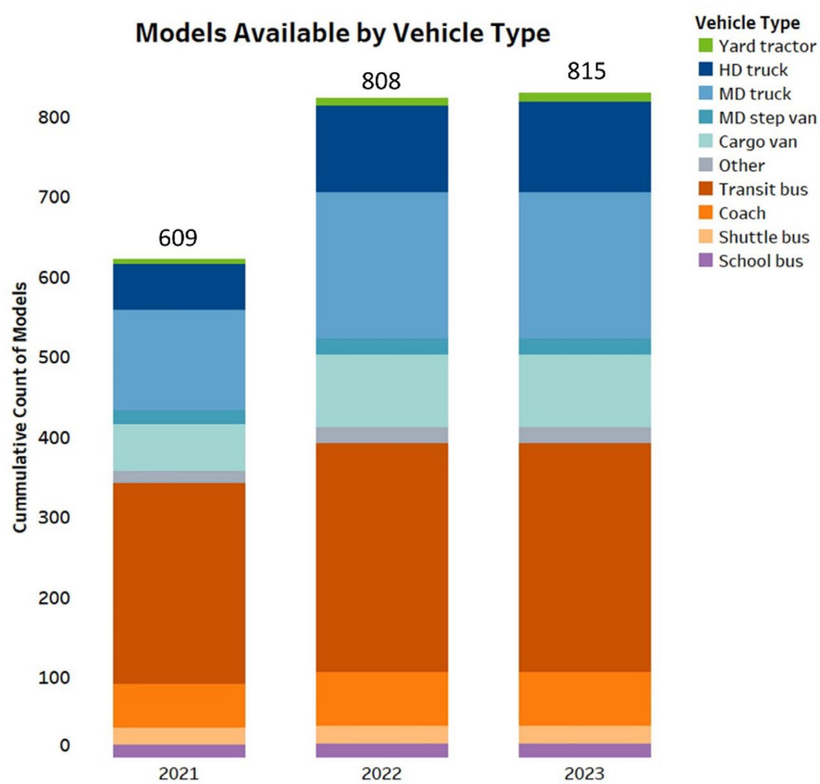


1.5. ZE-MHDV GLOBAL MARKET AND TECHNOLOGY READINESS

ZE-MHDV technology is operationally ready to tackle most duty cycles today. Present ranges meet or exceed the ranges required by most routes for trucks, buses, and vans on the road. Research shows that the majority of MHDVs on the road today drive regular distances well within the range capacity of available ZE-MHDVs (RMI, 2022). These vehicles also have hauling capacity comparable to their internal combustion engine (ICE) counterparts, and losses in freight efficiency due to extra weight of batteries can be mitigated through targeted weight exemption policies—already introduced in the U.S. and E.U. As of 2022, this capability is emerging with heavy freight tractors as well, achieving ranges of 400-480 kilometers (250-300 miles) with longer ranges projected by 2023. A global database of these vehicles and their high-level specifications can be found in the Zero-Emission Technology Inventory (ZETI) tool, where they are tracked globally. Examples of the operational capacity of the heaviest trucks include: Freightliner's Class 8 eCascadia (up to 370 kilometers, or 230 miles); Volvo's Class 8 VNRe (up to 440 kilometers, or 275 miles); Mercedes-Benz's Class 8 eActros (up to 400 kilometers, or 250 miles); Scania's

Class 8 Tractor (up to 350 kilometers, or 215 miles); Hyzon's Class 8 FCEV Tractor (up to 800 kilometers, or 500 miles); and Hyundai's Class 8 FCEV Xcient (up to 400 kilometers, or 250 miles) (CALSTART, 2022g). While most of the models are readily available in limited production, OEMs are rapidly scaling their capacity to deliver, with clear market signals that the future will be dominated by ZEVs. Moreover, most global OEMs have established similar 2040 dates for carbon neutral or "fossil free" operations including PACCAR, Volvo, GM, Scania, and others (full table of OEM commitments in Appendix) (CALSTART, 2021). As of 2022, there are over 800 unique models of ZE-MHDVs that can be purchased across countries, with more offerings added every month (CALSTART, 2022h).

Figure 3. Global ZE-MHDV Model Availability by Segment (2021 - 2023) (CALSTART, 2022h)

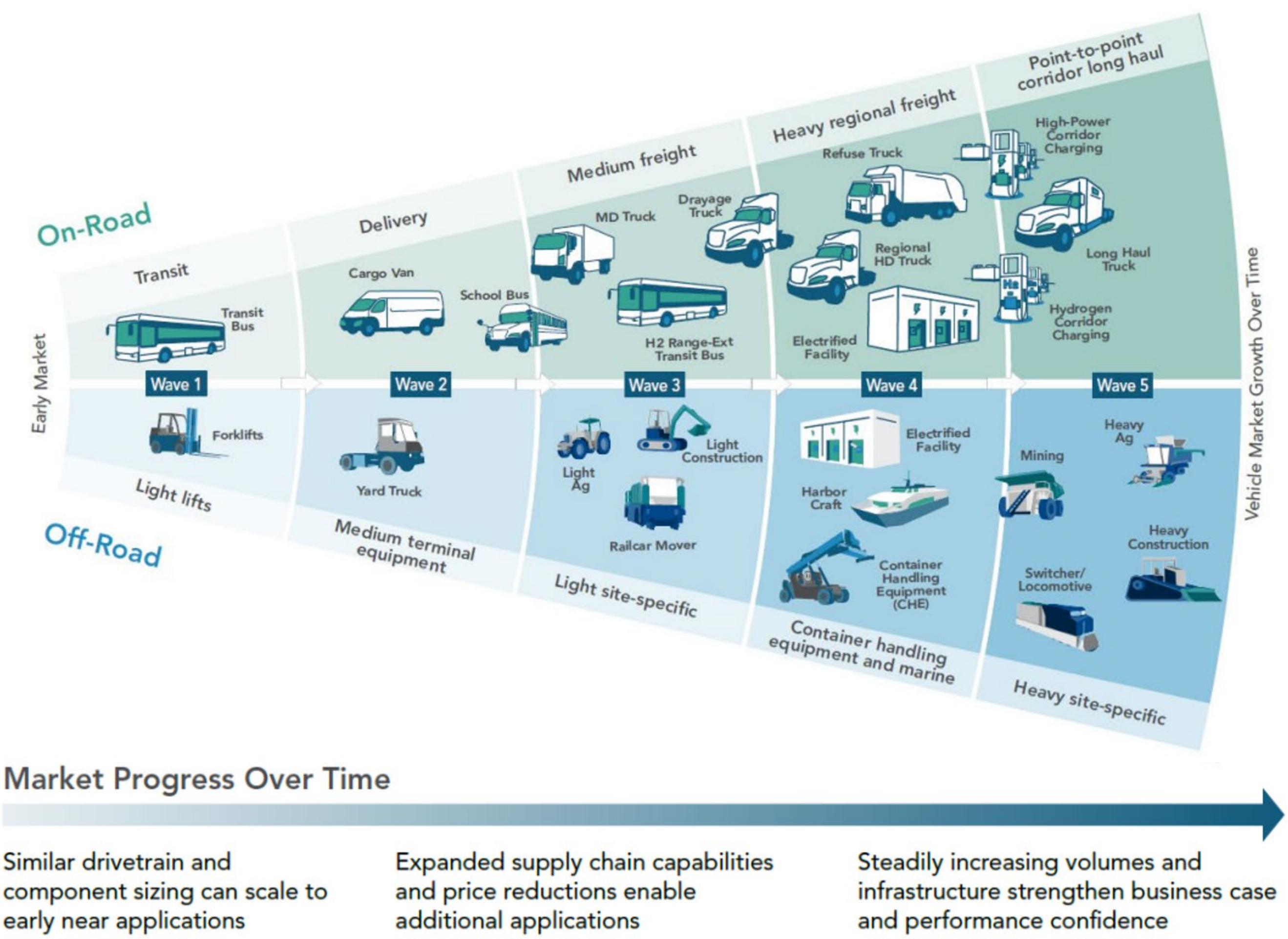


1.6. SMART MARKET SEGMENTATION

While technology has advanced rapidly across global markets, policymakers do not always have access to the most up-to-date information regarding model availability, production capability, and operational viability for specific vehicle segments and vocational uses. A better understanding of zero-emission technology capability can enable the development of smarter policies that are more effective in scaling up the ZE-MHDV market.

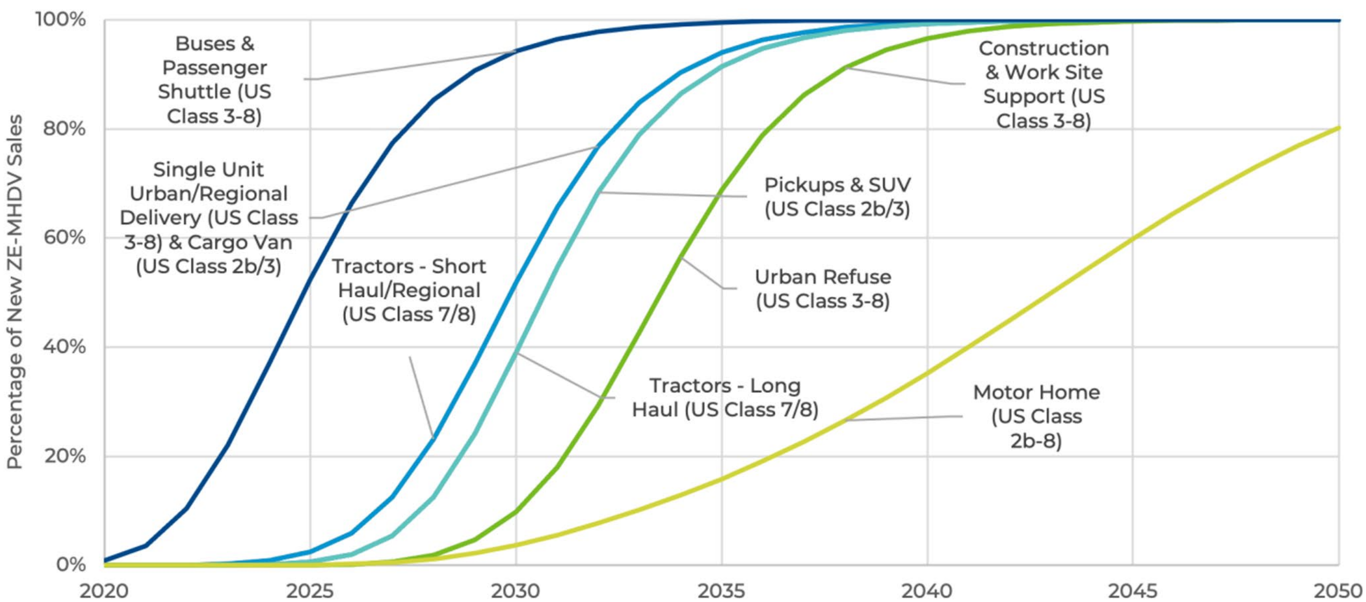
The California Air Resources Board (CARB) and CALSTART have developed a strategy for zero-emission technology commercialization that accelerates the ZE-MHDV market, based on early investments on first-success applications or "beachheads" where ZE technologies are most currently viable. These predictable pathways, or "waves," were first visualized by CARB in 2017; today's most current visualization of the generic beachhead process is shown as Figure 4 below. The core of the Beachhead Strategy resides in focusing investments on a smaller market segment and successfully deploying in or monopolizing that market, thereby helping advance the technology into larger markets or other applications. For reference, global truck makers have now moved to Wave 5 in terms of capability. The rapid expansion across these waves has been accomplished through technology transfer, leveraging similar powertrains while supply chains grow and costs go down, expanding infrastructure, and building confidence as technology improves (CALSTART, 2022i).

Figure 4. The Beachhead Strategy (CALSTART, 2022i)



The Global MOU aims toward a full transition to new ZE-MHDVs by 2040, and an interim target of 30% sales of new MHDVs being zero-emission by 2030. Recognizing the great diversity across MHDV segments, ambitious but feasible adoption curves were developed for eight MHDV segments, taking into account technology readiness (i.e. operational capacity), supply scalability (i.e., how fast manufacturers can scale up production), and fleet demand (i.e., likelihood that fleets will select a "novel" technology assuming cost parity and infrastructure availability). Figure 5 illustrates such disaggregated adoption curves which collectively illustrate the path to a full transition toward ZE-MHDV sales by 2040 (See Appendix for regional weight conversion table). While not all eight segments can reach 30% ZE sales by 2030, their aggregate sales will reach or surpass that threshold in any country that adopts the policies recommended in this action plan (CALSTART, 2022b).

Figure 5. Global ZE-MHDV Sales Targets by Segment (CALSTART, 2022b)

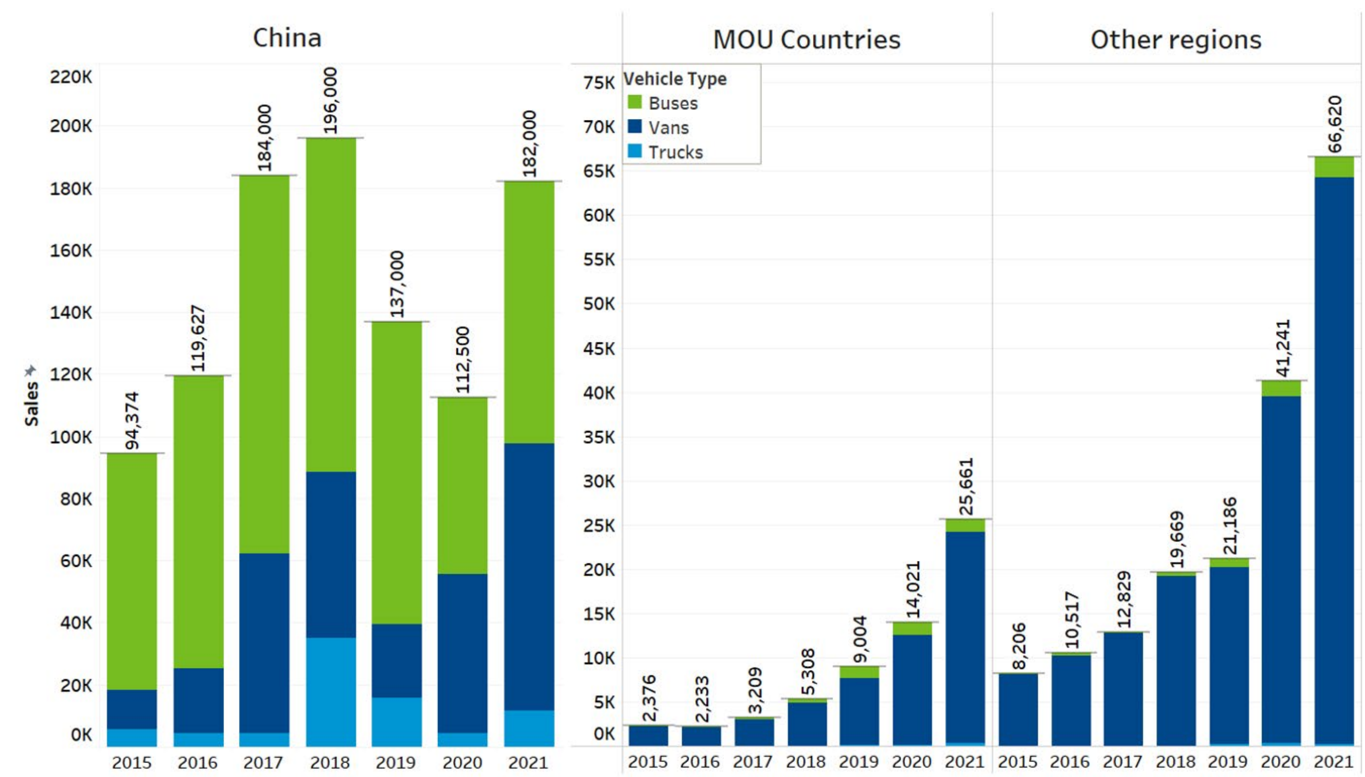


Note: E.U. Class N2 = U.S. Classes 2b-7 & E.U. Class N3 = U.S. Class 8

Figure 5 indicates that buses and then urban delivery and intracity regional trucks must be an early focus to lay the groundwork for vehicle segments with more demanding operational requirements. Vehicles that are rolled out in these early segments will be deployed in local and regional settings and most frequently return to base for charging overnight. That said, it is also important to keep in mind that longer-range ZE-MHDVs are becoming available now and need to be planned for actively. Early deployments also necessitate the development of associated infrastructure, increasing the volume of chargers and ensuring grid electrical upgrades, interoperability, make-ready programs, and utility charging rates can be established and fine-tuned as the share of ZE-MHDVs increases in the leading segments of the market. Further along the adoption timeline are long-haul tractor trucks and pickups/SUVs. This ordering reflects the timing for technology readiness of ZE technologies for different vehicle vocations, types, and weights, and recognize that ZE technologies can be transferred across vehicle types as technologies evolve and costs decrease. Following are more specialized vehicles like refuse and construction trucks, as well as mobile homes, all of which represent a relatively small, specialized share of MHDVs, often having other power demands such as from an ePTO unit.

While the global curves above represent the projected progression of the dominating ZE-MHDV platforms, there will always be variability depending on the country or region, the share of vehicles that constitute that MHDV market, vocational considerations, environmental factors and other elements. Specialized vehicles like refuse trucks for example, may have the capacity to advance more rapidly than projected, especially given other factors like public procurement, funding and financing and prioritization through policy. This sentiment can be applied to other segments as well, and the projections presented above should serve as a benchmark.

Figure 6. ZEV Sales in China, Global MOU Countries, and Other Regions (2015-2021)[2] (IEA, 2022)

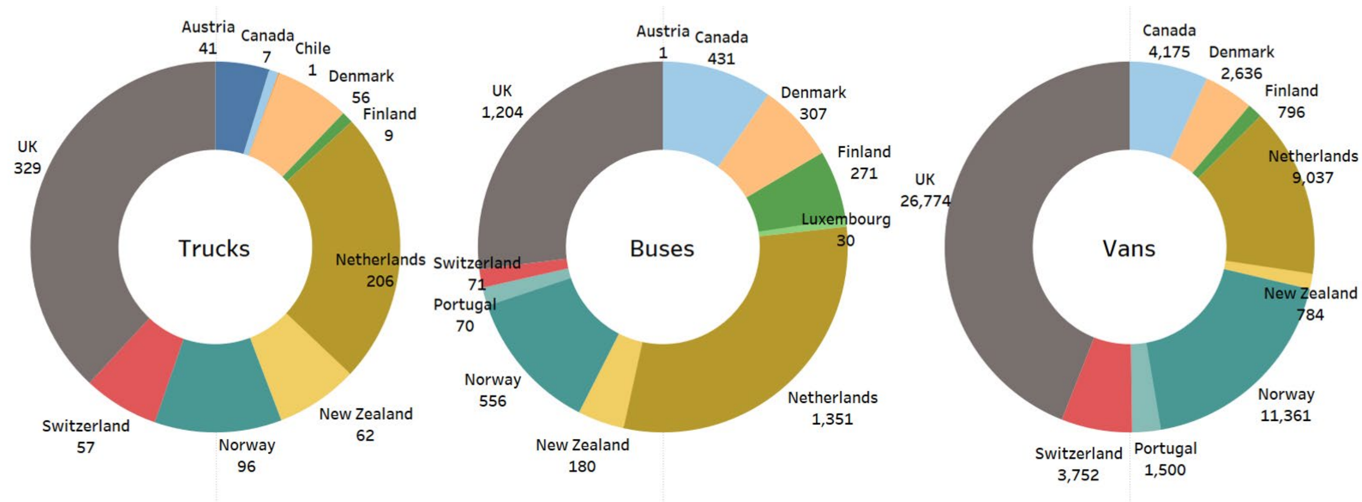


With an understanding of where countries need to be in terms of the share of new vehicle sales by segment, there must also be a baseline of where countries are today. Figure 6 shows the current sales volumes of ZE-MHDVs by global region and includes some countries that have yet to sign the Global MOU. It is unsurprising that China leads the world from the perspective of sales, though the Global MOU countries show rapid growth in urban segments like trucks and buses. Figure 7 provides additional perspective for the MOU countries specifically, taking a more detailed look at how the countries compare with one another in terms of vehicle stock—or vehicles currently operating across trucks, buses, and vans. Countries that have instituted more ambitious policy goals like the U.K., the Netherlands, and Norway lead deployments and are a testament to the influence of strong policy action on the overall ZE-MHDV market.

2 MOU Countries: Austria, Canada, Chile, Denmark, Finland, Luxembourg, The Netherlands, New Zealand, Norway, Portugal, Scotland, Switzerland, Turkey, United Kingdom, and Uruguay, Wales.

Other regions Include: Belgium, France, Germany, Greece, Iceland, India, Italy, Japan, Korea, Poland, Spain, Sweden, USA, and "other Europe".

Figure 7. Zero-Emission Bus, Van, and Truck Stock Among Global MOU Signatories in 2021 (IEA, 2022)



The clear conclusion is that accelerated action is needed from government and industry to speed ZE-MHDV uptake in the near term to set major markets on the right path toward the 2030 and 2040 targets outlined in the Global MOU. While OEMs have increased ambition through their own goals, governments also drive the market through regulations and incentives, two of the most impactful near-term policies that will ultimately move the market. Countries must identify, prioritize, and customize the policies and actions that will most effectively accelerate the uptake of ZE-MHDVs in their own jurisdiction.

Findings from ZETI and data drawn from research carried out by other leading experts affirm that the majority of MHDVs on the road today could be replaced by their zero-emission counterparts from an operational perspective (RMI, 2022) (CALSTART, 2022g) (ICCT, 2021a). This marks a major shift in the potential for the current technology, and investments must be made today to enable long-haul, extreme routes and demanding duty cycles. Such a fundamental change in the technology will naturally require a period of scaling that will take time and adjustment.

CHAPTER 2

COUNTRY-SPECIFIC ACTIONS AND THE ROAD TO 2040

The Multi-Country Action Plan summarizes policies and actions taken by Global MOU signatory countries to date that support the MOU's target of 30% sales of new ZE-MHDVs by 2030 and a full transition to new ZE-MHDVs by 2040. Preliminary data indicates that MOU countries fall somewhere on a continuum of implemented policy, from aggressive to little action taken. Offering policy recommendations to the Global MOU signatories based on objective realities of the technology and successful sequencing and combination of key policy elements is one of the goals of this MCAP. Elevating the ambitions of the signatory countries through these resources is key to accelerating the market for ZE-MHDVs. To effectively achieve this, it is important to establish the successful actions already taken by countries and that are currently ongoing.

Policies have been grouped into five dimensions, namely: *Targets, Regulations, Incentives, Infrastructure Investments, and Innovative Policies*. The importance of each will be elaborated in its respective section and will be followed by relevant examples of successful implementation across the MOU countries. There are numerous routes forward and there is not one "right" approach. However, it is important to develop an Action Plan addressing each of these dimensions. Providing policymakers with a suite of policies and actions that have proven effective in supporting ZE-MHDV deployments in other regions can provide guidance and confidence. Beyond taking away a greater understanding of what other MOU countries are implementing, the following sections will provide a sense of direction to countries that may be unsure of where to begin.

2.1. TARGETS

Setting clear and ambitious yet achievable ZE-MHDV targets allows fleet operators, manufacturers, utility providers, local authorities, and other stakeholders to better plan for a major technology transition, make the needed supply chain investments, explore innovative financing mechanisms, and educate their workforce. Overly modest targets that aim too low will not provide a sufficient signal. The proper scale up to enable such a massive technology shift requires early targets even when not all technology choices are predetermined. ZE-MHDV targets also help countries meet their broad economy-wide climate emission reduction goals by targeting a sector that is one of the biggest emitters while having substantial emission abatement potential because of technology readiness. It is exactly this level of confidence in ZE technologies that has led global manufacturers to set strong targets as early as 2025 and 2030 (CALSTART, 2021).

Importance of setting strong targets for ZE-MHDVs:

1. Lays the foundation for strong policies.
2. Allows ample timing and preparation by all government and industry stakeholders.
3. Provides clarity of direction; boosts confidence in technology and reduces investment risks.
4. Sends powerful signals to spur targets, policies, and deployment in other global markets.

The Global MOU signatories have collectively agreed to work together toward 30% of new MHDVs being zero-emission by 2030 and a full transition to ZE-MHDV for new fleets by 2040, with the aim to enable carbon neutrality by 2050. Figure 8 illustrates the alignment of ZE-MHDV targets despite the wide divergence of carbon neutrality goals. And while the Global MOU targets allow for flexibility in how the goals will be achieved, more specific targets for individual vehicle segments leverage the fact that ZE technologies are more readily available for some segments – in particular transit buses and urban delivery – which could move even faster than the aggregate MHDV fleet. This has indeed been the approach adopted by a few leading countries. For example, Norway, The Netherlands, New Zealand, Denmark, and Austria have targeted earlier dates for the full electrification of their transit buses, which lay the technology foundation for truck electrification given the great potential for technology transfer. Similarly, Norway and the United Kingdom have identified vans and lighter commercial vehicles as first movers that will lead to growth of the infrastructure network and innovations in logistics. Some subnational governments have also adopted more ambitious targets than those adopted nationally. For example, the Canadian province of Quebec aims for 100% sales of new transit buses to be zero-emission by 2025, and the State of California in the U.S. has also adopted a regulation to ensure a full transition to new zero-emission buses by 2029.

Figure 8. ZE-MHDV Targets Established by Government (CALSTART, 2022k)

UK 2035 Truck target includes trucks ≤ 26 tonnes, with full phaseout in 2040

The following recommendations can help guide the continued implementation of ZE-MHDV targets:

1. **Align and establish targets for specific MHDV segments with technology readiness and operational capability.** Figure 5 in the previous chapter indicates the levels of technology readiness by MHDV segment. For example, though there may be differences amongst countries,

ZE technologies are already readily available for wide commercialization for transit buses and urban delivery vehicles, which should be prioritized for immediate action.

2. **Establish target for 100% sales of zero-emission transit buses and urban delivery vehicles.** This will not only accelerate the transition to ZE technologies in those segments for which the technology is ready but will also lower air pollution and health impacts in cities.
3. **Support targets through roadmaps and planning**. Detailed planning through roadmaps can align industry and government stakeholders and provide them confidence that targets are achievable with careful planning and swift action.

2.2. REGULATIONS

It is also imperative to back ZE-MHDV targets with regulations to provide market certainty and give industry the confidence to invest heavily in ZE technologies. Regulations can take many forms and it will be up to each country to design the most adequate regulatory package. Many countries have adopted CO_2, energy efficiency and/or emission standards for new MHDVs that limit GHG emissions and, if sufficiently stringent, indirectly encourage ZEVs. To date, only a few government jurisdictions have adopted more explicit ZEV regulations for MHDVs, for example California with its Innovative Clean Transit regulation (ICT, for buses) and Advanced Clean Trucks (ACT) regulation, which require increasing ZEV sales shares over time (CARB, 2019) (CARB, 2022).

Importance of establishing strong regulations for ZE-MHDVs:

1. Provides more market certainty through penalties for non-compliance.
2. Provides a tangible regulatory timeline to help manufacturers, fleets and utilities to justify and plan investments.
3. Provides measurable process for meeting climate commitments in key sectors.
4. Provides critical co-benefits in criteria emissions reductions in communities most at risk from air pollution.

Depending on their level of stringency, local pollutant emission standards for nitrogen oxides, particulate matter and other harmful pollutants to human health may help accelerate the adoption of ZE technologies. Euro VI vehicle emission standards in Europe, and their equivalent regulations in other major MHDV manufacturing markets (e.g., North America, Japan, China, India, Brazil) have become the global standard for limiting emissions of harmful pollutants a vehicle may emit. Emission control technologies such as selective catalytic reduction (SCR) and diesel particulate filters (DPFs) have shown broad effectiveness, but they may be insufficient to adequately reduce urban air emissions in many world regions. Euro VI standards alone are also not stringent enough to have not forced ZE technologies onto new MHDVs. The next iteration of local pollutant emission standards, depending on their stringency, might change that.

In addition to local pollutant emission standards, many government jurisdictions have also adopted CO_2 standards and/or energy efficiency standards to limit GHG emissions. The table below compiled by the ICCT summarizes the provisions of current global fuel efficiency or GHG standards.

Table 1. HDV Fuel Efficiency, CO_2, or GHG Standards Around the World (ICCT, 2021b)

	United States and Canada	European Union	China	Japan	India
Type	Fleet Average	Flert Average	Individual Vehicle	Fleet Average	Individual Vehicle
Regulated Metric	CO_2 (g/ton-mile)[a] Separate standards for CH_4 and N_2O	CO_2 (g/ton-km)	Fuel Consumption (L/100 km)	Fuel Economy (km/L)	Fuel Economy (km/L)
Vehicle Scope	GVW > 3.85 tonnes 19 sub-categories	GVW > 16 tonnes 9 sub-categories	GVW > 3.5 tonnes 66 sub-categories	GVW > 3.5t 25 sub-categories	GVW > 12 tonnes 10 sub-categories
Year of First Implementation	Phase 1: 2015, 2017 Phase 2: 2021, 2024, 2027	2025 and 2030	Stage 1: 2012 Stage 2: 2014 Stage 3: 2019	Phase 1: 2015 Phase 2: 2025	Phase 1: 2018 Phase 2: 2021
Mandated Improvement[b]	Phase 1: 5% to 23% Phase 2: 10% to 27%	15% by 2025 30% by 2030	Stage 1: None Stage 2: 10% to 14% Stage 3: 12% to 16%	Phase 1: 1% to 12% Phase 2: 3% to 16%	Stage 1: None Stage 2: 5% to 16%

a In the United States, the Department of Transportation's National Highway Traffic Safety Administration (NHTSA) sets equivalent fuel consumption standards in gallons/1,000 ton-mile, nbased on a conversion factor of 10,180 gram CO_2 per gallon diesel

b Values presented as ranges indicate the minimum and maximum reduction mandated in the separate regulated sub-categories

New Zealand has also been proactive in establishing a 35% reduction of GHG emissions from freight by 2035. In Chile, a new energy-efficiency law mandates the setting of energy-efficiency standards for new vehicles sold. Chile's goal is to reduce energy intensity by 10% by 2030 and the law includes provisions that incentivize the deployment of zero-emission vehicles through multiplier credits. These pollution-limiting regulations would mean that manufacturers might be encouraged to sell increasing shares of ZE-MHDVs to meet each benchmark, depending on the level of stringency (Global Fuel Economy Initiative, 2021). By 2023, the European Commission must review the efficacy of the HDV CO_2 Reduction Targets to determine if a more ambitious reduction in the share of vehicle GHG emissions should be instituted.

Regulations like Euro VI or HDV CO_2 reductions are a strong start to establishing the right framework for impactful and equitable regulatory action but to date they have not been stringent enough to drive substantial levels of ZEV adoption. Another effective regulatory mechanism that has had a strong impact on ZE-MHDV adoption is sales or procurement requirements. The specific provisions of such requirements will vary depending on the policy or directive, but all generally hinge on the sale or purchase of a certain share of ZE-MHDVs per year in increasing amounts. Current examples of sales and procurement requirements for ZE-MHDVs are summarized in Table 2 below.

Table 2. Examples of Procurement and Sales Requirements (CALSTART, 2022k)

Country / Region	Policy	Sales or Procurement requirement
European Union	E.U Clean Vehicles Directive	Establishes minimum 25% - 40% clean vehicles acquired through public procurement by 2025; and 33% - 65% in 2030 depending on size of the member country's economy. At least half of the "clean" vehicles must be zero-emission
New Zealand	Requirements for Urban Buses	100% new zero-emission transit buses by 2025
California	Innovative Clean Transit Regulation / Advanced Clean Truck Regulation	(ICT): 25% new ZEBs sold beginning 2023 and 100% new ZEBs by 2029 (ACT): By 2035 ZE new sales for 55% of new vans/pickup, 75% of rigid trucks, and 40% of tractors
Austria	2030 Mobility Master Plan	100% new ZEBs by 2032 100% new HDVs < 18 tonnes by 2030 100% new HDVs by 2035
The Netherlands	Mission Zero	100% new ZEBs by 2025
Norway	National Transport plan 2018-2029	50% of new ZE trucks by 2030
Denmark	Together For a Greener Future	100% new ZEBs by 2025

The following recommendations can help guide the continued implementation of impactful regulations that will accelerate ZE-MHDV uptake:

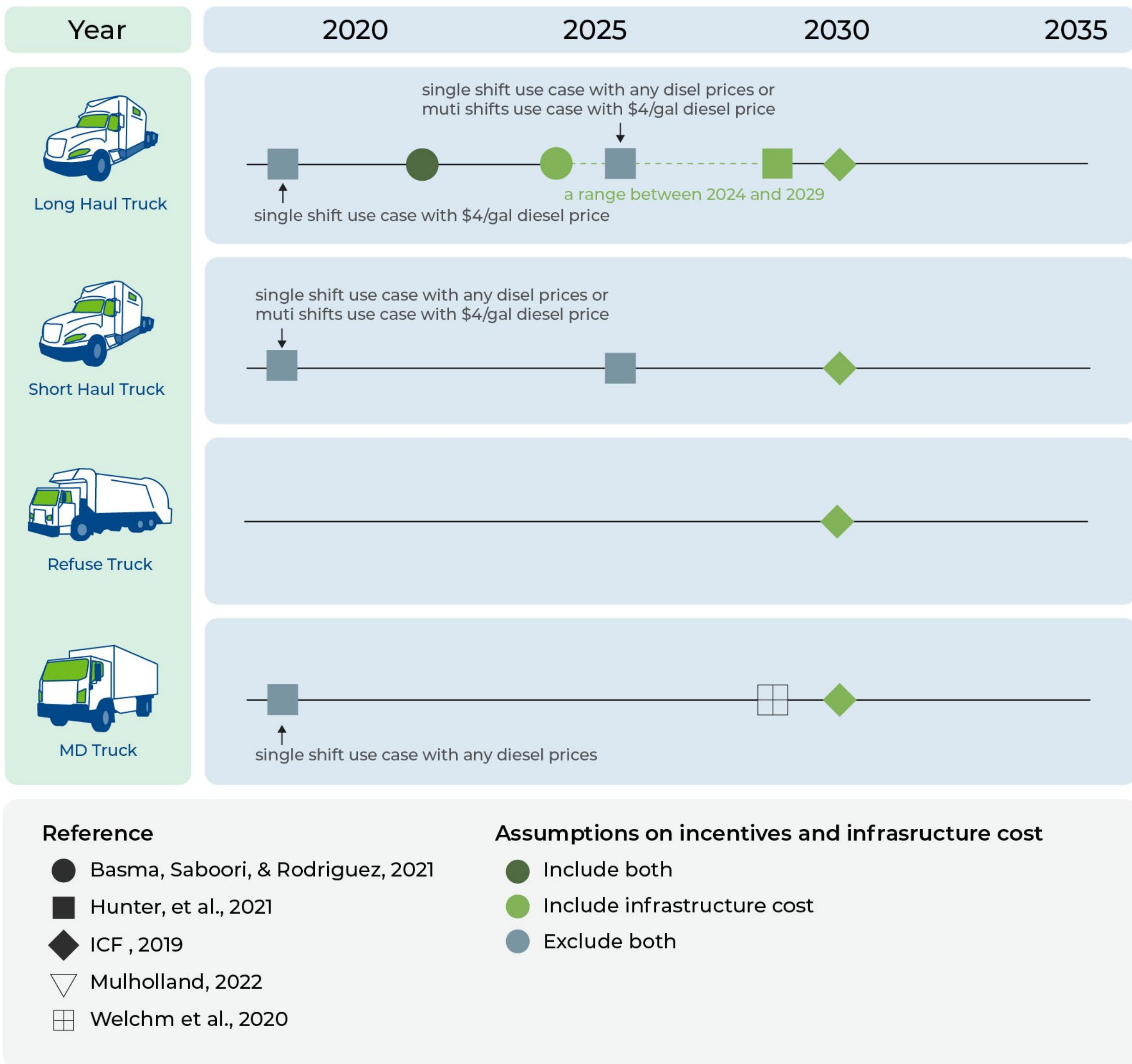
1. **Regulations must be specific and include strategic timelines and phase-in plans.** To ensure manufacturers can meet regulatory targets, ambitious yet achievable timelines and benchmarks should be clearly defined and communicated and connected to the capabilities of the technology.
2. **Countries should strengthen GHG and emission standards for MHDVs.** Although GHG and local pollutant standards have not been stringent enough to directly accelerate the adoption of ZE technologies, future versions of such standards will, if strengthened sufficiently.
3. **Countries should consider adoption of complementary sales requirements for ZE-MHDVs.** Although GHG and local pollutant standards can indirectly drive the adoption of ZE technologies if they are sufficiently strong, ZE-MHDV sales requirements and other ZEV mandates provide better clarity and certainty, alongside being much simpler to adopt and enforce.

2.3. INCENTIVES

The operational savings from ZE-MHDVs can offset higher capital costs because of higher energy efficiency and simpler maintenance, and battery-electric versions of most MHDV segments are expected to achieve cost parity with internal combustion engines on a TCO basis by 2030. The economic advantages of ZE-MHDVs are already apparent in select regions with favorable conditions, especially for urban vehicles and a few medium-duty regional trucks.

However, the reality is that most ZE-MHDVs in the market today still have much higher upfront costs, which dissuades many fleets, in particular small and medium-sized fleets, from investing. Targeted and timebound vehicle financial incentives can accelerate cost parity, encourage early investment by fleets, and support the early introduction of regulations. It is the right combination of early incentives and regulations that will provide both market certainty and the ability for fleets to invest. Figure 9 below evaluates existing TCO studies and the impact of incentives on when ZE-MHDV will achieve cost parity.

Figure 9. Earliest TCO Parity Year Between Battery-Electric Trucks and Diesel (CALSTART, 2022l)



Importance of implementing targeted and timebound ZE-MHDV financial incentives:

1. Accelerates TCO cost parity date and encourages fleets to begin acquiring ZE-MHDVs sooner.
2. Enables OEMs to scale production and accelerate R&D efforts more rapidly by inducing demand.
3. Enables smaller fleets with fewer resources to participate in the technology transition.
4. Speeds higher adoption levels by larger, first-mover fleets to help increase production volumes and build supply chains

Many countries, regions, and cities have already rolled out incentives in different formats and scale, the most common of which are direct vehicle subsidies, providing cost reductions directly on the upfront vehicle cost. In 2022, Canada launched its iMHZEV program offering point-of-sale reductions for ZE-MHDVs up to $200,000 per vehicle. In The Netherlands, subsidies differ between large (up to 40% of the incremental cost between ICE and ZEVs) and small companies (up to 60%) to ensure a more equitable transition. Incentives are also available for vans, coaches, and city buses in differentiated amounts, in alignment with the identified leading zero-emission segments. Similarly, Austria has introduced a framework that awards grants to trucks, buses, and infrastructure, up to 12,000 EUR for vehicles up to N1, and up to 120,000 EUR for ZE buses. Sweden, a global leader in ZEV policy, has also introduced subsidy support for up to 20-40% of the incremental cost of ZE-MHDVs. Table 3 summarizes the funding opportunities available in MOU countries. The earliest model to demonstrate the function, flexibility, and effectiveness of a voucher-based incentive program for commercial vehicles is the California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). In 2021 alone, the HVIP program received 2,014 truck and bus voucher requests through $247 million in available funding (CALSTART, 2022f).

Table 3. Current Funding Opportunities for ZE-MHDV Acquisition (CALSTART, 2022k)

		(Funding amount per vehicle)		
Country	Total funding (as of 2022)	Truck	Bus	Van
Austria	€167.2M for MHDVs; €85M for trucks and vans and infrastructure (N1, N2, N3); €51.2M for Buses and infrastructure; €91M for vehicles and infrastructure (including N1, M1, M2 & M3).	Up to 80% of additional costs (begins year-end 2022)	Up to 80% of additional costs	Up to €12,500
Canada	$547.5M for MHD vehicles over 4 years; $2.75B in grants for school and transit buses, $1.5B in financing.	$40,000 - $200,000	Up to 50% of purchase cost through grants and up to 100% of through financing.	Up to $10,000
Finland	€6M for trucks (through 2023); €6M for vans (through 2023)	Up to €50,000	Unspecified	Up to €6,000
New Zealand	€11.5M for freight vehicles, associated infrastructure and projects (NZ 20M)	~50% of purchase	~50% of purchase	~50% of purchase
Sweden	€100M for buses (SEK 1,100); €1M for MHD trucks (SEK 10M)	Up to 20% of purchase cost	20 % - 40% of purchase cost	Up to 20% of purchase cost
The Netherlands	€25M for trucks; €40M for buses; €22M for vans	12.5% - 37% of purchase cost depending on vehicle and company size	€25,000 - 75,000 per bus	10% - 12% of purchase cost
United Kingdom	€7.3M (£6.5M) for MHD trucks from 2021-2025 €232.7M (£205M) for buses	Small trucks (4.25 – 12 tonnes) 20% of purchase cost to a maximum of €18,168 (£16,000); and for medium and heavy trucks 20% of purchase cost to a maximum of €28,388 (£25,000)	Vans (below 2.5 tonnes) 35% of purchase cost to a maximum of €2,838 (£2,500); and for large vans (2.5 – 4.25 tonnes) a 35% discount to a maximum of €5,677 (£5,000)	Up to 35% of cost with maximun of €2,900 (£2,500)

Financial incentives can also come in the form of tax mechanisms, another common policy lever to spur adoption of ZE-MHDVs. Most countries' taxation systems allow for innovative ways in which these incentives might impact a fleet. Some operate in a similar way as upfront subsidies, while others may penalize the operation of combustion vehicles. For example, Norway has implemented a disincentive where motorists and manufacturers must pay a fee corresponding to the amount of CO2 emitted by operating a vehicle. Numerous policies in Switzerland exempt or reduce ZE-MHDVs from taxes and road fees. The EUrovignette in the E.U. defines a schedule of road fees levied on MHDVs that are reduced for cleaner vehicle technologies, benefitting and incentivizing the use of ZEVs (EEA,2022). In New Zealand, ZE-MHDVs are exempt from a road-user charge until 2025. In Canada, a tax write-off policy was expanded to include all ZE-MHDV and allows for 100% write off. In Uruguay there are specific tax deductions available for corporate freight vehicles and a 0% internal tax on EVs. In the U.S., there are up to $40k in tax credits available for the purchase of ZE-MHDVs. Through Chile's energy efficiency law, companies and operators can have accelerated depreciation of the zero-emission vehicle assets, allowing a greater amount of the investment to be written off early on. Portugal has also leveraged tax mechanisms to exempt ZE-MHDVs from certain taxes associated with the operation and purchase costs, and even includes deductions on electricity used for charging.

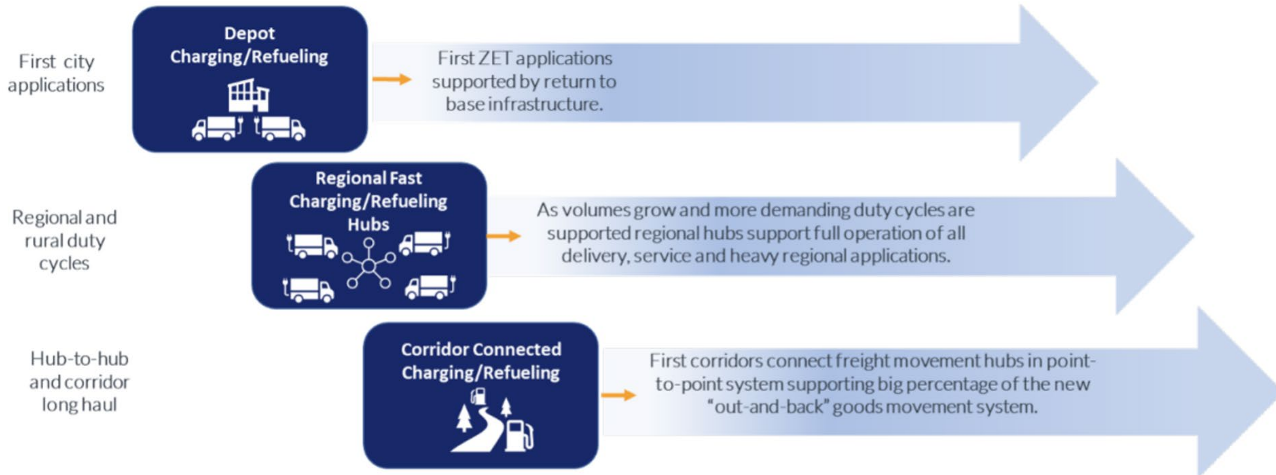
The following recommendations can help guide the continued implementation of incentives to support accelerated ZE-MHDV uptake:

1. **Incentives must be targeted and timebound**. Incentives are more impactful if targeted at those segments for which ZE technology is most available. Incentives are also more effective if their phase-in and phase-out dates are known, and directly linked to cost parity timelines.
2. **Incentives should be implemented alongside regulations**. It is the right combination of early incentives and regulations that will provide both market certainty and the ability for fleets to invest. Regions that implemented incentives without regulations have experienced decreasing sales after incentives were phased out despite strong demand.
3. **Incentives should target small fleets.** By building in set-asides for small fleets, or fleets operating in urban areas, governments can make sure smaller players in the industry or those with fewer resources can still play a role in MHDV decarbonization.

2.4. INFRASTRUCTURE INVESTMENTS

Infrastructure availability is one of the most pressing issues to address today in the transition to zero-emission technologies. Battery-electric vehicles are less costly and more efficient to operate than those powered by gasoline and diesel. When paired with renewables, costs can drop even lower. However, installing the infrastructure needed to recharge large vehicle fleets requires planning, installation, and often distribution grid upgrades that cost local utilities and fleets time and money. Establishing a sound framework that enables this work in a timely, cost-efficient way is vital to scale up charging infrastructure. Governments must enable, encourage, and require utilities to plan for, invest in, and take an active role in installing ZE-MHDV infrastructure at the pace required to meet rapid market growth. Figure 10 establishes a framework for ZE-MHDV infrastructure phase-in, including overlapping and concurrent growth of a full ZET ecosystem starting with depot charging/refueling, moving toward regional fast charging hubs, and finally charging/refueling corridors.

Figure 10. ZEV Infrastructure Phase-in Progression (CALSTART, 2022j)



The progression of infrastructure deployment aligns with market transformation strategies like the Beachhead Theory of Change and the six-stage 2040 roadmap described in the last chapter. Beginning this effort with the first city applications allows for the deployment of private infrastructure at depots and domicile locations in and around cities. This stage is important as it allows first-success segments to comfortably be launched even in limited capacity without the need for public infrastructure. However, it is important to note these markets will grow mostly in parallel, not in sequence. Launching long-haul and saturating cities with ZE-MHDVs requires fast charging and refueling hubs regionally, with specific high-volume freight corridors chosen strategically to enable longer distance truck and bus travel. As MHDVs move between established hubs, the infrastructure "backbone" will be solidified and the network completed with high-speed refueling available in high volumes along all routes. Though this vision of infrastructure development might seem further out in time, it is not too early to begin: several countries are correctly starting to plan for robust networks for ZE-MHDV refueling.

Importance of establishing strong infrastructure policies and investments:

1. Provides needed investments for the establishment and continued buildout of infrastructure network for ZE-MHDVs.
2. Allows electric utilities to plan for future demand and improve critical elements such as electricity rates, site upgrades/installations, make-ready incentives, and permitting.
3. Gives fleets ample time and resources to understand the variable needs of the new technology that may differ by vocation (plug-in systems, hydrogen fuel, electric road systems, battery swapping).
4. Ensures that an interoperable publicly available network of rapid-refueling stations is available, able to be used by all and reliable for fleets users.

By regulating, investing in, and incentivizing the deployment of electric charging and hydrogen fueling infrastructure for ZE-MHDVs, governments can help spur technology adoption, create jobs, promote prosperous and healthy communities, and support the faster transition to a zero-emission transportation future.

Countries have deployed numerous strategies to expand charging and refueling station availability. Most of these efforts have been geared toward light-duty vehicles. While this is also important and there are light-commercial vehicles that can benefit from these priorities, greater efforts are needed to expand the network for ZE-MHDVs and fleet operators specifically. To do this, countries have deployed specific policies that often fall into two categories: either investment through financial support, or network development through roadmaps, guiding expertise, and collaboration with public and private entities. The combination of comprehensive planning and financial support is needed to support a robust and reliable network. Table 4 below provides insight into the investments being made by each country.

Table 4. Infrastructure Funding Projects and Amounts (CALSTART, 2022k)

Country	Program	Total Funding	Funding per project
United States	National Electric Vehicle Infrastructure program (NEVI)	$5B USD through 2026	up to 80% project cost
Turkey	Electric Vehicles Fast Charging Stations Support Program	Providing approximately $7.5M for the investment of $54M to 20 investor companies to install fast chargers.	Up to €60,000 for truck projects Up to €120,000 for ZEB projects
Canada	Zero Emission Vehicle Infrastructure Program (ZEVIP) / Canada Infrastructure Bank's Charging and Hydrogen Refueling Infrastructure Initiative (CHRI)	$680M / $500M CDN	ZEVIP: $5000-$100,000CDN for EVSE & Up to 1,000,000CDN for H2 station; CHRI: large-scale implementations with total capital costs more than $10M CDN.
Austria	Emission Free Buses and Infrastructure (EBIN) and Emission Free Utility Vehicles and Infrastructure (ENIN)	Total of €227.2M that covers both vehicle incentives and infrastructure projects.	Up to 40% of investments costs for infrastructure; Up to €20,000 for publicly accessible charging infrastructure >=100kW
Finland	Roadmap to fossil-free transport	€22M for high powered charging + €12M dedicated to ZEB infrastructure	Up to 35% of Project cost
Denmark	2035 Infrastructure Plan	DKK 9.6M for commercial road transport €37M for heavy-duty transportation	-
New Zealand	Low Emission Transport Fund	$24m in FY2023/24	-

In the E.U., the Alternative Fuels Infrastructure Regulation (AFIR) is under revision and the current proposal aims to ensure that the Trans-European Transport Network (TEN-T) is sufficiently serviced by electric vehicle supply equipment (EVSE) and hydrogen stations to enable the successful deployment of ZEVs. The current proposal states that by 2026, there should be one charging pool every 60 kilometers and one hydrogen refueling station every 100 kilometers along TEN-T road networks. In the U.S., the recently announced National Electric Vehicle Infrastructure Formula Program (NEVI) program—part of the Infrastructure Investment and Jobs Act (IIJA)—will significantly expand alternative fuel infrastructure across the US and provide historic investments for the future of ZE-MHDVs.

The Netherlands has prioritized collaborations between grid operators and local/national charge point operators to roll out charging infrastructure more efficiently. The Netherlands Living Lab Heavy Duty is an example of such a program, that also acknowledges the importance of urban MHDV electrification. In the Netherlands, the Environmental Investment Allowance (MIA) program enables the deduction of up to 45% of the amount invested in EVSE or other environmentally beneficial business asset, including the vehicles themselves. Switzerland has dedicated swaths of government-owned land along highways to develop charging infrastructure, though mostly for light-duty vehicles. Similarly, New Zealand is close to completing its network of DC fast charging stations every 75 kilometers; however, the provisions of this project do not require ample space for large trucks, so more must be done to ensure that MHDVs are being prioritized in program design globally. In Chile, requirements to ensure EVSE interoperability have been introduced to build confidence in the network and ensure vehicles will be able to charge without concerns of having the right plug connection or protocol. The United States is proposing interoperability provisions for use of IIJA funds for infrastructure outlined in NEVI. The United Kingdom recently released a comprehensive plan covering the future of freight that specifies convening of stakeholders to develop and plan the rollout of supportive infrastructure for freight vehicles. Portugal envisions a future of nationwide refueling stations that will enable seamless use across the country through the Mobi.E program.

As countries gear up to enable the deployment of large volumes of ZE-MHDVs and associated supporting infrastructure, the subject of interoperability must be highlighted. Without consideration of national and supranational standards for refueling and charging, fleet confidence will lag, and vehicle operators will face uncertainty in the field as range anxiety is exacerbated. Interoperability may refer to many different elements of the connection and use of EVSE, but for sake of simplicity, there are two broad categories to consider. The first is the physical connector or plug used in the charging process. When an operator connects the vehicle to a charging station, the shape of the connectors must match to initiate a charge. While this sounds straightforward, there are several different kinds of connectors in use for different vehicles and charging speeds. A table of these connectors can be found in the Appendix. The second consideration surrounding interoperability is the communication between the vehicle and the EVSE. Without standardization across communication protocols, the likelihood of an error occurring increases significantly and may cause any number of issues from payment failure to the charge not being initiated. Further, as the capacity of ZEVs grow and their use becomes more robust in cases where mobile power, or vehicle-to-grid (V2G) may be required, more different protocols and standards must be in place to ensure driver safety and efficient operation. Numerous standards are already in place, but significantly more consideration and though must go into adopting and improving standards that will be especially salient in regions like the E.U. or North America where vehicles may be traveling across borders frequently to fulfill operations. Further information on international standards can be found in the Appendix.

To ensure a smooth rollout and uptake of ZE-MHDVs, it is important that infrastructure be in place and planned well ahead of major increases in vehicle volumes. In the short term, most vehicles will not require access to public refueling infrastructure, since deployments will largely concentrate in cities and urban contexts where depot and private charging will cover refueling needs. However, as the market grows, the need for publicly available, interoperable commercial ZEV infrastructure will also increase considerably and must be planned for accordingly.

The following recommendations can help support rapid deployment of ZE-MHDV infrastructure:

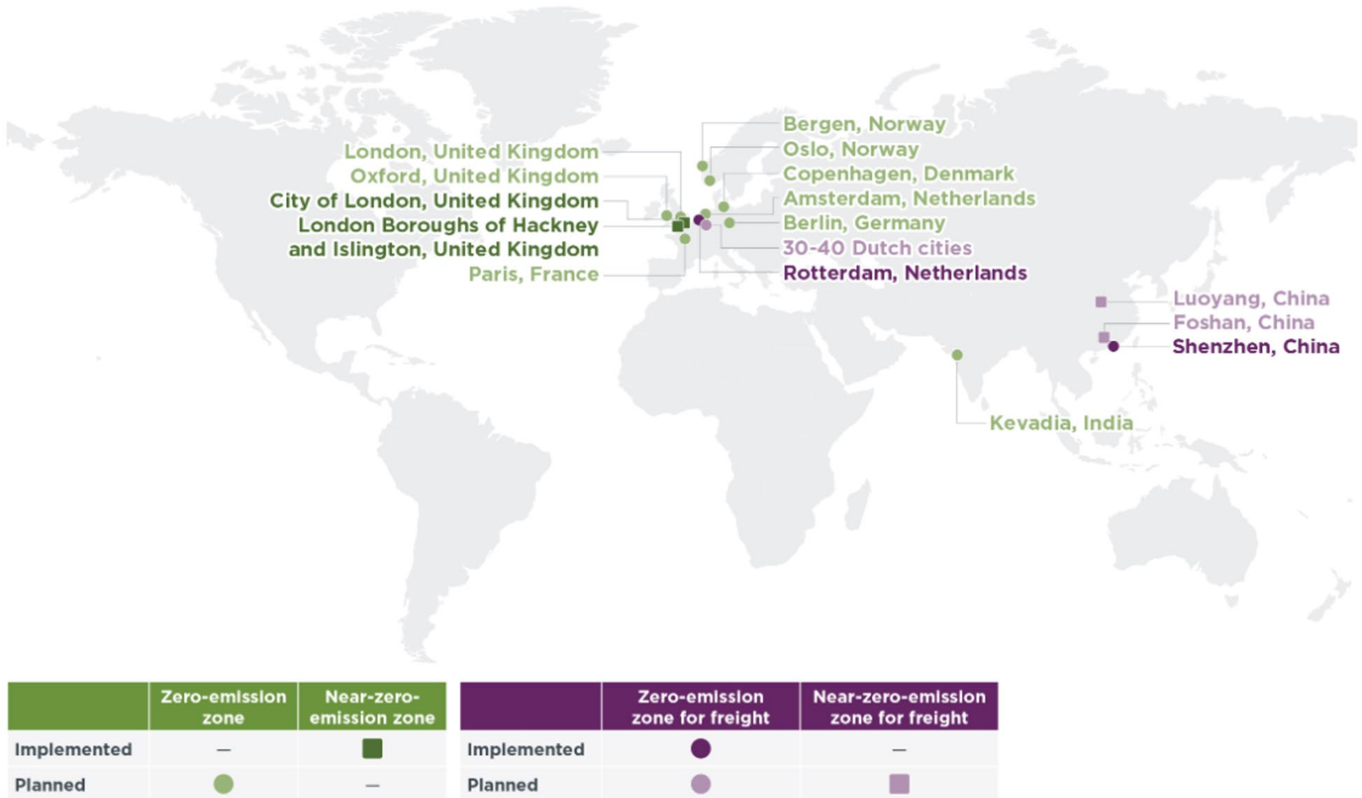
1. **Create roadmaps to forecast infrastructure demand and identify priority deployment locations.** Infrastructure roadmaps are needed to align national progress, through the identification of high-capacity freight corridors and urban hubs that result in highest impacts.
2. **Create regulatory structures that direct utility investment toward ZE-MHDV infrastructure.** Governments must ensure enough funding for "make-ready" infrastructure is available, so the costs of electrical upgrades and equipment installation do not fall unduly on fleets. Making ZE-MHDV infrastructure a co-equal priority with passenger EVs is important, as is requiring access to and adequately sized lanes at selected charging sites that can be used by ZE-MHDVs.
3. **Encourage interoperability standards and reliability metrics in the infrastructure system.** Ensuring vehicles can refuel with ease and efficiency they currently experience is key to ensuring successful infrastructure deployment. Encourage open systems and set goals but resist temptations to set standards alone. Interoperability and decisions on national and international standards must be approached collaboratively and objectively.
4. **Direct utility action toward beneficial rate structures for fleet charging.** Electric utilities must adjust electricity rate structures to ensure that fleets will not incur demand fees or higher costs from ZE-MHDV charging, particularly when charging off-peak. Utilities define different rates for different industries and must adjust similarly for MHDV charging.
5. **Jumpstart early markets with incentives, investments, industry engagement, user education, and workforce training.** Providing funding options to utilities and fleets to incentivize infrastructure deployment is critical to ensuring infrastructure is available to meet fleet needs. Engaging with local implementation partners to ensure industry is involved and the workforce has experience and knowledge of what is necessary to properly refuel and recharge the vehicles efficiently.
6. **Explore low-carbon fuel standards to spur innovation.** Specific focus on regulating the carbon intensity of fuels and feedstocks is needed to achieve significant CO_2 emission reductions. Market-based mechanisms such as low-carbon fuel standards can push fuel producers to innovate, while rewarding their progress toward low-carbon intensity solutions. Many countries have also levied taxes or fees on fuel producers, importers, and users based on emissions.

2.5. OTHER INNOVATIVE POLICIES

This section highlights innovative policies deployed across the world to spur ZE-MHDV uptake. Though there may be policies highlighted in this section that involve elements of the other four dimensions, these policies are best described as out-of-the-box approaches. Further, because many of these policies or programs are first of their kind, or conceptually novel, many are limited to subnational implementation. However, full rollout of policies highlighted in this section have the potential to further accelerate the deployment of ZE-MHDVs and increase the impact of the other dimensions above.

Zero-emission zones can be an effective approach to decarbonize cities and urban regions. Several countries have implemented ZEZs for MHDVs in their cities, meaning that vehicles entering the zone must emit no emissions, or pay a fee. The Netherlands has already designated over 40 cities for ZEZs for freight vehicles by 2030, 20 of which have already announced formal planning. Similarly, Norway has amended a plan that outlines different zones for which certain tolls are required, while ZEVs will be exempt from these fees. Oxford, London, and other cities in England have announced comparable pilots where fees, exemptions, and exclusions will limit the types of vehicles that may enter the city center. Other cities planning ZEZs include Copenhagen, Shenzhen, Paris, Oslo, and many more (ICCT, 2021c). The following figure from ICCT illustrates cities with implemented and planned ZEZs that include MHDVs.

Figure 11. Cities with implemented and planned zero-emission zones and variant globally as of 2021 (ICCT, 2021c)



Another key measure with widespread success is vehicle weight exemptions for ZE-MHDVs. These accommodate heavier vehicle weight because of batteries or hydrogen storage and avoid penalizing ZE-MHDVs through lower payloads. One of the provisions of the EU Clean Vehicles Directive has increased class weight limits by 2 tons. The U.S. has enacted a similar policy. Vehicle weight exemptions improve operational costs by allowing ZE-MHDVs to operate in a comparable capacity to internal combustion engine vehicles.

Another mechanism that reduces ZE-MHDV operational costs is exemptions or reductions in vehicle and road taxes. In Austria and Norway for example, ZE-MHDVs are exempt from numerous taxes that apply to conventional vehicles. In the Netherlands, taxation has shifted to a kilometer-based system for which ZEVs receive a discount. These avoided costs further reduce operational costs and can be a powerful inducement to fleet adoption.

The following recommendations can help support rapid deployment of unique and innovative policies for ZE-MHDVs:

1. **Implement zero-emission zones in cities.** By targeting cities, immediate reductions in air pollution can be achieved as well as quieter traffic. Fleets are compelled to explore zero-emission vehicle alternatives when there is an understanding that parts of a city will be inaccessible to them without zero-emission vehicles.
2. **Create weight exemptions to ensure ZE-MHDV are not penalized through lower payloads.** ZE-MHDVs are commonly heavier than ICE vehicles, mainly due to heavy batteries. Weight exemptions allow freight operations to proceed unhindered by increasing maximum vehicle weights allowed, thus avoiding payload penalties for ZE-MHDVs.
3. **Adjust vehicle and road user charges to provide economic benefits to ZE-MHDVs.** Operational incentives for ZE-MHDVs can accelerate cost parity with conventional vehicles, while resources levied from conventional vehicles can help fund ZE-MHDV investments.
4. **Explore carbon pricing schemes for MHDVs.** By charging polluters for their environmental impacts, relative incentives are given to ZE-MHDVs, and new revenue sources are created to fund clean technology investments.

CHAPTER 3

OUTLOOK FOR FURTHER ACTION

The countries that have signed the Global MOU represent a vanguard of innovators leading the way to a more sustainable transportation future. By working together toward the goal of 100% ZE-MHDV sales by 2040, these nations have taken the first step to ensure that the way goods and people are moved does not continue to have detrimental effects on air quality and devastating impacts on the planet. This Multi-Country Action Plan paves the way for accelerated action and highlights the framework for the implementation of policy measures to enable the MOU ambition.

As global climate discussions advance, the top priority of the Global MOU forum is to turn the Global MOU ambition into tangible action. The recommendations established by this action plan should set the trajectory for action and ensure there is collaboration and harmony between these leading nations on the road to driving MHDV emissions to zero.

The Global MOU forum will continue to pursue country signatories and endorsers and advocate for the proliferation of supportive policies that will advance ZE-MHDVs. Continuing to advocate the benefits to fleets, manufacturers, infrastructure providers, and other key stakeholders will be vital in accelerating supply chains and ramping up production to achieve necessary volumes and cost reductions for total market penetration across all vehicle segments.

APPENDIX

Table 5. Publicly Available Roadmaps for Carbon Neutrality, Electromobility, and Infrastructure Development

Country	Published Year	Document	URL
Austria	2021	Electromobility Plan	Link
Canada	2022	Carbon Neutrality Plan	Link
Chile	2022	Electromobility Plan	Link
China	2021	Carbon Neutrality Plan	Link
	2021	Electromobility Plan	Link
Denmark	2020	Carbon Neutrality Plan	Link
Finland	2021	Carbon Neutrality Plan	Link
Germany	2020	Infrastructure Development Plan	Link
	2020	Electromobility Plan	Link
	2021	Carbon Neutrality Plan	Link
India	2021	Carbon Neutrality Plan	Link
	2020	Electromobility Plan	Link
Luxembourg	2022	Electromobility Plan	Link
	2019	Carbon Neutrality Plan	Link
New Zealand	2022	Carbon Neutrality Plan	Link
	2022	Electromobility Plan	Link
Norway	2020	Carbon Neutrality Plan	Link
Portugal	2019	Carbon Neutrality Plan	Link
Scotland	2021	Carbon Neutrality Plan	Link
	2017	Electromobility Plan	Link
Switzerland	2022	Electromobility Plan	Link
	2021	Carbon Neutrality Plan	Link
The Netherlands	2019	Carbon Neutrality Plan	Link
	2020	Carbon Neutrality Plan	Link
Turkey		Carbon Neutrality Plan	Link
United Kingdom	2020	Electromobility Plan	Link

Country	Published Year	Document	URL
United States	2017	Electromobility Plan	Link
	2021	Carbon Neutrality Plan	Link
Uruguay	2022	Electromobility Plan	Link
Wales	2021	Carbon Neutrality Plan	Link

Table 6. Global MHDV Classification (Weight in Metric Tons) (CALSTART, 2022b)

<table>
<tr><th colspan="2">US</th><th colspan="6">EU</th><th colspan="4">China</th><th colspan="4">Japan</th></tr>
<tr><th></th><th></th><th></th><th></th><th colspan="2">Trailers & Semitrailers</th><th colspan="2">Trucks</th><th colspan="2">Tractors</th><th colspan="2">Trucks</th><th colspan="2">Tractors</th></tr>
<tr><th>Class</th><th>Weight</th><th>Class</th><th>Weight</th><th>Class</th><th>Weight</th><th>Class</th><th>Weight</th><th>Class</th><th>Weight</th><th>Class</th><th>Weight</th><th>Class</th><th>Weight</th></tr>
<tr><td colspan="2"></td><td>N1</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2b</td><td>3.86 - 4.54</td><td rowspan="6">N2</td><td rowspan="6">3.5 - 10</td><td rowspan="2">O1</td><td rowspan="2">< 0.75</td><td></td><td>3.5 - 4.5</td><td rowspan="7"></td><td rowspan="7">3.5 - 18</td><td rowspan="3">1 - 4</td><td rowspan="3">3.5 - 7.5</td><td rowspan="8">1</td><td rowspan="8">< 20.0</td></tr>
<tr><td>3</td><td>4.54 - 6.35</td><td></td><td>4.5 - 5.5</td></tr>
<tr><td>4</td><td>6.35 - 7.26</td><td rowspan="3">O2</td><td rowspan="3">0.75 - 3.5</td><td></td><td>5.5 - 7</td></tr>
<tr><td>5</td><td>7.26 - 8.85</td><td></td><td>7 - 8.5</td><td>5</td><td>7.5 - 8</td></tr>
<tr><td>6</td><td>8.85 - 11.79</td><td></td><td>8.5 - 10.5</td><td>6</td><td>8 - 10</td></tr>
<tr><td>7</td><td>11.79 - 14.97</td><td rowspan="5">O3</td><td rowspan="5">3.5 - 10</td><td></td><td>10.5 - 12.5</td><td>7</td><td>10 - 12</td></tr>
<tr><td rowspan="4">8a</td><td rowspan="4">14.97 - 27.22</td><td rowspan="10">N3</td><td rowspan="10">> 12.0</td><td></td><td>12.5 - 16</td><td>8</td><td>12 - 14</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">16 - 20</td><td rowspan="3"></td><td rowspan="3">18 - 27</td><td>9</td><td>14 - 16</td></tr>
<tr><td rowspan="2">10</td><td rowspan="2">16 - 20</td><td rowspan="8">2</td><td rowspan="8">> 20.0</td></tr>
<tr><td></td><td>20 - 25</td></tr>
<tr><td rowspan="6">8b</td><td rowspan="6">> 27.7</td><td rowspan="6">O4</td><td rowspan="6">> 10</td><td></td><td>25 - 31</td><td></td><td>27 - 35</td><td>11</td><td>> 20</td></tr>
<tr><td rowspan="5"></td><td rowspan="5">> 31</td><td></td><td>35 - 40</td><td rowspan="5"></td><td rowspan="5"></td></tr>
<tr><td rowspan="4"></td><td>40 - 43</td></tr>
<tr><td>43 - 46</td></tr>
<tr><td>46 - 49</td></tr>
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</table>

Table 7. OEM Commitments to ZEV Sales and Carbon Neutrality (CALSTART, 2021)

OEM	Commitment	Date
Scania	At least 90% zero-emission vehicle sales worldwide, with remainder powered by 100% fossil-free energy	2040
GM Group	100% carbon neutral in global products and operations	2040
Stellantis	70% low-emission vehicle sales in Europe, and 40% in the US	2030
Ford Group	100% fossil free new vehicle sales	2040
Daimler Group	100% carbon neutral in driving operation in Europe, North America, and Japan	2039
Toyota Group	100% CO2 neutral in life cycle by 2050	2050
Changan Automobile Group	100% electric vehicle sales	2025
Great Wall Motor Company Ltd. (GWM)	100% CO_2 neutral, with interim target of 80% new energy vehicle sales by 2025	2045
Mahindra & Mahindra	100% carbon neutral in operations	2040
VW Group	100% CO2 neutral balance sheet	2050
Renault	100% CO2 neutral worldwide, with interim target of 100% CO2 neutral in Europe by 2040	2050
Nissan	100% carbon neutral across operations and product life cycle	2050
Mitsubishi	100% carbon neutral, with 50% EV sales by 2030	2050
Isuzu	100% CO2 neutral in vehicle operation and plants sheet	2050
Paccar	100% fossil free new vehicle sales	2040
Suzuki	90% reduction in CO2 emissions in driving operation	2050
Volvo Trucks Group	100% fossil free new vehicle sales	2040
CNH Industrial	100% fossil free new vehicle sales	2040
Honda	100% battery-electric and fuel cell electric vehicle sales in North America, with interim targets of 40% by 2030 and 80% by 2035	2040
Mazda	90% reduction in CO2 emissions in driving operation and energy production	2050
Hyundai Kia Automotive Group	100% CO2 neutral in all operations	2050

Table 8. Private Sector Demand for ZE-MHDVs (CALSTART, 2021)

Company	Operating Area	Target/Actions	Announced
Amazon	Global	Orders 100,000 BEV light-commercial vehicles from Rivian. Amazon aims to be net-zero emissions by 2040.	2022
Anheuser-Busch	United States	Orders up to 800 hydrogen fuel cell Nikola heavy-duty trucks.	2019
DHL Group	Global	Delivery of mail and parcels by EVs in the medium term and net-zero emissions logistics by 2050.	2019
FedEx	Global	Transition to an all zero-emission vehicle fleet and carbon neutral operations by 2040.	2018
H2 Mobility Association	Switzerland	19 of Switzerland's largest retailers invest in Hyundai hydrogen trucking services that will deploy up to 1,600 heavy-duty zero-emission trucks.	2019
Ingka Group (IKEA)	Global	Zero-emission deliveries in leading cities by 2020 and in all cities by 2025.	2018
Japan Post	Japan	Electrify 1,200 mail and parcel delivery vans by 2021 and net-zero emissions logistics by 2050.	2019
JD	China	Replace entire vehicle fleet (>10,000) with New Energy Vehicles by 2022.	2017
SF Express	China	Launch nearly 10,000 BEV logistics vehicles.	2018
Suning	China	Independent retailer's Qingcheng Plan will deploy 5,000 new energy logistics vehicles.	2018
UPS	North America	Order 10,000 BEV light-commercial vehicles with potential for a second order.	2019
Various Companies	Multinational	Walmart, Pepsi, Anheuser-Busch, FedEx, Sysco and other large multinational corporations pre-order 2,000 Tesla Semi models within six months of truck's debut.	2018
Walmart	United States	Electrify the whole vehicle fleet by 2040.	2020

Table 9. Common Standards on EV Communication (Arrow, 2021)

Standard Name	Description
ISO/IEC 15118	Communication interface for bi-directional charging/discharging of electric vehicle
SAE J2847	Communication between plug-in vehicles and off-board DC chargers
IEC 61851-24	Electric vehicle conductive charging system - Part 24: Digital communication between a DC EV charging station and an electric vehicle for control of DC charging
SAE J2931	Security rewuirements for digital communication between the Electric Vehicle Supply Equipment (EVSE) and the utility, ESI, Advanced Metering Infrastructure (AMI), and/pr Home Area Network (HAN)
IEC 61850	Communication networks and systems for power utility automation - ALL PARTS

Figure 12. EV Connector Types (Arrow, 2021)

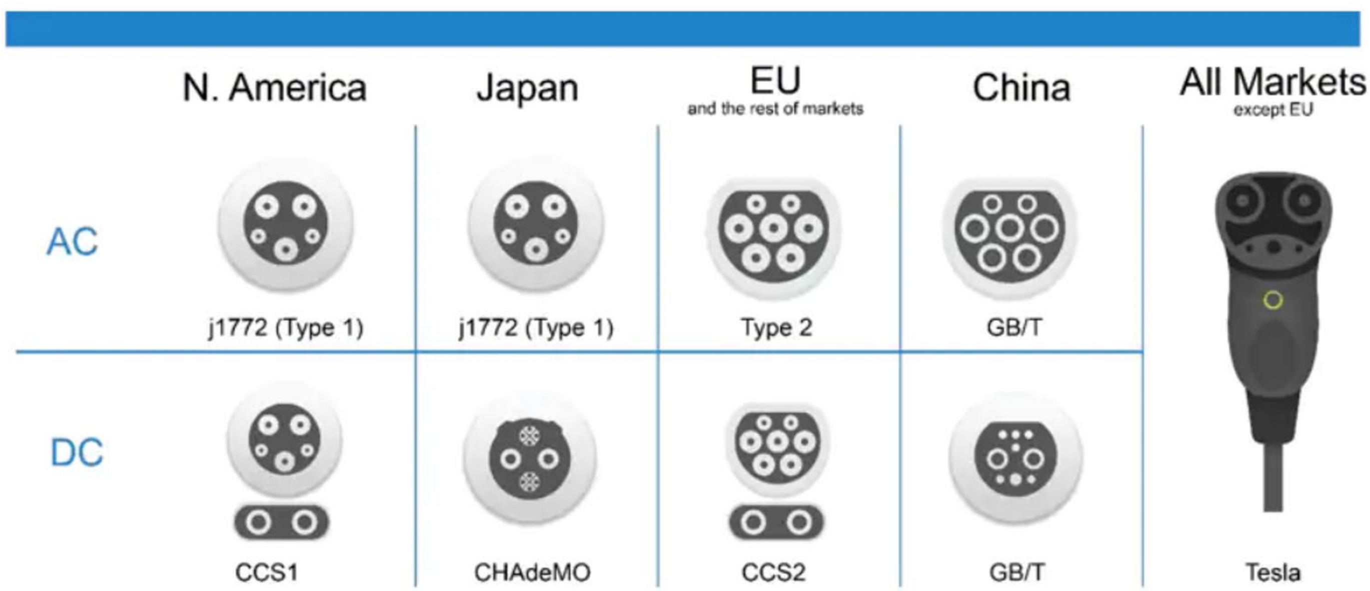

Table 10. Criteria Pollutants from On-Road Vehicles (U.S Department of Energy, 2022)

Criteria Pollutants regulated by U.S. EPA	
Pollutant Type	**Description**
Carbon Monoxide (CO)	At low levels, CO can exacerbate cardiovascular disease. At high levels, it can damage the central nervous system. At extremely high levels, CO is poisonous and can cause death. In the United States, 56% of CO (up to 95% in cities) is emitted by on-road vehicles.
Oxides of Nitrogen (NO_x)	NO_x can cause damage to respiratory airways. The high diversity, mobility, and reactivity of NO_x enable this pollutant to contribute to numerous environmental problems such as acid rain, climate change, deteriorated water quality, ground-level ozone, air toxins, and particulate matter. Approximately 55% of human-made NOx emissions come from motor vehicles.
Particulate Matter (PM)	PM can aggravate asthma, emphysema, bronchitis, heart disease, and lung disease. It is a carrier of many toxic compounds, contributes to haze, pollutes fresh and coastal waters, and contaminates farmland and natural ecosystems. PM is emitted directly from vehicles (especially diesel) and is formed through the atmospheric reactions of NO_x and oxides of sulfur (SO_x).
Ozone (O3)	Often referred to as smog, ozone is a powerful oxidant that can reduce lung function, aggravate asthma, increase chances for respiratory illness, and lead to permanent lung damage. It can also damage plant tissue, kill plants, and reduce farm yields. Ozone is not a direct vehicle emission; it is formed in the air through reactions of NO_x, volatile organic compounds (VOCs), and atmospheric air in the presence of sunlight. Generally, O3 formation in urban areas is more VOC-sensitive, while it is more NO_x -sensitive in rural areas. Not all volatile organic compounds are equal when it comes to forming ozone. The following two metrics compare the potential between different VOCs.
Oxides of Sulfur (SO_x)	SO_x can aggravate respiratory illness and heart and lung disease. It forms PM and is a primary cause of acid rain. Most vehicle emissions studies do not consider SO_x because vehicles contribute such a small portion of the total amount emitted by human activity. In 2006, ultra-low sulfur diesel regulations reduced the contribution of SO_x even further. Although SO_x is not a major concern for conventional and alternative fuel vehicles, it is a concern for electric vehicles since electricity generation is the largest source of SO_x.
Lead	Lead, which causes brain and nervous system damage in children, has been successfully removed from fuels worldwide, but may persist in certain segments like aviation.

Table 11. Zero-Emission Vehicle Technologies (CALSTART, 2022e)

Vehicle Types	Description
Battery-Electric Vehicles	Or BEVs are vehicles whose propulsion system is powered by an electric battery. The electric motor(s) draw power from the battery to drive the vehicle. While the specific battery chemistry and type of motor may differ by region or brand, these vehicles emit no emissions and can even be safely operated indoors and in enclosed spaces. BEVs must be refueled through electrical charging equipment, the most common of which is a plug-in system.
Electric Road System Vehicles	Or ERSVs are vehicles that may be fully zero-emission or hybrid electric vehicles. By connecting to a catenary or other electric road system, these vehicles can travel with significantly reduced on-board energy storage as the energy is drawn directly from the electric road system to propel the vehicle. When operating on a road or highway without the infrastructure the vehicle would switch to an on-board battery or combustion engine for propulsion.
Hydrogen Fuel Cell Electric Vehicles	Or FCEVs are vehicles whose primary propulsion system is powered by an onboard fuel cell, often accompanied by a small battery. There are several different types of fuel cells, but the most common in transportation applications are known as polymer electrolyte (or proton exchange) membrane fuel cells (PEM). These fuel cells take advantage of a chemical reaction between hydrogen fuel, a catalyst, and oxygen to produce electricity, with the only biproduct being steam or water, making them a zero-emission solution. FCEVs must be refueled using compressed or liquefied hydrogen at a designated refueling station.

Table 12. Types of Refueling Systems for ZEVs (CALSTART, 2022j)

Technology Type	Description
Conductive Electrical Charging	Conductive charging is the preferred charging method used worldwide due to its ease of use, high reliability, and efficiency. It involves a physical connection, via cable, between the energy system and the vehicle. Global standards for safety, interoperability, and communication allow all vehicle types to use these systems. Standards currently support charging rates for depots and hubs (J1772 and Combined Charging System – CCS), as well as the first corridors. A new global Megawatt Charging System (MCS) is being approved for extremely high-rate fast charging to enable extensive long-haul freight operations.
Inductive Electrical Charging	Inductive—or wireless—charging involves the transfer of electricity through magnetic induction. No direct connection with the vehicle is required. What is needed is installation of an in-ground system to provide the power and an on-vehicle system to receive the power. Such systems are less efficient and currently expensive and require careful placement of the vehicle over the system. Development work is also ongoing for dynamic electric vehicle charging (or DEVC) technology which can wirelessly provide charging power to a compatible electric vehicle traveling across it at highway speeds. Significant inductive infrastructure and road construction would be needed to implement.
Battery Swap	This system is based on the mechanical replacement of a battery pack when it is depleted with a fully charged pack. It requires fully standardized battery pack sizes across vehicle makers, consistent operational voltages and chemistries, a common under-vehicle frame and mounting to facilitate the swapping, a battery storage and charging facility, and a mechanical replacement system. It has to date proven too complex for multiple vehicle types and public operations. Some systems are in operation in industrial applications such as ports, and it has been implemented in transit systems in China, which is now exploring its use for passenger cars.
Catenary	The catenary is an old and well-known system that is being evaluated for possible broader use in transportation. A catenary is at its simplest an overhead electrical power connection that a vehicle can attach to via a pantograph to power its electric motor. It is commonly used in railway and urban trolley systems; it has also been in declining use in some urban transit bus systems and is used in some mining operations. While well-proven, it would be very expensive to implement along an entire freight movement system and would require all vehicles to carry the connecting pantograph and power conversion systems, which add weight and cost.

Technology Type	Description
FCEV - Hydrogen Fueling	Hydrogen can be stored and distributed as a gas or a liquid. Hydrogen for transportation is typically stored and dispensed as a high-pressure gas which is then transferred to tanks on board fuel cell-powered electric vehicles. Storage pressures range from 350-700 bar (5,000-10,000 PSI). The higher-pressure tanks are most common for transport because they provide more storage per volume. Hydrogen fueling stations therefore require a bank of storage tanks, compressors, and high-pressure dispensers to transfer the fuel to the vehicle. Because hydrogen fuel cost increases significantly if it needs to be transported long distances from where it is generated, many large-scale hydrogen stations may benefit from co-located hydrogen production facilities. Electrolysis from renewable energy is the preferred method of splitting water into hydrogen and oxygen gases. Other methods of H2 production include steam-reformed methane and as a byproduct of petroleum production.

FURTHER READING

A selection of literature covering key areas in ZE-MHDV fleet electrification curated by topic.

Commitments

- CALSTART (2021): Review of Commitments for Zero-Emission Medium- and Heavy-Duty Vehicles. Available online at https://globaldrivetozero.org/publication/country-policy-targets-briefing
- ICCT (2021): Decarbonizing bus fleets: Global overview of targets for phasing out combustion engine vehicles. Available online at https://theicct.org/blog/staff/hdv-fleets-phase-out-targets-dec21
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Policies

- CALSTART (2022): Global MOU Policy Tracker Dashboard. Available online at https://globaldrivetozero.org/progress-dashboard
- ICCT (2021): A Global Overview of Zero-Emission Zones in Cities and Their Development Progress. Available online at https://theicct.org/publication/a-global-overview-of-zero-emission-zones-in-cities-and-their-development-progress/#:~:text=A%20zero%2Demission%20zone%20(ZEZ,upon%20payment%20of%20a%20fee
- CALSTART (2022): Building a Beachhead: California's Path to Accelerating Zero-Emission Commercial Vehicles. Available online at https://globaldrivetozero.org/publication/building-a-beachhead-californias-path-to-accelerating-zero-emission-vehicles
- ICCT (2020): California's Advanced Clean Trucks regulation: Sales requirements for zero-emission heavy-duty trucks. Available online at https://theicct.org/publications/california-hdv-ev-update-jul2020
- ICCT (2021): Decarbonizing road transport by 2050: Effective policies to accelerate the transition to zero-emission vehicles. Available online at https://theicct.org/publications/zevtc-effective-policies-dec2021
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- T&E (2021): What Fit-for-55 means for heavy duty vehicles – Briefing. Available online at https://www.transportenvironment.org/discover/what-fit-for-55-means-for-heavy-duty-vehicles-briefing
- CALSTART (2020): Voucher Incentive Programs: A Tool for Clean Commercial Vehicle Deployment. Available online at https://globaldrivetozero.org/publication/voucher-incentive-programs-a-tool-for-clean-commercial-vehicle-deployment

Market Status and Outlook

- CALSTART (2022): Global Sales Targets for Zero-Emission Medium- and Heavy-Duty Vehicles – Methods and Application. Available online at https://globaldrivetozero.org/site/wp-content/uploads/2022/02/CALSTART_Global-Sales_White-Paper.pdf
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