WHITE PAPER

ANALYSIS OF PUBLIC SALES COMMITMENTS OF MEDIUM- AND HEAVY-DUTY VEHICLE MANUFACTURERS AND EXPECTED VOLUMES

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LIST OF ACRONYMS

ACT	California's Advanced Clean Trucks regulation
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
EV	electric vehicle
GHG	Greenhouse Gas
ICE	Internal Combustion engine
MHDV	Medium- and Heavy-duty vehicles
OEM	Original Equipment Manufacturer
R&D	Research and Development
TCO	Total Cost of Ownership
ZE	Zero Emission
ZE-MHDV	Zero-emission Medium- and Heavy-duty Vehicle
ZEV	Zero-emission Vehicle

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CHAPTER 1

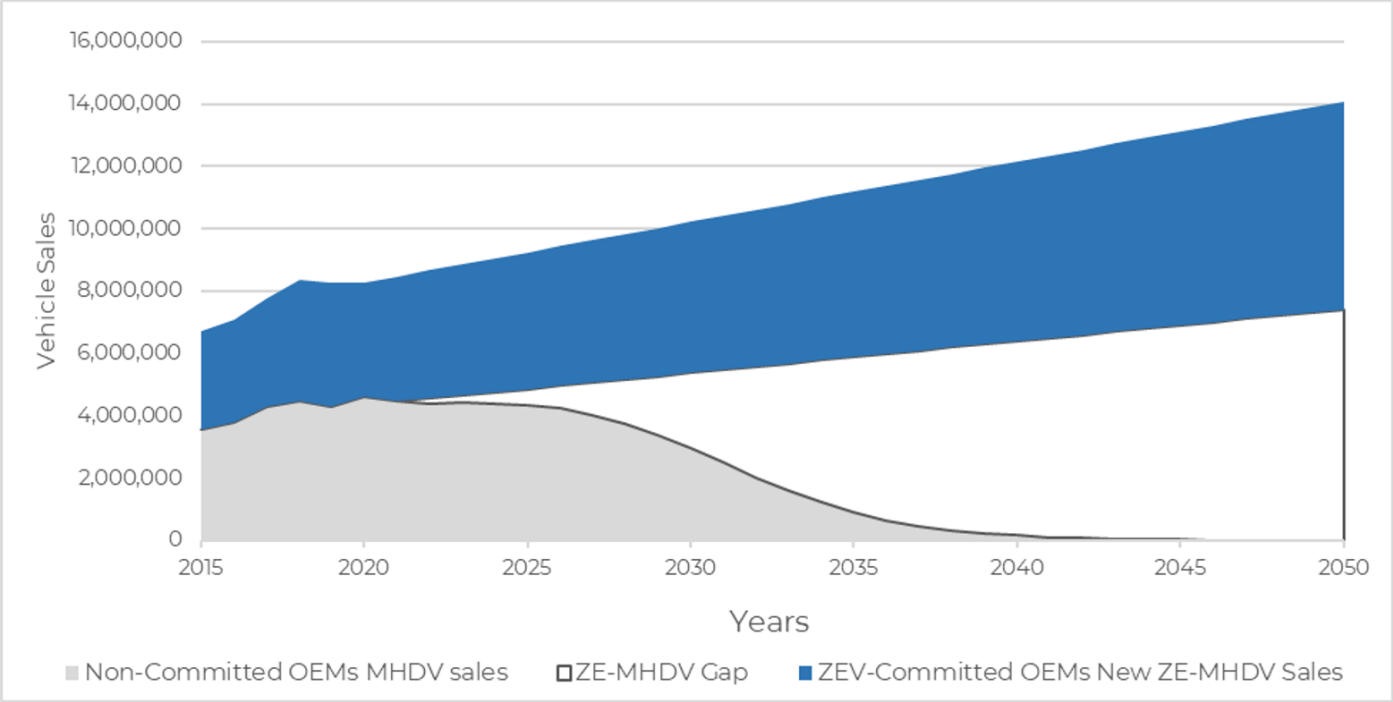
EXECUTIVE SUMMARY

Constituting only 4% of the global on-road vehicle fleet, medium- and heavy-duty Vehicles (MHDVs) are responsible for 36% of on-road fuel consumption, and upwards of 73% of NOx emissions. The disproportionate impact of medium- and heavy-duty vehicles (MHDVs) is the driving force behind the changing policy and technology landscape across leading nations globally. Without clear targets, backed by direct action established by all stakeholders, achieving carbon neutrality by 2050 will not be possible.

National and sub-national governments are setting targets to increase the number of zero-emission medium- and heavy-duty vehicles (ZE-MHDVs) on the road and defining policies to tackle key barriers currently stalling their adoption, such as financial support, infrastructure deployment, and countries' regulatory environment. However, nations are lagging in their ability to keep up with the private sector. Established OEMs that have built their business model around the internal combustion engine are beginning to shift their focus toward zero-emission transportation technologies, like battery-electric and hydrogen fuel cell vehicles, by committing themselves to a long-term shift in production. Major manufacturers such as General Motors, Ford, Daimler, Paccar, Nissan, Renault, Mahindra & Mahindra, and Volkswagen, among many others (table 2), have announced commitments to transitioning their products towards zero-emission technology to achieve a carbon neutral future. Not all the commitments are the same in nature, but all signal a major shift away from ICE vehicles and toward zero-emission alternatives around the year 2040.

This analysis has modeled MHDV sales to approximate what the future market may look like as ZE-MHDV penetration is boosted by OEM commitments and the adoption of government targets in line with a 100% target for ZE-MHDVs by 2040 globally to enable net-zero carbon emissions by 2050. Using current market shares of the OEMs included in this analysis, and a constant growth rate over the next few decades, projections were established that highlight the rate at which OEMs must ramp up production for ZE-MHDVs to achieve the goals they have established for themselves. The figure below outlines the projections of this analysis.

Figure 6. ZE-MHDV Sales Gap, 2015-2050



With non-committed OEMs indicated in grey, the analysis assumes that their offerings will lose relevance and ultimately be obsolete by 2040. The white area indicates the ZE-MHDV gap, or the share of the market by 2050 that could be captured by current established ZEV-committed OEMs, or "born-ZEV" OEMs—those manufacturers whose businesses were founded on zero-emission technologies. This represents a major opportunity for OEMs that can make the necessary arrangements to position themselves to capture market share from those OEMs with no outlined commitments or plan for decarbonization. The analysis further models the potential growth of born-ZEV OEMs and how their influence might impact the gap outlined above.

There is no doubt that a technology shift of this magnitude would be a historic achievement and a tremendous feat of planning and innovation. The likelihood of fulfilling the commitments that have been outlined by OEMs, governments, and fleets grows with each new commitment established. Even so, commitments must be backed up with swift, direct action; as urgency grows to decarbonize key polluting sectors, there is little time to waste, especially with such a significant share of the market up for grabs in the coming decades.

CHAPTER 2

BACKGROUND AND MOTIVATION

Constituting only 4% of the global on-road vehicle fleet, medium- and heavy-duty Vehicles (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 emissions (GHGs) and other harmful pollutants makes them a major target for decarbonization. In the United States alone, the transportation sector contributes 29% of the country's total GHG emissions (EPA, 2021). Over the next decades, emissions from MHDVs, in particular freight vehicles, are forecast to significantly increase. Without decisive action, GHG emissions from freight are expected to double between 2020 and 2050, and harmful particulate matter (PM2.5) associated with diesel emissions is projected to increase by more than 40% during this time (IEA, 2021). If meaningful action is to be taken against climate change, there must be a coordinated global undertaking to reduce the impact of medium- and heavy-duty vehicles (MHDVs) on the road and ensure that the future of transportation and goods movement does not have an adverse impact on the environment and public health.

2.1. GOVERNMENT COMMITMENTS TO INCREASE ZERO-EMISSION MEDIUM- AND HEAVY-DUTY VEHICLE ADOPTION

National and sub-national governments are setting targets to increase the number of zero-emission medium- and heavy-duty vehicles (ZE-MHDVs) on the road and defining policies to tackle key barriers currently stalling their adoption, such as financial support, infrastructure deployment, and countries' regulatory environments (ICCT, 2021). These actions send clear signals to the market for the need to transition to a zero-emission transportation future.

A prime example of these actions can be seen in California. In 2020, California, through the California Air Resource Board (CARB), instituted a first-of-its kind regulation to ensure the expedited decarbonization of one of the state's biggest polluters, MHDVs. The Advanced Clean Truck (ACT) regulation requires manufacturers to sell ZE-MHDVs in increasing amounts from 2024 to 2035 (CARB, 2021). The regulation separates MHDV into three categories based on classification, which respectively have different targets to be met over the timeframe. The momentous announcement of the ACT was met with great enthusiasm in the United States and inspired a memorandum of understanding (MOU) between 15 other states along the east coast, sending strong signals to manufacturers, fleets, and other regions

that decarbonizing MHDVs is a top priority, and one that is critical to mitigating impact on the climate and public health. California's ACT rule also spurred international action through a joint partnership between CALSTART and the Netherlands to launch a multi-national agreement banning the sales of ICE MHDVs by 2040.

In a historic announcement at the 26th Conference of Parties (COP 26) 15 leading nations pledged their support to a Global Memorandum of Understanding that establishes zero-emission medium- and heavy-duty vehicle (ZE-MHDV) sales targets that will enable net-zero carbon emissions by 2050. The signatories of the MOU include a diverse array of national governments as well as partners from the private sector and NGOs. Austria, Canada, Chile, Denmark, Finland, Luxembourg, Netherlands, New Zealand, Norway, Scotland, Switzerland, Turkey, United Kingdom, Uruguay and Wales have all pledged their support to the MOU and will work towards a goal of 100% ZE-MHDV sales by 2040 and an interim target of 30% ZE-MHDV sales by 2030.

As nations accelerate their ambitions toward climate action, it is imperative that the transportation sector is the subject of direct action by national governments. With many countries setting carbon neutrality targets around 2050, there must be recognition of fleet turnover time and an acknowledgement that achieving net-zero carbon emissions will require countries to achieve 100% zero-emission sales by 2040.

Government commitments are the first step toward regulatory certainty and indicate to OEMs what will be expected from them in the years to come. Similarly, fleet commitments (see Table 1) are the first step toward demand certainty: early-adopters are signaling their intention to procure ZE-MHDVs in the short-, medium- and long- term, thus ensuring there will be a market for the OEMs increased production. With governments and fleets committed to reducing their transportation footprint, the key to unlock fast adoption lies largely with OEMs.

Table 1. Private Sector Demand for ZE-MHDVs

COMPANY	OPERATING AREA	TARGET / ACTIONS	ANNOUNCED
Amazon	Global	Orders 100 000 BEV light-commercial vehicles from start-up company Rivian. Amazon aims to be net-zero emissions by 2040.	2020
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

COMPANY	OPERATING AREA	TARGET / ACTIONS	ANNOUNCED
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

Source: IEA Global EV Outlook 2021 (IEA, 2021)

2.2. OBJECTIVES OF THIS WHITEPAPER

Truck and bus manufacturers have begun to announce sales targets for the decarbonization of their MHDV offerings. This study seeks to:

1. Map the level of penetration, regional presence, and ambition of ZE-MHDV-oriented commitments set forth by market-leading OEMs;
2. Approximate the speed at which OEMs must ramp up their ZE-MHDV manufacturing and sales to achieve their internal commitments and a potential scenario of 100% ZE-MHDV sales by 2040; and
3. Identify the potential market gap for ZE-MHDVs that could exist if OEMs without commitments fall short of electrifying their vehicle offerings.

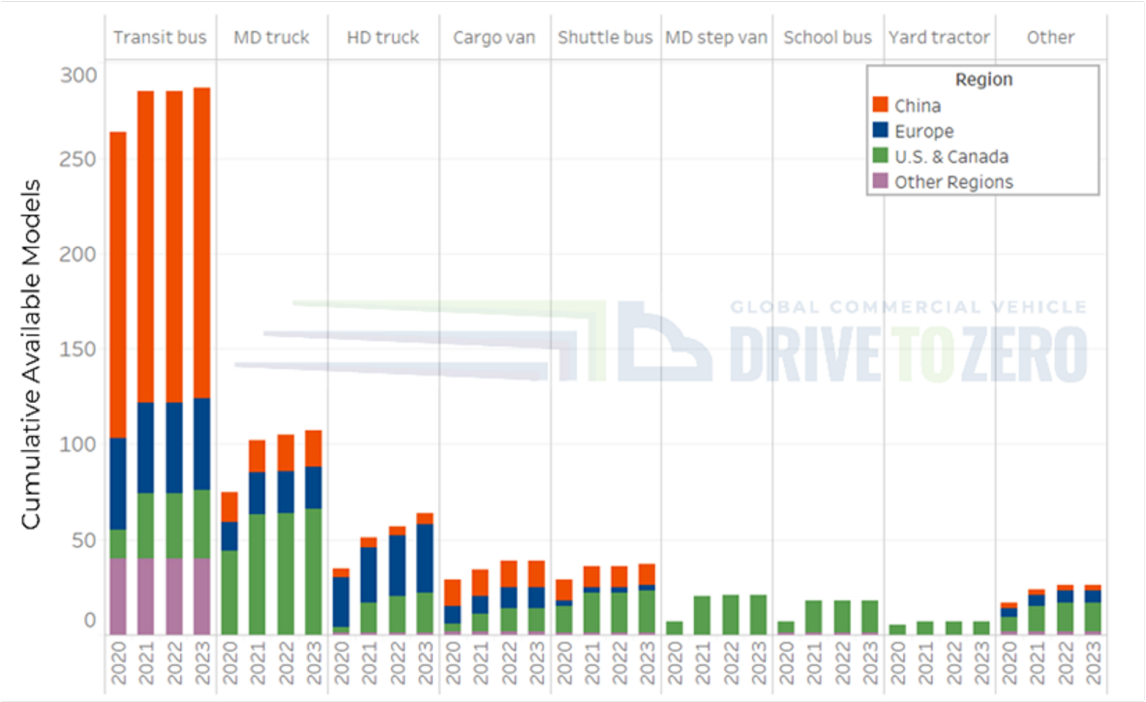
Our assessment builds on current OEM market shares and sales volumes, current market share of MHDVs versus diesel counterparts, and publicly announced commitments by OEMs to achieve a percentage of ZE-MHDV sales between 2025 and 2055. For underlying assumptions and research scope, please refer to *Appendix I. Methodological Note*.

CHAPTER 3

ZERO-EMISSION MEDIUM- AND HEAVY-DUTY VEHICLE COMMITMENTS BY OEMs

OEMs have been increasing ZE-MHDV model availability to prepare for a zero-emission future, meet government requirements, and satisfy fleet demand (Figure 1) (CALSTART, 2021). OEMs have begun by focusing on those vehicle applications where zero-emission technologies will succeed first, starting with transit buses and moving on to urban delivery vans, medium-duty trucks, heavy-duty regional-haul trucks, and eventually long-distance trucks, as many electric-drive components are transferrable across applications (CALSTART, 2020a).

Figure 1. Cumulative ZE-MHDVs by Platform



As component innovation advances and economies of scale increase production efficiencies, OEMs are expected to bring down vehicle costs, closing the price gap between ZE-MHDVs and their ICE counterparts. CALSTART's analysis on the Total Cost of Ownership (TCO) for different vehicle applications shows a promising scenario for ZE-MHDV adoption that will lead to TCO parity and outgrow the need for incentives between 2025 and 2030 (Figure 2) (CALSTART, 2020).

Figure 2. TCO Comparison Between Four MHDV Platforms

Established OEMs that built their business model around the internal combustion engine are beginning to shift their focus toward zero-emission transportation technologies. As zero-emission vehicle availability increases and production lines are restructured, the commitments set by OEMs are useful to identify in order to determine which OEMs are planning ahead to retain their global presence amidst the ZE-MHDV market transformation.[1]

1 Some OEMs without commitments, such as BYD and Navistar, are investing heavily in technology development and producing ZE-MHDVs at a scale that exceeds their ZEV-committed counterparts. The alignment between current technological development, investment in R&D, and ZEV commitments is a critical topic for future research.

As of July 2021, **19 leading OEMs, representing 45% of the global MHDV market, have made public commitments to phase out diesel-powered vehicles between 2025-2055** (Table 1).

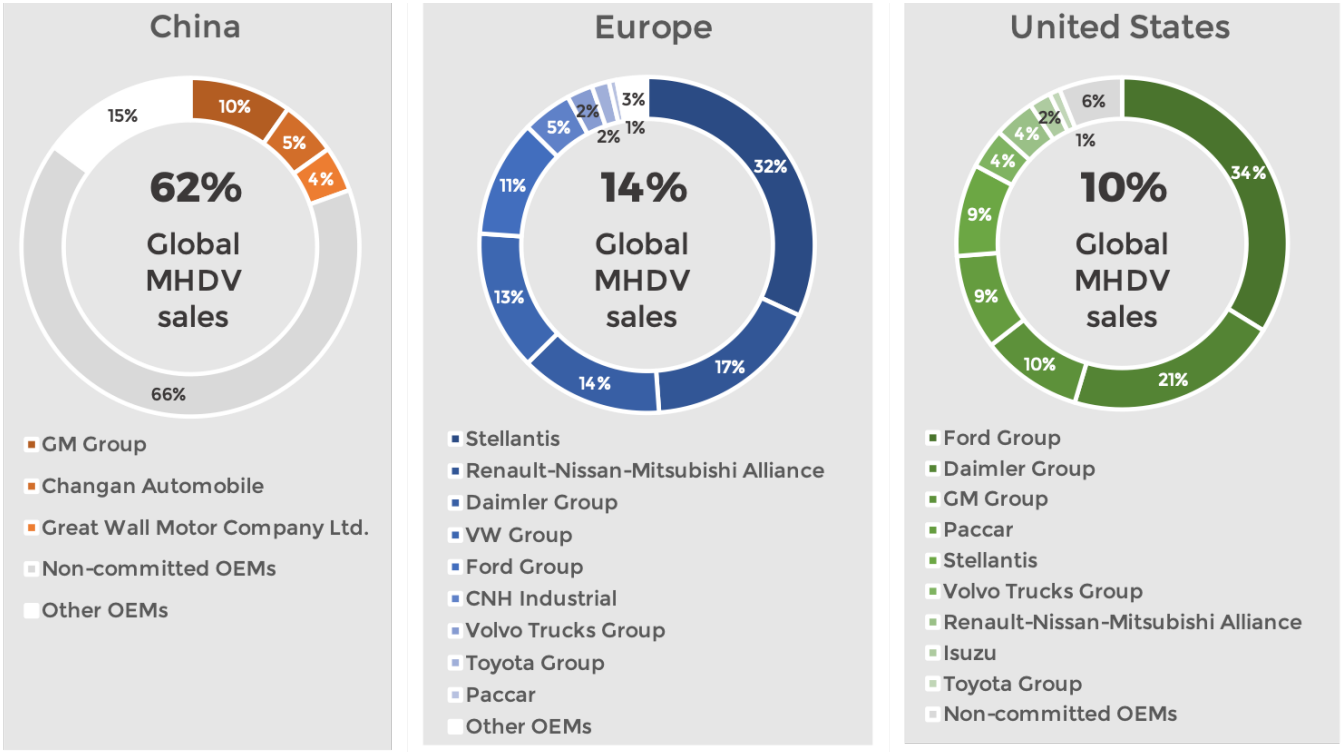
Table 2. OEM Commitments to ZEV Sales and Carbon Neutrality

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% CO2 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

Research included all OEMs with >100,000 sales in 2020 and publicly available commitments to 70%-100% ZEV sales or carbon neutrality. Based on publicly available information as of July 15th, 2021.

The distribution of sales by OEMs committed to ZEV adoption varies geographically. As of 2020, ZEV-committed OEMs dominate the second- and third-largest markets in the world, concentrating 97% of European sales and 94% of U.S. sales. However, in the Chinese MHDV market—three times larger than the European market and six times larger than the U.S. market—ZEV-committed OEMs control under 20% of total MHDV sales (Figure 3).

Figure 3. Regional Market Share of ZEV-Committed OEMs, 2020



The market share of ZEV-committed OEMs does not reflect current ZE-MHDV sales. Despite having the lowest percentage of ZEV-committed OEM sales across regions, the Chinese market is the leader in ZE-MHDV sales, concentrating 77%[2] of ZE-MHDV sales in 2020. This analysis also found that 93% of global ZE-MHDV sales from non-committed OEMs took place in China (2020). What will happen with that market share as demand moves away from diesel and national regulations set ZEV adoption timeframes is uncertain. This uncertainty presents itself as an opportunity for OEMs to focus on increasing their market presence with zero-emission offerings as ZE-MHDV penetration grows.

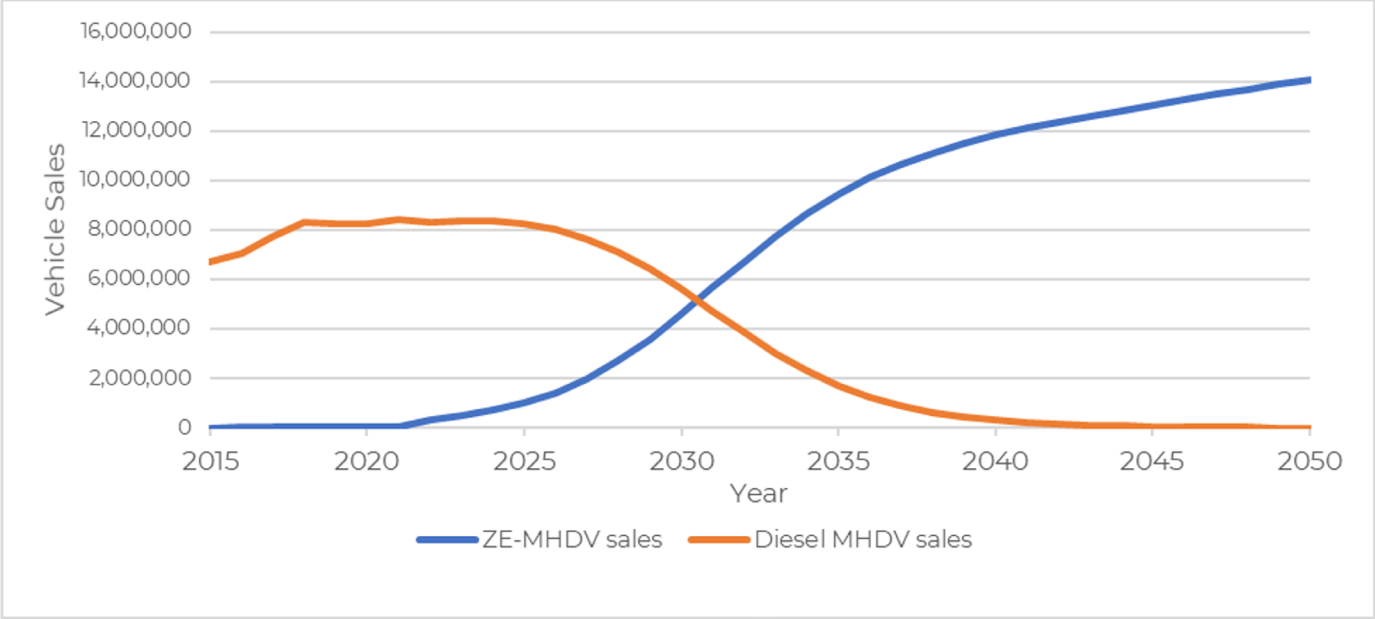
2 Other sources may indicate a higher percentage of total global sales of ZE-MHDV in China, however this was the figure derived from data available to us and may vary depending on vehicle platforms included.

CHAPTER 4

MEETING ZE-MHDV VEHICLE COMMITMENTS: OEM SALE SCENARIOS

This study has modeled MHDV vehicle sales to approximate what the future market could look like as ZE-MHDV penetration is boosted by OEM commitments and the adoption of government targets in line with a 100% target for ZE-MHDVs by 2040 globally to enable net-zero carbon emissions by 2050. This analysis indicates that ZE-MHDV sales would ramp up considerably as technology prices drop, with 2025-2030 acting as the critical timeframe for this acceleration (Figure 4).

Figure 4. Global ZE-MHDV Sales Needed to Meet 2040 Target

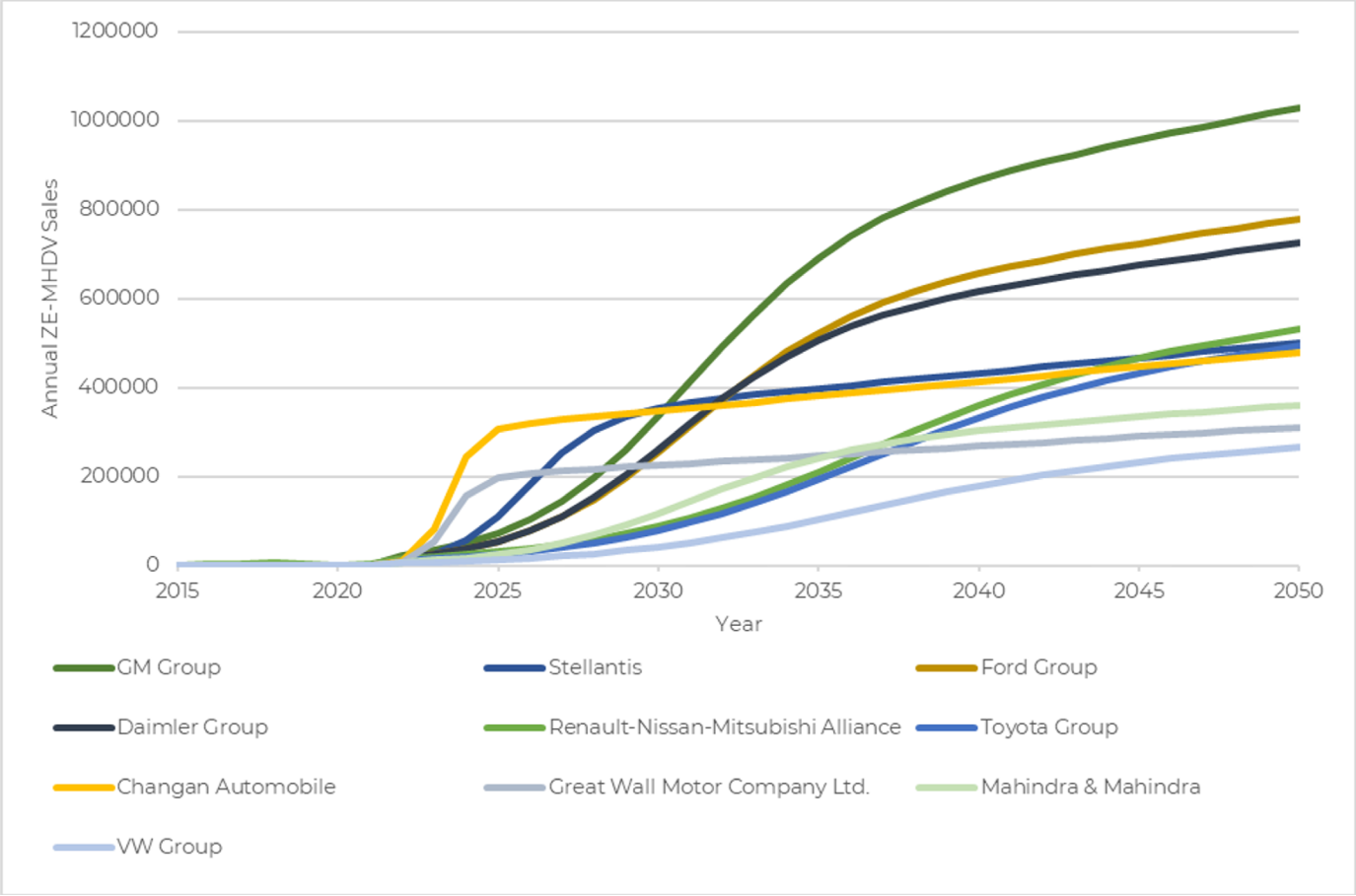


This level of ambition, made actionable through regulation and early incentives to stimulate adoption, is likely to define the size of the ZE-MHDV market in the mid- and long-term. The distribution of this growing market across current and future market participants will depend on each OEM's ability to move fast and successfully to meet fleet demand.

If ZEV-committed OEMs expect to reach their ZE-MHDV targets and retain or expand their 2020 market

share, ZE-MHDV production must be rapidly scaled up (Figure 5). These projected estimates assume that the current market share of ZEV-committed OEMs remains constant over time. The longer it takes OEMs to speed up ZE-MHDV production, the higher the risk of falling short of their commitment, losing market share, or facing steeper and more challenging adoption curves.

Figure 5. ZE-MHDV Sales to Meet OEM Commitments, 2011-2050



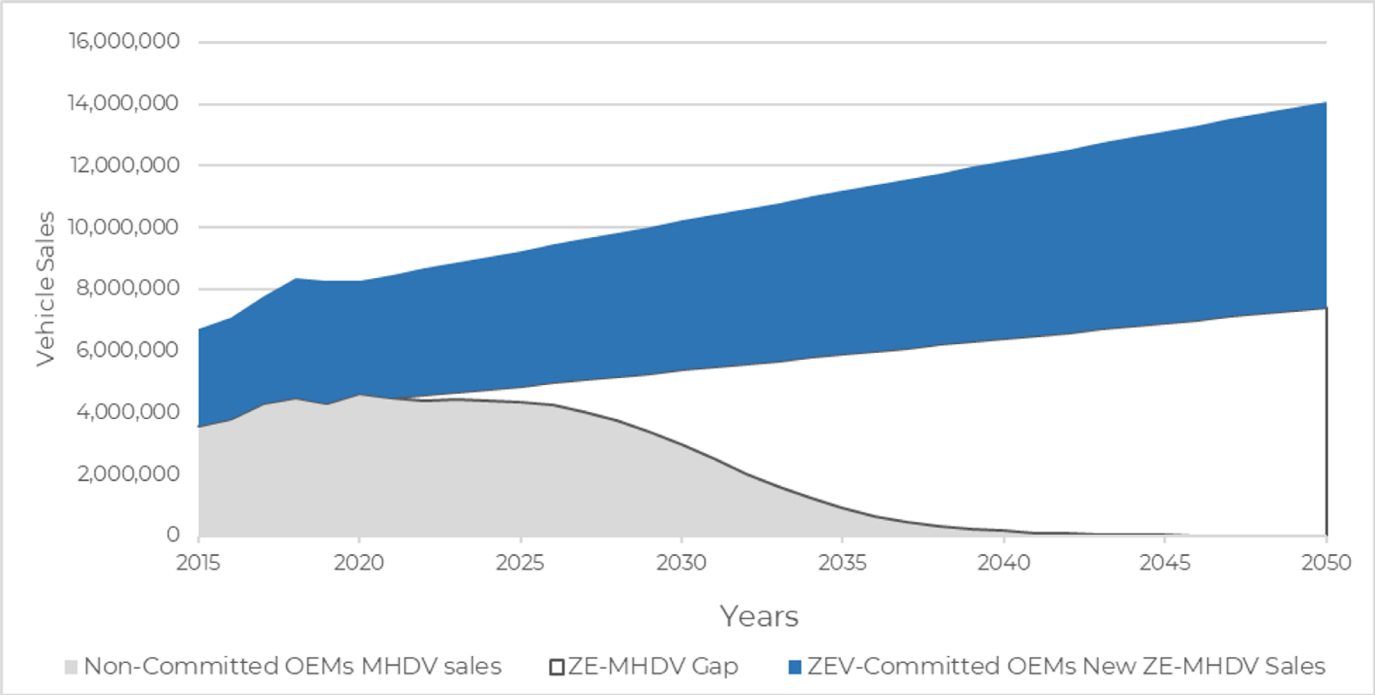
If ZEV-committed OEMs successfully embrace ZE-MHDV technology and retain their market share, the question remains of what will happen with the current market share of non-ZEV-committed OEMs going forward. Failure by these OEMs to adapt their offerings to zero-emission technology could lead to a loss in sales as ZE-MHDV penetration grows and more global markets become averse to diesel. This analysis identifies this potential loss in sales as the ZE-MHDV gap emerges (Figure 6), which could be filled by:

a. non-ZEV-committed OEMs who make the shift to ZE-MHDVs;

b. born-ZEV OEMs; or

c. ZEV-committed OEMs who accelerate their ZE-MHDV production sufficiently to increase their market share.

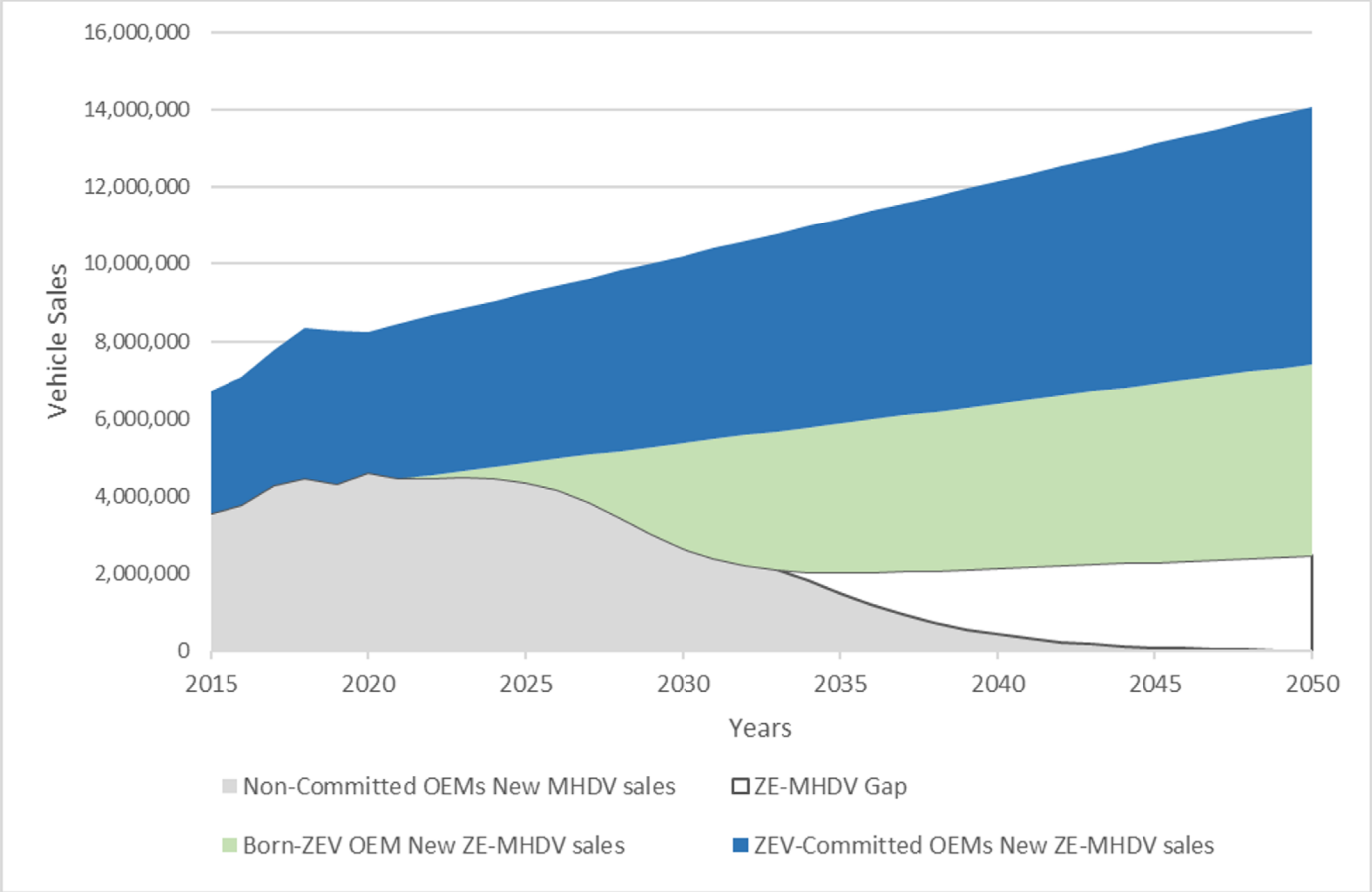
Figure 6. ZE-MHDV Sales Gap, 2011-2050



By 2030, the ZE-MHDV gap is estimated to be around 2.4 million vehicles worldwide, assuming the global MOU's 2040 target is adopted at a global scale. This is equivalent to three times the annual sales in the U.S. market in 2020 (827,383 vehicles). By 2050, the ZE-MHDV gap could be as large as nine times the annual sales of the U.S. market in 2020.

Born-ZEV OEMs like Arrival, Nikola, and Tesla are positioning themselves to fill a large share of the ZE-MHDV gap. Their rise is expected to reshape market shares and increase pressure on established OEMs to speed up their ZE-MHDV production timelines. If born-ZEV OEMs have an outstanding growth early on—emulating what Tesla has accomplished in the passenger car segment between 2011 and 2018—they could potentially fill the gap up to 2030. However, as born-ZEV OEMs stabilize and ZE-MHDV demand continues to grow, the gap could reach triple the size of the 2020 U.S. market by 2050, roughly 2.4 million vehicles (Figure 7).

Figure 7. ZE-MHDV Sales Gap Assuming Strong Performing Born-ZEV OEMs



CHAPTER 5

CONCLUSIONS

Achieving a 100% ZE-MHDV sales target by 2040 would be a historic move by governments and manufacturers spearheading a global transformation toward zero-emission technologies. This joint ambition is vital for OEMs, fleets, and infrastructure providers to rapidly scale up ZE-MHDV production and deployment together with supportive infrastructure. A zero-emission vision of the future that is shared by regulators, OEMs, and fleets will only accelerate the development of ancillary business models and companies able to ease the transformation. The global MOU and its 15 signatory countries marks the beginning of the major changes coming to the way transportation and goods movement is done.

An incremental transition from ~100% ICE MHDV production to 100% ZE-MHDV production by 2040 would require OEMs to begin their structural transformation as soon as possible. Not doing so would increase the pressure to ramp up production at a faster pace in future years, which may limit OEMs' ability to reach their commitments, allow fleets to familiarize themselves with new vehicle offerings, and keep up with state and national regulations banning sales of ICE MHDVs. Building key partnerships and establishing industry-wide coordination are vital in accelerating the technology switch, but OEMs without foresight and investment into new technologies and infrastructure risk missing the opportunity to get a head start early. The growing list of born-ZEV incumbents looking to establish the future of transportation gets longer each day and with innovation happening globally, OEMs across the board must double their efforts to decarbonize and ensure longevity.

National governments now must move past aspirations and put in place the regulation needed to provide market certainty. Supporting early adoption with incentives and investments that lower the cost of technology and securing sustainable revenue sources to sustain these investments while they are needed in the early market are vital. OEMs must translate their commitments into concrete investments in R&D, redirecting production lines to achieve economies of scale, and strengthening their position remain competitive in the future zero-emission transportation landscape.

APPENDIX I

METHODOLOGICAL NOTE

CALSTART researched thirty leading OEMs—representing 89% of global MHDV sales in 2020—to identify existing commitments and sales targets for zero-emission vehicles, new energy vehicles and carbon neutrality (driving operation, operation and production, and company-wide carbon neutrality). In addition to the OEMs listed in Table 1, CALSTART researched publicly available information on BAIC Group, Donfeng Motor Corp, China FAW Group Corp, China National Heavy Duty Truck Group, Anhui Jianghuai Automotive Group, Jiangling Motors Co. Group, Shaanxi Automobile Group, Shanghai Automotive Industry Corporation (SAIC), Tata Group, BYD Auto, and Navistar. Some of the OEMs not included in Table 1 may have ZE-MHDVs in production or development, but no publicly available commitments to achieve carbon neutrality or ZE-MHDV sales up to a certain threshold.

Market Modeling was based on Marklines data obtained in June 2021 for the following countries: Austria, Belgium, Canada, Chile, China, Czech Republic, Denmark, Finland, France, Germany, Greece, India, Ireland, Italy, Japan, Luxembourg, Netherlands, Norway, Portugal, Romania, Slovakia, Spain Sweden, and United States. "Medium- and heavy-duty vehicle" sales are limited to the "Unclassified" segment and the following type classifications: buses, heavy trucks, heavy trucks (chassis), heavy trucks/buses, large buses, large buses (chassis), light trucks, light trucks (chassis), medium buses, medium buses (chassis), medium/heavy trucks, mini trucks, mini trucks (chassis), semi-trailers, small buses, small buses (chassis), and trucks.

CALSTART's adoption curves for ZE-MHDV sales take current ZE-MHDV sales registered in Marklines as the starting point and simulate the pace of uptake based on OEM commitments and cost reductions in vehicle technology. Unless otherwise indicated, they reflect ZE-MHDV penetration of 95-100% by 2040.

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