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Laying the Groundwork

Exploring the challenges and opportunities in the transition to zero-emission medium- and heavy-duty vehicles

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Executive summary

The medium- and heavy-duty vehicle (MHDV) sector is a key facilitator of economic growth in Canada but is also a key contributor to GHG emissions. Canada has announced goals to decarbonize the on-road MHDV sector and reach targets for 35% of new MHDV sales to be zero-emission (ZE) by 2030, and 100% ZE by 2040. A credible roadmap that includes an investment strategy and policy coordination are needed to get there. Otherwise, Canada risks low zero-emission vehicle (ZEV) supply, slow market transformation and potential inability to meet our climate targets. Although Canada has some strong policies in place that are helping decarbonize the MHDV sector like the carbon tax, clean fuel regulation and purchase subsidies, there are gaps in our policy framework that need to be filled to accelerate the transition to ZE MHDVS. Given the complexity of the sector and the multiple vehicle classes that exist, designing a suitable policy mix to meet Canada's ZEV adoption targets and decarbonization goals is a complex challenge for policymakers.

To help Canada achieve its announced ZE MHDV sales targets, this report provides foundational knowledge on the state of the ZE transition for Canada's MHDV sector, identifies the myriad decarbonization challenges and opportunities for MHDVs, and the policy tools being used globally to advance a ZE MHDV transition. This research is complemented by technical modeling that assesses the impact of key policies and regulations, and a preliminary recommendations report that offers details on Pembina's early insights and preliminary policy recommendations. We will draw from these streams of work to inform our final policy recommendations for our MHDV strategy.

Challenges and opportunities for ZEV deployment

Recognizing the complexity of the ZEV transition, Pembina Institute conducted an in-depth academic and non-academic literature review to identify short- and long-term barriers that could impede decarbonization efforts and progress toward a ZEV transition. We examined the challenges and opportunities as it relates to three overarching MHDV sub-categories: buses, medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs). Our findings show that MDVs, buses and HDVs face distinct challenges and opportunities in transitioning to ZEVs.

Four categories of challenges were identified, all of which need to be overcome for Canada to reach its 2030 and 2040 sales targets for ZEVs; informational and societal barriers, financial barriers, technological barriers, and regulatory barriers.

Examples of these barriers include high upfront costs for ZEVs, lack of awareness and education, limited ZEV availability and driving range, lack of supportive policies, and policy rollbacks and regulatory stickiness.

Upon deeper examination of challenges and barriers, we identified that the pathway to electrification is not uniform for all MHDVs. For buses, we found that transit and school buses are well suited for electrification given their tendency to have access to overnight depot charging, relatively well-established short- to medium-distance service routes, and near-term estimates demonstrating a competitive total cost of ownership (TCO) compared to internal combustion engine (ICE) equivalents. While intercity buses share some of these characteristics, transitioning to ZEVs may be more challenging where there are longer travel routes between cities.

We find that many MDV vocations are also prime candidates for near-term electrification. Like transit and school buses, these vehicles tend to service short-distance routes, can charge overnight in depots, are predicted to have a competitive TCO with ICEVs in the near future and have a growing range of commercially available models. On the other hand, many HDVs, especially long-haul trucks will take longer to transition given the scale and cost of deploying a network of publicly available charging and refueling stations and the need for more commercially available models capable of performing rigorous duty-cycles.

Global best practices

We undertook a comprehensive review of policy tools and measures implemented across the world. There are many pathways for the federal government to reach 100% new ZEV sales by 2040, but it often requires a multi-pronged approach to supporting the whole supply chain, from workforce development, regulations, incentives for the business community and investors.

When it comes to financial incentives, many jurisdictions are using them to incentivize ZE MHDV adoption and decarbonization measures, the most prominent tools being upfront subsidies and tax credits. Innovative financing measures such as preferential-rate loans have also been used. A wide range of policies and regulations are also being used across the globe, including vehicle emissions standards, taxes on ICEVs, clean fuel standards, ZEV sales standards and procurement mandates. Catalyzing charging and fueling infrastructure deployment tends to be supported through subsidies, tenders, interoperable charging standards and R&D funding. Most existing capacity-building measures include workforce training, awareness and education programs and cross-jurisdictional collaboration efforts.

1. Introduction

Medium and heavy-duty vehicles (MHDVs) are an essential component of Canada's economy but represent a growing share of transportation emissions. Not only is the transportation sector a critical contributor to the national economy on its own (approximately 3.6% of GDP in 2021[1]), it is also a facilitator for many other industries. The manufacturing, retail, agriculture and energy sectors are just a few of the sectors that depend on reliable and efficient on-road freight vehicles.

As a result of a growing economy, on-road freight activity rose by 53% (measured in tonne-kilometres)[2] over the last two decades. Consequently, on-road freight emissions grew by 225% (from 20 to 65 Mt CO_2e).[3] Despite representing only 17% of Canada's total vehicle stock, MHDVs account for over 37% of vehicle-related greenhouse gas (GHG) emissions (Table 1). With more than 2 million MHDVs on the road and freight activity steadily increasing, emissions from MHDVs are expected to bypass those from passenger cars by 2030 in Canada.[4] At a time when the demand for on-road freight services has never been higher, zero-emission vehicles (ZEVs)[5] can help decouple growth from rising emissions.

[1] Parliament of Canada, "Road Transportation: Heavyweight of the Canadian Economy", https://lop.parl.ca/sites/PublicWebsite/default/en_CA/ResearchPublications/202204E#:~:text=The%20transportation%20and%20warehousing%20sector,than%205.2%25%20of%20Canada%27s%20workforce

[2] Natural Resources Canada, "Comprehensive Energy Use Database - Table 42: Freight Truck Secondary Energy Use and GHG Emissions by Region." https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=tran&juris=ca&rn=42&page=0

[3] Government of Canada, "Canada's 2030 Emissions Reduction Plan – Chapter 2". https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030/plan/chapter-2.html#toc9

[4] ECCC, *Discussion paper for heavy-duty vehicles and engines in Canada,* 6.

[5] ZEVs include plug-in battery electric vehicles, plug-in hybrid electric vehicles and hydrogen fuel cell vehicles.

Table 1. Canadian vehicle types, kilometres travelled and GHGs produced

Vehicle Type	Stock share	VKT share	GHGs share
Light-duty vehicles	82.5%	92.0%	60.5%
Medium Trucks	8.3%	5.9%	14.1%
Heavy Trucks	8.4%	1.7%	23.0%
Buses			
School Buses	0.3%	0.2%	0.5%
Urban Transit	0.4%	0.1%	1.7%
Intercity Buses	0.1%	0.0%	0.2%

Source: Calculated based on data from Natural Resources Canada[6]

In 2021, the federal government announced updated economy-wide emissions reduction targets of 40–45% below 2005 levels by 2030 and net-zero by 2050.[7] To ensure the transportation sector helps achieve these targets and rising MHDV emissions are stemmed, Canada's vehicle stock will need to transition to ZEVs. Announced targets aim for 35% of new MHDV sales to be ZEVs by 2030 and 100% by 2040. Current measures adopted by the federal government to accelerate ZEV deployment include[8]:

- ***Incentives*** such as the iMHZEV program, a 100% tax write-off for businesses on ZEV acquisitions, and a Zero Emission Transit Fund
- Deployment of ***charging and refuelling infrastructure*** through the Zero Emission Vehicle Infrastructure program and the Electric Vehicle Infrastructure Demonstration program
- ***Policies and regulations*** like the Clean Fuel Regulation, Carbon Tax and Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulation
- ***Capacity-building*** through the Zero Emission Vehicle Awareness Initiative and the Green Freight Program.

Despite progress that has been made to encourage ZEV adoption in Canada, there are diverse and complex challenges yet to be overcome. In response, this report identifies the myriad decarbonization challenges and opportunities for MHDVs, collates the latest

[6] Natural Resources Canada, "Comprehensive Energy Use Database". https://oee.rncan.gc.ca/corporate/statistics/neud/dpa/menus/trends/comprehensive_tables/list.cfm

[7] Government of Canada, "Government of Canada confirms ambitious new greenhouse gas emissions reduction target". https://www.canada.ca/en/environment-climate-change/news/2021/07/government-of-canada-confirms-ambitious-new-greenhouse-gas-emissions-reduction-target.html

[8] See Appendix A. for a review of key federal programs for transitioning to ZE MHDVs.

research findings on the unique considerations of vehicle sub-groups, and shares examples of policy actions taken globally to accelerate MHD ZEV deployment.

2. ZEV deployment challenges and opportunities

There are a wide range of challenges to overcome to reach Canada's GHG and ZEV adoption targets. The range of potential barriers to transform the MHDV sector can be classified into four categories: informational, societal, financial, technological and regulatory.[9] Some challenges can likely be overcome in the short term (e.g., informational, and regulatory barriers),[10] while others may take longer to remedy (e.g., technological).[11]

To address these barriers, we present a brief description of potential solutions that can aid in Canada's journey to reaching 2030 and 2040 ZEV adoption targets and ultimately, its GHG emission reduction goals. Across potential solutions provided, we identify actors from government, utilities, OEMs, academic institutions and ENGOs who will play a role in shaping the trajectory of the MHDV sector.

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[9] Joerr Rogelj et al., "Paris Agreement climate proposals need a boost to keep warming well below 2 C." *Nature* 534, no. 7609 (2016), 635. https://www.nature.com/articles/nature18307

[10] Georgina Santos, "Road transport and CO_2 emissions: What are the challenges?" *Transport Policy* 59 (2017), 73. http://www.sciencedirect.com/science/article/pii/S0967070X17304262

[11] Chris Midgley, "The biggest challenges to decarbonization are still ahead", *S&P Global,* December 10,2019. http://www.spglobal.com/en/research-insights/articles/the-biggest-challenges-to-decarbonization-are-still-ahead

2.1 Informational and societal challenges

Table 2. Informational/societal barriers and opportunities

Challenge	Description	Potential solutions
Lack of consumer awareness	Despite market readiness of certain ZEV technologies and availability of alternative fuels, uptake is slow because consumers/fleet owners are in many cases not aware of these technologies and their advantages.	Government, ENGOs and academic institutions can increase awareness and education through targeted outreach campaigns, as well as tailored support for fleets. Public ZEV procurement can also demonstrate ZE technology to the public.
ZEV-ready workforce	Planners, fleet managers, truck operators, engineers, mechanics and other technical workers may have less experience with new and emerging near- and zero-emission technologies.	Training programs can be established to build capacity across the existing workforce where needed, and college and trade programs can provide training and certification for the emerging workforce
Inadequate understanding of policy best practice	Good policy design requires understanding which policy options are cost-efficient and most effective at reducing emissions. ZE MHDV technologies vary in their technological feasibility and market readiness. A lack of understanding of the different MHDV classes can lead to less-than-optimal policy design.	Research and knowledge-sharing provided by academic institutions, ENGO's and industry can inform government on effective policy design and mixes.
Slow change in consumer preferences	Due to years of familiarity and lock-in with existing ICEV technologies and usage patterns, changing consumer behaviour toward adopting ZE technology can take years. Acceptability of cleaner technologies remains low among the majority of consumers[12] and addressing this will require behavioural change.[13]	Though a combination of policies that discourage the use of fossil fuels (e.g., carbon tax) and those that facilitate faster uptake of ZEVs (e.g., ZEV sales standard), consumer preferences/usage patterns can potentially be modified slowly over time. Governments can build consumer confidence and familiarity in ZE technology through public procurement schemes.

[12] International Energy Agency, *Net Zero by 2050* (2021), 67. www.iea.org/reports/net-zero-by-2050

[13] Nicholas Stern, *Stern Review: The economics of climate change*, (Cambridge University Press, 2006), 11.

2.2 Financial challenges

Table 3. Financial barriers and opportunities

Challenge	Description	Potential solutions
High upfront costs for ZEVs	Currently, ZE MHDVs have a higher purchase price than ICE MHDVs. A ZE Class 8 tractor truck can be up to two to five times more expensive at the point of purchase than an ICE equivalent.[14]	In the short term, governments can provide purchase subsidies to off-set the high-upfront cost of ZEVs, such as the Government of Canada's iMHZEV program[15] with subsidies up to $200 thousand.
Lack of funding for local governments	Municipalities may find it difficult to install charging infrastructure and procure ZE MHDVs due to financial constraints.	Federal and provincial governments can continue to support municipalities with clean infrastructure support programs (e.g. ZEVIP) and targeted vehicle purchase subsidies.
Cost of charging/ refueling equipment and installation	Level 1 charging (i.e., regular wall outlets) is inexpensive, but can provide insufficient power for MHDV applications. Level 2 and 3 charging provides more power, making it faster and more appropriate for MHDVs, but can be expensive to purchase and install. The cost of equipment and installation for a hydrogen station can exceed $2-3 million.[16]	Governments can provide financial support for charging/ refueling equipment and installation services. Support can prioritize small- and minority-owned businesses that may be more financially constrained.
Higher biofuel prices	Since the pandemic, high prices are slowing the growth of biofuels like ethanol, renewable diesel.[17]	Increased supply should ease the short-term upward pressure on biofuel prices.

[14] Ben Sharpe and Hussein Basma, *A meta-study of purchase costs for zero-emission trucks* (International Council on Clean Transportation, 2022), 3. https://theicct.org/wp-content/uploads/2022/02/purchase-cost-ze-trucks-feb22-1.pdf

[15] Transport Canada, "Medium and heavy-duty zero-emission vehicles." https://tc.canada.ca/en/road-transportation/innovative-technologies/zero-emission-vehicles/medium-heavy-duty-zero-emission-vehicles

[16] David Welch et al., *Moving Zero-Emission Freight Toward Commercialization* (CALSTART, 2020), 39. https://globaldrivetozero.org/site/wp-content/uploads/2020/12/Moving-Zero-Emission-Freight-Toward-Commercialization.pdf

[17] International Energy Agency, "Biofuels", 2021. https://www.iea.org/reports/renewables-2021/biofuels?mode=transport&region=World&publication=2021&flow=Consumption&product=Ethanol

2.3 Technology challenges

Table 4. Technology barriers and opportunities

Challenge	Description	Potential solutions
Temporary supply-side constraints	Consequences stemming from the COVID-19 pandemic, underinvestment in new capacity and concerns regarding tightening nickel and aluminum supplies from Russia have resulted in semiconductor shortages, mineral resource disruptions and high battery metal prices.[18]	Such constraints are temporary and should only last two to three years.[19,20] In the long term, diversification of mineral and metal supplies should be prioritized.
Limited driving range for ZEVs	Currently, battery size/capacity can limit the distance a ZEV can be driven before requiring refuelling/recharging, resulting in a driving range inferior to ICEV equivalents.	Limited range is becoming less of a constraint for some ZE MDVs and buses, as the set of current and announced models with increasing range continues to expand.[21] For example, GreenPower's Class 4 cargo truck has a range of 250 km.[22] Lion Electric's Class 6 and Class 8 trucks have ranges of 320 km and 274 km respectively.[23]
ZEV battery increases vehicle weight	ZEV batteries are heavy and require space, potentially reducing the weight-carrying capacity of MHDVs.	Based on current estimates, battery-induced increase in weight causes about a 3% reduction in payload.[24] Ongoing R&D and investments will enable further improvements in

[18] Tae-Yoon Kim, "Critical minerals threaten a decades-long trend of cost declines for clean energy technologies," *International Energy Agency,* May 18, 2022. https://www.iea.org/commentaries/critical-minerals-threaten-a-decades-long-trend-of-cost-declines-for-clean-energy-technologies

[19] Kevin Stankiewicz, "Intel CEO now expects chip shortage to last into 2024", *CNBC,* April 29, 2022. http://www.cnbc.com/2022/04/29/semiconductor-shortage-intel-ceo-says-chip-crunch-to-last-into-2024.html#:~:text=Intel%27s%20Pat%20Gelsinger%20now%20expects,for%20its%20fiscal%20second%20quarter

[20] VentureBeat, "KPMG: 56% of chip leaders expect shortage to last in 2023," March 7, 2022. http://venturebeat.com/business/kpmg-56-of-chip-leaders-expect-shortage-to-last-in-2023/

[21] International Energy Agency, *Global Electric Vehicle Outlook 2022* (2022), 39. https://www.iea.org/reports/global-ev-outlook-2022

[22] GreenPower Motor Company, "EV Star Cargo." https://greenpowermotor.com/gp-products/ev-star-cargo-plus/

[23] Lion Electric, "Discover Lion's all-electric commercial truck fleet." https://trucks.thelionelectric.com

[24] Amol Phadke et al., *Why Regional and Long-Haul Trucks are Primed for Electrification Now* (Lawrence Berkeley National Laboratory, 2021), 1. https://eta-publications.lbl.gov/sites/default/files/updated_5_final_ehdv_report_033121.pdf

		battery energy density, decreasing battery-weight induced payload reductions.
ZEV critical mineral constraints	ZEV production requires critical minerals like lithium, cobalt and graphite. Canada does not have well-developed supply chains for these minerals. Ramping up mineral extraction can pose a barrier to rapid deployment of ZEVs.[25]	Canada is rich in such critical minerals. The move towards electrification could be an opportunity for the country to develop a strong supply chain. Ontario's Critical Mineral Strategy, "is a comprehensive, five-year roadmap that will secure the province's position as a reliable global supplier of responsibly sourced critical minerals", suggesting that the province expects to resolve critical mineral supply chain constraints in the near term[26]
Limited ZEV models	The number of commercially available ZE MHDV models has been limited but is growing, with ZE truck and bus availability set to grow from 433 models in 2020 to 544 by the end of 2022 in key global markets.[27]	Strong supply-side policies, such as a ZEV sales standard can accelerate the number of commercially available models supplied by OEMs.[28]
Lack of market readiness for some heavy-duty ZEV trucks	While the number of commercially available ZE MDV and bus models continues to grow, long-haul ZEVs are still a few years from being commercially available at the scale required for deep decarbonization of the HDV sector.	OEMs need to continue to invest in R&D to ensure that models are commercially available for long-haul applications. In the meantime, retrofits can help reduce emissions among ICE HDVs currently in use.
Lack of grid-readiness to accommodate a	Increased uptake of ZEVs will increase demand pressure on the electricity grid, potentially affecting its stability.	Utilities will need to start planning/ building additional electricity generation capacity, and devise demand management strategies to balance demand and supply.

[25] Ignacio de Blas, Margarita Mediavilla, Iñigo Capellán-Pérez and Carmen Duce, "The limits of transport decarbonization under the current growth paradigm," *Energy Strategy Reviews* 32 (2020). http://www.sciencedirect.com/science/article/pii/S2211467X20300961

[26] Government of Ontario, *Ontario's Critical Minerals Strategy, 2022-2027* (2022), 8. http://www.ontario.ca/files/2022-03/ndmnrf-ontario-critical-minerals-strategy-2022-2027-en-2022-03-22.pdf

[27] CALSTART, "New Data Tracks 26% Growth of Zero-Emission Truck And Bus Model Availability Globally In Midst Of Economic, Supply Chain Challenges," new release, March 9, 2022. https://globaldrivetozero.org/2022/03/09/new-data-tracks-26-growth-of-zero-emission-truck-and-bus-model-availability-globally-in-midst-of-economic-supply-chain-challenges-3-9-22/

[28] Virginia McConnell, and Benjamin Leard, "Pushing New Technology into the Market: California's Zero Emissions Vehicle Mandate." *Review of Environmental Economics and Policy* 15, no. 1 (2021), 173. https://www.journals.uchicago.edu/doi/abs/10.1086/713055?journalCode=reep#:~:text=Over%20its%2030%20years%2C%20California%27s,the%20life%20of%20the%20program

high number of ZEVs		Such large-scale changes and upgrades will likely require time.
Lack of adequate battery recycling ecosystem	Widespread ZEV deployment will result in an influx of degraded batteries, where recycling and second-life applications will be needed. The battery recycling industry is only beginning to emerge, and there is a long way to go before a comprehensive battery recycling ecosystem is in place.[29]	Government and industry need to develop a clear policy framework for end-of-life management of batteries, which should offer clear guidance on the collection and transport of degraded batteries, as well as battery design and labelling to enable an efficient recycling process.[30]
Lack of public recharging/ refuelling infrastructure	ZE MHDV operations that are not suited for return-to-base, overnight charging will rely on public charging and refuelling stations along key transport corridors. Installation of such a high number of chargers/refuelling stations is a costly and time-consuming process.	Government can immediately start long-term planning for a strategic and coordinated approach to infrastructure deployment. At the same time, dedicated investment in high-powered charging and high-flow rate refuelling stations will be needed.
Uncertain availability of advanced biofuels	Constrained supply of waste biomass limits the decarbonization of biofuels produced from crop residues and other second-generation biofuels.[31]	Policy makers may prioritize policies that encourage alternative biofuels, notably hydrogen-based biofuels.
High costs of hydrogen-based biofuels	Advanced biofuels or e-fuels are hydrocarbon fuels produced from hydrogen (obtained from clean electricity) and CO_2 (from carbon capture). These e-fuels can be good substitutes for fossil fuels for long-haul trucking. However, they are too expensive currently and may achieve parity with fossil fuels only by 2050.[32]	Governments may consider more hydrogen support polices to encourage R&D investment in processes that can bring down technology costs.

[29] U.S. Department of Energy, *Medium- and Heavy-Duty Vehicle Electrification An Assessment of Technology and Knowledge Gaps* (2019), 35. http://info.ornl.gov/sites/publications/Files/Pub136575.pdf

[30] International Energy Agency, *The Role of Critical Minerals in the Clean Energy Transition* (2021), 186. https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

[31] Bunyod Holmatov et al., "Can crop residues provide fuel for future transport? Limited global residue bioethanol potentials and large associated land, water and carbon footprints." *Renewable and Sustainable Energy Reviews* 149 (2021), 12. https://doi.org/10.1016/j.rser.2021.111417

[32] Falko Ueckerdt et al., "Potential and risks of hydrogen-based e-fuels in climate change mitigation." *Nature Climate Change* 11, no. 5 (2021), 387. https://doi.org/10.1038/s41558-021-01032-7

Land-use effects of conventional biofuel production	Crops meant for biofuel production compete with food crops for the same land. With a large global population still lacking access to nutritious food, allocating land for large volumes of biofuel production could become a technical and political challenge.	Policymakers need to have the well-designed incentives in place to encourage biofuel production, but not at the cost of food crops.

2.4 Regulatory challenges

Table 5. Regulatory barriers and opportunities

Challenge	Description	Potential solutions
Lack of supportive policies	Absence of strong climate/decarbonization policies can often result in inaction by the various stakeholders (e.g. consumers, automakers, fuel suppliers) who continue to move along the business-as-usual pathway.	Governments can work with experts and affected stakeholders to identify an optimal mix of policies that achieve emissions reduction targets while minimizing implementation costs.
Lack of coordination between governments	Lack of complementary goal setting and policies across different governments can send mixed and confusing signals to consumers and suppliers, leading to inaction.	Governments should coordinate their climate strategies, implementing complementary policies across federal, provincial and municipal governments.
Policy rollbacks and lack of regulatory stickiness	Sustained ZEV uptake cannot happen without long-term consistent policy signals.[33] Introducing the right policies is a first step toward transport decarbonization, but long-term success requires that policies stick, and are adaptive (increasing or decreasing in stringency) to changing conditions.	New ZEV policy developments should consider contextual elements that enable co-benefits and facilitate the participation of diverse stakeholders in the policy-making process.

[33] Annukka Berg, Jani Lukkarinen and Kimmo Ollikka, "'Sticky' Policies – Three Country Cases on Long-Term Commitment and Rooting of RE Policy Goals," *Energies* 13 (2020), 2. https://doi.org/10.3390/en13061351

2.5 Summary

To transform the MHDV sector, a diverse range of obstacles will need to be addressed through policy support, multi-stakeholder collaboration, technology improvements and innovation.

While the challenges we have identified above apply to the MHDV sector as a whole, we recognize that MHDV sub-groups may face distinct barriers. Therefore, to determine a more streamlined and targeted approach to aligning the MHDV sector with Canada's ZEV adoption targets and GHG goals, our research goes more in-depth. In the following section, we explore the specific market barriers and opportunities for buses, MDVs and HDVs, respectively.

3. Unique decarbonization challenges and opportunities for MHDV sub-groups

Pathways to decarbonization are not uniform for all MHDVs due to the differing needs of each vehicle class and vocation. The MHDV category includes a diverse range of vehicles, each of which faces distinct barriers and opportunities to electrification. To understand the distinct barriers, we segment our research into three categories: buses, MDVs and HDVs. For each vehicle category, we consider factors such as vehicle cost and model availability, operational characteristics, and charging and refuelling requirements.

Table 6. Weight classes and vocations, MHDVs

Class	GVWR (lbs)	Vehicle examples	Vehicle classification
2b	8,501 to 10,000	utility van, full size pickup, step van	Medium-duty
3	10,001 to 14,000	walk-in, conventional van, city delivery	Medium-duty
4	14,001 to 16,000	large walk-in, conventional van, city delivery	Medium-duty
5	16,001 to 19,500	large walk-in, city delivery	Medium-duty
6	19,501 to 26,000	beverage, single axle van, school bus	Medium-duty/ bus
7	26,001 to 33,000	furniture, medium conventional, city/transit bus	Heavy-duty/ bus
8	33,000+	dump truck, cement truck, heavy haul	Heavy-duty

Source: Environment and Climate Change Canada[34]

3.1 Buses

Buses are predicted to be first in line for electrification. Transit vehicles, school buses and intercity buses are all unique in their own ways in terms of usage and technology

[34] Environment and Climate Change Canada, *Discussion paper for heavy-duty vehicles and engines in Canada: transitioning to a zero-emission future*, (2021), 5. https://www.canada.ca/content/dam/eccc/documents/pdf/cepa/21199_HDV%20Discussion%20Document_Dec%2016_MinO%20Approved_Final_EN.pdf

requirements, however they are alike in their role as a ZEV 'first-mover' among the broader MHDV sector.

Vehicle types and vocation examples

School buses

- There are approximately 49,000 school buses in Canada.[35] However, they vary substantially by vehicle type, size, weight and usage. The majority of Canada's school buses are Type A2 and Type C; 45% are urban, while 51% are rural operating.[36] The needs of urban versus rural fleets are different, particularly when it comes to range, charging infrastructure and the investments required for electrical upgrades.
- School buses are well-suited for electrification, primarily in the form of BEV and PHEV vehicles. There are limited examples of hydrogen-powered school buses and we do not anticipate that will change on the path to net-zero.
- Several provinces have already begun the turnover of diesel, gas and propane-powered school buses to BEVs.[37,38]

Transit buses

- There are approximately 32,000 urban transit buses in Canada.[39]
- Transit buses provide service covering short to medium distances, and typically have frequent stops within a pre-defined route.
- In Toronto, transit buses generally cover around 200 km per day in a 16-hour shift.[40]

[35] Natural Resources Canada, *Comprehensive Energy Use Database*, Table 49: Bus Explanatory Variables. https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=tran&juris=ca&rn=49&page=0

[36] Task Force on School Bus Safety, *Strengthening School Bus Safety in Canada: Report of The Task Force on School Bus Safety* (2020), 11. https://comt.ca/Reports/School%20Bus%20Safety%202020.pdf

[37] British Columbia Ministry of Education and Child Care, "Fleet of the future: electric school buses coming soon," news release, May 6, 2021. https://news.gov.bc.ca/releases/2021EDUC0031-000848

[38] Jasmin Legatos, "Quebec unveils funding to electrify 65 per cent of all school buses by 2030", *Electric Autonomy*, April 28, 2021. https://electricautonomy.ca/2021/04/28/quebec-electric-school-buses-2030/

[39] *Comprehensive Energy Use Database*, Table 49: Bus Explanatory Variables.

[40] Mobility Innovators, "Toronto Transit Commission Electric Bus Program: Head-to-Head Evaluation of Electric Buses," May 16, 2022. https://mobility-innovators.com/toronto-transit-commission-electric-bus-program-head-to-head-evaluation-of-electric-buses/

- At the end of a shift, transit buses are retired to depots where they are stored and maintained.
- Their operating conditions —short to medium distances travelled along fixed routes coupled with return-to-depot operations — make transit buses a prime candidate for electrification. As such, transit buses have been identified as a target for initial application of ZE technology within the MHDV sector.
- Among MHDVs, transit buses have achieved the most widespread uptake of ZE technology, with more than 600 ZE transit buses on order or operating in Canada.[41]

Intercity buses

- Intercity bus services are generally used to transport passengers between cities or towns. There are approximately 11,000 in Canada.[42]
- Intercity buses service major cities and smaller centres, with popular routes offering service between Montreal and Ottawa, as well as Toronto all the way to Vancouver, and other destinations throughout Canada and the United States. They tend to travel longer distances compared to transit buses (e.g., for direct service from Ottawa and Toronto, an intercity bus operated by Megabus travels a total of 449 km with three stops in between).
- Unlike transit buses, intercity buses tend to have a higher gross vehicle weight rating (GVWR) and primarily travel along highway routes rather than within urban centers.[43]
- Electrified intercity bus travel is being piloted across North America, including service between Seattle and Vancouver – a distance of225 kilometres – that can be completed on one charge.[44]

ZEV market outlook

- Prices for battery electric transit buses in California are predicted to rise from US$753,000 in 2019 to US$784,000 in 2030, and the price of FCEVs to decline

[41] ZEV Task Force, *Multi-State Medium- and Heavy-Duty Zero-Emission Vehicle Action Plan* (2022), 17. https://www.nescaum.org/documents/multi-state-medium-and-heavy-duty-zev-action-plan-dual-page.pdf

[42] *Comprehensive Energy Use Database*, Table 49: Bus Explanatory Variables.

[43] Nader A. El-Taweel and Hany E. Z. Farag, "Incorporation of Battery Electric Buses in the Operation of Intercity Bus Services," *IEEE* (2019), https://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=8790598

[44] Lucas Combos, "FlixBus Pilots Electric Bus From Seattle to Vancouver," *Patch,* July 21, 2022. https://patch.com/washington/seattle/flixbus-pilots-electric-bus-seattle-vancouver

from US$1.2 million and US$808,000 in 2030, according to an ICF study.[45] Battery electric Type C school buses were also estimated to rise slightly, from US$300,000 to US$316,000 in 2030.[46] The price of diesel vehicles in both categories was also predicted to rise by more than 30% over the same time horizon.

- Electrifying buses is already cost-competitive in certain contexts on a total cost of driving basis, depending on vehicle and fuel prices (and where there is major policy support for rapid bus electrification).[47]
- BEV buses are already cost-competitive in some applications and by 2032 are projected to be well below total cost of ownership (TCO) of diesel.[48] For 40-foot transit buses BEVs have the lowest TCO today and in 2030.[49]
- For Type A and Type C school buses, TCO analysis finds that lower operation and maintenance costs allow for BEV models to be almost cost-competitive in 2030 with diesel and natural gas counterparts, even without upfront purchase incentives.[50]
- ZEV urban buses in Canada are predicted to reach TCO parity with ICEVs between 2022 and 2025.[51]
- A study in the United States estimated the diesel bus TCO per mile in 2027 to be US$3.04 compared to US$2.08 for electric transit buses. For school buses, the diesel TCO cost per mile in 2027 is US$2.07 compared to US$1.58 for BEVs.[52]

ZEV operational and technological considerations

- A complex bus network incorporating many vehicles has been established over the years based on the operational characteristics of diesel buses. Transitioning

[45] ICF International, *Comparison of Medium- and Heavy-Duty Technologies in California* (2019). 45. https://efiling.energy.ca.gov/GetDocument.aspx?tn=236878

[46] ICF, *Comparison of Medium- and Heavy-Duty Technologies in California*, 46.

[47] Catherine Ledna et al., *Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis* (NREL, 2022), 27. https://www.nrel.gov/docs/fy22osti/82081.pdf

[48] NREL, *Decarbonizing Medium- & Heavy-Duty On-Road Vehicles,* 27.

[49] ICF, *Comparison of Medium- and Heavy-Duty Technologies in California*, 45.

[50] ICF, *Comparison of Medium- and Heavy-Duty Technologies in California*, 31-32.

[51] Yihao Xie, Tim Dallmann and Rachel Muncrief, *Heavy-duty Zero-Emission Vehicles – Pace and Opportunities for a Rapid Global Transition* (ZEV Transition Council, 2022), 6. https://theicct.org/wp-content/uploads/2022/05/globalhvsZEV-hdzev-pace-transition-may22.pdf

[52] Vishnu Nair, Sawyer Stone, Gary Rogers, Sajit Pillai, *Medium and Heavy-Duty Electrification Costs for MY 2027- 2030* (Environmental Defense Fund, 2022), 80, 86. https://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf

to ZE buses may require that agencies identify routes and schedules that optimize performance of ZE buses, establish major retraining programs for staff, and build relationships with utilities and retrofit depots, all while minimizing disruptions to services.

- Where agencies will need to establish training for existing staff, there is a dearth of programs at universities and institutions to train the next generation of workers in the transit and bus sector. Most college and university training programs focus on ZE innovation and research for passenger vehicles and the automotive sector, rather than on transit and buses.
- Interviews with Canadian transit agencies revealed a lack of transit-level data sharing where transit agencies and cities can retrieve real-time data regarding ZE buses and charging and refuelling systems through accessible repositories.[53]
- The space requirements for on-board batteries may reduce luggage capacity for ZE intercity buses.

ZEV infrastructure needs

- In cases where there is access to overnight depot charging, and service routes are relatively short and predictable, the range of currently available battery electric buses can be sufficient. However, for long-distance routes, such as those travelled by intercity buses between distant cities, currently available models may not deliver adequate range.
- Fleets need to have "electric ready" bus depots, possibly new IT systems, and backup power and energy management systems to ensure reliable service.[54]
- Space available to install charging and refuelling infrastructure at depots may be limited, especially for small depots located in urban centers. Electric buses need 25% more space at depots than a diesel bus.[55]

[53] Josipa Petrunic, Elnaz Abotalebi and Abhishek Raj, *Best Practices and Key Considerations for Transit Electrification and Charging Infrastructure Deployment to Delivery Predictable, Reliable and Cost-Effective Fleet Systems* (CUTRIC-CRITUC, 2020), 133. https://cutric-crituc.org/wp-content/uploads/2020/06/Best-Practices-and-Key-Considerations-for-Transit-Electrification-and-Charging-Infrastructure-Deployment-to-Deliver-Predictable_-Reliable_-and-Cost-Effective-Fleet-Systems.pdf

[54] Clean Energy Canada, *Catching the Bus: How Smart Policy Can Accelerate Electric Buses Across Canada* (2020), 7. https://cleanenergycanada.org/wp-content/uploads/2020/06/CEC-Bus-RoundtableReport-5.pdf

[55] CPT, *What are the Challenges to Transitioning to a Zero Emission Coach Fleet?* (2022), 13. https://www.cpt-uk.org/media/jmrhe0sj/zero-emission-coach-taskforce-phase-one-report.pdf

3.2 Medium-duty vehicles

There are about 25 million on-road motor vehicles on Canadian roads.[56] MDVs (weight classes 2b-6, weighing more than 4,500 kg but less than 15,000 kg) constitute 2.4% (or 600,000) of the total road motor vehicle fleet. The MDV segment varies significantly by weight, class and vocation.

Vehicle types and vocation examples

Key sub-categories of MDVs examined by Pembina are:

- pickup trucks (Class 2b)
- delivery vans (Class 3-5)
- box/delivery trucks (Class 5-6)

Table 7. Weight classes and vocations, MDVs

Class	GVWR (lbs)	Vehicle examples
2b	8,501 to 10,000	utility van, full size pickup, step van
3	10,001 to 14,000	walk-in, conventional van, city delivery
4	14,001 to 16,000	large walk-in, conventional van, city delivery
5	16,001 to 19,500	large walk-in, city delivery, bucket
6	19,501 to 26,000	beverage, single axle van, rack

Source: Environment and Climate Change Canada[57]

Vocations

- Medium-duty trucks are mainly used for last-mile urban delivery with daily range of less than 160 km. Common uses for box trucks include residential and commercial moving, as well as parcel, furniture, appliance, and wholesale food and snack delivery.
- Class 3 to 5 cargo vans may be used to transport urban freight (e.g., mail vans) or passengers (e.g., minibuses).
- Pick-up trucks are more commonly used for transporting passengers and trade-related heavy goods (e.g., wood drilling equipment).

[56] Statistics Canada, "Vehicle registrations, by type of vehicle," September 10, 2020. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701

[57] ECCC, *Discussion paper for heavy-duty vehicles and engines in Canada,* 5.

Pathways to decarbonization

- Medium-duty trucks are a fit case for electrification, as validated in a recent demonstration project conducted by the North American Council for Freight Efficiency (NACFE), where three organizations (Frito Lay, Dave and Ross, Roush Freeway Racing) tested out medium-duty box trucks. The conclusion of the study was that 100% of medium box trucks are ready for electrification.[58]

ZEV market outlook

- Market readiness of a vehicle class can be assessed on key metrics, such as model availability, purchase price parity (relative to ICEVs), electric range, TCO and consumer demand.[59] All these metrics suggest that ZE MHDVs are ready for deployment, with few remaining barriers.
- Model availability for Class 3 to 5 vehicles is well established, with multiple companies offering models in 2022 (e.g. Ford E-Transit[60], Mercedes-Benz eSprinter[61], Lightning eMotors[62], Rivian commercial van[63], GreenPower EV Star Cargo[64], Canco MPDV[65]). For Class 6 trucks the number of available models is lower, but growing (e.g., Lion Electric Lion6[66], Peterbilt 220EV[67] , ROUSH CleanTech F-650[68]).

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[58] North American Council for Freight Efficiency, "Electric Trucks Have Arrived: The Use Case For Medium-Duty Box Trucks." http://nacfe.org/medium-duty-box-trucks/?mc_cid=920880a3f6&mc_eid=56394b21d2

[59] Diana Lowell and Jane Culkin, *Medium-& Heavy-Duty Vehicles: Market structure, Environmental Impact, and EV Readiness* (MJB&A, 2021). https://www.mjbradley.com/sites/default/files/EDFMHDVEVFeasibilityReport22jul21.pdf

[60] Ford, "E-Transit Cargo Van." https://www.ford.ca/commercial-trucks/e-transit/models/cargo-van/

[61] Mercedes-Benz, "eSprinter." https://www.vans.mercedes-benz.com/vans/en/mercedes-benz-vans/insights/stories/mercedes-benz-esprinter-emission-free

[62] Lightning eMotors, "Lightning eMotors Enters Canada's Commercial EV Market with Fully Electric Refrigerated Delivery Vehicles." https://lightningemotors.com/lightning-emotors-enters-canadas-commercial-ev-market-with-fully-electric-refrigerated-delivery-vehicles/

[63] Rivian, "Rivian commercial van." https://rivian.com/fleet

[64] GreenPower, "EV Star Cargo." https://greenpowermotor.com/gp-products/ev-star-cargo/

[65] Canco, "Multi purpose delivery vehicle." https://www.canoo.com/mpdv/

[66] Lion Electric, "Lion 6." http://pages.thelionelectric.com/lion6/

[67] Peterbilt, "Electric Vehicles." http://www.peterbilt.com/electric-vehicles

[68] ROUSH CleanTech, "ROUSH CleanTech Enters Electric Vehicle Market with the Ford F-650," May 1, 2018." https://www.roushcleantech.com/roush-cleantech-enters-electric-vehicle-market-with-the-ford-f-650/

- Electric range is less of a barrier for most MDV use cases, as several commercially available vehicles between Class 3-to 6 have a range of 160 km or more, which is sufficient to cover most urban freight deliveries. Examples of these vehicles include GM's EV600 (250 miles or 400 km), Ford's E-Transit (125 miles or 135 km), Lion Electric's Lion 6 (150+ miles or 180 km).
- ZE MDVs are approaching price parity with ICEVs. For example, a Ford electric cargo van, costing ~US$46,000[69,70] is about 15% to17% costlier than its ICE counterpart, which costs ~US$41,000[71,72] Moreover, Canada's new purchase incentives through the iMHZEV program can be used to overcome this barrier.
- Many ZE MDVs are market-ready based on their low TCO.
    - Evidence from six major European cities demonstrates that electric cargo vans can start to reach TCO parity with diesel vehicles by 2025.[73]
    - For Class 4 delivery trucks, a battery electric vehicle with a range of 150 miles (240 km) is predicted to have lower TCO (US$671,000) relative to an ICE truck (US$690,000) by 2025.[74] A recent National Renewable Energy Laboratory study corroborates this finding, suggesting that BEVs will reach cost parity with ICEVs in both the light-medium-duty (~class 4), and medium-duty (~class 6) segments by mid-decade.[75]
    - Another U.S. study estimates the TCO per mile of a Class 3 electric delivery truck is expected to be US$0.58/mile, or about 20% lower than a Class 3 diesel delivery truck (US$0.7/mile) by 2027. The same study finds that the TCO per mile of a Class 5 electric delivery truck will be US$0.68/mile, which is 30% lower than a Class 5 diesel delivery truck costing US$1.08/mile by 2027.[76]

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[69] Ford, "2022 E-Transit. Van", / https://www.ford.com/commercial-trucks/e-transit/2022/

[70] Car and Driver, "2022 Ford E-Transit", https://www.caranddriver.com/ford/e-transit

[71] Ford, "2022 Ford Transit -Cargo Van", https://www.ford.ca/trucks/transit-passenger-van-wagon/

[72] Car and Driver, "2022 Ford Transit ", https://www.caranddriver.com/ford/transit

[73] Hussein Basma, Felipe Rodríguez, Julia Hildermeier, and Andreas Jahn, *Electrifying Last-Mile Delivery: A total cost of ownership comparison of battery-electric and diesel trucks in Europe* (ICCT, 2022), i. https://theicct.org/publication/tco-battery-diesel-delivery-trucks-jun2022/

[74] Andrew Burnham et al., *Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains* (Argonne National Laboratory, 2021), 150, 151. https://publications.anl.gov/anlpubs/2021/05/167399.pdf

[75] NREL, *Decarbonizing Medium- & Heavy-Duty On-Road Vehicles*, 20.

[76] Environmental Defense Fund, *Medium and Heavy-Duty Electrification Costs for MY 2027- 2030*, 98, 104.

- The North American Council for Freight Efficiency finds that return-to-base urban delivery trucks with daily trips of less than 160 km are well-suited for transition to BEVs, based on cost of ownership.[77]

- Demand for ZE MDVs is picking up, with large corporations and retailers already ordering battery electric trucks for their urban delivery fleet: Amazon (100,000), UPS (11,000), Pride Group (~6,000), FedEx (500), and Pepsi (100). Most recently, Walmart announced that it will buy 4,500 electric last-mile delivery trucks.[78]

ZEV operational & technological considerations

- The medium-duty truck category faces the fewest constraints to electrification, with some suggesting that 65% of medium trucks could be electrified today.[79]
- Batteries can take up some cargo space, though this can be circumvented by optimizing battery sizes to suit duty cycle and improved chassis design.[80]
- Drivers may require training before using ZEVs, but some initial trials indicate positive feedback from those who tested them.[81]

ZEV infrastructure needs

- Most categories in the MDV segment can be charged using a home base/depot Level 2 chargers (about $20k) in five to eight hours.[82] These include pickup trucks (Class 2b), delivery vans and box trucks (Class 3-5), and even some Class 6 trucks.[83] Level 3 chargers typically cost more (~$50k), but can charge ZEVs three

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[77] North American Council for Freight Efficiency, *Medium-Duty Electric Trucks: Cost of Ownership* (2018). https://nacfe.org/emerging-technology/medium-duty-electric-trucks-cost-of-ownership/

[78] CleanTechnica, "Walmart Orders 4500 Electric Delivery Vehicles From Canoo", July 13, 2022. http://cleantechnica.com/2022/07/13/walmart-orders-4500-electric-delivery-vehicles-from-canoo-video/

[79] North American Council for Freight Efficiency, "Electric trucks reach a tipping point", May 9, 2022. https://nacfe.org/news/electric-trucks-reach-a-tipping-point/

[80] North American Council for Freight Efficiency, "Electric trucks have arrived: The use case of medium duty box trucks." https://nacfe.org/medium-duty-box-trucks/

[81] "Electric trucks have arrived: The use case of medium duty box trucks."

[82] Metro Vancouver, "Capital and Installation costs" *EV Strata Condo*. www.metrovancouver.org/services/air-quality/climate-action/climate-solutions/ev-strata-condo/key-info/chargers-installation-costs/Pages/default.aspx#:~:text=Installing%20a%20Level%202%20charging,the%20cost%20of%20the%20installation

[83] Dana Lowell and Jane Culkin, *Medium and Heavy-duty Vehicles: Market structure, Environmental Impact, and EV Readiness,* prepared by M.J. Bradley & Associates for Environmental Defense Fund (2021), 18. http://blogs.edf.org/climate411/files/2021/08/EDFMHDVEVFeasibilityReport22jul21.pdf

to four times faster than Level 2 chargers. Public electric chargers are required for some Class 6 trucks with greater daily mileage, which will have to be Level 3 (or higher) to avoid lengthy charging times.
- Fleets that lease depot space could face challenges with installing recharging and refuelling infrastructure.

3.3 Heavy-duty vehicles

Vehicle types and vocation examples

Key sub-categories of HDVs examined by Pembina are:
- short-haul tractor-trailers
- long-haul tractor-trailers
- heavy rigid trucks

Table 8. Weight classes and vocations, HDVs

Class	GVWR (lbs)	Vehicle examples
7	26,001 to 33,000	furniture, medium conventional, city/transit bus
8	33,000+	dump truck, cement truck, heavy haul tractors

Source: Environment and Climate Change Canada[84]

Vocations

- Short-haul tractor-trailers are used in a variety of applications and can include food or beverage trucks and drayage trucks. This segment has higher payloads than urban delivery vehicles but tends to travel similar daily distances (less than 300 km)[85] and is relatively well-suited for electrification thanks to its return-to-base operating behaviour that allows for overnight charging in depots.[86]
- Long-haul tractor-trailers are used to transport the heaviest loads across long distances. These vehicles come equipped with a sleeper cab and tend to travel across multiple jurisdictions for shipping pick-ups and drop-offs.

[84] ECCC, *Discussion paper for heavy-duty vehicles and engines in Canada,* 5.

[85] ZEV Transition Council, *Heavy-duty Zero-Emission Vehicles*, 15.

[86] North American Council for Freight Efficiency, “Amping Up Charging Infrastructure for Electric Trucks.” https://nacfe.org/emerging-technology/electric-trucks-2/amping-up-charging-infrastructure-for-electric-trucks/

- The heavy rigid trucks category includes a wide variety of vehicles such as garbage trucks, cement mixers and mobile cranes. These vehicles vary in terms of typical distance travelled and fuelling/charging needs. For example, a refuse hauler could travel up to 400 km per day and use a single depot for overnight refuelling, whereas a concrete pump truck could face varying distance usage and may not return to a depot for several days.[87]

Pathways to decarbonization

- The shorter daily average distances travelled and return-to-base behaviours of short-haul tractor-trailers and some heavy rigid truck applications makes these segments suitable for battery electric powertrain applications.[88]
- Vehicles that are larger, heavier and subject to longer and less predictable trips may be challenging to decarbonize through battery electric technology and could find greater success from hydrogen fuel cell powertrain applications.[89]
- Leading up to 2030, the sales of battery electric vehicles are likely to predominate given that battery technology is more cost-effective and readily available compared to hydrogen fuel cell powertrains. Infrastructure to charge battery electric vehicles is also more widely available than hydrogen refuelling stations.[90]
- After 2030, the sales of hydrogen fuel cell trucks are predicted to increase as their upfront cost reaches parity with diesel vehicles and as hydrogen is supplied at a more competitive price.[91]
- In cases where applications of battery electric and hydrogen fuel cell powertrains for the heaviest types of vehicles remains several years out of reach, retrofits and efficiency technologies can play a role in reducing emissions. Retrofits can offer immediate emissions reductions through improving the fuel efficiency of

[87] California Air Resources Board, *Appendix E: Zero Emission Truck Market Assessment* (2019). https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2019/act2019/appe.pdf

[88] ZEV Transition Council, *Heavy-duty Zero-Emission Vehicles,* 6.

[89] CALSTART, *Moving Zero-Emission Freight Toward Commercialization* (2020), 27. https://globaldrivetozero.org/site/wp-content/uploads/2020/12/Moving-Zero-Emission-Freight-Toward-Commercialization.pdf

[90]Andrew Burke, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities for Battery-Electric Heavy-Duty Trucks at Safety Roadside Rest Areas* (National Center for Sustainable Transportation, 2022), 3. https://rosap.ntl.bts.gov/view/dot/60846

[91] NCST, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities*, 3.

vehicles on the road and can act as an interim step for the hard-to-decarbonize HDVs in the long-term transition to ZEVs.[92]

- Some research indicates that to meet Canada's climate goal of net-zero emissions by 2050, ICE HDVs still in use will need to be fully powered by biofuels, or their emissions offset using negative emissions solutions and next-generation carbon capture and storage.[93]

ZEV market outlook

- High upfront capital costs and limited model availability are major market barriers for all types of ZE HDVs. Class 8 BEVs and FCEVs have an estimated purchase price 2.8 and 3.6 times that of diesel in 2020, respectively.[94]
- Battery electric and hydrogen fuel cell electric trucks will have a difficult time competing with diesel-powered trucks for the next 10 years on an upfront-cost basis, especially for Class 7 and 8 trucks.[95]
- Across approximately 50 vehicle manufacturers, roughly 30 models of battery electric and fuel cell electric Class 7 and 8 vehicles are currently or soon to be commercially available in Canada and the United States. In contrast, roughly 30 models of ICE Class 7 and 8 vehicles are available from a sample of just three vehicle manufacturers.[96]
- While there are a few commercially available models suitable for short-haul operations, only a limited number of models can fulfill rigorous duty cycles for long-haul operations.[97] Many ZEVs suitable for the long-haul segment are in pre-commercial demonstration trails.[98]

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[92] Maddy Ewing, *Long-haul trucking fleets take emission reductions into their own hands* (Pembina Institute, 2021). https://www.pembina.org/pub/long-haul-trucking-fleets-take-emission-reductions-their-own-hands

[93] Canadian Climate Institute, *Canada's Net Zero Future- Finding Our Way in the Global Transition* (2021), 53. https://climatechoices.ca/wp-content/uploads/2021/02/Canadas-Net-Zero-Future_FINAL-2.pdf

[94] Claire Buysse, "How Much Does an Electric Semi Really Cost?" *International Council on Clean Transportation*, February 24, 2022. https://theicct.org/cost-electric-semi-feb22/

[95] Andrew Burke, Marshall Miller, Anish Sinha, Lew Fulton, *Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses: Methods, Issues, and Results* (Institute of Transportation Studies, 2022), 11. https://itspubs.ucdavis.edu/publication_detail.php?id=3768

[96] CALSTART, "Drive to Zero's Zero-emission Technology Inventory (ZETI) Tool Version 7.0," (2022). https://globaldrivetozero.org/tools/zeti/

[97] Owen MacDonnell and Cristiano Façanha, *How Zero-Emission Heavy-Duty Trucks Can Be Part of the Climate Solution* (CALSTART, 2021), 6. https://calstart.org/wp-content/uploads/2021/05/How-Zero-Emission-Heavy-Duty-Trucks-Can-Be-Part-of-the-Climate-Solution.pdf

[98] NCST, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities*, 4.

- Currently available and announced models are predominantly battery electric, especially in short-haul applications.[99] For long-haul operations, both battery electric and fuel cell electric powertrains are expected to play a role. Each face distinct challenges to achieving market readiness.

ZEV operational & technological considerations

BEVs

- While payload penalties will decrease over time with technological improvements, current battery electric trucks have a lower maximum payload capacity compared to diesel vehicles.[100]
- The high rates of daily utilization for long-haul operations create challenges for battery electric powertrains.[101]
- The vehicle distances travelled by long-haul trucks in Canada is nearly double that of short-haul trucks.[102] A range of at least 600 km, but more likely 800 km to 900 km would be needed to cover the extensive distances travelled by long-haul trucks. However, very few commercially available models have ranges that can complete this distance.[103]
- Because batteries suitable for such ranges would be unpractically large and heavy, advances in battery technology are needed. The energy density of a lithium battery will have to about double from present values in order for 800 km to900 km electric long-haul trucks to be practical.[104]
- Until such advances, driving behaviour may need to be adapted for battery electric long-haul trucks to be feasible. Drivers would need to arrange for multiple recharging stops (relying primarily on publicly accessible stations) throughout their journey if completing a long trip with a shorter-range truck.

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[99] CALSTART, *How Zero-Emission Heavy-Duty Trucks Can Be Part of the Climate Solution*, 7.

[100] Colton Kasteel and Maddy Ewing, *How to Lighten the Climate Load: Technology and policy options to decarbonize B.C.'s heaviest trucks* (Pembina Institute, 2021), 14. https://www.pembina.org/pub/how-lighten-climate-load

[101] ZEV Transition Council, *Heavy-duty Zero-Emission Vehicles,* 11.

[102] Natural Resources Canada, *Long Haul Activity Is the Majority of Activity in Both Canada and the US (Class 8b Trucks, 2014)* (SmartWay Trends and Statistics, 2018). https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/greening-freight-programs/smartway-fuel-efficient-freight-transportation/smartway-tools-and-resources/smartway-trends-and-statistics/21076

[103] NCST, *Assessment of Requirements*, *Costs and Benefits of Providing Charging Facilities*, 4.

[104] NCST, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities*, 4.

HFCEVs

- While payload losses are not substantial for fuel cell trucks, constraints with the design and location of on-board hydrogen storage systems can result in lower payload capacity compared to diesel vehicles.[105]
- Most models available today utilize 350-bar or 700-bar onboard hydrogen storage tanks, providing 370 km and 600 km of driving range, respectively.[106] To complete the extensive travel distances associated with long-haul operations, frequent refuelling may be required.
- With current technology, refuelling with a 350-bar tank is estimated to take eight to20 minutes and a 700-bar tank is estimated to take 30-50 minutes.[107]
- Liquid and cryo-compressed hydrogen storage tanks can offer higher ranges of about 800 km to900 km, with quicker refuelling times. However, the technology readiness of such options is still quite limited today.[108]106

Infrastructure needs

BEVs

- Not only will more charging stations have to be built to allow for frequent recharging stops, but high-power recharging infrastructure is required. Several companies are developing high-power battery chargers, but primarily for light-duty applications that are between 50 kW and 250 kW. However, higher power chargers are needed for trucking operations with rigorous duty cycles. For example, a battery electric truck with a 400 km to500 km range completing a 900 km journey would require two 45 to 60 minute recharging stops and a charger with 450 kW.[109]

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[105] Hussein Basma and Felipe Rodríguez, *Fuel cell electric tractor-trailers: Technology overview and fuel economy* (ICCT, 2022), 25. https://theicct.org/wp-content/uploads/2022/07/fuel-cell-tractor-trailer-tech-fuel-1-jul22.pdf

[106] ICCT, *Fuel cell electric tractor-trailers*, 18.

[107] ICCT, *Fuel cell electric tractor-trailers,* 19.

[108] ICCT, *Fuel cell electric tractor-trailers*, 18.

[109] NCST, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities,* 12.

- Charging battery packs for trucks with greater than 600 km of range in less than an hour will require MWs of power.[110] This technology is still in the early stages of commercial deployment.[111,112]
- Clearly, the time it takes to recharge a battery electric truck is considerably longer than the refuelling process for a diesel equivalent, though charging can occur during mandatory off-duty time (a minimum of 10 hours of off-duty time in a day is required: eight-consecutive off-duty hours and a minimum of two additional hours beyond this).[113]
- The cost of establishing such high-power charging facilities is another issue. One study estimated the installation cost for four 500 kW charging units at a rest stop to be approximately US$1.5 million.[114]
- Furthermore, current demand charges penalize investments in EV charging infrastructure, particularly for fast charging that is needed for long-haul operations.[115]

HFCEVs

- A lack of a built-out network of hydrogen fuelling stations remains a significant barrier and establishing such a network will be costly. The cost per station is estimated to exceed US$2 million to US$3 million.[116]
- Hydrogen prices are also prohibitively high. Estimates indicate that to break even with diesel, the cost of hydrogen refuelling needs to be US$1.55/kg, but prices are upwards of US$15/kg in California in 2019.[117]
- Future prices will depend on several factors, including the method used to produce hydrogen (i.e., hydrogen produced with renewables versus hydrogen derived from fossil fuels), transmission and distribution infrastructure, and the prices of key inputs (electricity, natural gas).

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[110] NCST, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities*, 17.

[111] Scania, "Megawatt charging in sight," July 7, 2022. https://www.scania.com/group/en/home/newsroom/news/2022/megawatt-charging-in-sight.html

[112] Mark Kane, "Tesla Installs First Megachargers at Frito-Lay in California," January 7, 2022. https://insideevs.com/news/559293/tesla-installs-first-megachargers-fritolay/

[113] Government of Canada, "Commercial Vehicle Drivers Hours and Service Regulations." https://laws-lois.justice.gc.ca/eng/regulations/SOR-2005-313/FullText.html

[114] NCST, *Assessment of Requirements, Costs, and Benefits of Providing Charging Facilities*, ii.

[115] ChargePoint, "Understanding Demand Charges Part 1: What are they and why they need to change," March 9, 2022. https://electricautonomy.ca/2022/03/09/chargepoint-understanding-demand-charges/

[116] David Welch et al., *Moving Zero-Emission Freight Toward Commercialization*, 39.

[117] "How Much Does an Electric Semi Really Cost?"

4. Opportunities to overcome ZEV adoption challenges

Establishing a pathway to transition MHDVs to ZE technology will require careful consideration of the diverse challenges and opportunities of different vehicle types. To understand what options are available to Canadian policymakers to transform the sector, the Pembina Institute has reviewed progress across the globe to decarbonize the on-road freight sector and/or increase the adoption of ZE MHDVs. Our jurisdictional scan of strategies, policy tools, financial and non-financial incentives focused on state, provincial and federal governments in North America and Europe.

Our research found that initiatives to deploy ZE MHDVs have gained traction globally. During COP26, a Global Memorandum of Understanding on ZE MHDVs was endorsed by 15 countries, subnational governments and industry leaders.[118] The Global MOU sets a target for 30% of truck and bus sales to be ZE by 2030, and 100% to be ZE by 2040. Other notable actions to support the rollout of ZE MHDVs include:

- California's Advanced Clean Trucks regulation directs automakers to grow their share of annual sales that are ZE MHDVs, such that 55% of Class 2b- to 3, 75% of Class 7 to 8 trucks and 40% of tractor sales are ZE by 2035. States including Oregon, Washington and New York and others have followed suit.
- Purchase incentives, subsidies and tax credits for ZEVs, retrofits and fuel-saving devices are becoming more common practice. Some jurisdictions are also reserving funds and providing bonuses for small- and minority-owned businesses, to improve equity.
- Infrastructure rollout is being catalyzed through mandatory deployment targets in the EU, as well as through grants, tenders and loan programs.
- Capacity-building within the MHDV sector is being supported through workforce training programs in California and other initiatives like the Multi-State ZEV Task Force.

We present our complete findings in Table 9, where measures are categorized in four buckets: financial incentives, standards and regulations, capacity-building supports and tools to facilitate infrastructure deployment.

[118] Clean Energy Ministerial, "COP26 Drive to Zero MOU for Zero Emissions Trucks". https://www.cleanenergyministerial.org/cop26-drive-to-zero-mou-for-zero-emissions-trucks/

Table 9. Jurisdiction review summary

	Description	Examples
Financial Incentives		
Point-of-Purchase	Several jurisdictions offer some form of purchase incentives for ZE MDHVs. Subsidies differ by vehicle class (i.e., Class 2b to8). Different subsidy amounts can be awarded based on vehicle class and the size of the enterprise that is applying (i.e., small, medium, or large companies). Bonus amounts for different use cases are offered, such as for disadvantaged communities (e.g., California) or minority-owned businesses (e.g., New Jersey). Reserve funds can be set up to ensure that funding is available for certain target groups (e.g., California). Limits on the number of applications for each fleet can be imposed (e.g., California, < 30/year/fleet) or caps can be set for total funds an applicant can receive (e.g., New Jersey, < 1.5 million/applicant).	California New Jersey New York Netherlands Spain British Columbia Quebec
Retrofits	Some jurisdictions offer incentives for the replacement of diesel equipment or vehicles. Programs can support replacing or converting a diesel vehicle with one that operates on alternative fuels (e.g., natural gas, electric). Programs tend to also offer incentives for the installation of technologies that reduce diesel engine idling, improve aerodynamics or allow low rolling resistance tires. Alternatively, some purchase incentive programs require the scrappage of a diesel vehicle to qualify for subsidies toward the purchase of a ZE MDHV.	California Indiana
Tax Incentives	A number of jurisdictions offer some form of tax incentive for ZE MHDVs. Tax incentives can be in the form of exemptions or reductions in vehicle registration or ownership tax. Reductions can vary by powertrain type (i.e., PHEV vs. BEV), and/or class. Exemptions/reductions can be offered for a fixed time period. Tax incentives can be offered as a tax credit or rebate. Tax credits can decrease over time and can apply differently based on vehicle class.	Utah Colorado Austria Greece Italy

		China Japan British Columbia
Innovative financing tools	There are several innovative financing mechanisms that jurisdictions use to support private investment. Concessional loans with preferential terms (e.g., below-market or zero interest rates, longer maturity, flexible eligibility requirements, first-loss guarantees) for ZE vehicles can facilitate uptake by offering fleets financial flexibility in the short term. Utility bill financing can offer a mechanism to set preferential loan terms and shift costs of purchases over time. Both electricity and gas utilities (for hydrogen and renewable natural gas) in Canada could be direct by governments to provide on-bill lending.	Canada British Columbia
Manufacturing	Several jurisdictions offer funding to support automakers in the transition to ZE MHDVs. Governments offer competitive grants for manufacturers to develop and demonstrate ZE MHDV technologies. Loan programs such as the U.S. ATVM is a direct loan program with funding to assist automakers in development ZEVs, including MHDVs (expansion of the program to MHDVs pending).	New York United Kingdom California European Union United States (a) United States (b)
Standards & Regulations		
ZEV Sales Standards	Several jurisdictions have adopted sales standards for ZE MDHVs. California's ACT has two components; a sales requirement for manufacturers, along with reporting requirements. Other U.S. States have since adopted or plan to adopt California's ACT as a major component of their plans to advance MDHV electrification.	California
Fleet Procurement Mandates	Fleet procurement mandates are relatively uncommon but are in development or established in some jurisdictions. The EU Clean Vehicle Directive requires member states to comply with minimum procurement targets for clean MHDVs. National targets have been identified.	European Union California Washington

	California is developing an Advanced Clean Fleets regulation that would require public fleets to procure a certain percentage of ZE MHDVs.	
Fuel Economy & GHG Standards	Nearly 80% of HDVs sold in 2020 were bought in markets where fuel economy standards or vehicle efficiency regulations covered at least some vehicle categories.[119] Some jurisdictions with standards in place continue to increase the stringency of targets to accelerate ZE MDHV deployment. Where current targets in the EU require a 15% reduction in GHG emissions from 2025, and 30% by 2030, an upcoming review of this regulation is scheduled. The EPA published a proposal in March 2022 to set more stringent standards for HDVs and engines starting in MY 2027.	European Union (GHG) China (GHG) China (Fuel Economy) India (Fuel Economy) Japan (Fuel Economy) United States (GHG)
Clean Fuel Standards	ZE MHDV deployment is supported by clean fuel standards in several jurisdictions. Carbon intensity targets vary by jurisdiction. By 2030: • California aims for 79.22 gCO_2/MJ (gasoline) 80.36 gCO_2/MJ (diesel) • British Columbia aims for 70.51 gCO_2e/MJ (gasoline) 75.81 gCO_2e/MJ (diesel)	California British Columbia Oregon European Union United Kingdom Quebec
Interoperable Charging Standards	Establishing interoperable charging standards will help support the business case for infrastructure deployment. Standards are not yet well established, though jurisdictions are beginning to move towards establishing them. The United States issued a notice on June 9, 2022, to establish standards to build out an EV charging network that is interoperable. The Chilean transport minister worked with the Chilean transit company to establish heavy vehicle chargers.	United States Chile

[119] International Energy Agency, *Tracking Transport* (2021). https://www.iea.org/reports/tracking-transport-2021

<table>
<tr><th colspan="3">Capacity-building</th></tr>
<tr><td>Workforce Training & Support</td><td>Workforce training and support specific to the ZE MHD sector is not common across jurisdictions, where current efforts primarily focus on LDVs. Notable programs within the ZE MHDV space include:
California’s ZEV Truck Program, which allocated US$1.8 million to San Diego Miramar College to support the establishment of MDHV programs to meet workforce needs.
Quebec’s Programme Competences aims to make a ZE heavy vehicle and bus specific program during 2023 to deal with growing developments in the sector.
Although not specific to MHDVs, British Columbia’s CleanBC Go Electric program offers an EV maintenance training program in three post-secondary institutions through a partnership with Trades Training BC.</td><td>California
Quebec
British Columbia</td></tr>
<tr><td>Community Outreach</td><td>Community outreach programs are being utilized across a number of jurisdictions to support general EV deployment, and specific programs directed toward rural and disadvantaged communities have been developed.
Given that program should be co-developed and tailored to specific needs of communities, community outreach programs will look different across regions.
Some examples include:
California’s Clean Transportation Program Rural Electric Vehicle Charging which funds projects to demonstrate EVs in rural and disadvantaged communities.
The U.S. toolkit for planning and funding rural electric mobility infrastructure focuses on LDVs, but also addresses funding opportunities and planning for ZE buses and MHDVs.</td><td>California
United States (a)
United States (b)</td></tr>
<tr><td>Taskforces</td><td>Some jurisdictions have developed taskforces specifically designed to support the deployment of ZE MHDVs, while other taskforces have been developed to guide general EV deployment.
The Multi-State ZEV Task Force is an MOU signed by numerous states to support deployment of ZE MDHVs.
At the federal level, several taskforces have been established:
The Electric Vehicle Working Group will make recommendations on development, adoption and integration of ZE LMHDVs.</td><td>Multi-State ZEV Task Force
United States (a)
United States (b)</td></tr>
</table>

	• The Joint Office of Energy and Transportation will guide implementation of the Bipartisan Infrastructure Bill.	
Infrastructure		
Deployment Mandates	While uncommon, mandatory targets can be set for the deployment of infrastructure. The EU Alternative Fuels Infrastructure Regulation obligates member states to meet deployment targets under binding legislation.	European Union
Grants, Tenders & Loan Programs	Across jurisdictions, a range of funding is offered for deployment of infrastructure. Grants for charging infrastructure tend to vary by charging capacity, with more aid being offered to fast charging stations. Aid can also vary depending on the location of the charging station being installed (urban vs. rural). In some jurisdictions, tenders have been established that package several locations together that providers are required to install infrastructure within. The cost of providing sufficient local electricity can be pre-financed and locations can be assessed for sufficient grid connection. Loan programs that offer favourable terms (e.g., contributions to a loss reserve account, grace periods) can be offered to support deployment.	Grants: California France Poland Korea Tenders: Switzerland Loans: California
Cross-border Collaboration	Arrangements have been made across a number of jurisdictions to collaborate on the deployment of charging and refuelling infrastructure. In several cases, regions have signed memoranda of understanding (MOUs) to join efforts to deploy infrastructure. Collaborative efforts tend to focus on identifying key corridors for MHDVs and ways to support rural communities. MOUs can include other stakeholders outside government, including utilities and trucking associations.	West Coast Clean Transit Corridor Regional EV Midwest Coalition California Electric Transportation Coalition Regional Charging Network
Utility Partnerships	In several jurisdictions, governments have established partnerships or regulatory conditions that require utilities to support ZE MDHV infrastructure deployment.	California New York United States

	Governments can work with utility regulators to direct investor-owned electric utilities to utilize funding that supports make-ready installations for MHDVs (e.g., California). Governments can provide loan and grant programs through local utility organizations.	
R&D Funding & Demonstration Support	Large funding packages to support R&D and demonstrations have been launched by governments across several jurisdictions. In many cases, funding supports the development of hydrogen refuelling with sufficient flow-rates to support HDVs, as well as the development of 1+ MW charging stations. Government funding is allowing alternative infrastructure to be explored that demonstrates and researches electric road systems (inductive and conductive MDHV charging).	United States (a) United States (b) Germany (a) Germany (b) British Columbia

5. Conclusion

As a preliminary step in the Pembina Institute's ongoing work to develop a strategy to help Canada achieve its announced ZE MHDV sales targets, this report has assessed the current state of progress in Canada, the myriad decarbonization challenges and opportunities for MHDVs, and the policy tools being used globally to advance a ZE MHDV transition.

Across the sector, several challenges remain. For buses, we find that transit and school buses are first in line for electrification, while intercity buses may take longer to transition to ZEVs due to their long-haul routes. For MDVs (Class 2b to 6), we find that many vocations are also well suited for electrification. Similar to buses, purchase prices for ZE MDVs remain higher than their ICE counterparts; however, improvements in model availability and low operating costs of battery electric vehicles makes ZE box trucks and return-to-base delivery vehicles cost-competitive. For HDVs, we find that stickier and more expensive challenges remain. Examples include the need for widespread deployment of a publicly accessible, high-capacity charging and refuelling network, where excessively high costs and further R&D are limiting factors.

Considering the nuanced challenges faced by sub-groups of MHDVs, we conclude that targeted, rather than uniform policy solutions will be needed to accelerate the ZEV transition. Additional research by the Pembina Institute identifies recommendations for federal policymakers on how to proceed.[120] Over the coming months, Pembina will be seeking feedback from all relevant stakeholders to inform the further development of our recommendations. As we continue to refine our work, we will draw from the foundational research we have gathered in this preliminary report.

[120] Kasteel, Colton, Sarah McBain, Chandan Bhardwaj. *Towards Clean MHDVs: Preliminary policy solutions to decarbonize Canada's MHDVs*. The Pembina Institute, 2022.

Appendix A. Existing Canadian policies and programs

Table 10. Key federal measures

Category	Policies and programs
Incentives and subsidies	$550M iMHZEV program 100% tax write-off for business (until 2024, and decreasing thereafter) on ZEV acquisitions $2.75B Zero Emission Transit Fund $1.5B CIB Zero Emission Bus Initiative
Charging and fuelling infrastructure	$500M CIB investment in large-scale ZEV charging and refuelling infrastructure $680M Zero Emission Vehicle Infrastructure Program $76M Electric Vehicle Infrastructure Demonstration Program
Policies and regulations	Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations Clean Fuel Regulations Carbon Tax
Capacity-building	Zero Emission Vehicle Awareness Initiative $200M Green Freight Program $33.8M for hydrogen trucking demonstration projects $295M to retool the Ontario Oakville Assembly Complex $2.2M Greening Government Fleets