PEMBINA institute

Towards Clean MHDVs

Preliminary policy solutions to decarbonize Canada's MHDVs

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Executive Summary

Canada needs a clear, comprehensive strategy for how it will decarbonize the on-road medium- and heavy-duty vehicle (MHDV) sector and reach announced targets for 35% of new MHDV sales to be zero-emission (ZE) by 2030, and 100% ZE by 2040. Without a shared vision, credible roadmap, investment strategy and policy coordination, we risk low zero-emission vehicle (ZEV) supply, a slow market transformation and potential inability to meet our climate targets.

We know that to overcome the myriad decarbonization challenges faced by the MHDV sector, a range of policy tools and measures will be needed. However, not all policies, regulations and incentives are equal in efficacy, and it is important to understand which measures can play a catalytic role, versus a supportive role for the sector.

Pembina Institute is currently developing a pan-Canadian strategy that will help Canada meet its ambitious mid-century and 2040 goals. Our aim is to develop recommendations that can be adopted by the federal government to achieve deep emission reductions, accelerate the deployment of ZEVs, provide market certainty, improve public health, and generate economic growth and technological innovation.

This preliminary research provides a range of policy solutions available to the federal government to overcome the challenges and barriers to transition to ZE MHDVs in Canada and makes recommendations on which to prioritize. This document is complemented by a working research document that examines the unique challenges and barriers within the MHDV sector.

Based on the Institute's research to date, the transition to ZEVs can be completed most cost-effectively through a ZEV sales standard that employs sales requirements segmented by vehicle type. We have also determined that supportive public-private investments to build out ZEV infrastructure and systems will be needed. These two measures along with other complementary measures can shift Canada's MHDV stock to be largely electrified by 2040 and help annual greenhouse gas (GHG) emissions from the sector to fall to approximately 21 Mt by 2030 and 4 Mt by 2050 (compared to 29 Mt by 2030 and 26 Mt by 2050 if the ZEV sales standard were not in place).

Early findings and recommendations

ZEV sales standard: After considering in detail the advantages and disadvantages of various decarbonization pathways, Pembina Institute determined that the transition to ZEVs can be completed most cost-effectively through **a ZEV sales standard that employs sales requirements segmented by vehicle type**. Pembina Institute's recommended ZEV sales standard would require:

- Most buses to reach 100% ZEV sales by 2030
- Most medium-duty vehicles (MDV) to reach 50% ZEV sales by 2030 and near 100% by 2040
- Heavy-duty vehicles (HDV) to reach 10% ZEV sales by 2030 and near 100% by 2040.

ZEV infrastructure investments: In addition to a targeted ZEV sales standard, Pembina Institute sees a role for public investments and subsidies to crowd-in private capital and reach the $10 billion to $15 billion needed in investments for charging infrastructure by 2040.

Other complementary policies and regulations are needed. Some of these measures include:

- Short- to medium-term purchase incentives to improve ZEV accessibility while upfront costs remain high
- Capacity-building programs to build fleet awareness and understanding of the ZEV transition
- Labour market programs to address skills gaps in ZEV maintenance, repair and infrastructure installation.

Discussion questions

As a part of this strategy development process, we are seeking input from stakeholders on our preliminary recommendations. Through a series of consultations, we aim to develop a final Canadian ZE MHDV strategy in spring 2023. Key questions we are seeking feedback on are:

1. How might Canada's ZEV sales standard be further segmented, by vehicle class or vocation?
2. Which complementary regulations should be prioritized and strengthened?
3. How should the cost-burden of investments in charging and fueling infrastructure be distributed between public and private entities?
4. What role should purchase incentives play in facilitating the ZE transition and by when should they be phased out?
5. What innovative financing tools should be prioritized, in lieu or in support of direct subsidies?
6. What capacity-building and labour force programs are most needed?

Introduction

To respond to the dramatic emission reductions needed in Canada's transportation sector, the federal government is in the early stages of developing an integrated medium- and heavy-duty vehicle (MHDV) strategy. To inform the federal government's strategy, Pembina Institute has developed preliminary recommendations on how to reach Canada's ZEV adoption targets and GHG reduction goals for the MHDV sector. Over the coming months, we will continue to develop and refine our recommendations through ongoing research and analysis, as well as extensive stakeholder engagement.

To identify a mix of policy and program measures that ensure a cost-effective pathway to decarbonize the transportation sector, we used several qualitative and quantitative research strategies.

Data analysis, jurisdictional scan and literature review

We reviewed the current state of progress in Canada and are undertaking an ongoing jurisdictional scan of strategies, policies and programs implemented across sub-national and national governments (primarily in North America and Europe). This scan allows us to identify and review key demand- and supply-side policies and programs that support the uptake of ZE MHDVs, along with best practices for strategic deployment of ZEV infrastructure and support for capacity-building among key stakeholders.

Stakeholder engagement

The ZEV landscape is complex and as part of our work to build a decarbonization roadmap for Canada's MHDVs, Pembina Institute is ensuring our strategy is comprehensive and endorsed by a coalition of key stakeholders. This project includes ongoing consultation through a variety of mediums including roundtables, interviews, workshops and surveys. We have identified the following stakeholder groups as priority actors shaping the trajectory of Canada's pathway to net-zero on-road MHDVs:

- Federal, provincial, territorial and municipal governments
- Energy suppliers and regulators
- Electric vehicle supply equipment (EVSE) and hydrogen infrastructure providers
- Freight and logistics companies and associations
- Public health agencies
- Fleet managers and operators
- Battery manufacturers and associated value chain suppliers
- Automakers and parts manufacturers
- Independent research consultants and think tanks

Energy-economy modelling

Pembina Institute partnered with Navius Research Inc. to assess the impact of a suite of policies and regulations that could decarbonize Canada's MHDV sector in a cost-effective manner.

Navius's gTech model is a Canada-focused energy economy model that includes a detailed representation of the various end-use energy demand sectors (e.g., buildings, transportation). The model is notable in that it contains a rich representation of technologies and fuels used to satisfy energy demand in each sector. For example, it divides the MHDV sector into three segments: medium-duty vehicles (MDV), heavy-duty vehicles (HDV) and buses. Although, it would have been ideal to have the model further disaggregated into vehicle sub-classes (e.g., class 2B to class 8), the gTech model currently does not include this level of resolution. This key limitation prevented us from analysing policy strategies specific to each vehicle sub-class.

The model includes multiple vehicle drivetrains such as internal combustion engine vehicles (ICEV), battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and fuel cell electric vehicles (FCEV). The corresponding fuel types include diesel, gasoline, biofuels, electricity and hydrogen.

By estimating the market share of different technology and fuel types going out to 2050, the model can be used to calculate the GHG emissions from different vehicle technologies using publicly available estimates of life cycle emissions and using that data to calculate emissions for the nation's entire vehicle stock. Further, the model connects the outputs of Canada's energy demand sectors to a macro-economic sub-model allowing it to calculate economic indicators like GDP and employment, and hence compare the economic costs of different policy scenarios.

For each simulated policy scenario, we received the following key outputs:

- New market share of different drivetrains (BEVs, PHEVs, FCEVs and ICEVs), disaggregated by segment (MDVs, HDVs and buses)
- Total electricity, biofuel and hydrogen demand
- Economic impacts
- National GHG emissions

We used this energy-economy modelling to help us answer four main research questions:

1. Which technologies and fuels (e.g., biofuels vs electrification) will play a dominant role in achieving net-zero emissions by 2050 in Canada?
2. What is the most cost-effective policy option for achieving 100% new ZEV sales by 2040?
3. What is the best way to design Canada's ZEV sales standard?

4. What is the charging infrastructure and hydrogen refuelling infrastructure needed to achieve Canada's ZEV transition and decarbonization goals?

Scope of work

While the breadth of our research was wide, we were not able to cover all aspects and issues pertaining to the decarbonization of the MHDV sector. Research areas out of scope for this work include:

- Policy and regulatory actions needed to address the vehicle supply chain, critical minerals supply and post-consumer recycling.
- Questions associated with upstream energy supply and the carbon intensity factors of different fuels used in ZEVs (e.g., electricity, green/ blue/ turquoise hydrogen).
- Actions taken by provinces, territories and municipalities. This research is focused on the actions that should be taken by the federal government. While some recommended policies and regulations overlap with provincial jurisdiction, we choose to focus on federal measures at this juncture.

Policy options for Canada

While the key regulation and focus of our research is a ZEV sales standard, which enforces minimum sales of ZEVs across the country, we recognize that other policies and non-regulatory measures have an important role to play in helping accelerate the ZEV transition. We separate these measures into four key categories:

Policies and regulations

- **Regulations** such as mandates for 100% zero-emission vehicle sales and stringent vehicle emissions standards
- **Policies** such as strategic investments for a domestic zero-emission automotive industry and value chain, R&D and demonstration support, and public procurement schemes

Incentives and subsidies

- Financial incentives for **ZEV purchases** including rebates, grants, tax credits, preferential rate lending, and more
- Subsidies, tax credits and loan programs for **ZEV manufacturing**

Charging and fuelling infrastructure

- **Projects** funded partially or wholly by government to grow the number of publicly accessible stations
- **Minimum standards and requirements** for charging infrastructure to ensure interoperability

Capacity-building

- Zero-emission vehicle **awareness and education** initiatives
- **Skills training** for the operation, maintenance and repair of commercial zero-emission vehicles

Supportive policies and regulations

Policies and regulations can directly and indirectly incentivize ZEV adoption. There are a wide range of clean transportation polices and regulations that can help the MHDV sector reach net-zero emissions by 2050. Those explored here (Table 1) have been well researched and tested across the globe.

Along with well-designed policies and regulations, long-term strategic planning is critical to ensure that policies and regulations are consistent, effective, coordinated, accountable and transparent.

Table 1. Examples of policies and regulations that accelerate the ZEV transition

Policy tools	Description	Examples
ZEV sales standard	This policy requires automakers to earn ZEV credits each year. Automakers can secure credits by, 1) manufacturing and selling ZEVs; or 2) purchasing credits from other automakers. Unique design features include non-compliance penalties, potential allocations of credits per ZEV type and the allowance for credit-banking across multiple years.	B.C. Zero-Emission Vehicles Act QC Zero-Emission Vehicles Standard California Zero-Emission Vehicle Program
Vehicle emission standard	This policy requires automakers to reduce the emissions from new vehicles over time. Automakers can comply by either improving the fuel economy of internal combustion vehicles or by selling ZEVs.	Canada's Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulation
Taxes on internal combustion engine vehicles	This policy implements a tax on internal combustion engine vehicles. This tax increases the purchase price of internal combustion engine vehicles and allows ZEVs (which have no such tax) to reach price parity sooner.	Norway's CO_2-differentiated motor vehicle registration tax France's Bonus-Malus scheme
Procurement targets/ requirement	This policy sets targets for public sector procurement of ZEVs; targets rise over time.	California Zero-Emission Vehicle Program EU Clean Vehicle Directive
Clean fuel standards	Clean fuel standards set a required carbon intensity for fuel suppliers to meet, with a benchmark standard that declines over time. Fuel suppliers can choose to comply by meeting the standards or by purchasing credits on the market.	Canada's Clean Fuel Regulations B.C. Low Carbon Fuel Standard California Low Carbon Fuel Standard

Incentives and subsidies

Otherwise known as the "carrot" approach, incentives and subsidies have proven historically effective at accelerating adoption, and the deployment and manufacturing of clean transportation technologies. Many incentive and subsidy programs serve to lower the payback time on ZEVs and decarbonization investments across the globe (Table 2).

A wide variety of incentives can be used to reduce the barriers to deployment of near-zero and ZE MHDVs. While upfront rebates and tax incentives that lower the direct purchase price of ZEVs are the most well-known, there are many more innovative approaches that can be taken by policymakers to support private investment including grants, rebates, preferential-rate loans, tax credits and guarantees.

Table 2. Examples of incentives and subsidies for MHD ZEVs

Policy tools	Description	Examples
ZEV purchase subsidies	This policy offers subsidies to consumers and/or businesses to help offset part of the high upfront purchase price of ZEVs. Subsidies can be designed to provide different amounts based on vehicle class, technology, business size and if the vehicles are primarily operating in low-income communities.	Canada Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles Program California Hybrid And Zero-Emission Truck And Bus Voucher Incentive Program B.C. Specialty Use Vehicle Incentive Program
ZEV purchase tax incentives	In addition to, or in substitute of subsidies to offset the incremental cost of ZEVs, governments can offer tax incentives to improve their business case. 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. 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 vehicle class. Exemptions/reductions can be offered for a fixed time period.	Canada ax write-off for commercial zero-emission vehicles U.S. Qualified Commercial Clean Vehicles Credit
Concessional lending	Concessional loans with preferential terms (e.g., below-market or zero interest rates, longer maturity, flexible eligibility requirements, first-loss guarantees) for vehicles with relatively lower lifecycle GHG emissions could provide fleets with the financial flexibility needed in the short term to allow for quick adoption while providing a flexible payback period.	Canada Infrastructure Bank Zero-Emission Buses Initiative
On-bill financing	Utility bill financing models also offer a mechanism to set preferential loan terms and shift costs for purchasers over time. Both electricity and gas utilities (for hydrogen, RNG) in Canada could be directed by governments to provide on-bill lending services.	B.C. Greenhouse Gas Reduction Regulation
Manufacturing subsidies & production tax credits	Governments can provide direct subsidies to Original Equipment Manufacturers (OEM) for the manufacturing of ZEVs in Canada.	U.S. Clean Energy Manufacturing Tax Credit
R&D subsidies & pilot programs	Governments offer grants and loans for the development and demonstration of innovative ZE MHDV technologies.	B.C. Commercial Vehicle Pilot Program B.C. Advanced Research and Commercialization Program

Utility rate design	Utilities can provide incentives to vehicle owners by using tools such as preferential rates and time-of-use rates to encourage uptake of ZE technologies. Governments can work with utilities to provide subsidized rates for electrification.	California Public Utilities Commission SB 250 TE programs
Clean fuel regulations	Clean fuel regulations can indirectly subsidize ZE fleets by enabling credit sales through the accounting of the clean fuels passing through their locally owned charging or fuelling stations. The credits can be accumulated and then sold on the market for revenue, to reinvest in their fleets.	B.C. Low Carbon Fuel Standard Canada Clean Fuel Regulations

Charging and fuelling infrastructure & energy supply

To make confident investments in zero- and near-zero-emission vehicles, operators and fleets need to know their vehicles will be able to refuel or recharge reliably, at convenient times and locations.

Public-private investments in key long-haul corridors continue to be a critical priority for federal and provincial governments. Additional subsidies are also needed to support the build-out of depot and private fuelling/charging infrastructure. Increasingly stringent low-carbon fuel standards like Canada's Clean Fuel Regulations help with this by providing fleets who install local charging infrastructure with new revenue streams via the credit markets. (Table 3)

Table 3. Examples of infrastructure and energy supply policies for ZEVs

Policy tools	Description	Examples
Charging and fuelling infrastructure subsidies	This policy requires funding and strategic deployment of adequate charging and refuelling infrastructure.	Canada's Zero-Emission Vehicle Infrastructure Program U.S. Alternative Fuel Refueling Infrastructure Credit B.C. Low Carbon Fuel Standard Part 3 Agreements
Interoperable charging standards	Interoperable charging standards help support the business case for infrastructure deployment and provide consumers and businesses with confidence to purchase BEVs, knowing that there will be consistency in the charging stations they use to refuel their vehicle. Standards are not yet well established, though some jurisdictions are beginning to establish them.	U.S. National Electric Vehicle Infrastructure minimum

		standards and requirements[1] Chile Heavy Vehicle Chargers[2]
Clean electricity standard	This policy aims to reduce GHG emissions from electricity generation which allows for gains from electrifying end-use sectors to be maximized.	Canada's forthcoming Clean Electricity Standard

Capacity-building

Fleets require accessible and easily digestible information and resources that can help them to effectively make the switch to near-zero and zero- emission technologies. Moreover, vehicle operators and maintenance workers require adequate training.

Some existing government programs integrate non-financial supports for industry adopting fuel efficiency measures. These measures include fleet efficiency assessments, training and coursework, and fleet and technology certifications. (Table 4)

Table 4. Examples of capacity-building measures for ZEVs

Policy tools	Description	Examples
Workforce training	Governments can support the deployment of ZEVs through establishing a skilled workforce. Programs can be developed to provide training and certification for fleets in operating ZEVs, as well as for technicians in ZEV maintenance and the installation of charging and fuelling infrastructure.	CleanBC Heavy-Duty Vehicle Efficiency program BC Go Electric EV Maintenance Training California Energy Commission's IDEAL ZEV Workforce Pilot
Awareness and education programs	Consumer awareness, education and confidence in ZEVs can be supported through targeted outreach programs for fleets owners, drivers and the general public. Programs can be tailored to provide support for small and minority-owned fleets, as well as disadvantaged communities.	Canada's Zero Emission Vehicle Awareness Initiative California Energy Commissions' Clean Transportation Program Rural Electric Vehicle Charging

[1] U.S. Department of Transportation, "Biden-Harris Administration Takes Key Step Forward in Building a National Network of User-Friendly, Reliable, and Accessible Electric Vehicle Chargers," news release, June 9, 2022. https://www.transportation.gov/briefing-room/biden-harris-administration-takes-key-step-forward-building-national-network-user

[2] ABB, "ABB powers e-mobility progress in Chile with innovative charging solution," news release, March 4, 2020. https://new.abb.com/news/detail/57902/abb-powers-e-mobility-progress-in-chile-with-innovative-charging-solution

Cross-jurisdictional collaboration	Collaboration within and across government, stakeholders and community members can accelerate the transition to ZEVs by facilitating knowledge-sharing and the translation of knowledge into evidence-based decision making. In particular, coordination is needed to establish a seamless network of charging and refuelling stations across Canada.	Multi-State ZEV Task Force West Coast Clean Transit Corridor The Regional Electric Vehicle Midwest Coalition

Preliminary recommendations

To overcome the decarbonization challenges faced by the MHDV sector, a range of policy tools and measures will be needed. However, not all policies, regulations and incentives are created equal. Some measures will lead the sector's transition to ZEVs, while others will be more supportive. After carefully considering the advantages and disadvantages of different decarbonization pathways, Pembina Institute determined that the ZEV transition for MHDVs can be overcome most cost-effectively through **a ZEV sales standard that employs sales requirements segmented by vehicle type**.

A thorough examination of the available academic literature has given us confidence that this pathway is most appropriate. While other measures such as incentives, infrastructure subsidies and capacity-building programs are clearly needed as well, they may play a complementary role in the transition. Reviewing the literature, it is clear that in absence of a ZEV sales standard, depending on purchase incentives and subsidies for charging infrastructure would be costlier for Canada and would not guarantee the same end results for emissions reductions or ZEV sales.[3,4] The ZEV sales standard should be viewed as the federal government's premier tool to drive innovation, economies of scale and ZEV adoption in the MHDV sector.

Notably, feedback gathered from our engagement with stakeholders across the MHDV sector also revealed widespread support for a bold ZEV sales standard. In meetings held by Pembina Institute, stakeholders agreed that a sales standard is critical to accelerate ZEV adoption and ensure adequate domestic vehicle supply. Several groups noted that Canada's chosen ZEV sales standard should be designed with meaningful nuances to account for differences between vehicle types and vocations.

Designing the optimal pathway to 100% ZEV sales by 2040

To test the theory that the ZEV sales standard emerges as an effective mechanism for Canada, we used energy-economy modelling to compare multiple ZEV sales standard designs against current policies and a scenario where the federal government provides up to $1 billion in ZEV purchase incentives. Feedback from stakeholders throughout Pembina Institute's engagement process suggested that Canada should follow California's lead in adopting a beachhead strategy that ensures vehicle types are subject to different ZEV sales requirements based on feasibility.

[3] Scott Peterson and Jeremy J. Michalek, "Cost-effectiveness of plug-in hybrid electric vehicle battery capacity and charging infrastructure investment for reducing US gasoline consumption." *Energy policy* 52 (2013). https://doi.org/10.1016/j.enpol.2012.09.059

[4] Jonn Axsen and Michael Wolinetz, "Reaching 30% plug-in vehicle sales by 2030: Modeling incentive and sales mandate strategies in Canada." *Transportation Research Part D: Transport and Environment* 65 (2018). https://doi.org/10.1016/j.trd.2018.09.012

CALSTART defines the beachhead strategy as follows: "the Beachhead strategy targets first-success applications or "beachheads" where ZE technologies are currently viable according to duty cycle, business case, industrial capacity, and performance measures. These initial applications act as cornerstones for the development of adjacent or near-early markets for next-generation vehicle and equipment applications that follow predictable pathways."[5] To the best of our knowledge, ours is the first study to quantitatively analyse a beachhead strategy for the uptake of ZE MHDVs in Canada and compare different policy scenarios to achieve 100% new ZEV sales by 2040. In doing so, we are able to provide quantitative feedback to the federal government's recently announced Emissions Reduction Plan, and its targets to reach ZEV sales shares of 35% by 2030 and 100% by 2040 for all new MHDVs.[6] The policy scenarios modelled are included in Table 5.

Table 5. Policy scenarios modelled

Scenarios	Description
Baseline scenario	All federal/provincial policies currently in place (including carbon tax and clean fuel regulation)
Baseline + Purchase Subsidies scenario	Purchase subsidies worth $1 billion as in the federal iMHZEV program, plus Baseline
ZEV sales standard 1 scenario (Uniform targets)	All MHDV sub-classes (buses, MDVs, HDVs) are required to achieve the same sales target of 35% by 2030 and 100% by 2040
ZEV sales standard 2 scenario (Beachhead)	Buses are required to reach 100% ZEV sales by 2030 MDVs are required to reach 35% by 2030 HDVs are required to reach 25% by 2030
ZEV sales standard 3 scenario (Beachhead)	Buses are required to reach 100% ZEV sales by 2030, MDVs are required to reach 50% by 2030 HDVs are required to reach 10% by 2030
ZEV sales standard 4 scenario (Beachhead)	Buses are required to reach 100% ZEV sales by 2030 MDVs are required to reach 60% by 2030 HDVs are required to reach 0% by 2030 (HDVs here reach 100% by 2045)
ZEV sales standard 5 scenario (Ambitious)	Buses and MDVs are required to reach 100% ZEV sales by 2030 HDVs are required to reach 40% by 2030

[5] CALSTART, *The Beachhead Strategy: A Theory of Change for Medium- and Heavy-Duty Clean Commercial Transportation* (2022). https://calstart.org/wp-content/uploads/2022/04/The-Beachhead-Strategy_April-2022.pdf

[6] ECCC, *2030 Emissions Reduction Plan,* 57.

Analysis results

ZEV sales

- We find that the current baseline) policies in place in Canada, as of Summer 2022, are not nearly strong enough to meet ZE MHDV sales goals for 2030 or 2040, as the ZEV new sales market share reaches only 50% by 2050 under the baseline scenario.
- Canada's sales targets are not met under the scenario with purchase subsidies.
- Only the ZEV sales standard and its different design scenarios comes close to achieving Canada's sales targets.

GHG emissions

- Under the current baseline policies scenario, annual GHG emissions from on-road MHDVs are expected to be 25 Mt in 2050. All the ZEV sales standard scenarios result in an average 80% decline in GHG emissions relative to the baseline by 2050 (~5 Mt).
- In effect, the ZEV sales standard scenarios come close to achieving the net-zero by 2050 goal, while the purchase subsidies scenario has a negligible impact on emissions reductions in 2030.

Technology costs

- The ZEV sales standard scenarios are found to accelerate the decline in technology costs (EV battery costs and hydrogen fuel cell costs), relative to the baseline scenarios.
- For example, hydrogen fuel cell costs in 2050 are $175/kW under the baseline scenario and $150/kW under the ZEV sales standard scenarios. The decline in fuel cell costs also starts to happen sooner,by 2030, under every ZEV sales standard scenario, clearly illustrating the beneficial impacts the policy has on technology costs.

Alternative ZEV sales standard designs

A few key observations can be made about the alternative ZEV sales standard scenarios we examined (scenarios ZEV sales standard 1-5 in Table 5):

- The ZEV sales standard 3 scenario leads to higher uptake of ZEVs overall, relative to the uniform sales target strategy (ZEV sales standard 1 and 2). Moreover, the ZEV sales standard 3 leads to 15% fewer emissions (4.1 MT) by 2050, relative to the uniform sales target scenario (ZEV sales standard 1 with 5.4 MT of GHG emissions) and the ZEV sales standard 2 scenario (4.4 MT). This suggests clear benefits of a beachhead strategy over a uniform sales target strategy.
- Additionally, ZEV sales standard 3 (50% ZE MDVs and 10% ZE HDVs by 2030) has lower GDP impacts than ZEV sales standard 2 (30% ZE MDVs and ZE HDVs by 2030).
- Another variant of the beachhead strategy is the ZEV sales standard 4 scenario as listed in Table 5. The ZEV sales standard 4 scenario assumes a delayed adoption of ZE HDVs,

such that that there is 0% uptake of ZE HDVS in 2030. Interestingly, we find that the ZEV sales standard 4 is costlier than ZEV sales standard 2 and 3. This suggests that there are additional costs of unnecessarily delaying ZE HDV uptake. Having some ZE HDV uptake earlier (e.g., 10% by 2030 in ZEV sales standard 3) is more cost-effective than having 0% ZE HDV uptake by 2030.

- An ambitious ZEV strategy (ZEV sales standard 5), requiring 40% to 45% ZE HDVs by 2030, leads to fewer emissions (3.5 Mt in 2050 compared to 4.1 under ZEV sales standard 3), but it does so at higher costs (1.6% GDP loss relative to 1% GDP loss under ZEV sales standard 3). Arguably, a more ambitious ZEV sales standard does not present significantly worthwhile emissions benefits given the additional costs it imposes. Moreover, the rapid electrification required under the ambitious ZEV sales standard 5 may face feasibility challenges.

Summary

Of the policy pathways evaluated, a ZEV sales standard outlined in all scenarios, offers several advantages compared to other policy scenarios. A ZEV sales standard:

- Achieves (or comes close to achieving) ZEV sales goals for 2030 and 2040
- Induces substantial GHG reductions by 2050
- Reduces energy consumption more than other scenarios, thus contributing the most to energy security
- Facilitates larger and quicker declines in technology costs
- Minimizes compliance risks as ZEVs do not suffer from long-term uncertainty in availability and economic feasibility, as would be faced with biofuels

In addition, there are clear benefits of exploring a beachhead strategy for the design of the ZEV sales standard. Our modelling results indicate that a strategy requiring faster uptake of ZE MDVs and buses leads to more emissions reductions and higher ZEV uptake than a strategy that requires equal uptake of ZEVs across all segments, namely MDVs, HDVs and buses. In fact, under an optimistic technology costs scenario,[7] a beachhead strategy (ZEV sales standard 3) that requires slower uptake of ZE HDVs (10% by 2030) and quicker uptake of ZE MDVs (50% by 2030) is 0.1% less costly than a strategy that requires the same level of ZEV uptake for both MDVs and HDVs by 2030 (ZEV sales standard 2). In addition, our recommended beachhead strategy offers advantages in terms cost-effectiveness over a sales standard that delays the uptake of ZE HDVs.

[7] In the optimistic technology costs scenario EV battery costs reach $50/kWh by 2035 and stay there until 2050; and hydrogen fuel cell costs reach $160/kW by 2035 and decline linearly to reach $110/kW by 2050.

Recommended ZEV sales standard — in detail

Based on our research findings, we find clear benefits of adopting a beachhead strategy for the design of the ZEV sales standard. In particular, the most suitable ZEV sales standard of those examined appears to be a beachhead strategy that requires 10% ZE HDVs, 50% ZE MDVs and near 100% ZE buses by 2030 (ZEV sales standard 3). In addition, our supplementary research gathered in a complementary report (i.e., case studies of the different MHDV sub-classes), allows us to offer more detailed/disaggregated guidance on the sales requirement for the different MHDV sub-classes for our recommended design of the ZEV sales standard 3. Figure 1 depicts our recommended sales requirements for the different sub-classes of MDVs, HDVs and buses (the requirements are also available in table format, in Appendix A).

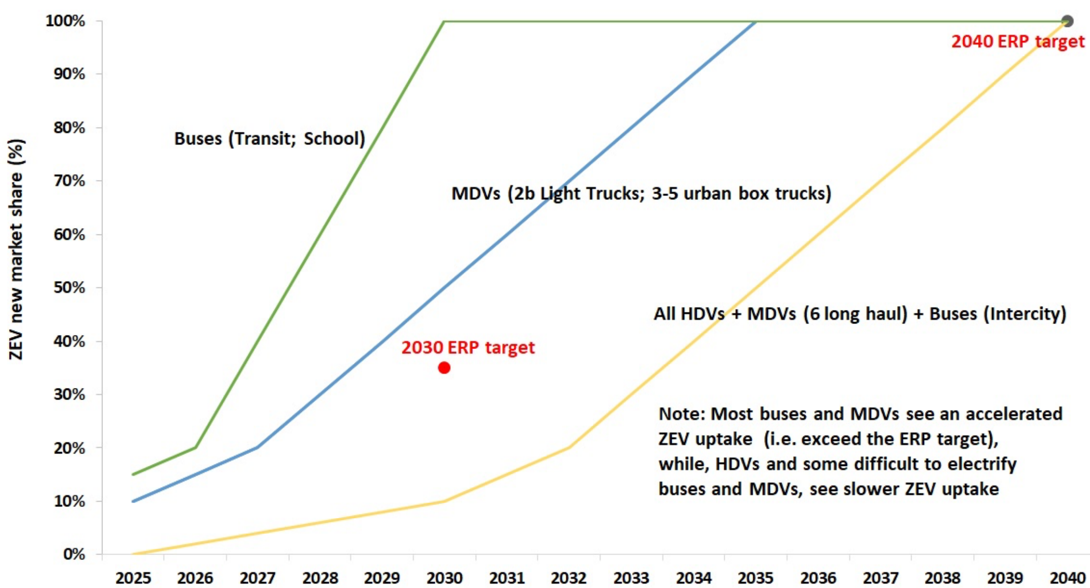

Figure 1. Detailed sales requirements as per our recommended ZEV sales standard design (expanded based on ZEV sales standard 3)

Complementary policy measures

Evidence implies that a mix of policy tools is needed to facilitate a low-carbon transition within the transport sector.[8,9] We suggest that **a suite of complementary measures should be considered to support the ZEV sales standard** as the primary driver in meeting Canada's ZE MHDV 2030 and 2040 goals.

In some cases, tailored policy support is required to address the unique opportunities and challenges of transitioning buses, MDVs and HDVs to ZEVs.

Policies and regulations

Existing policies and regulations in Canada, including a carbon tax, vehicle emissions standards and a clean fuel regulation, are important players in accelerating transport decarbonization. While these policy tools are not seen as leaders in the transition to ZE MHDVs, they have the potential to play a complementary role.

A strong carbon tax can have a substantial impact on stemming transport emissions, but research suggests that further increases to the stringent carbon price will be a political challenge.[10] Instead, carbon pricing can bolster other policy measures. For example, vehicle emissions standards on their own have several drawbacks, including potentially inducing increased vehicle usage through promoting vehicle efficiency gains which lowers operating costs. However, when implemented in combination with carbon pricing, this effect can be mitigated.[11]

Where we recommend that a ZEV sales standard leads Canada's transition to ZE MHDVs, it is important that existing policies continue to rise in stringency and ongoing evaluation of the interaction between these policies and their effectiveness is undertaken.

[8] Jonn Axsen, Patrick Plötz and Michael Wolinetz, "Crafting strong, integrated policy mixes for deep CO_2 mitigation in road transport," *Nature Climate Change* 10, (2020), 809. https://doi.org/10.1038/s41558-020-0877-y

[9] Bhardwaj, Chandan, Jonn Axsen, Florian Kern, and David McCollum, "Why have multiple climate policies for light-duty vehicles? Policy mix rationales, interactions and research gaps." *Transportation Research Part A: Policy and Practice* 135 (2020), 313. https://www.sciencedirect.com/science/article/pii/S0965856419302988?casa_token=fdDAL80hU10AAAAA:QPAT0fEGjDOZZfQZdXImbwm6XPUMoj-3JIbFl_JN1X_yHjo33bfLz0AhYVtYMhDv8V-2pWSk_Q

[10] Zoe Long, Jonn Axsen and Shelby Kitt, "Public support for supply-focused transport policies: Vehicle emissions, low-carbon fuels, and ZEV sales standards in Canada and California," *Transportation Research Part A* 141 (2020), 112. https://doi.org/10.1016/j.tra.2020.08.008

[11] "Crafting strong, integrated policy mixes for deep CO_2 mitigation in road transport," 812.

Charging and fuelling infrastructure

To support an ambitious ZEV sales standard, adequate charging and refuelling infrastructure needs to be deployed. Feedback collected from our stakeholder engagement reveals that there is widespread concern regarding future zero-emission infrastructure, its availability and its rate of deployment.

Charging and fuelling infrastructure needed

Table 6 depicts the EV charging infrastructure needs under Pembina Institute's recommended ZEV sales standard. We estimate that 12,000 Level 2 private depot chargers will be required by 2025; as EV uptake increases infrastructure needs rise exponentially to 210,000 chargers by 2040 and 337,000 chargers by 2050. Further, we expect that Level 3 chargers installed at private home base depots may need to increase from approximately 4,000 in 2025 to 87,000 in 2050. The word "private" refers to the fact that these chargers are installed at the fleet owner's home base station/depot and are typically financed by private owners.

Table 6. EV charging stations required under ZEV sales standard 3

Charger type	Stations required					
	2025	2030	2035	2040	2045	2050
Private depot chargers (Level 2)	12,180	52,680	144,380	210,000	282,310	337,400
Private depot chargers (Level 3)	3,850	19,600	34,650	58,450	86,450	87,500
Public chargers (Level 3+)	1,800	9,150	16,170	27,280	40,340	40,830

To supplement private home base/depot chargers, public chargers will also be required. We expect the need for public chargers to increase from about 2,000 in 2025 to 40,000 in 2050. Total EV charging infrastructure cost for installation alone, is expected to be about $300 million to $500 million in 2025, rising to about $5 billion to $9 billion by 2040 and $7 billion to $13 billion by 2050 (Table 7).

Table 7. EV charging infrastructure cost under ZEV sales standard 3

Charger type	Charging infrastructure costs ($millions)					
	2025	2030	2035	2040	2045	2050
Low estimates[12]						
Private depot chargers-Level 2	48	210	577	840	1,129	1,349
Private depot chargers-Level 3	115	588	1,039	1,753	2,593	2,625
Public chargers (Level 3)	144	732	1,294	2,182	3,227	3,267
Total	**308**	**1,530**	**2,911**	**4,776**	**6,950**	**7,241**
High estimates						
Private depot chargers-Level 2	1,823	790	2,165	3,150	4,235	5,061
Private depot chargers-Level 3	192	980	1,733	2,922	4,322	4,375
Public chargers (Level 3)	180	915	1,617	2,728	4,034	4,083
Total	**555**	**2,685**	**5,515**	**8,800**	**12,591**	**13,519**

Increased uptake of hydrogen fuel cell vehicles will increase the need for hydrogen fuelling stations. We estimate that the number of fuelling stations needed will be about 2,800 in 2030 and over 7,000 in 2050 (Table 88). The median costs are expected to be about $3.5 billion in 2030 and $9 billion in 2050.

[12] Calculated using lower and higher values for charger installation costs from these sources:

Fixr, "How Much Does It Cost to Install an Electric Vehicle Charging Station at Home?" https://www.fixr.com/costs/home-electric-vehicle-charging-station

Metro Vancouver, "Capital and Installation costs" *EV Strata Condo*.

Table 8. Hydrogen stations and cost under ZEV sales standard 3

	2030	2035	2040	2045	2050
Number of stations	2,813	3,882	4,888	5,617	7,328
Total cost ($billion)[13]	3.5	4.6	6.2	7.5	9.2

We estimate that by 2030, Canada will need an investment of $4 billion by 2030 for the approximately 85,000 EV and hydrogen fuelling stations required to meet the demand of the estimated 333,000 ZEVs.

Support required

The federal government is currently offering $680 million in support for charging infrastructure projects through the federal Zero Emissions Vehicle Infrastructure Program (ZEVIP).[14] Eligible Level 2 and Level 3+ (fast chargers) infrastructure projects can receive a maximum of 50% of project costs as funding support under the ZEVIP. Stakeholders involved in Pembina Institute's engagement activities voiced concern regarding the current design of the ZEVIP and advocated for dedicated financial support specific to MHDVs. The current ZEVIP is not seen to adequately address the needs of MHDV projects and the infrastructure upgrades needed to support these vehicles.

In designing new infrastructure funding programs, questions remain regarding their duration and how support will differ for the public and private sector. As previously noted, Level 2 chargers can cost between $6,000 and $20,000. Arguably, larger fleet owners, who typically own dozens of fleet vehicles, should be expected to pay – at least partially – for home base/depot Level 2 infrastructure themselves. This seems justified especially for MDV and bus fleets, given that these MHDV sub-groups are already starting to have a favourable business case (e.g., lower total cost of ownership compared to internal combustion engine vehicles.)[15,16] Previous Pembina Institute research has found that regional low-carbon fuel standards and the federal Clean Fuel Regulations can also generate private capital for fleets who install their own

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[13] Calculated using hydrogen station costs from: U.S. Department of Energy, "Hydrogen program record." https://www.hydrogen.energy.gov/pdfs/21002-hydrogen-fueling-station-cost.pdf

[14] Government of Canada, "Zero Emissions Vehicle Infrastructure Program." https://www.nrcan.gc.ca/energy-efficiency/transportation-alternative-fuels/zero-emission-vehicle-infrastructure-program/21876

[15] 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

[16] 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/

charging infrastructure, further improving infrastructure investment payback periods in the short- to medium-term.[17]

For vehicles travelling longer distances, and with rigorous duty-cycles like long-haul HDVs, the government will need to play a more prominent role and invest in Level 3+ private and public chargers. Stakeholders overwhelmingly agreed that Canada needs a national infrastructure roadmap and that a province-to-province approach will not suffice. Cross-jurisdictional infrastructure planning will be needed to prepare key trucking corridors with adequate access to a network of high-capacity fast charging and hydrogen refuelling stations. To support this, a portion of federal infrastructure funding should be reserved for high-capacity chargers and hydrogen refuelling stations with complementary investments directed toward expanding grid capacity for high-capacity electricity access.

Capacity-building

While other policy tools and initiatives play a role in enabling the transition to ZE MHDVs, it is imperative that stakeholders across the sector are also equipped with the capacity to "hit the ground running" with fleet electrification.

- Prior research by Pembina Institute indicates that a lack of readily available information for fleets continues to be a major barrier in their uptake.[18] Similar feedback was voiced by key actors in the MHDV sector throughout our stakeholder engagement activities. Undertaking feasibility studies, navigating infrastructure needs and understanding fleet requirements can present barriers to adoption. Many fleet managers and operators may not be familiar with where to start with an assessment or feasibility study. Targeted education and awareness funding, accessible to public sector and non-profit organizations, could help create programs that build operator confidence, and in turn accelerate adoption and ensure successful long-term management of ZE fleets.
- Feedback gathered from our stakeholder engagement pointed toward the need for knowledge-sharing from early adopters to help others navigate the transition to ZE MHDVs. Greater data availability is also needed to help fleets understand which technology options can act as appropriate replacements for existing fleet vehicles for specific use cases.
- Across the MHDV sector, new skills training programs should be established to enable workers within this segment of Canada's labor force to adapt to changing job

[17] Dunsky Energy & Climate Advisors, *Electric School Buses: The benefits to British Columbians and options for accelerating the transition*, prepared for Pembina Institute (2022), iii. https://www.pembina.org/pub/electric-school-buses

[18] Pembina Institute, *Building a zero-emission goods-movement system: Opportunities to strengthen Canada's ZEV freight sector* (2020), 3. https://www.pembina.org/pub/building-zero-emission-goods-movement-system

requirements and an evolving labour market. Recent research by Pembina Institute identifies examples of programs addressing skills gaps in ZEV maintenance and repair, as well as charging infrastructure installation, such as CPA Montreal and the Electric Vehicle Infrastructure Training Program.[19] Additional and complementary programs should be established to offer greater access to training and a wider variety of skill building opportunities.
- Capacity-building measures to build confidence in ZE MHDVs can also include enhanced support for development, demonstration, pre-commercial pilot and early commercial implementation projects. This will be particularly important in supporting appropriate pathways toward decarbonizing the HDV sector in Canada.

Incentives and subsidies

As indicated in our recommendations surrounding the ZEV sales standard, energy-economy modelling used in this research found that currently promised purchase incentives fail to drive achievement of the 2030 ZE MHDV sales targets as a lead policy; they also have a small incremental impact on emissions reductions. Other researchers have reached similar conclusions.[20] However, this finding does not mean purchase incentives are without merit in the short term.

Our in-depth literature review reveals that buses, MDVs and HDVs will follow different trajectories in reaching cost parity with ICEVs. This validates the ongoing approach by many government programs to provide varied ZEV incentives based on vehicle type (e.g., Canada's iMHZEV program):

- For transit buses, the purchase price of a BEV and FCEV is estimated to be approximately US$169,000 and US$193,000 more than a diesel bus in 2030, respectively. The gap was higher in 2019, with a price differential of US$227,000 for BEVs and US$624,000 for FCEVs compared to diesel equivalents.[21]
- For type C school buses, the purchase price of a BEV is anticipated to be US$177,000 more than a diesel equivalent in 2030, down from a price differential of US$195,000 in 2019.[22]
- There are still price differentials between ZE and ICE MDVs. However, estimates anticipate that the price of a BEV van and pickup truck with a 400-mile (~645 km) range will drop by 27% and 29% respectively, by 2040 relative to 2020. For BEV van and pickup

[19] Cedric Smith and Sarah Winstanley, *Net-Zero Skills: What will Canada need for the coming energy transition?* (Pembina Institute, 2022), 43. https://www.pembina.org/pub/net-zero-skills

[20] "Reaching 30% plug-in vehicle sales by 2030."

[21] ICF, *Comparison of Medium- and Heavy-Duty Technologies in California*, 10.

[22] ICF, *Comparison of Medium- and Heavy-Duty Technologies in California*, 10.

trucks with a 200-mile (~320 km) range, price reductions of 20% and 22% are anticipated, respectively.[23]

- For Class 8 heavy-duty vehicles, the price gap between diesel and BEVs or FCEVs is still significant. Class 7 and 8 BEVs and FCEVs will have a difficult time competing with diesel equivalents for the next 5-10 years in terms of up-front purchase costs.[24]

In the short term, purchase incentives can help bridge the gap between the high upfront costs of ZE MHDVs and their ICE counterparts, accelerating interest in years when the ZEV sales standard has low stringency. Canada's iMHZEV program, the Zero Emission Transit Fund and the Canada Infrastructure Bank (CIB)'s ZE bus program are already doing this work. For example, Pembina Institute's research examining the business case of electric school buses in British Columbia showed that with upfront subsidies, electric school buses can outperform diesel buses in TCO, in less than 4.4 years for Type C buses and 5.8 years for Type D buses.[25] Without these subsidies, however, entities are slower to proceed with uptake due to limited budgets. Pembina Institute has also found in previous research that the tight profit margins for owner-operators of long-haul trucks make an upfront investment in ZEVs prohibitive, so long as prices remain high.[26] Innovative lending mechanisms such as those created by the CIB could help reduce public expenditure while helping fleets and owner-operators electrify, thereby reduce their operating costs as well.

Feedback from Pembina Institute's stakeholder engagement agreed that large purchase incentives should remain a short-term measure and decrease over time, while the ZEV market matures and technology costs decline. Stakeholders also suggested that subsidies be made more accessible to small businesses and operators to improve equitable distribution.

[23] Eamonn Mulholland, *Cost of electric commercial vans and pickup trucks in the United States through 2040* (ICCT, 2022), 10. https://theicct.org/wp-content/uploads/2022/01/cost-ev-vans-pickups-us-2040-jan22.pdf

[24] ITS, *Evaluation of the Economics of Battery-Electric and Fuel Cell Trucks and Buses*, 11.

[25] Pembina Institute, *Electric School Buses,* 13.

[26] Pembina Institute, *How to Lighten the Climate Load,* 44.

Next steps

Below, we identify our remaining research questions and next steps for our research.

ZEV sales standard

In fall 2022, we will refine and pursue additional analysis for implementing a ZEV sales standard in Canada. To do so, we aim to engage with stakeholders and explore the following research gaps:

- ZEV sales standard design features and how requirements should change by vehicle type, class and/or vocation.
- We will also examine other design features of the ZEV sales standard like penalties, banking and credits per vehicle.
- Alternative cost-effective policy scenarios including analyzing a more stringent version of Canada's vehicle emissions standards,or feebate, subject to stakeholder feedback.

Complementary policies and regulations

Analyses undertaken in this report provide evidence-based support for implementing a ZEV sales standard as the leading policy to transition Canada's MHDVs to ZE technologies. However, we also recognize the important role that other policies and regulations play in decarbonizing the MHDV sector.

In subsequent iterations of our work, we will aim to explore with greater specificity how other existing and future potential policies and regulations may interact with the ZEV sales standard such as:

- Clean electricity standard
- Carbon pricing
- Canada's cap on oil and gas emissions
- Vehicle emissions standards
- ZEV procurement mandates

Charging and fuelling infrastructure

In this report, we provide initial estimates for the scale of charging and fuelling infrastructure deployment and investment required to keep pace with a ZEV sales standard in Canada. Such projections are based on a series of assumptions that we seek to refine over time. Further, we hope to gather feedback from relevant stakeholders on barriers to achieving an infrastructure roll-out of this scale and potential solutions to overcoming those barriers. Lastly, we seek to investigate how the investment burden of installing new charging infrastructure should be shared between public and private entities.

Incentives and subsidies

While purchase subsidies are shown to be limited in their potential for inducing ZEV uptake and GHG reductions, they are seen to play an important role in the short term to confront the high upfront costs of ZE MHDVs. In our future work we hope to validate the role of purchase incentives through further research, as well as obtain insight on how they should be phased out over time.

Through additional research and engagement with stakeholders, we also seek to investigate the role of innovative financial mechanisms like on-bill financing and concessional lending in helping fleets access ZE MHDVs.

Capacity-building

Pembina Institute will continue to work with stakeholders to identify areas where capacity-building support is most needed. We anticipate this work involving;

- assessing how existing education and awareness programs can be improved;
- examining how capacity-building initiatives can be designed equitably;
- investigating areas of Canada's labour market that need the most support during the transition to ZE MHDVs; and
- identifying ways to facilitate network building and knowledge-sharing across the sector.

Appendix A. ZEV sales standard recommendation

Table 9. Detailed sales requirements as per our recommended ZEV sales standard design (expanded based on ZEV sales standard 3)

Year	MDVs				HDVs	Buses		
	2b light truck	3-5 urban box trucks	6 long-haul	4-6 non box trucks		School	Transit	Intercity
2025	10%	10%	0%	0%	0%	15%	15%	0%
2026	15%	15%	2%	2%	2%	20%	20%	2%
2027	20%	20%	4%	4%	4%	40%	40%	4%
2028	30%	30%	6%	6%	6%	60%	60%	6%
2029	40%	40%	8%	8%	8%	80%	80%	8%
2030	50%	50%	10%	10%	10%	100%	100%	10%
2031	60%	60%	15%	15%	15%	100%	100%	15%
2032	70%	70%	20%	20%	20%	100%	100%	20%
2033	80%	80%	30%	30%	30%	100%	100%	30%
2034	90%	90%	40%	40%	40%	100%	100%	40%
2035	100%	100%	50%	50%	50%	100%	100%	50%
2036	100%	100%	60%	60%	60%	100%	100%	60%
2037	100%	100%	70%	70%	70%	100%	100%	70%
2038	100%	100%	80%	80%	80%	100%	100%	80%
2039	100%	100%	90%	90%	90%	100%	100%	90%
2040	100%	100%	100%	100%	100%	100%	100%	100%

Appendix B. Modelling results

Battery electric vehicles are projected to account for the vast majority of new market share for all vehicles. Total market share for vehicle types under the ZEV sales standard 3 scenario are presented in Table 10 and in Figures 2, 3 and 4.

Table 10. Projected vehicle stock, by technology (under ZEV sales standard 3)

		Buses	MDVs	HDVs
2030	Hybrid	36%	18%	-
	EV	38%	20%	14%
	HFCEV	<1%	2%	25%
	ICE	25%	61%	61%
2040	Hybrid	30%	9%	-
	EV	48%	68%	33%
	HFCEV	<1%	2%	40%
	ICE	22%	22%	27%
2050	Hybrid	20%	2%	-
	EV	64%	92%	53%
	HFCEV	1%	1%	42%
	ICE	15%	5%	5%

* Values presented may not add up to exactly 100% due to rounding.

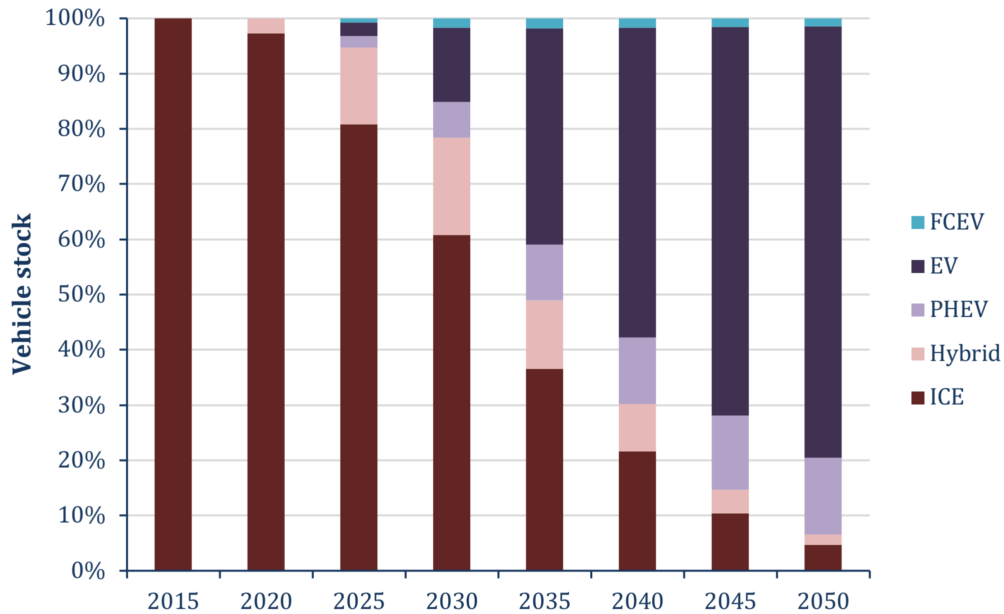

Figure 2. Medium-duty vehicles, % vehicle stock by technology

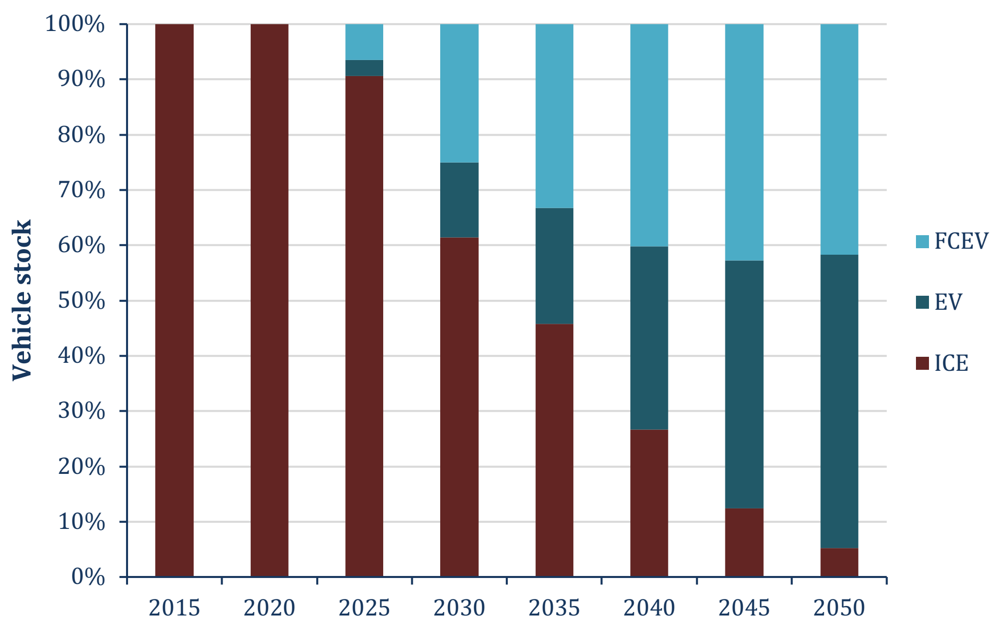

Figure 3. Heavy-duty vehicles, % vehicle stock by technology

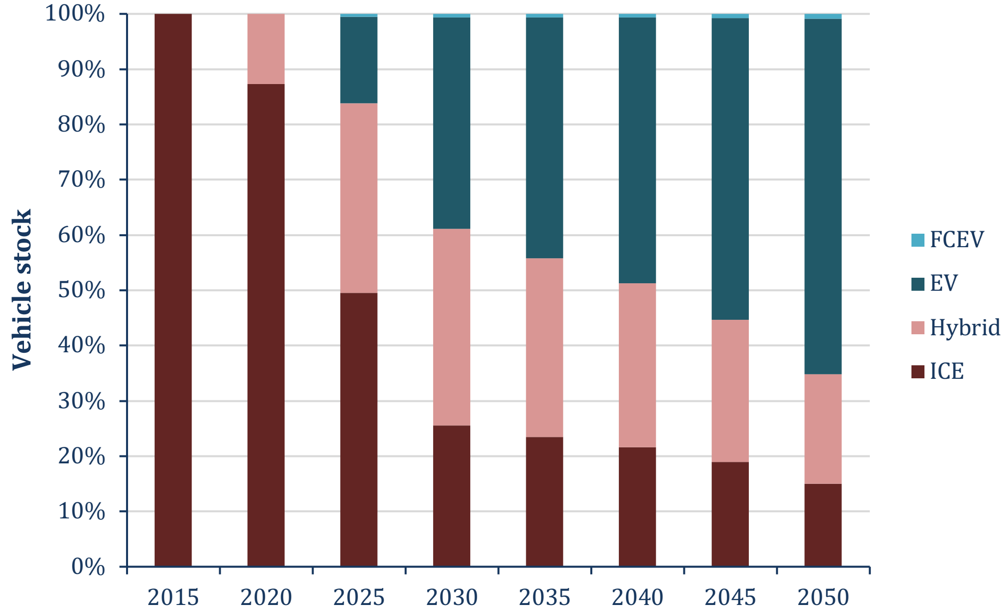

Figure 4. Buses, % vehicle stock by technology