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ZeroX2040

Comparing policy pathways for 100% medium- and heavy-duty zero emission vehicle sales in Canada

A technical analysis to inform the zero-emission vehicle strategy

Chandan Bhardwaj

November 2023

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Acknowledgements

The Pembina Institute acknowledges that the work we steward and those we serve span across many Nations. We respectfully acknowledge the space our organization is headquartered in as the traditional and ancestral territories of the Blackfoot Confederacy, comprised of the bands Siksika, Piikani, and Kainai, the Îyârhe Nakoda Nations, including the bands of Goodstoney, Chiniki, and Bearspaw, and the Tsuut'ina Dené. These Lands are also home to the Métis Nation of Alberta — Region 3 whose Peoples have deep relationships with the Land.

These acknowledgements are some of the beginning steps on a journey of several generations. We share them in the spirit of truth, justice, reconciliation, and to contribute to a more equitable and inclusive future for all of society.

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Executive summary

The transport sector contributes approximately a quarter of the total greenhouse gas (GHG) emissions in Canada. Medium- and heavy-duty vehicles (MHDVs), while an essential component of Canada's economy, represent a growing share of transportation-generated emissions. Despite making up only 17% of Canada's total vehicle stock, MHDVs account for over 37% of vehicle-related GHGs. Given that emissions from MHDVs are expected to bypass those from passenger cars by 2030, it is increasingly urgent that the federal government fully address the rising levels of carbon pollution produced from this sector.

Recognizing this sector's emissions trajectory, the Government of Canada included ambitious sales targets for automakers in its 2030 Emissions Reduction Plan (ERP) in March 2022. By 2030, 35% of all new medium- and heavy-duty vehicle sales (both domestic and for export) must be zero-emission (ZE) vehicles; by 2040 (based on feasibility), 100% of sales must be ZE MHDVs. While the setting of the ZE MHDV sales targets in the ERP 2022 is an important first step, as yet there is no concrete, implementable plan in place that outlines how this transition will take place.

In this report, we assess the effectiveness of the existing/legislated policies in achieving ZEV sales and GHG reduction goals in the MHDV sector. In addition, we compare two candidate policies, namely the ZEV sales standard and the ZEV purchase subsidies (both of which were suggested in the government's Emissions Reduction Plan 2022), in their ability to contribute to ZEV sales and GHG reduction goals.

We find that under current policies in Canada (which includes a carbon price rising to $170/tonne by 2030, the Clean Fuel Regulation, and a heavy-duty vehicle emissions standard aligned with the U.S.) the ZE MHDV market share falls well short of the 2030 and 2040 sales targets announced in the federal Emissions Reduction Plan 2022.

ZEV purchase subsidies help increase ZE MHDV uptake in the near-term but fail to meaningfully boost adoption rates through mid-century. Even if the federal government's current Incentives for Medium and Heavy-duty Zero Emission Vehicles or iMHZEV program (offering purchase incentives for MHD ZEVs) is increased 20-fold to $20 billion, ZEV sales increase by only 3 to 7 percentage points (relative to the baseline with existing policies) by 2030, falling short of the 2030 sales target. Relatedly, the incremental impact of ZEV purchase subsidies on GHG reduction is negligible.

In contrast, a national ZEV sales standard is likely to be an effective policy for decarbonizing the MHDV sector. Our results show that a ZE MHDV sales standard:

1. Achieves (or comes close to achieving) Canada's ZE MHDV sales goals of 35% by 2030 and 100% by 2040.
2. Induces substantial GHG reductions by 2050 (80% relative to business-as-usual), decreasing emissions from MHDVs from 34 Mt in 2020 to 10 Mt or less in 2050.
3. Reduces energy consumption by more than 25% from 500 PJ in 2020 to 400 PJ in 2050.
4. Facilitates larger and quicker declines in technology costs.

Further, a staggered ZEV sales standard design offers potential benefits compared to a standard with uniform ZEV sales requirements for all vehicle classes (as currently proposed in the ERP 2022). Certain vehicle types (e.g., urban delivery trucks and school and transit buses) can be more easily converted to ZEVs than others (e.g., long-haul trucking). Instead of imposing a uniform requirement across all vehicle classes, overall ZEV share can be increased (while keeping costs the same) by imposing a less stringent standard on HDVs compared to MDVs, such that requires up to 10% new ZEV sales for most HDVs, 50% new ZEV sales for most MDVs, and near 100% new ZEV buses sales by 2030.

1. Introduction

The transportation sector is the second-largest contributor of greenhouse gas emissions (GHG) in Canada, accounting for 22% of the national emissions in 2021. Between 1990 and 2021, GHG emissions in Canada's transport sector grew by 27%. During that period, emissions from freight medium- and heavy-duty vehicles (MHDVs) almost doubled, and now constitute about half of the total transport sector emissions.[1]

Canada has committed to reducing its GHG emissions to net-zero levels by 2050.[2] As part of its GHG reduction strategy, the federal government has implemented several policies in the last few years. For example, in 2019, Canada implemented the carbon tax, which puts a price on GHG emissions across all sectors in the economy.[3] As of 2023, the price of carbon is \$50/tonne of CO_2e, which will rise by \$15/tonne to reach \$170/tonne by 2030. In 2022, Canada implemented the Clean Fuel Regulation (CFR), which requires fuel suppliers to reduce the carbon intensity of the fuel supplied,[4,5] where the carbon intensity limits decrease annually from 91.5 gCO_2e/MJ (or grams of CO_2 equivalent per megajoule) in 2023 to 81 gCO_2e/MJ for 2030 and thereafter.[6] Further, since 2013, Canada has in place the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations (also referred to as fuel economy standards or simply emissions standards) which

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[1] Environment and Climate Change Canada, "Greenhouse gas emissions by economic sector." https://www.canada.ca/en/environment-climate-change/services/environmental-indicators/greenhouse-gas-emissions.html#transport

[2] Government of Canada, "Net Zero Emissions by 2050." https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

[3] Government of Canada, "How carbon pricing works." https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/putting-price-on-carbon-pollution.html

[4] Carbon intensity of a fuel measures the amount of carbon dioxide released during fuel combustion.

[5] Government of Canada defines 'carbon intensity' as "quantity in grams of CO_2e per megajoule of energy contained in that fuel, energy source or material input that is released over the life cycle of that fuel, energy source or material input, including during the activities carried out during the stages of the life cycle, such as (a) the extraction or production of the feedstock used to produce the fuel, energy source or material input; (b) the processing, refining or upgrading of the feedstock to produce the fuel, energy source or material input; (c) the transportation or distribution of the feedstock, of intermediary products or of the fuel, energy source or material input; and (d) the combustion of the fuel."

[6] Government of Canada, "Clean Fuel Regulations (SOR/2022-140)- Requirements for Liquid Fuels." https://laws-lois.justice.gc.ca/eng/regulations/SOR-2022-140/page-2.html#h-1358838

establish increasingly stringent annual emission standards for MHDVs.[7] These Canadian heavy-duty vehicle emissions regulations are aligned with those of the U.S. Environmental Protection Agency.[8]

To supplement the policies discussed above, the federal government released the 2030 Emissions Reduction Plan in March 2022.[9] As part of the plan, the government set out ambitious targets requiring that 35% of new MHDV sales be zero emission (ZE) by 2030, and 100% MHDV sales be ZE by 2040 (based on feasibility).[10] The government proposes to implement a ZEV sales standard to achieve the target and support the standard with ZEV purchase incentives.[11]

This report examines two policy pathways for Canada to meet its 2040 ZE MHDV sales targets.[12] First is the ZEV sales standard, which requires automakers to sell a minimum number of ZEVs as part of their total new vehicle sales. The ZEV sales standard for MHDVs, called the Advanced Clean Trucks (ACT) Regulation, is already in place in California.[13] Other North American jurisdictions, such as the U.S. states of Oregon, Washington, and the Canadian province of British Columbia are in the process of implementing similar standards.[14,15]

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[7] Government of Canada, *Regulations Amending Certain Regulations Made Under the Canadian Environmental Protection Act, 1999*, SOR/2022-204. https://canadagazette.gc.ca/rp-pr/p1/2021/2021-12-18/html/reg5-eng.html

[8] Government of Canada, "Guidance document for the Heavy-duty Vehicle and Engine Greenhouse Gas Emission Regulations made under the Canadian Environmental Protection Act, 1999." https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/publications/vehicle-emission-regulations-guidance-document.html

[9] Government of Canada, "2030 Emissions Reduction Plan." https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/climate-plan-overview/emissions-reduction-2030.html

[10] A zero-emission vehicle or ZEV is vehicle with zero (or near zero) tailpipe emissions, and includes mainly battery electric vehicles or BEVs (which run only on electricity), plug-in hybrid electric vehicles or PHEVs (which run on both electricity and diesel/gasoline) and fuel cell electric vehicles FCEVs (which use hydrogen fuel cells to power their electric motors).

[11] "2030 Emissions Reduction Plan."

[12] The selection of the two policy pathways is based on the fact the Emissions Reduction Plan 2022 proposes the use of ZEV sales standard and purchase incentives as key options for achieving the ZEV sales targets.

[13] California Air Resources Board, "Advanced Clean Trucks." https://ww2.arb.ca.gov/our-work/programs/advanced-clean-trucks

[14] State of Oregon, "Oregon's New Rules for Medium- and Heavy-Duty Trucks and Engines." https://www.oregon.gov/deq/aq/Documents/cfpMHDtruckRulesFAQ.pdf

[15] Government of British Columbia, *B.C. Medium- and Heavy-Duty Zero-Emission Vehicles: 2023 Consultation Paper*. https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/electricity-alternative-energy/transportation/bc_mhd_zev_2023_consultation_paper_20230516.pdf

We compare alternative ZEV sales standard scenarios, where the scenarios differ in how the sales targets are staggered across the different MHDV sub-classes (e.g., school and transit buses, urban delivery medium-duty vans and trucks, long-haul heavy-duty tractors), depending on the ease with which a sub-class can transition to ZEVs. Adopting a staggered sales target approach follows the idea of a "beachhead strategy", proposed by CALSTART and the California Air Resources Board. 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."[16] Examination of a ZEV sales standard scenarios with staggered sales targets, reflective of the real-world market conditions of ZEV technologies across different MHDV sub-classes, can offer insights on how a staggered beachhead approach compares to an approach with uniform sales targets across all MHDV sub-classes in terms of indicators such as overall ZEV sales, GHG reduction impacts, and GDP impacts.

The second policy we examine is purchase subsidies for ZE MHDVs. The federal government implemented the four-year $550 million iMHZEV Program in 2022,[17] which offers point-of-sale incentives for the purchase of MHD ZEVs, ranging from $10,000 for utility trucks and step vans to $200,000 for coach buses.[18] We simulate how ZEV sales (and other impacts e.g. GHG emissions reduction) change when the duration and the magnitude of the subsidy program is increased.

Specifically, we examine the following research questions:

1. What is the most effective policy option (between purchase subsidies and ZEV sales standard) for achieving 100% new ZEV sales by 2040?
2. What is the best way to design Canada's ZEV sales standard?

[16] CALSTART, The Beachhead Strategy: A Theory of Change for Medium- and Heavy-Duty Clean Commercial Transportation (2022), 1. https://calstart.org/beachhead-model-background/

[17] Transport Canada, "Minister of Transport announces new Incentives for Medium- and Heavy-Duty Zero-Emission Vehicles Program," media release, July 11, 2022. https://www.canada.ca/en/transport-canada/news/2022/07/minister-of-transport-announces-new-incentives-for-medium--and-heavy-duty-zero-emission-vehicles-program.html

[18] Transport Canada, "Incentives for 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/incentives-medium-heavy-duty-zero-emission-vehicles

For each simulated policy scenario, we analyzed the following key outputs: new market share of different drivetrains (e.g., battery electric vehicles, plug-in hybrid electric vehicles, fuel cell electric vehicles and internal combustion engine vehicles) disaggregated by segment (MDVs, HDVs and buses); total electricity, biofuel and hydrogen demand; economic impacts; and GHG emissions.

Other policies may also be used to achieve Canada's decarbonization or ZEV transition targets. As a first option, the carbon tax, a cost-effective policy tool that is already in place in Canada, could be further strengthened to achieve decarbonization goals. However, Canada's carbon tax is already projected to rise to $170/tonne by 2030, making it among the most stringent carbon taxes in the world. Given the public opposition to taxes,[19] policymakers will likely find it difficult to increase its stringency further. A second option is the clean fuel regulation. However, here too, the government may be reluctant to modify the policy given it was just enacted in 2022.

As a third option, the fleet-wide MHDV GHG emission standards can be designed to achieve similar outcomes as the MHD ZEV sales standard in terms of ZEV sales and GHG emissions reduction. More stringent GHG standards that cannot be met through improvements to existing diesel vehicle technologies can spur development of MHD ZEV sales, as MHD ZEVs are more energy efficient. However, this will require roughly tripling of the stringency of the emissions standards (from the current regulation requiring 30% reduction in grams/mile of emissions per vehicle relative to 2010 levels by 2030, to a 90% reduction per vehicle by 2040). Historically, Canada's emission standards have closely aligned with the U.S. standards.[20] In fact, in December 2021, the Canadian government proposed amendments to the MHDV emission standards to maintain further alignment with the U.S. standards.[21] We assume here that Canada will continue to align its GHG standards with those in the U.S., to ensure policy uniformity over an integrated North American market, and not change the stringency of the GHG standards significantly. For these reasons, we focus our attention on ZEV sales standard and purchase incentives in this paper.

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[19] Ekaterina Rhodes, Jonn Axsen, and Mark Jaccard, "Exploring citizen support for different types of climate policy," *Ecological Economics* 137 (2017). https://www.sciencedirect.com/science/article/pii/S0921800916302348

[20] Government of Canada, *Discussion paper on heavy-duty vehicles and engines in Canada: transitioning to a zero-emission future* (2021). https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/heavy-duty-vehicle-engines-zero-emission-future-discussion-paper.html

[21] *Regulations Amending Certain Regulations Made Under the Canadian Environmental Protection Act, 1999*

2. Model

The Pembina Institute partnered with Navius Research Inc. who used their gTech model to conduct the analysis. The gTech model is an energy economy modelling tool that covers the different end-use energy demand sectors (e.g., transportation, buildings). It employs a computable general equilibrium framework that balances supply and demand for 86 commodities and services, to capture the impact of policy shock across the entire Canadian economy. See Appendix A for more information on modelling.

The gTech covers a rich representation of fuels and technologies that may be used to satisfy end-use energy demand in each sector. Relevant to our analysis, gTech categorises MHDVs into three vehicle segments: buses, medium-duty vehicles (or MDVs), and heavy-duty vehicles (or HDVs). Buses includes school, transit and coach/inter-city buses. MDVs, typically weighing higher than 4,500 kilograms, include step/cargo vans, urban delivery trucks, short-haul box trucks. HDVs include Class 7&8 tractor-trailers weighing 12,000 kilograms or more, typically used for long-haul travel. A key limitation of the model is that it does not disaggregate the three vehicle segments further into constituent vehicle sub-classes (e.g., the use case of school bus is very different from an intercity coach, but the model combines the two sub-classes under the single segment 'buses'). This limits our current study from analyzing policies that are specific to each vehicle sub-class.

Nonetheless, for each vehicle segment, the model chooses between 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.

3. Policy scenarios

In order to identify the most efficient pathway to decarbonize MHDVs in Canada, we analyze three categories of policy scenarios.

1. **Baseline scenario** — This scenario includes the policies currently in place (or close to legislated) in Canada, such as the carbon tax (rising to $170/tonne by 2030), clean fuel regulation, and MHDV GHG emissions standard at the federal level, as well as provincial policies (e.g., clean fuel standard in British Columbia).
2. **ZEV purchase subsidies** — We consider three MHD ZEV purchase subsidy scenarios, where the total subsidy amounts of $1 billion, $10 billion and $20 billion between 2023 and 2030.
3. **ZEV sales standard scenarios** — The scenarios assume that a growing share of MHDV sales are ZEVs.

The scenarios differ in how the sale trajectories vary across the different MHDV sub-classes. The policy scenarios modelled are listed in Table 1.

Table 1. Policy scenarios modelled

Scenario	Description
Baseline	All federal/provincial policies currently in place (including carbon tax and clean fuel regulation)
Baseline + Subsidy ($1 billion)	Purchase subsidies worth approximately $1 billion as in the current federal iMHZEV program, plus Baseline
Baseline + Subsidy ($10 billion)	High purchase subsidies, worth $10 billion, plus Baseline
Baseline + Subsidy ($20 billion)	Ambitious purchase subsidies, worth $20 billion, plus Baseline
Baseline + ZEV Standard 1 (Uniform)	All MHDV sub-classes (buses, MDVs, HDVs) are required to achieve the same sales target of 35% by 2030 and 100% by 2040
Baseline + ZEV Standard 2	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
Baseline + ZEV Standard 3	Buses are required to reach 100% ZEV sales by 2030 MDVs are required to reach 50% by 2030

(Recommended Beachhead)	HDVs are required to reach 10% by 2030
Baseline + ZEV Standard 4	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)
Baseline + ZEV Standard 5 (Ambitious)	Buses and MDVs are required to reach 100% ZEV sales by 2030 HDVs are required to reach 40% by 2030

4. Results

4.1 ZEV sales

Figure 1 depicts the ZEV new market share for Canada’s MHDV sector under the different policy scenarios. For the sake of clarity, we do not represent all the scenarios that we modelled. Instead, we include the ones that help convey the key result insights.

First, the current “baseline” policies in Canada (as of Summer 2023) are not nearly strong enough to meet ZEV sales goals in 2030 or 2040. The current policies lead to only 8% ZEV new market share in 2030 and 35% new market share in 2040. The total ZEV share is constituted by 18% ZEV market share in the heavy-duty vehicles, 46% share in the medium duty vehicles, and 65% share among buses. The total MHD ZEV market share under the Baseline scenario falls well short of the 100% new ZEV sales target for 2040 announced in the Emissions Reduction Plan 2022.

Adding purchase subsidies to the Baseline scenario increases ZEV market share, albeit the long-term impact is small. Under the Baseline + Subsidy ($10 billion) scenario, new ZEV market share increases by 4 percentage points, relative to the Baseline, reaching 39% by 2040. Under the Baseline + Subsidy ($20 billion) scenario, new ZEV market share increases by 6 percentage points, relative to the Baseline, reaching 41% by 2040. However, as can be seen, Canada’s sales targets are not met even under the ambitious scenarios with purchase subsidies (with subsidies increasing 10-fold and 20-fold from the current less than $1 billion iMHZEV program).

Adding the ZEV sales standard scenarios to the Baseline significantly increases ZEV sales. Only the ZEV sales standard and its different design scenarios comes close to achieving Canada’s sales targets. As a representative case, we depict two ZEV sales standard design scenarios — the Baseline + ZEV Standard 1(Uniform) scenario (this is ZEV sales standard, as proposed in the Emissions Reduction Plan 2022, where sales targets apply equally across all MHDV subclasses), and the Baseline + ZEV Standard 3 (Recommended Beachhead) scenario (where the sales targets are staggered across vehicle classes, with more ambitious sales targets for buses and less ambitious targets for HDVs). The new ZEV market share for MHDVs (combined across the subclasses) is 2 percentage points higher in 2030 and 5 percentage points higher in 2035 in the Baseline + ZEV Standard 3 (Recommended beachhead) scenario, compared to the Baseline + ZEV Standard 1 (Uniform) scenario. Due to the higher overall ZEV market share, and since it more closely captures the differences in market readiness of the different MHDV subclasses, Baseline + ZEV Standard 3 (Recommended beachhead) is our recommended scenario out of ZEV sales standard designs examined in this study.

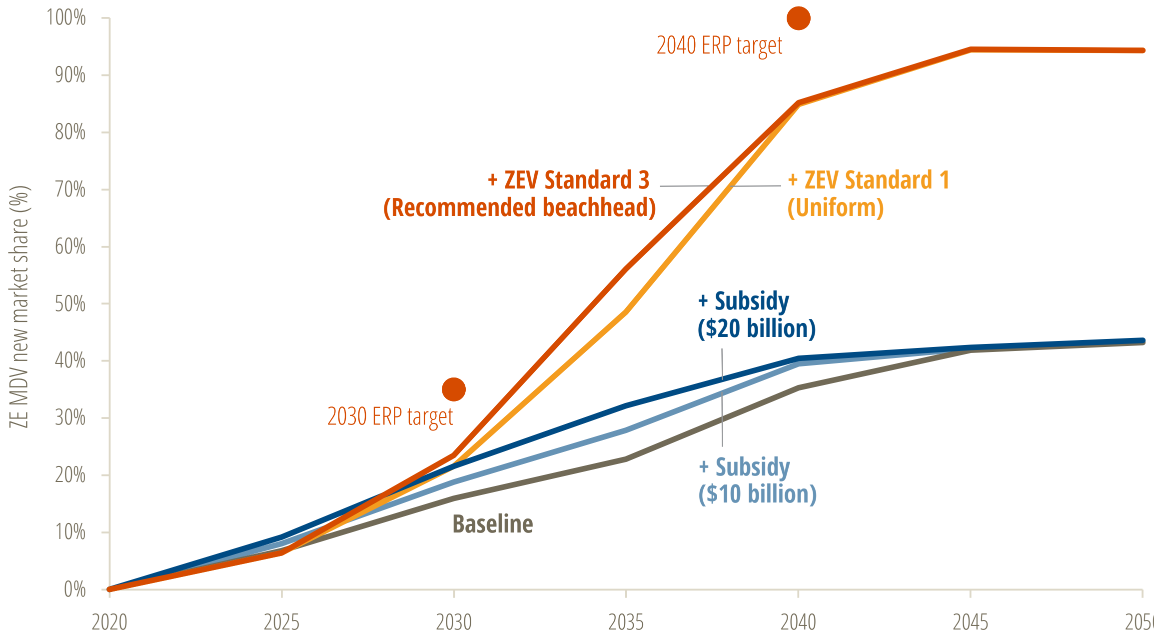

Figure 1. ZEV new market share (combined across different MHDV subclasses) under selected policy scenarios

4.2 GHG emissions

The projected GHG emissions from Canada's MHDV sector are depicted in Figure 2. Under the current baseline policies scenario, annual GHG emissions from on-road MHDVs are expected to decrease from 35 Mt (where MT indicates million tonnes) in 2020 to 21 Mt in 2050. Key mechanisms that drive this change include a shift away from diesel usage under the effect of the carbon tax; reduced carbon intensity of the fuels used due to the clean fuel regulation; and improved energy efficiency of vehicles partly due to shifting to ZEVs and partly under the effect of the vehicle emission standard. While the almost 40% decline in emissions from 2020 to 2050 is notable, it still is much higher than the net-zero target for 2050.

Addition of subsidies to the Baseline induce a less than 1% incremental reduction in GHG emissions. This is because the decrease in emissions due to increased ZEV sales (Figure 1), is partially offset by an increase in overall vehicle sales. In contrast to the subsidy scenarios, all the ZEV standard scenarios result in an average 80% decline in GHG emissions, which drop from 35 Mt in 2020 to 7 Mt (or lower) by 2050.[22]

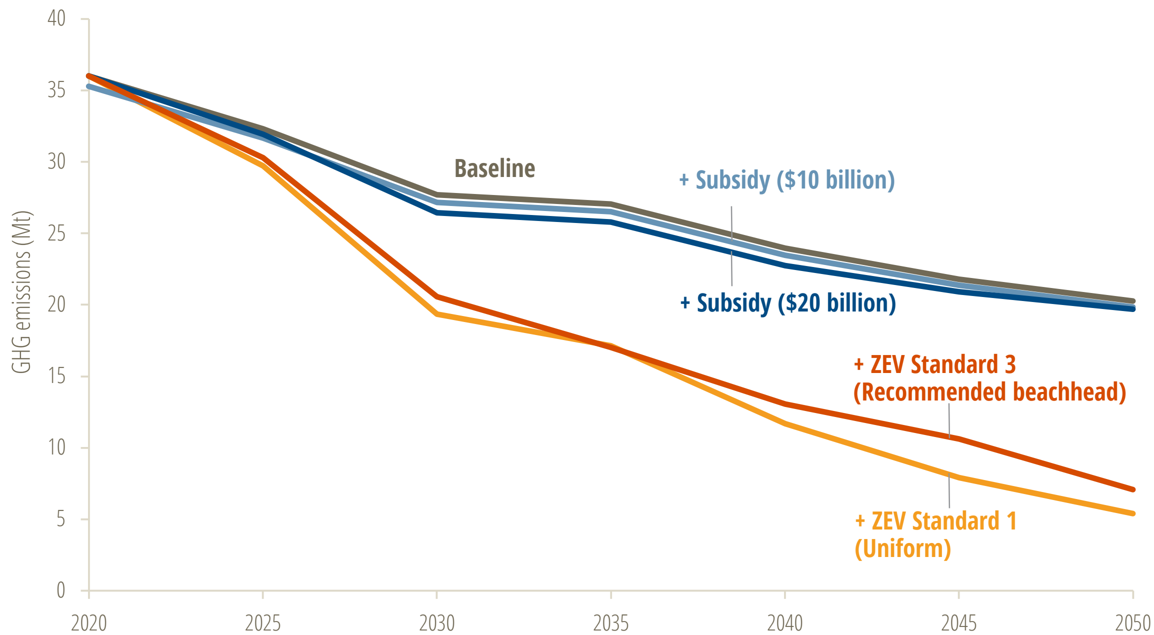

Figure 2. GHG emissions from Canada's MHDV sector under selected policy scenarios

4.3 Energy consumption

Figure 3 depicts the total energy consumption from Canada's MHDV sector under different policy scenarios. Under the Baseline scenario, the total energy consumption initially starts to decrease under the combined effect of the carbon tax, the clean fuel regulation and fuel economy improvements for MHDVs. However, this trend is reversed post-2030, as the total number of MHDVs as well as total freight activity (in terms of tonnes per km) increases with increased economic activity in the country.

On adding the subsidy scenarios, the total energy consumption decreases by a small margin. By 2050, the energy consumed reduces by 1% under the Baseline + Subsidy ($10 billion), and about 3% under the Baseline + Subsidy ($20 billion) scenario, relative to the Baseline.

[22] For the sake of clarity, only two representative cases, ZEV Standard 1 (Uniform) and ZEV Standard 3 (Recommended beachhead) are depicted.

The addition of the ZEV sales standard leads to significant reduction in energy consumption. Under both representative ZEV standard scenarios depicted here, namely ZEV Standard 1 (Uniform) and ZEV Standard 3 (Recommended beachhead), energy consumption reduces by more than 25%, from 500 PJ in 2020 to 400 PJ in 2050. ZE MHDVs, on average, have higher energy efficiency and hence use less energy than their diesel counterparts. Increasing the number of ZE MHDVs decreases oil consumption and increases electricity consumption, but overall, the total energy consumption decreases. All else being equal, reduced energy and oil consumption increases energy security due to reduced dependence on imports and volatility in oil prices.

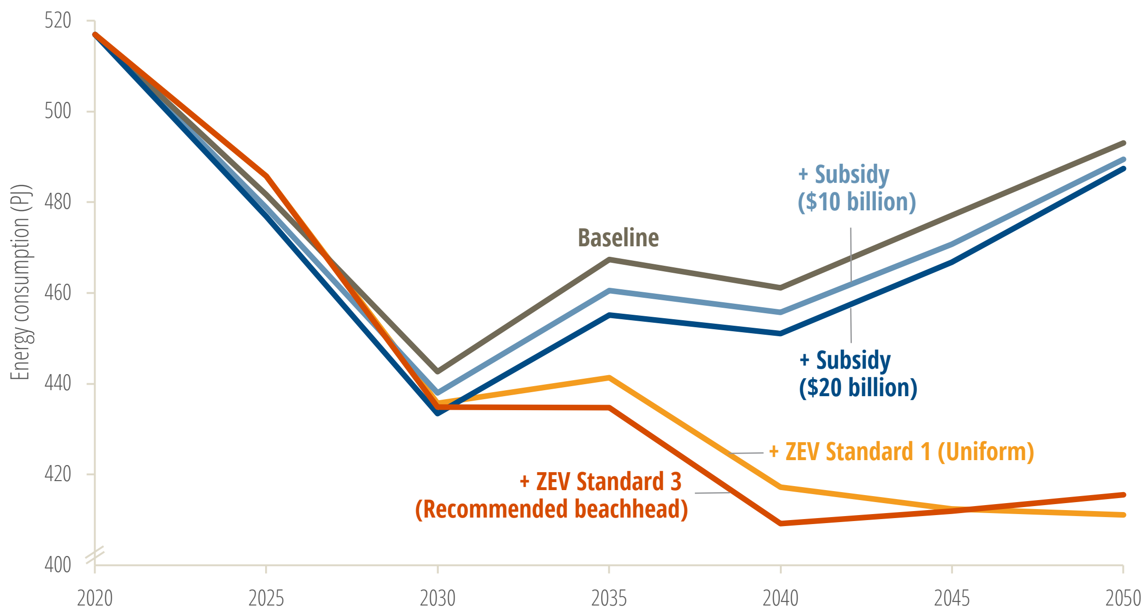

Figure 3. Total energy consumption from Canada's MHDV sector under selected policy scenarios

Note: y-axis has been truncated to more clearly show small differences in values.

4.4 Technology costs

The ZEV standard scenarios are found to accelerate the decline in technology costs (e.g. costs for electric vehicle batteries and hydrogen fuel cells), relative to the baseline scenarios. For example, as shown in Figure 4, hydrogen fuel cell costs drop from $250/kW in 2020 to $169/kW in 2050 under the Baseline scenario.

The decline in fuel costs is accelerated to $155/kW (8% decline relative to Baseline) under the Baseline + ZEV Standard 3 (Recommended beachhead) scenario, and to $153/kW under the Baseline + ZEV Standard 1 (Uniform) scenario. A higher uptake of

ZEVs in the initial years, as mandated by the ZEV standard, induces increased investments in the technology early on, leading to faster declines in technology costs. 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.

In contrast, the purchase subsidy scenarios have a negligible impact on fuel cost reduction.

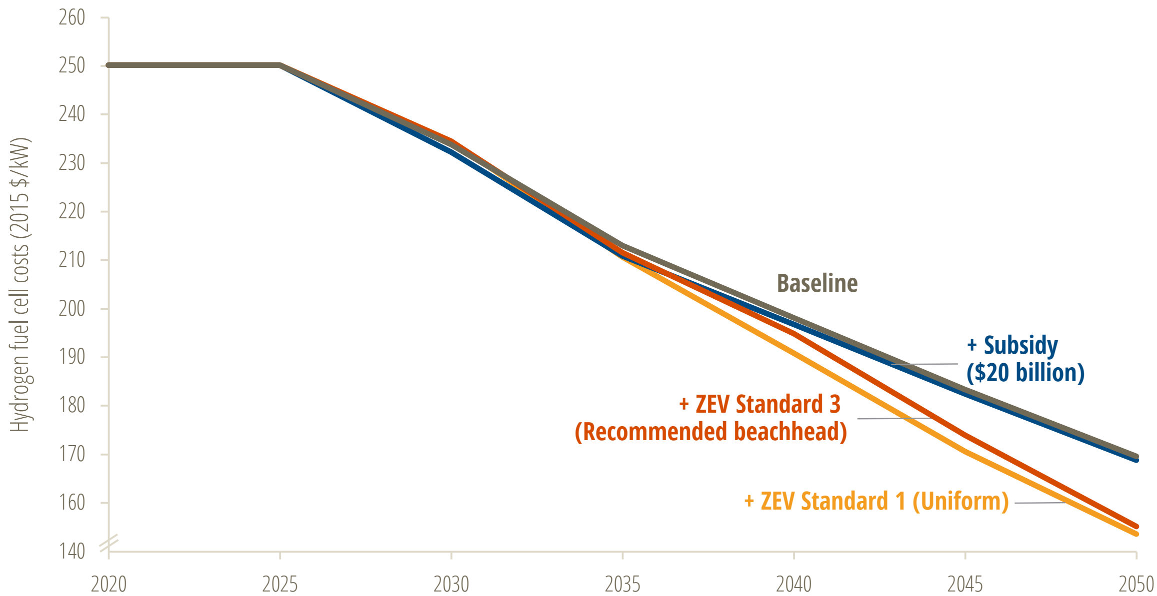

Figure 4. Hydrogen fuel cell costs under selected policy scenarios

Note: y-axis has been truncated to more clearly show small differences in values.

4.5 Gross domestic product

Figure 5 depicts Canada's total gross domestic product (GDP) across all economic sectors over time. For the baseline scenario, total GDP of the country is expected to increase from $2.2 trillion in 2023 to $3.4 trillion in 2050.

Under the subsidy scenarios, the change in GDP is negligible, decreasing by less than 0.2% under both the Baseline + Subsidy ($10 billion) and Baseline + Subsidy ($20 billion). For the sake of clarity, we do not depict these scenarios as they were visually indistinguishable from the Baseline scenario.

Compared to the subsidy scenarios, the decrease in GDP is more meaningful under the ZEV standard scenarios. The drop in GDP (indicative of non-zero policy costs) is caused by the costs of shifting to more expensive ZEVs and installing ZEV-related infrastructure. However, here too, the policy impact is small as the impact is less than 1% across all ZEV sales standard scenarios. For example, for 2050, GDP under the Baseline + ZEV Standard 3 (Recommended beachhead) is lower than Baseline GDP by 0.6% (depicted in the figure below). Similarly, for 2050, GDP under the Baseline + ZEV Standard 1 (Uniform) is lower than Baseline GDP by 0.5% (not shown here as it practically coincides with the Baseline + ZEV Standard 3 (Recommended beachhead) scenario. Notably, Canada's GDP continues to grow under all scenarios, and is well above its current levels even under the most ambitious ZEV sales standard scenarios, implying that the economic impact of the policy is small.

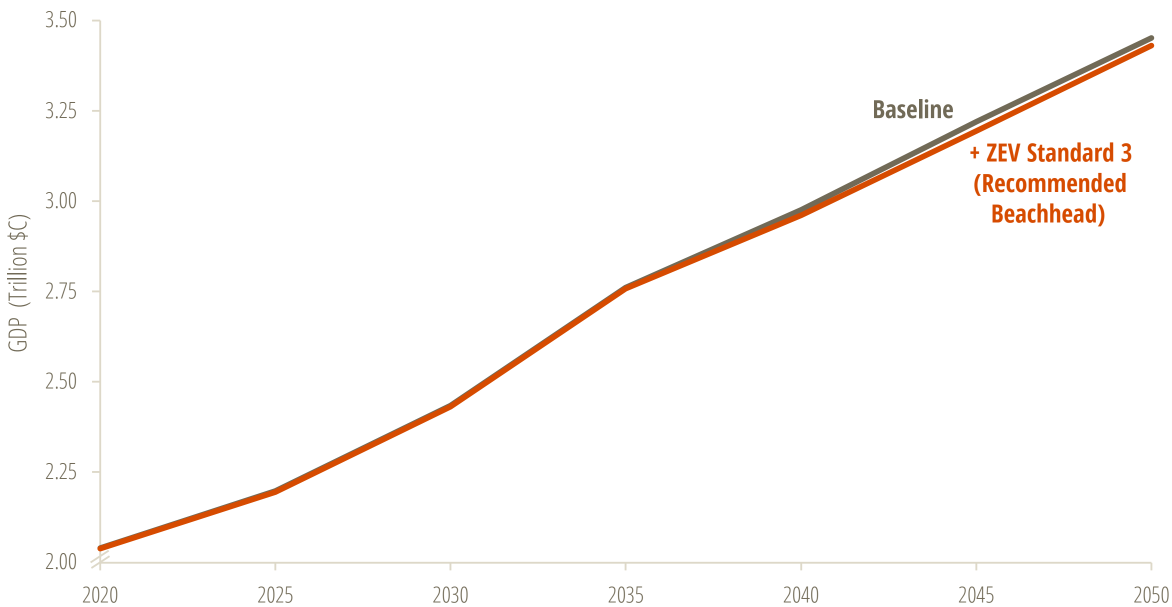

Figure 5. National gross domestic product under selected policy scenarios

Note: y-axis has been truncated to more clearly show small differences in values.

5. Conclusions and policy implications

To achieve its climate goals of reaching net zero GHG emissions by 2050 in the MHDV sector, Canada has announced ambitious plans to convert its MHDV fleet to ZEVs. Specifically, in its Emissions Reduction Plan 2022, the federal government has set targets for shares of ZEVs in new MHDV sales, rising from 35% to 2030 to 100% by 2040. To facilitate ZEV uptake (and in turn to accelerate GHG reduction) Canada has been legislating a bunch of climate policies. These include, notably, the carbon tax, the clean fuel regulation, and the vehicle emission standard (alternatively the GHG standard or fuel economy standard) for MHDVs, among others.

In this report, we assess the effectiveness of the existing/legislated policies in achieving ZEV sales and GHG reduction goals in the MHDV sector. In addition, we compare two candidate policies, namely the ZEV sales standard and the ZEV purchase subsidies (both of which were suggested in the government's Emissions Reduction Plan 2022), in their ability to contribute to ZEV sales and GHG reduction goals. We compare alternative designs of the two policies. For the ZEV sales standard, we compare the impacts of the policy relative to the baseline (existing) policies, as well as the impacts of varying ZEV sales targets across the different sub-classes (e.g., buses, MDVs, HDVs). Specifically, we examine how an approach with staggered ZEV sales targets across different sub-classes (to reflect their differences in market readiness), compares to an approach with uniform ZEV sales targets across all MHDV sub-classes. For the ZEV purchase incentives, we compare different stringencies ($1 billion, $10 billion or $20 billion) of the policy.

We find that current policies in Canada (which includes a carbon price rising to $170/tonne by 2030, the Clean Fuel Regulation, and a heavy-duty vehicle emissions standard aligned with the U.S.) increase ZEV market share to about 30-60% of new medium-duty sales and 10-50% of heavy-duty sales by 2050 (depending on the development of battery and hydrogen fuel cell technology). This ZEV market share falls well short of the 100% ZEV sales targets announced in the federal Emissions Reduction Plan 2022. Additional policies will be required if Canada is to achieve its ZEV sales goals by mid-century.

As one candidate policy, ZEV purchase subsidies help increase ZE MHDV uptake in the near term but fail to meaningfully boost adoption rates through mid-century. Even if the current iMHZEV program (offering purchase incentives for MHD ZEVs) is increased 20-fold to $20 billion, ZEV sales increase by only 3 to 7 percentage points (relative to the baseline with existing policies) by 2030, falling short of the 2030 sales target. The long-term incremental impact on ZEV adoption is even lower, where the ZEV market under the subsidy scenarios is higher compared to the baseline by less than 1 percentage point by 2050. Relatedly, the incremental impact of ZEV purchase subsidies on GHG reduction is negligible.

In contrast, a national ZEV sales standard is likely to be an effective policy for decarbonizing the MHDV sector. Our results show that a ZE MHDV sales standard:

- Achieves (or comes close to achieving) Canada's ZE MHDV sales goals of 35% by 2030 and 100% by 2040, in contrast to current policies which result in ZEVs accounting for only 30-60% of new MDV sales and 10-50% of HDV sales by 2050.
- Induces substantial GHG reductions by 2050 (80% relative to business-as-usual), decreasing emissions from MHDVs from 34 Mt in 2020 to 10 Mt or less in 2050. This is because fossil energy consumption (mainly diesel) is displaced with electricity and hydrogen, which emit fewer emissions due to high proportion of hydro and renewable electricity in Canada. In addition, total energy consumption goes down since ZEVs are more energy efficient compared to diesel vehicles.
- Reduces energy consumption by more than 25% from 500 PJ in 2020 to 400 PJ in 2050. ZE MHDVs, on average, have higher energy efficiency and hence use less energy than their diesel counterparts. Increasing the number of ZE MHDVs decreases oil consumption and increases electricity consumption, but overall, the total energy consumption decreases. All else being equal, reduced energy and oil consumption increases energy security due to reduced dependence on imports and volatility in oil prices.
- Facilitates larger and quicker declines in technology costs. The ZE MHDV standard accelerates investments in ZEV-related R&D and development of supply chains driving innovation, economies of scale and hence quicker declines in technology costs.

Further, a staggered ZEV sales standard design offers potential benefits compared to a standard with uniform ZEV sales requirements for all vehicle classes. Certain vehicle types (e.g., urban delivery trucks and school and transit buses) can be more easily converted to ZEVs than others (e.g., long-haul trucking). Instead of imposing a uniform requirement across all vehicle classes, overall ZEV share can be increased (while keeping costs the same) by imposing a less stringent standard on HDVs compared to MDVs, such that requires up to 10% new ZEV sales for most HDVs, 50% new ZEV sales for most MDVs, and near 100% new ZEV buses sales by 2030.

Appendix A. Modelling assumptions

Some modelling assumptions, as provided by Navius Research Inc., are presented here.[23]

A.1 Battery and fuel cell cost assumptions

The cost of plug-in electric and hydrogen fuel cell vehicles is determined endogenously in gTech (i.e., they are a modeled result based on cumulative technology adoption). The capital cost trajectories for these technologies are shown in Table 2. These trajectories include reference, low, and high-cost assumptions to account for uncertainty in these emerging technologies.

Table 2. Battery and hydrogen fuel cell electric vehicle capital costs (2020 C$)

	Reference	Low	High	Sources
Plug-in electric vehicles	Battery pack costs decline from $502/kWh in 2015 to a minimum of $84/kWh.	Battery pack costs decline to a minimum of $75/kWh.	Battery pack costs decline to a minimum of $104/kWh.	Bloomberg New Energy Finance[24] ICCT[25] Nykvist et al.[26]
Hydrogen fuel cell	Fuel cell stack system costs	Fuel cell stack system costs	Fuel cell stack system and	SA Consultants[27]

[23] More detailed input assumptions about technology costs and policy scenarios are found in Navius, *Assumptions for MHDV ZEV modeling* (2022). https://www.pembina.org/reports/Pathway NZ MHDV--Modelling Assumptions.pdf.

[24] Bloomberg New Energy Finance, *Electric Vehicle Outlook 2020*. https://about.bnef.com/electric-vehicle-outlook-2020/

[25] Nic Lutsey and Michael Nicholas, *Update on electric vehicle costs in the United States through 2030* (International Council for Clean Transportation, 2019). https://theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

[26] Björn Nykvist, Frances Sprei, and Måns Nilsson, "Assessing the progress toward lower priced long range battery electric vehicles," *Energy Policy* 124 (2019). https://www.sciencedirect.com/science/article/abs/pii/S0301421518306487

[27] Strategic Analysis Consultants, *Mass production cost estimation of direct H_2 PEM fuel cell systems for transportation applications* (2017). https://www.energy.gov/eere/fuelcells/articles/mass-production-cost-estimation-direct-h2-pem-fuel-cell-systems-7

electric vehicles	decline from $306/kW in 2015 to a minimum of $74/kW. Fuel tanks decline from $31/kWh in 2015 to a minimum of $11/kWh.	decline to a minimum of $39/kW and fuel tanks decline to a minimum of $10/kWh.	hydrogen tank costs decline to a minimum of $121/kW and fuel tanks decline to a minimum of $27/kWh.	IEA[28]

A.2 Charging and fuelling infrastructure requirements & energy supply

The development of charger assumptions draws on work by the ICCT.[29] Infrastructure costs are based on a mix of 50 kW chargers, for overnight charging and charging while loading and unloading, as well as 400 kW ultra-fast chargers used for rapid top-ups en route when quick turnaround is needed for high utilization vehicles. The costs vary primarily as a function of electric MHDV adoption. Greater adoption of electric vehicles enables more sharing of charging infrastructure. Because each charger has higher utilization, more vehicles can be charged with a given number of chargers and the total charging infrastructure investment per vehicle declines.

Starting costs are based on early market conditions when electric MHDVs operating in a given region number in the tens to hundreds. For MDVs, we assume this situation requires roughly one charger per vehicle, where one in five is ultra-fast. For heavy-duty vehicles, we assume roughly 1.5 chargers per vehicle, where one in three chargers is ultra-fast.

The lowest possible infrastructure costs represent a market where there the number of electric MHDVs in a given region number in the tens of thousands. In this situation, we assume that the number of chargers per vehicle has declined to less than 0.5 for medium-duty and less than 0.75 for heavy-duty (i.e., each charger can supply between 1.3 and 2 vehicles). Furthermore, in the mature market, the cost per charger declines by about 40% relative to the early market due to economies of scale and learning.

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[28] IEA, "Breakdown of cost-reduction potential for electrochemical devices by component category," 2020, https://www.iea.org/data-and-statistics/charts/breakdown-of-cost-reduction-potential-for-electrochemical-devices-by-component-category

[29] Dale Hall and Nic Lutsey, *Estimating the Infrastructure Needs and Costs for the Launch Of Zero-Emission Trucks* (International Council for Clean Transportation, 2019). https://theicct.org/wp-content/uploads/2021/06/ICCT_EV_HDVs_Infrastructure_20190809.pdf