Fresh Energy

COALITION for CLEAN TRANSPORTATION

Minnesota Medium- and Heavy-Duty (MHD) Zero Emission Vehicle Modeling Report

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The business of sustainability

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Acknowledgement

This study was conducted by ERM for Fresh Energy, along with Sierra Club, MN350, and the Coalition for Clean Transportation. This study is intended to provide input to state policy and energy discussions about actions required to promote further adoption of electric vehicles.

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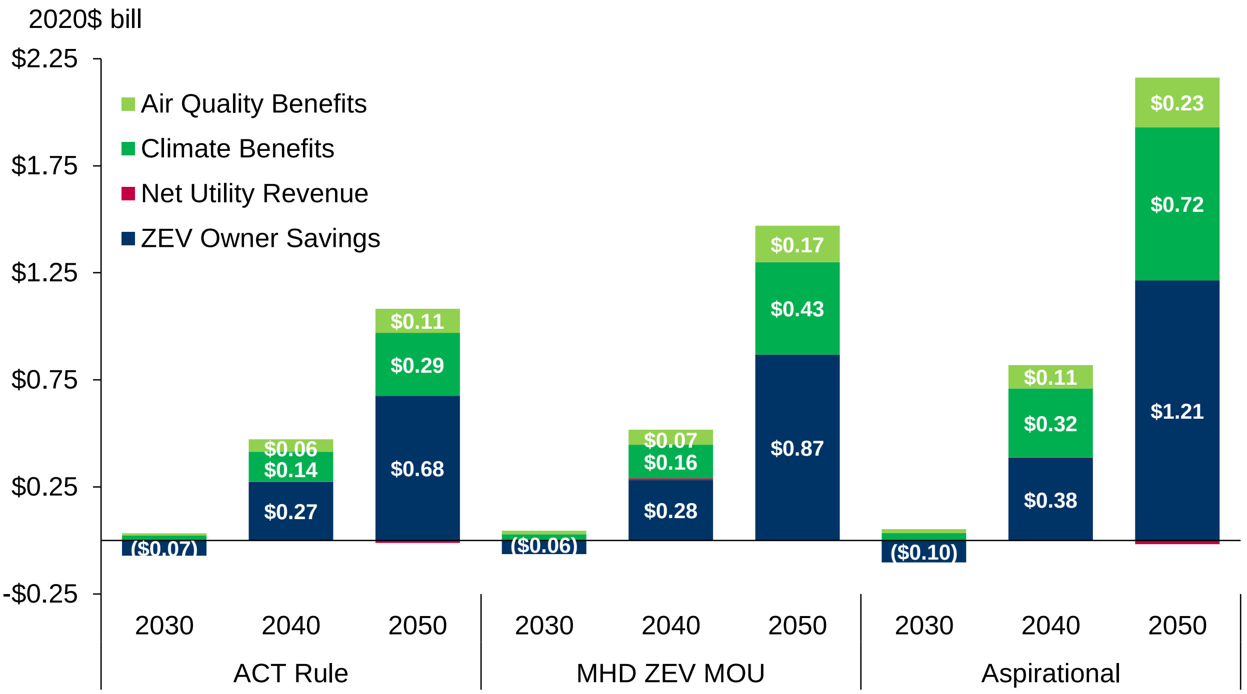
1. EXECUTIVE SUMMARY

This report summarizes the projected environmental and economic effects of Minnesota adopting policies requiring manufacturers to sell a greater number of on-road medium-and heavy-duty (MHD) zero-emission vehicles (ZEVs[1]) over the next 30 years. Environmental benefits include reduction in fuel consumption and associated greenhouse gas (GHG), nitrogen oxide (NOx) and particulate matter (PM) emissions from greater use of ZEVs instead of internal combustion engine (ICE) vehicles. Economic impacts consist of financial investments needed to purchase, install and maintain charging infrastructure, along with annual financial benefits to Minnesota drivers and fleets from owning ZEVs—from fuel and maintenance cost savings compared to owning gasoline or diesel vehicles.

This study evaluated on-road MHD ZEV costs and benefits for three distinct levels of ZEV adoption ambition – Minnesota adopting California's Advanced Clean Truck Rule (ACT Rule Scenario), Minnesota meeting the goals of the Multi-State ZEV Memorandum of Understanding (MOU) goals (MHD ZEV MOU Scenario), and a much more aggressive scenario increasing ZEV penetration to nearly 96% of in-use MHD vehicles (Aspirational Scenario) by 2050. The levels of ZEV penetration in the Aspirational Scenario are unlikely to be achieved without policy action at the state and local level, to both incentivize individuals and fleets to purchase ZEVs and to support the necessary roll-out of ZEV charging infrastructure.

Figure 1 provides the cumulative societal benefits from each of the ZEV penetration scenarios.

Figure 1. Projected Societal Benefits of Minnesota MHD ZEV Adoption



Bars without data labels are less than $0.05 billion. They were excluded to improve readability of the figure.

As shown in the figure, each of the different scenarios will provide significant net benefits from greater MHD ZEV use of $1.1 billion, $1.5 billion, and $2.1 billion annually by 2050 for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios, respectively. The cumulative benefits between 2022 and 2050

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[1] ZEVs include both battery electric (EV) and hydrogen fuel cell electric (FCV) vehicles

amount to **$9.9 billion, $12.1 billion, and $18.5 billion** for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios respectively.

ZEV owner savings (~60 percent) and climate benefits (~30 percent) make up most of the societal benefits shown above.

The average MHD ZEV owner by 2030 will save **over $16,000** over the life of the vehicle, largely due to reduced fuel use (gasoline, diesel fuel, natural gas) and purchase of lower cost, regionally produced electricity instead of fuels imported to the state. Total ownership costs for individual vehicle types will vary – see Appendix A.3 for detailed estimates by vehicle type. Under the ACT Rule Scenario, ZEVs will reduce annual fuel use in the state by more than 380 million gallons in 2050 while under the Aspirational Scenario annual fuel savings grow to nearly 720 million gallons by 2050. This projected fuel savings will help to promote energy security and independence and will keep more of vehicle owners' money in the local economy, thus generating even greater economic impact.

Reductions in fuel use will also **reduce cumulative net GHG emissions by over 35 million metric tons of CO2 equivalents (MMT CO2e)**[2] **through 2050** under the ACT Rule Scenario and over 88 MMT CO2e under the Aspirational Scenario. The switch from ICE vehicles to ZEVs is also projected to reduce cumulative NOx and PM emissions in the state by over 85,000 tons and 750 tons, respectively by 2050 under the ACT Rule Scenario. Under the Aspirational Scenario, these cumulative NOx and PM savings increase to nearly 165,000 tons and 2,400 tons, respectively.

The number of ZEV vehicles projected under each of the scenarios will require infrastructure investments by individual vehicle owners as well as public and private fleets, and also require building out public charger networks to ensure adequate charging of the ZEV fleet. For this analysis, it is assumed that about 80-90% of vehicles will charge overnight at their place of business, while the remainder will need public infrastructure for charging. The only exception to this is for combination trucks, with 70 percent of vehicles assumed to use high-power public fast chargers since they are primarily used for long-haul freight operations.

Figure 2 summarizes the estimated charging infrastructure investment required to support ZEVs under the different penetration scenarios.

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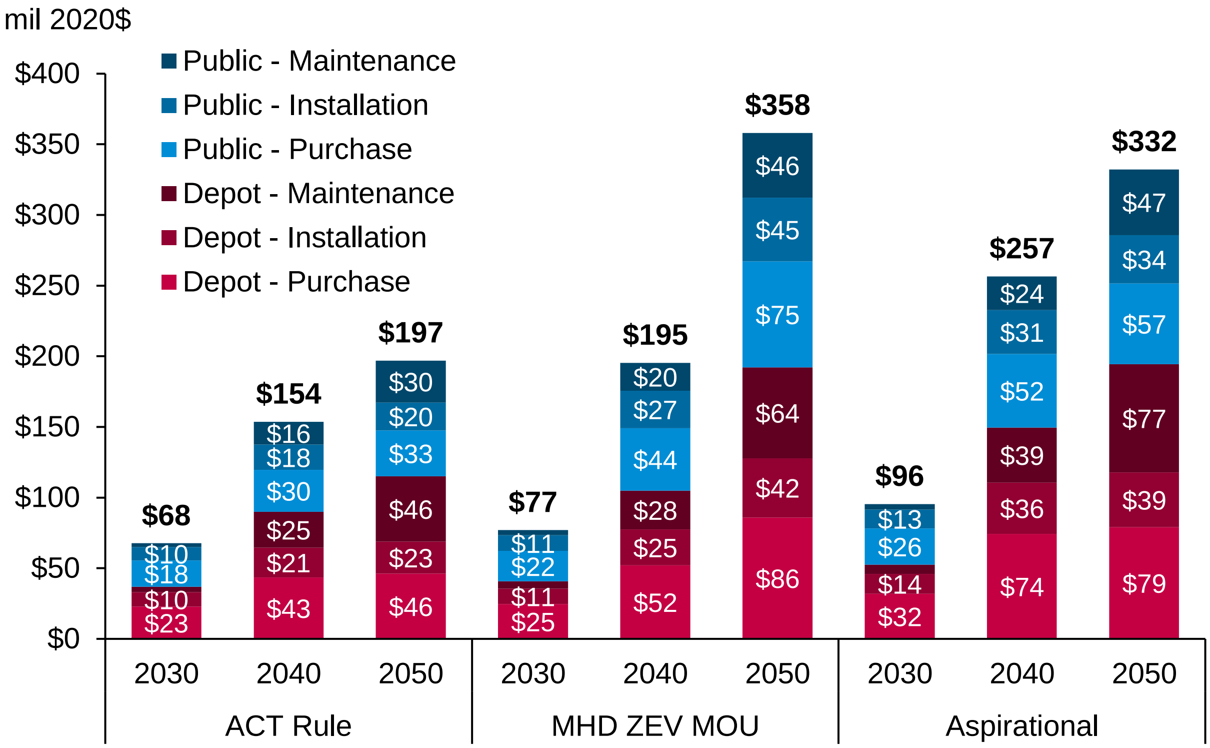
[2] Life-cycle emissions (well to wheels), net of emissions from electricity generation

Figure 2. Projected Annual Cost for Charging Infrastructure



Bars without data labels are less than $10 million. They were excluded to improve readability of the figure

2. INTRODUCTION

The sections below provide the individual results of the modeling analysis, including a description of the current Minnesota MHD fleet as well as the policy scenarios contemplated, environmental benefits and the economic impacts of the different policy scenarios.

2.1 Current MHD Vehicle Fleet

While MHDVs only make up 9 percent of on-road vehicles in Minnesota, they account for 31 percent of greenhouse gas (GHG) emissions, 62 percent of nitrogen oxide (NOx) emissions, and 55% of fine particulate matter ($PM_{2.5}$) (identified as PM going forward). Table 1 summarizes the current MHD fleet in Minnesota,[3] broken down by the four major vehicle types used as the basis for the analysis.

Vehicle Type ***Weight Class***	**No. of Vehicles**	**Annual VMT (billion miles)**	**Annual Fuel (million gallons)**
Heavy-Duty Pickups and Vans ***Class 2b***	222,146	2.52	134.4
Buses ***Class 3–8***	28,499	0.52	65.0
Single-Unit Works and Freight Trucks **Class 3–8**	162,926	2.00	246.4
Combination Trucks **Class 7–8**	52,924	3.17	465.2
TOTAL	**466,495**	**8.21**	**911.0**

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[3] ERM analyzed data from the Federal Highway Administration's 2019 Highway Statistics to calculate miles traveled by vehicle type within Minnesota. To determine the Minnesota MHD fleet, national average annual VMT per vehicle was applied to the Minnesota VMT.

3. POLICY SCENARIOS

Three scenarios, representing increasing levels of ambition, were evaluated. These three scenarios are shown below:

- **ACT Rule:** Minnesota adopts requirements analogous to those adopted by California, Massachusetts, New York, New Jersey, Oregon, and Washington under the Advanced Clean Trucks Rule, which requires an increasing percentage of new trucks purchased in the state to be ZEVs beginning in the 2025 model year. The percentage of new vehicles that must be ZEV varies by vehicle type, but for all vehicle types the required ZEV percentage increases each model year between 2025 and 2035 (see Figure 3).
- **MHD ZEV MOU:** Minnesota joins the sixteen states, District of Columbia, and the Canadian province of Quebec currently part of the Multi-State Medium- and Heavy-Duty Zero Emission Vehicle MOU. The MHD ZEV MOU sets ZEV sales targets with 30% by 2030 and 100% by 2050 (see Figure 3).
- **Aspirational:** Minnesota takes further actions to ensure more rapid and continued increases in new ZEV sales, such that virtually all new trucks are ZEV by 2040 (see Figure 3), with Class 4-8 Trucks (non-tractor) as well as Transit and School Buses achieving 100 percent ZEV sales in 2035 and Class 2B–3 Trucks, Combination Trucks, and other Buses achieving 100 percent ZEV sales in 2040 (see Figure 3). In addition, a rapidly decarbonizing grid is assumed with 100% zero-emitting electricity generation by 2040 consistent with climate goals set by Governor Waltz in January 2021.[4] See Appendix A.1 for more information.

All three of these Minnesota policy scenarios are compared with a “business as usual” (Baseline scenario) in which all new trucks sold in the state continue to meet existing U.S. Environmental Protection Agency NOx and PM emission standards and ZEV sales increase only marginally, never reaching more than 1 percent of new vehicle sales each year.[5]

The Baseline, ACT Rule, and MHD ZEV MOU Scenarios assume a “business-as-usual” (BAU) grid mix where Minnesota continues its current trajectory and by 2050, there is no more coal generation and zero-emitting sources make up 71 percent of generation. See Appendix A.1 for more information.

The analysis was conducted using ERM’s STate Emission Pathways (STEP) Tool. The climate and air quality impacts of each policy scenario were estimated on the basis of changes in MHD fleet fuel use and include both tailpipe emissions and “upstream” emissions from production of the transportation fuels used in each scenario. These include petroleum fuels used by conventional internal combustion engine vehicles (gasoline, diesel, natural gas) and electricity and hydrogen used by ZEVs. It is anticipated that most MHD ZEVs will be EVs but some classes of vehicles such as combination trucks will have trouble transitioning to entirely EVs and may instead become FCVs. As can be seen in Figure 4, a small portion of MHDVs under the Aspirational Scenario are FCVs. Starting in 2030, an increasing percent of ZEV combination truck sales are FCVs, growing to 30 percent by 2050. In 2050, just over a quarter (26 percent) of combination trucks are FCVs.

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[4] Governor Walz, Lieutenant Governor Flanagan, House and Senate DFL Energy Leads Announce Plan to Achieve 100 Percent Clean Energy in Minnesota by 2040 (mn.gov)

[5] The baseline ZEV sales assumptions are consistent with projections in the Energy Information Administration’s Annual Energy Outlook 2021. “Annual Energy Outlook 2021,” Reference Case Projections Tables, US Energy Information Administration (EIA), table 49, https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php

Figure 3. Minnesota MHD ZEV Sales by Scenario

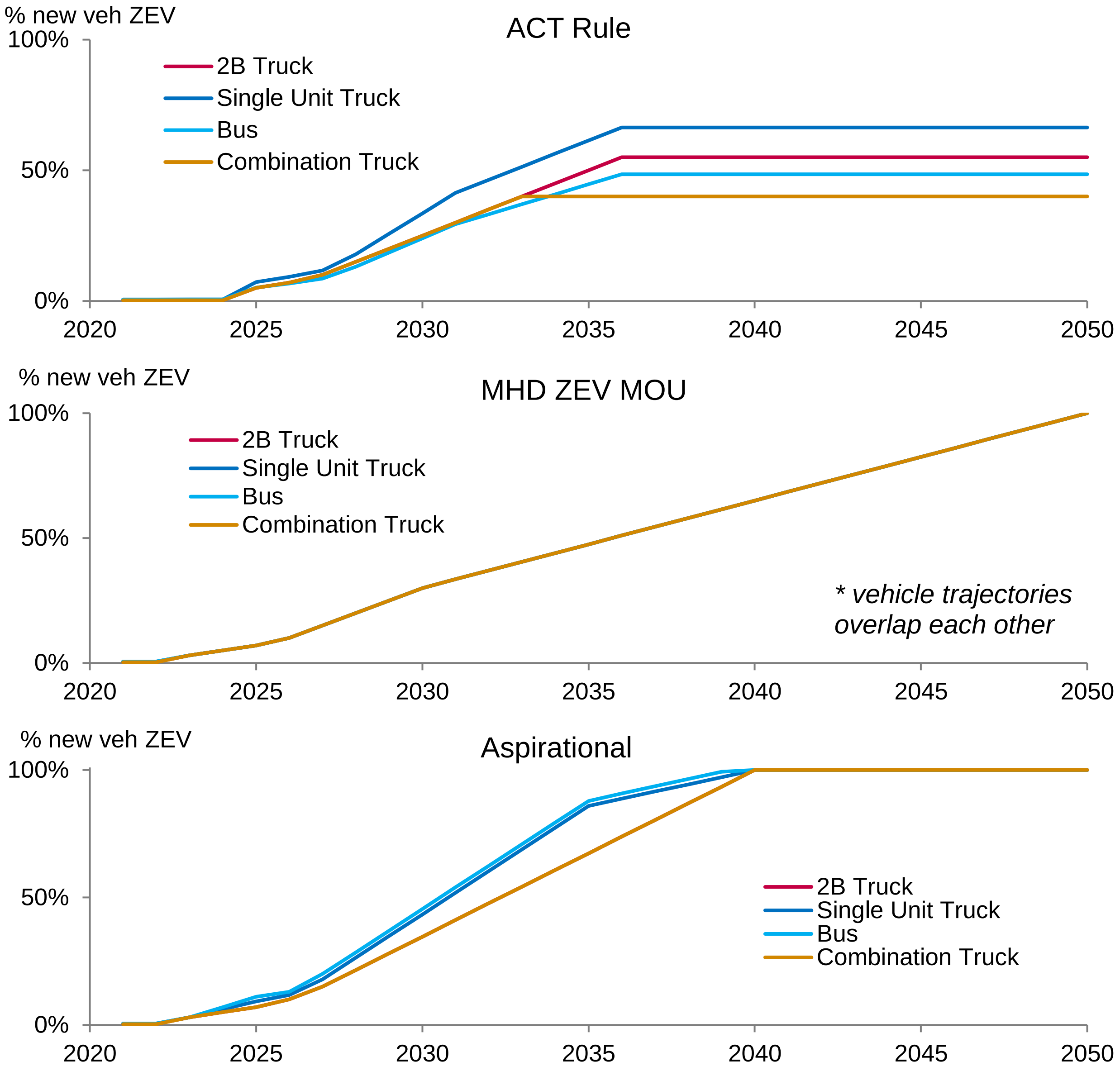
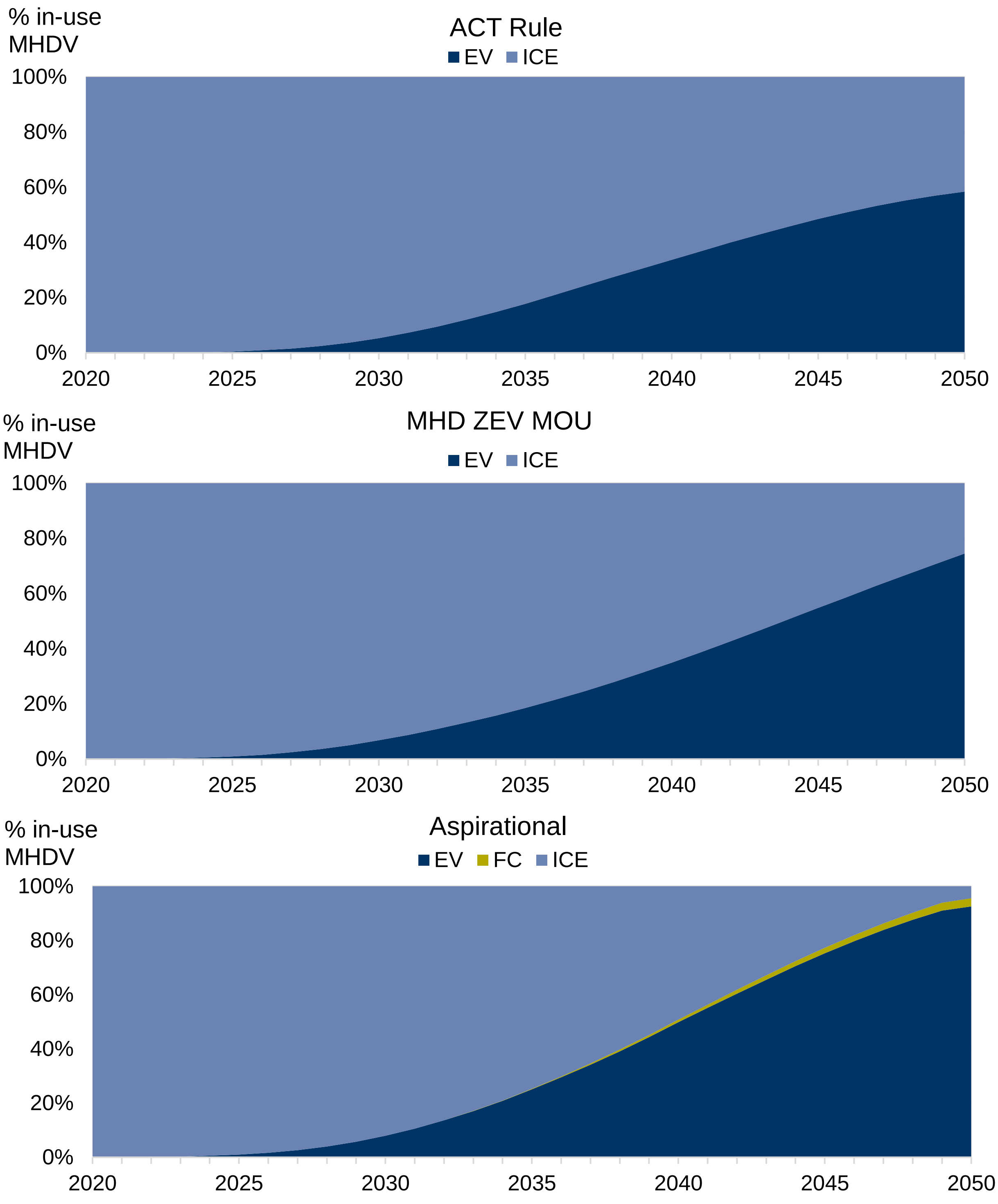


Figure 4. Minnesota MHDV In-Use Fleet by Scenario



4. CLIMATE BENEFITS

A benefit of transitioning from conventional vehicles to ZEVs is reduced greenhouse gas (GHG) emissions. To evaluate climate impacts, the analysis estimated changes in all combustion related GHGs, including carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The model takes a lifecycle view of emissions considering upstream emissions from petroleum production (well-to-tank), tailpipe emissions (tank-to-wheel), and emissions that will result from the increased electricity generation required to power electric vehicles (well-to-wheel). The generation mix mentioned above and discussed more in Appendix A.1 was used to calculate the emissions from electricity. Estimated emissions from ZEV charging along with upstream emissions for gasoline, diesel fuel, and natural gas are based on Argonne National Laboratories' Greenhouse gases, Regulated Emissions, and Energy use in Technologies (GREET) Model outputs. Tailpipe emissions were calculated using the U.S. EPA's Motor Vehicle Emission Simulator (MOVES) model.

4.1 Changes in Fuel Use

Under all modeled policy scenarios, a significant portion of the Minnesota MHD fleet is assumed to turn over to EV and FCV trucks and buses. This will result in replacement of petroleum fuels—primarily gasoline and diesel fuel—with electricity and hydrogen.

Figure 5 shows the share of petroleum-based fuels for each of the four vehicle classes (Class 2B, Buses, Single Unit Trucks, and Combination Trucks) and the total fuel saved under each of the policy scenarios.

Under the Baseline Scenario, total annual petroleum fuel use by the Minnesota MHD fleet in 2050 is projected to be 780 million gallons. Under the ACT Rule Scenario, annual petroleum fuel use in 2050 falls to an estimated 400 million gallons (–49 percent), and cumulative reductions in diesel and gasoline use by the MHD fleet total 4.8 billion gallons between 2022 and 2050. This petroleum fuel is replaced by a cumulative 91 million megawatt-hours (MWh) of electricity between 2022 and 2050. Annual electricity use for MHD EV charging in 2050 is estimated to be 7.8 million MWh. This represents a 15 percent increase over the estimated baseline electricity use by Minnesota residential and commercial customers in 2050 of 53.9 million MWh.[6]

Under the MHD ZEV MOU Scenario, estimated annual petroleum fuel use by the MHD fleet in 2050 falls to 224 million gallons (–71 percent), and cumulative reductions in diesel and gasoline use by the MHD fleet total 6.0 billion gallons between 2022 and 2050. This petroleum fuel is replaced by a cumulative 115 million MWh of electricity between 2022 and 2050. Annual electricity use for MHD EV charging in 2050 is estimated to be 11.4 million MWh, a 21 percent increase to the estimated baseline electricity.

Under the Aspirational Scenario, estimated annual petroleum fuel use by the MHD fleet in 2050 falls to 61 million gallons (–92 percent), and cumulative reductions in diesel and gasoline use by the MHD fleet total 8.2 billion gallons between 2022 and 2050. This petroleum fuel is replaced by a cumulative 139 million MWh of electricity and 1.0 billion kilograms of hydrogen between 2022 and 2050. Annual electricity use for MHD EV charging in 2050 is estimated to be 12.5 million MWh, a 23 percent increase to estimated baseline electricity.

Figure 5. Petroleum Based Fuel Use by Vehicle Type for Each Policy Scenario

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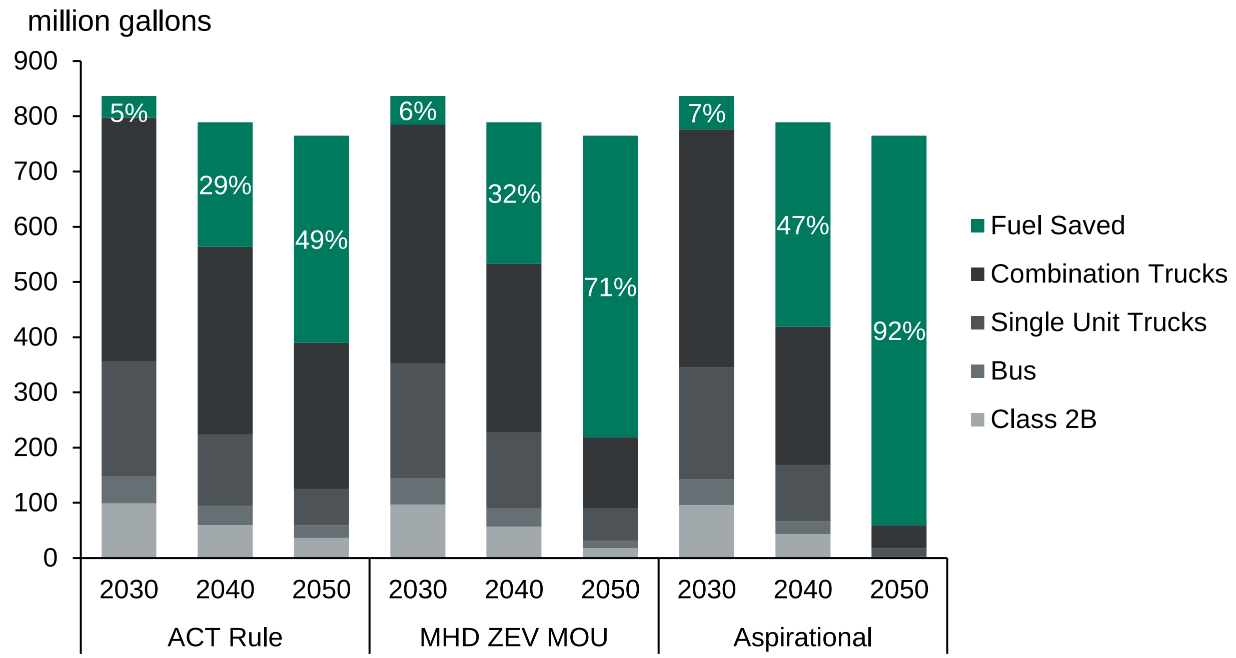
[6] "Annual Energy Outlook 2021," Reference Case Projections Tables, US EIA, tables 54.11, 54.13, and 54.16, https://www.eia.gov/outlooks/aeo/tables_ref.php.



4.2 Reduction in GHG Emissions

The projected annual greenhouse gas emissions measured in million metric tons carbon-dioxide equivalent (MMT CO_2e) from the Minnesota MHDV fleet under each scenario are shown in Figure 6. The figure also illustrates a baseline trajectory, in which the Minnesota MHDV fleet adopts ZEVs at a very low rate (less than 1% sales in 2050) and keeps its current mix of gasoline and diesel vehicles. Reductions associated with each scenario are compared against this baseline.

As shown, under the baseline scenario annual MHD fleet GHG emissions are projected to fall by 13 percent through 2050 as the current fleet turns over to new, more efficient gasoline and diesel trucks that meet more stringent EPA new engine and vehicle emission standards. The EPA has indicated it plans to further tighten GHG standards for MHDVs within the US for model years as early as 2027.[7] If such measures are adopted, it is expected that the baseline GHG emissions for this analysis would be lower and result in smaller reductions than presented in this report.

Compared with the baseline, by 2050, annual fleet GHG emissions are estimated to be reduced by 33 percent, 49 percent, and 83 percent for the ACT Rule, MHD ZEV MOU, and Aspirational Scenarios respectively as diesel and gasoline trucks are replaced with ZEVs.

Between 2022 and 2050, **cumulative GHG emission reductions compared to the baseline for each scenario total 39.8 MMT CO2e, 50.4 MMT CO2e, and 91.4 MMT CO2e** for the ACT Rule, MHD ZEV MOU, and Aspirational Scenarios, respectively. These estimates of GHG reductions from each policy scenario account for reductions in petroleum fuel use (gasoline, diesel fuel) by the MHD fleet, the decreased upstream emissions from gasoline and diesel production, as well as increased emissions from electricity and hydrogen production to fuel the EVs and FCVs that will replace gasoline and diesel trucks and buses.

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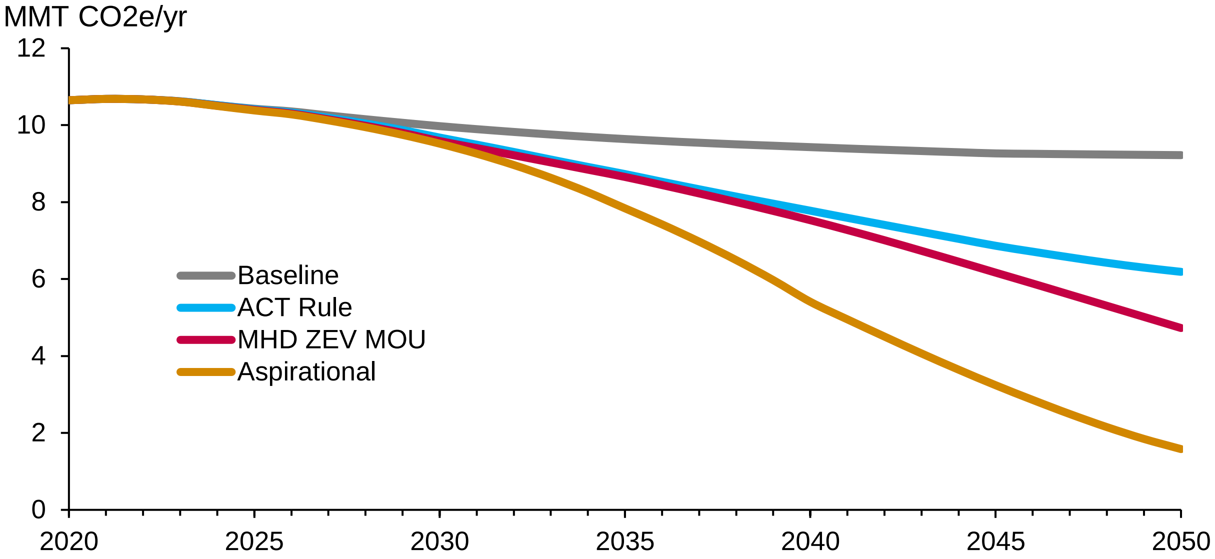
[7] Heavy-Duty 2027 and Beyond: Clean Trucks Proposed Rulemaking. Office of Transportation and Air Quality, US Environmental Protection Agency, (EPA-420-F-22-007). March 2022. https://www.epa.gov/system/files/documents/2022-03/420f22007.pdf

Figure 6. Projected MHD Fleet Greenhouse Gas Emissions



Climate benefits are monetized using the social cost of greenhouse gas values with a 3 percent discount rate reported by the Interagency Working Group on Social Cost of Carbon, Methane, and Nitrous Oxide[8]. This estimate represents the monetary value of the net harm to society associated with the impacts of incremental increases in greenhouse gas emissions in a given year. These impacts include sea level rise, damage inflicted by stronger storms, flooding due to severe rain events, health and agriculture impacts from extreme summer temperatures, increased environmental migration, and many other consequences of climate change. Table 1 summarizes the modeled monetized social value of cumulative GHG reductions (2022-2050) estimated for each of the policy scenarios. For further detail on cumulative GHG emissions reductions, see Appendix A.5.

Table 1. Cumulative Reduction of Greenhouse Gas Emissions (2022-2050) and Monetized Value

	Cumulative GHG Reduction (MMT)	Monetized Value of GHG Reduction (2020$ bill)
ACT Rule	39.8	$3.1
MHD ZEV MOU	50.35	$3.9
Aspirational	91.4	$7.2

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[8] Interagency Working Group on Social Cost of Greenhouse Gases, *Technical Support Document: Social Cost of Carbon, Methane, and Nitrous Oxide: Interim Estimates under Executive Order 13990* (United States Government, February 2021), https://www.whitehouse.gov/wp-content/uploads/2021/02/TechnicalSupportDocument_SocialCostofCarbonMethaneNitrousOxide.pdf.

5. AIR QUALITY BENEFITS

The model quantifies the reductions in two criteria pollutants known to have adverse impacts on human health: nitrogen oxides (NOx) and fine particulate matter ($PM_{2.5}$) (identified as PM going forward). Reductions in NOx and PM will improve air quality resulting in public health benefits from reduced mortality, hospital visits, and minor incidences[9] within Minnesota. Figures 7 and 8 show estimated annual on-road MHDV related NOx and PM emissions[10], respectively. The baseline shown is a scenario with very low MHD ZEV adoption (less than 1% in 2050). Under the Baseline Scenario, annual MHD fleet NOx emissions are projected to fall by 47 percent and annual fleet PM emissions are projected to fall 73 percent from 2022 levels through 2045, as the current fleet turns over to new gasoline and diesel trucks with cleaner engines that meet more stringent EPA new engine emissions standards.[11] After 2045 baseline annual NOx and PM emissions are then projected to start rising again as annual fleet VMT continues to grow.

Compared with the baseline, by 2050 the ACT Rule is estimated to reduce annual fleet NOx and PM emissions by 44 percent and 30 percent, respectively, as diesel and gasoline trucks are replaced with electric vehicles. The MHD ZEV MOU Scenario reduces NOx and PM emissions by 67 percent and 45 percent respectively compared to baseline in 2050. The Aspirational Scenario has the lowest fleet emissions due to replacement of virtually all gasoline and diesel trucks and buses with EVs and FCVs by 2050, when annual NOx and PM emissions are estimated to be 90 percent and 87 percent lower, respectively, than baseline emissions.

Over the next 30 years, **cumulative NOx emission reductions total 85,500 metric tons (MT), 112,700 MT, and 163,500 MT** for the ACT Rule, MHD ZEV MOU, and Aspirational Scenarios respectively (compared with the Baseline Scenario). **PM emissions** also see a dramatic reduction totaling **770 MT, 1,010 MT, and 2,320 MT** for the ACT Rule, MHD ZEV MOU, and Aspirational Scenarios respectively.

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[9] Minor incidences include reduced cases of acute bronchitis, exacerbated asthma and other respiratory symptoms, and reduced activity days and lost work days.

[10] This analysis does not consider tire- and brake-wear PM emissions which account for between 10 to 60 percent of all vehicle-related PM emissions depending on the vehicle class. It remains unclear how tire- and brake-wear emissions will differ for ZEVs compared to ICE vehicles. Due to regenerative braking in ZEVs, brake-wear emissions may decrease. On the other hand, due to the heavier weight of EVs, tire-wear emissions may increase. As more ZEVs are deployed, a better understanding of these emissions will emerge.

[11] This analysis does not consider the impact of the NOx regulation EPA proposed on March 7, 2022. If this regulation is adopted, it would lower baseline NOx emissions for Minnesota.

Heavy-Duty 2027 and Beyond: Clean Trucks Proposed Rulemaking. Office of Transportation and Air Quality, US Environmental Protection Agency, (EPA-420-F-22-007). March 2022. https://www.epa.gov/system/files/documents/2022-03/420f22007.pdf

Figure 7. Projected MHD Fleet NOx Emissions

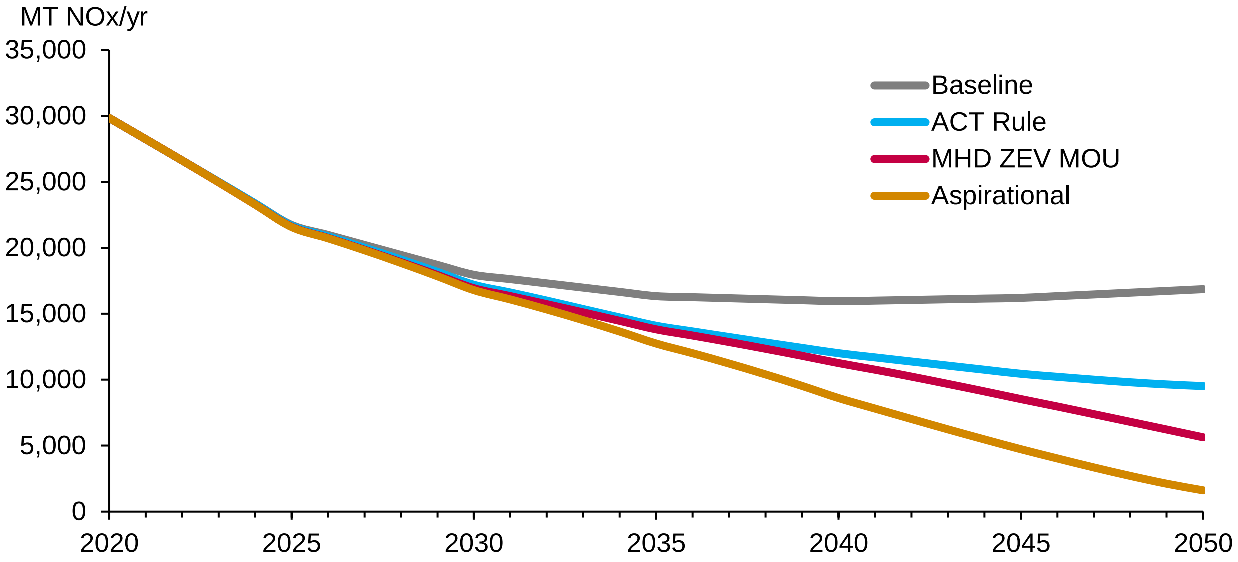
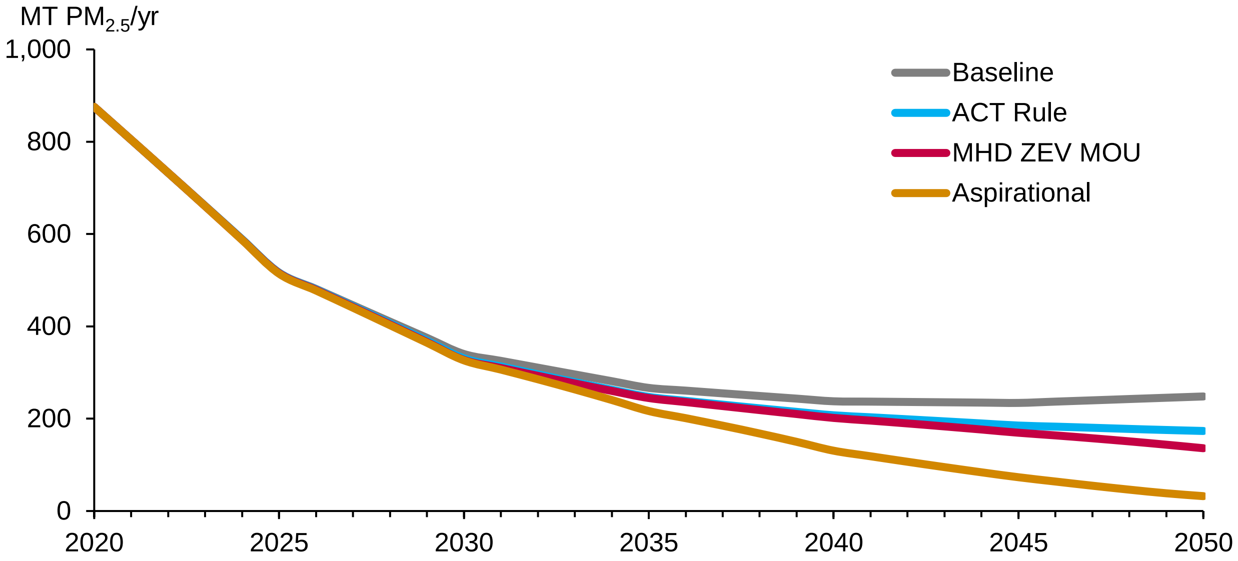


Figure 8. Projected MHD Fleet $PM_{2.5}$ Emissions



5.1 Public Health Benefits

The reduced annual NOx and PM emissions under the policy scenarios will reduce ambient particulate levels in the air, which will reduce the negative health effects on Minnesota residents breathing in these airborne particles. Estimated public health impacts include reductions in premature mortality and fewer hospital admissions and emergency room visits for asthma. There will also be reduced cases of acute bronchitis, exacerbated asthma, and other respiratory symptoms, and fewer restricted activity days and lost workdays. Cumulative estimated reductions in these health outcomes in Minnesota under the modeled policy scenarios are shown in Table 2; these benefits were estimated using the U.S. EPA's CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool.

Table 2. Cumulative Public Health Benefits of Policy Scenarios, (2022-2050)

Health Metric	ACT Rule	MHD ZEV MOU	Aspirational
Avoided Premature Deaths	111	145	211
Avoided Hospital Visits[a]	91	119	172
Avoided Minor Cases[b]	70,614	92,465	134,789
Monetized Value, 2020$ (millions)	$1,294	$1,691	$2,465

a Includes hospital admissions and emergency room visits.

b Includes reduced cases of acute bronchitis, exacerbated asthma, and other respiratory symptoms, and reduced restricted activity days and lost workdays.

6. ECONOMIC IMPACTS

Transitioning the MHD fleet to ZEVs will have significant economic impacts from the purchase, installation and maintenance of EV charging infrastructure, increased revenue to utilities from EV charging, as well as savings to vehicle owners from reduced fuel and maintenance. Sections 6.1 and 6.2 below contemplate economic impacts related to MHD EVs, while Section 6.3 includes costs and benefits associated with all ZEVs (EVs and FCVs)

6.1 EV Charging Infrastructure Requirements

MHD EVs are assumed to charge overnight at their depot and are typically used for local or regional operations in which they begin and end the day at the same location. Since most vehicles are assumed to charge overnight, they are already charging during lower electric grid load periods, sometimes referred to as “off-peak”.

Combination trucks (i.e., a subset of Class 7 and 8 trucks) are treated slightly different than the rest of MHDVs. Approximately 30 percent of these vehicles are used for local/regional hauling and can use overnight depot charging. The remainder are used primarily for long-haul freight operations, which do not return to the same location every night and can travel 500 miles or more per day. As such, these vehicles will need to use a shared, public network of higher-power chargers (greater than 500 kilowatts per port) and are assumed to plug in as needed to maintain state of charge.

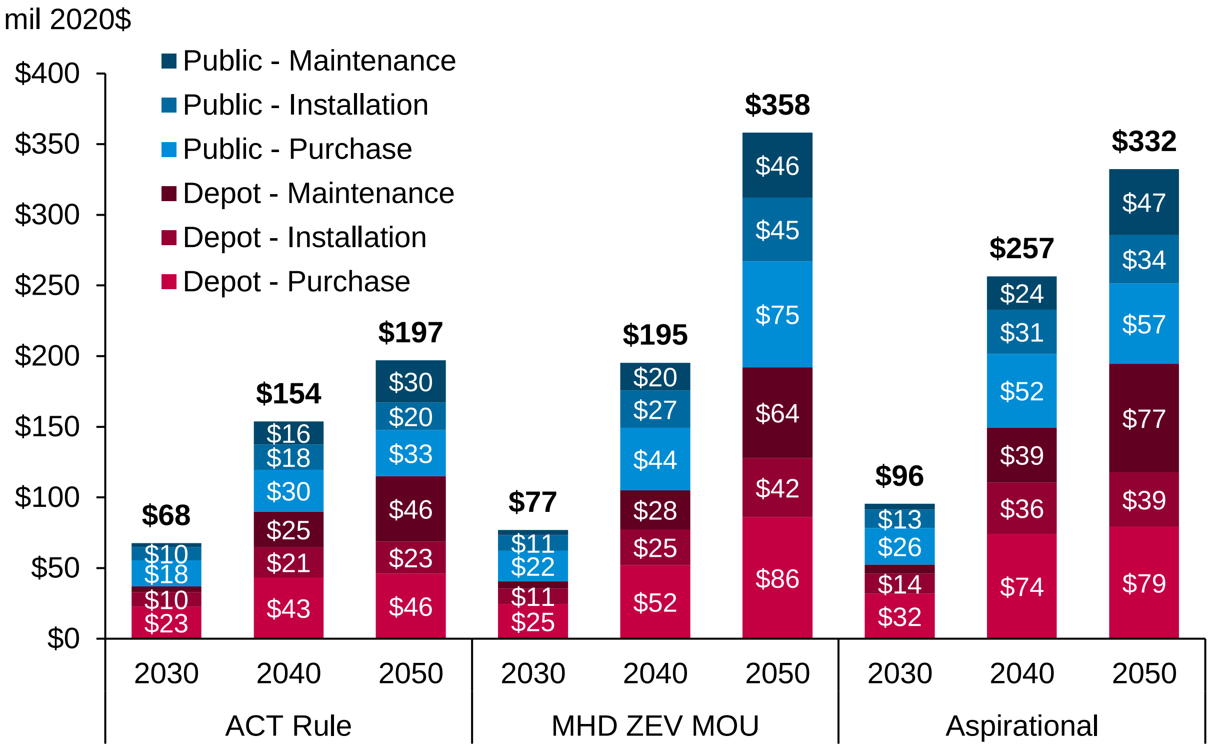
The model includes depot-based chargers that will require energy demand in the range of 10-50 kilowatts (kW) per port depending on the vehicle type. Modeled public chargers include direct current fast-chargers (DCFC) ranging from 150 kW to support single-unit trucks, while the higher-capacity 500 kW public chargers are needed mostly for combination trucks and transit buses.

The model assumes one charger port per MHDV that is charged per night in the depot. Since not all MHDVs are assumed to be used every day, this means roughly 0.8 charger ports per depot charging MHDV. The number of public chargers required for MHDVs is calculated assuming between 12 and 22 hours available for vehicles to be charging, the length of time it takes the vehicle to charge, and the percent of vehicles by class using public chargers.

Table 3. Projected Charging Infrastructure Required for Policy Scenarios

Metric		ACT Rule			MHD ZEV MOU			Aspirational		
		2030	2040	2050	2030	2040	2050	2030	2040	2050
Charge Ports	Depot	18,179	136,834	253,323	23,777	139,599	318,168	28,524	206,331	411,609
	Public 150 kW	225	1,627	3,035	277	1,583	3,616	343	2,394	4,741
	Public 500 kW	229	1,407	2,600	321	1,835	4,471	348	2,532	5,681

Figure 9. Projected Annual Cost for Charging Infrastructure



Bars without data labels are less than $10 million. They were excluded to improve readability of the figure

To transition a major portion of the Minnesota MHD fleet to EVs will require a substantial investment in charging infrastructure. In considering charging infrastructure costs, the model includes the cost of charging equipment, installation, and regular maintenance. Soft costs such as lease acquisition and permitting are outside the scope of the modeling. Policies and regulations to make charging equipment easier to install might lower these costs.

As Table 3 and Figure 9 indicate, for MHDV depot-based chargers, by 2050, the model projects fleet owners will have purchased and installed between 250,000 and 410,000 depot chargers for an annual investment of between $91 million and $205 million. In addition to this private investment, by 2050 the Minnesota MHD fleet will also require between 5,640 and 10,400 high speed public charging ports with a yearly investment of between $82 million and $167 million. For further detail on charging infrastructure costs, see Appendix A.4.

As of February 2022, there were 75 publicly accessible charging stations in Minnesota with a total of 235 DCFC ports (>50 kW). Over half of these DCFC ports are Tesla superchargers that currently can be used only by Tesla owners. In Minnesota, there are only 111 DCFC ports fully available to any vehicle.[12]

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[12] "Alternative Fuels Data Center: Alternative Fueling Station Locator," US Department of Energy, accessed on 03/01/2022, https://afdc.energy.gov/stations/#/analyze.

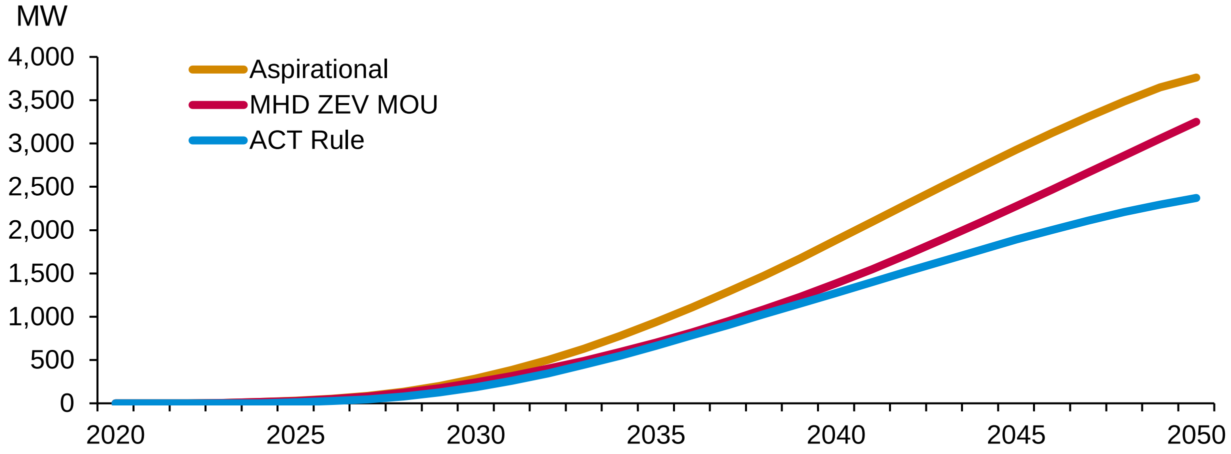
6.2 Utility Impacts of EV Charging

Current annual electricity sales to residential and commercial customers in Minnesota total 47.0 million MWh and are projected to grow to 53.9 million MWh in 2050.[13]

Additional annual electricity sales for MHD EV charging are estimated to total 0.7 million MWh, 0.9 million MWh, and 1.1 million MWh in 2030, rising to 7.8 million MWh, 11.4 million MWh, and 12.5 million MWh in 2050 for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios respectively. As MHD EV saturation increases in Minnesota, this additional electricity will represent a sizable increase to the baseline electricity projection. **In 2050, charging for MHD EVs are projected to account for 14.5 percent, 21.1 percent, and 23.2 percent of baseline electricity sales for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios respectively.**

In addition to increased electricity sales, MHD EVs are modeled to increase the peak electricity demand. The model assumes the amount of grid capacity that needs to be added to the transmission and distribution system for MHD EV charging as the incremental load incurred by EVs between 3:00 p.m. and 9:00 p.m. (i.e., the current peak load hours in the Minnesota system). As shown in Figure 10, in 2030, incremental peak charging demand is estimated at 186 MW, 242 MW, and 285 MW rising to 2,370 MW, 3,250 MW, and 3,760 MW in 2050 for the ACT Rule, MHD ZEV MOU, and Aspirational Scenarios respectively.

Figure 10. Incremental Capacity Required for MHD EV Charging



To estimate the net impact of MHD EV saturation on utility costs, the model considers the additional revenue from increased electricity sales, the cost of generation and transmission of that additional electricity, and the cost of building additional capacity into the electric system due to the increased load caused by MHD EVs. To calculate the revenue, current residential and commercial electricity rates are adjusted through 2050 based on the U.S. Energy Information Administration's (EIA) 2021 Annual Energy Outlook projection for electricity prices for the West North Central region.

For the increased capacity cost, commercial demand rates for Minnesota are used as a proxy for incremental capacity cost. The demand rates are adjusted in the same manner as the electricity rates.

Figure 11 shows modeled annual utility revenue in dark blue. The different elements of incremental annual cost that utilities would incur to purchase and deliver additional electricity to support MHD EV

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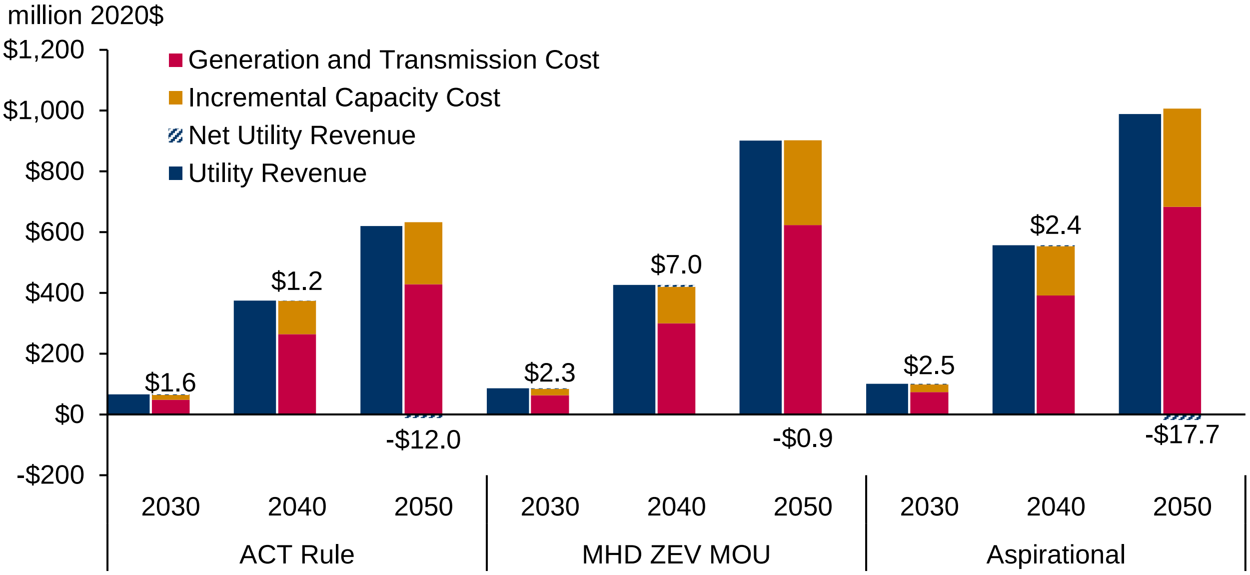
[13] "Annual Energy Outlook 2021," Reference Case Projections Tables, US Energy Information Administration (EIA), table 54, https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php

charging are shown in red (volumetric generation and transmission costs) and orange (costs required to upgrade or expand system capacity). The dashed blue bar represents net utility revenue or the difference between the additional revenue from the sale of electricity for MHD EV charging minus the costs to supply that electricity.

In 2030 and 2040, the net utility revenue for MHD EV charging is positive with annual savings of $1.2 million, $7 million, and $2.4 million in 2040 for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios respectively as shown in Figure 11. For all three scenarios, this value becomes slightly negative by 2050. Is it important to note that these values are calculated based on currently available utility tariff information and are likely to change over time as tariffs are adjusted to a more electrified economy. One reason for the negative net utility revenue forecast in 2050 is the relatively high percent of combination trucks in Minnesota's MHD fleet, which are projected to utilize high speed, 500 kW DCFCs throughout the day, which is generally costlier to the electric grid than a lower power depot charger used overnight. Although not considered in this modeling, additional measures could help to mitigate the impact of these high demand chargers. For example, battery storage installed at the charger location could lower the amount of current the charger pulls from the grid while still enabling the vehicle to charge quickly at the speed it needs. As charging, battery, and other electric grid management technology continues to evolve, more solutions will likely emerge.

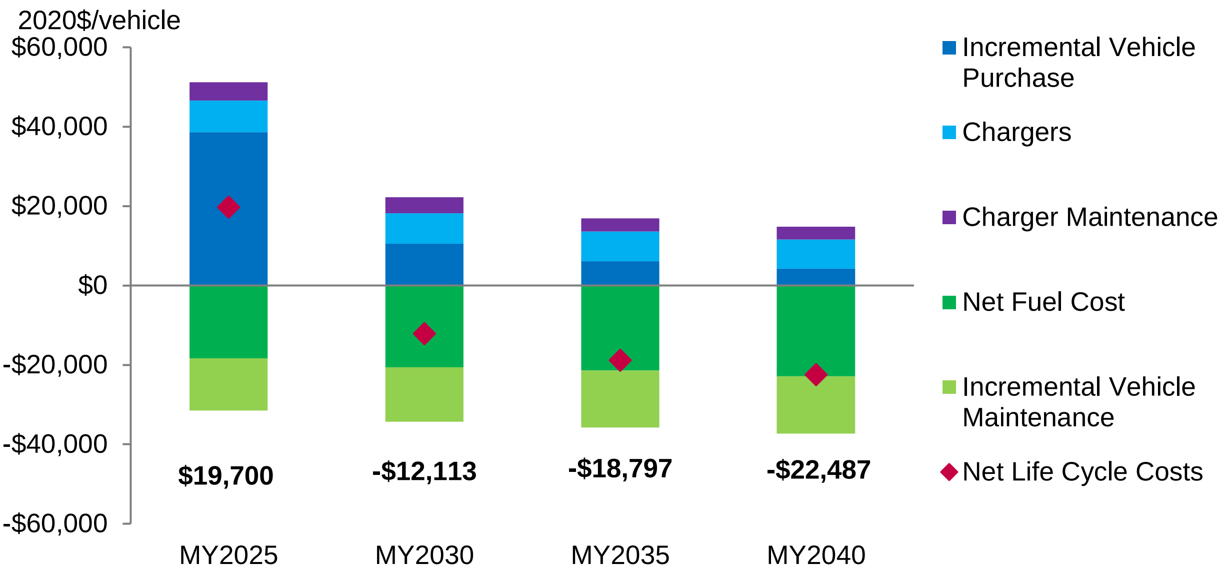
Figure 11. Projected Annual Utility Costs and Revenue from MHD EV Charging



6.3 ZEV Owner Benefits

The model estimates the impact of MHD ZEV ownership by assessing the differences in fuel, maintenance, charger, and vehicle cost of ZEVs compared with baseline conventional vehicles (internal combustion engines that operate on petroleum fuels, such as gasoline or diesel). Figure 12 shows projected average lifetime incremental costs for new ZEVs purchased in Minnesota compared with lifetime costs for combustion vehicles purchased in the same model year; the bars show fleet average values for all Class 2B–8 ZEVs purchased each year under the Aspirational Scenario. Incremental fuel and maintenance costs are discounted lifetime costs, assuming 21-year vehicle life, and 6 percent annual discount rate. Vehicle financing, which is often used by fleets when purchasing vehicles, was not considered in this analysis.

Figure 12. Projected Lifetime Incremental Costs for Minnesota ZEVs Compared with Combustion Vehicles



Net fuel costs include reductions in purchases of diesel fuel and gasoline[14] (due to fewer combustion vehicles), offset by the increased purchase of electricity and hydrogen to power ZEVs. Net maintenance costs include net savings in annual vehicle maintenance for the ZEVs in the fleet compared with combustion vehicles, offset by annual costs to maintain the charging and hydrogen fueling infrastructure needed to support in-use ZEVs.

For MHD ZEVs, current vehicle offerings remain low, but many new models are being announced[15]. Given that this market is in its infancy, incremental costs for these vehicles will initially be high, but like the light-duty space, these costs are projected to fall as technology improves and increased demand spreads out costs across the country.

As shown in Figure 12, the average MHD ZEV in Minnesota is projected to produce over $30,000 in discounted fuel and maintenance cost savings over its lifetime (green and dark green bars). For ZEVs purchased in the very near term, this savings may not be enough to offset the projected incremental cost of vehicle purchase (dark blue) and fueling infrastructure (light blue) for some ZEVs, resulting in net increased lifetime costs compared with those of combustion vehicles (red diamond). However, by 2030 incremental ZEV purchase costs are projected to fall significantly, such that the average ZEV will reach lifetime cost parity with combustion vehicles, when discounted lifetime fuel and maintenance savings are considered. **By 2040, the average ZEV purchased that year is projected to produce nearly $20,000 in discounted lifetime net savings (2020$) compared with the costs of an equivalent combustion vehicle.**

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[14] Diesel and gasoline prices used in this analysis are based on the Energy Information Administration's Annual Energy Outlook 2021 which takes a long-term view on price changes and does not account for short term volatility. "Annual Energy Outlook 2021," Reference Case Projections Tables, US Energy Information Administration (EIA), table 57.4, https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php

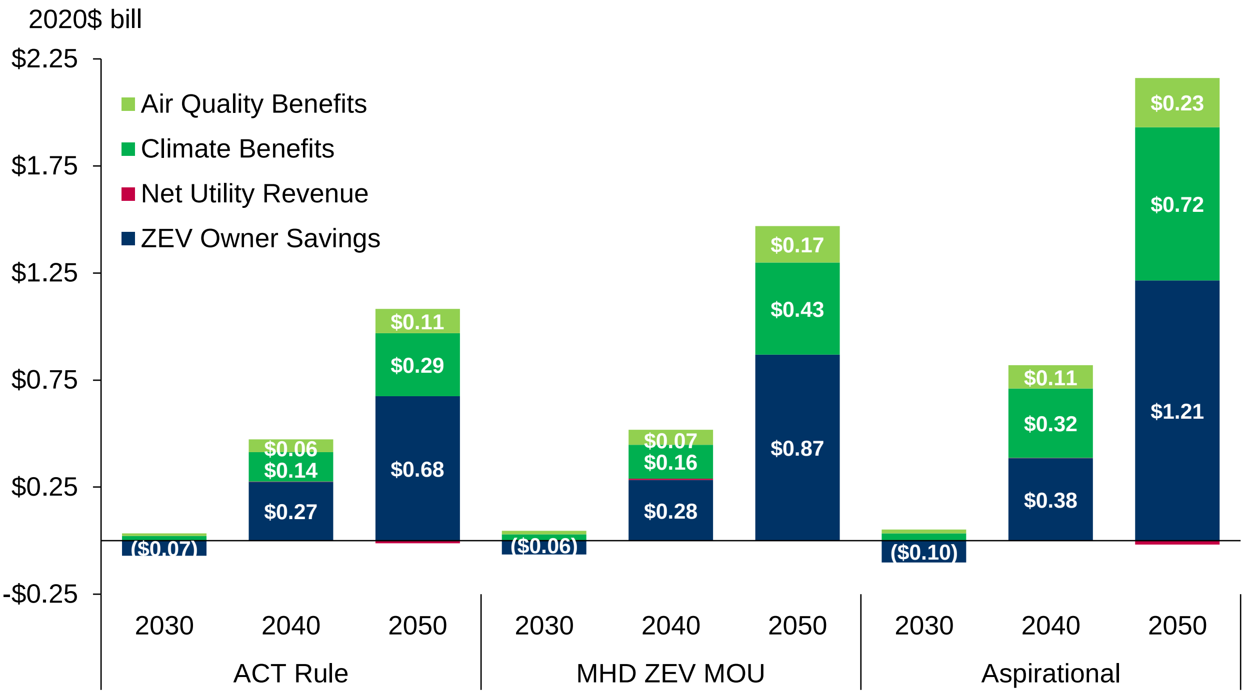
[15] Dana Lowell and Alissa Huntington, *Electric Vehicle Market Status-Update* (M.J. Bradley & Associates and Environmental Defense Fund, April 20, 2021), 33, https://mjbradley.com/sites/default/files/EDF_EV_Market_Report_April_2021_Update.pdf.

It is important to reiterate that the values in Figure 12 are fleet average values, which mask a significant amount of variability across vehicle types and among different fleets of the same vehicle type. See Appendix A.3 for more information on ZEV cost parity by vehicle type.

7. NET SOCIETAL BENEFITS

Figure 13 shows the annual total net societal benefits, combining four classes of costs and benefits discussed above: air quality benefits, climate benefits, net utility revenue, and ZEV owner savings. ZEV owner savings (~60 percent) and climate benefits (~30 percent) make up most of the societal benefits. As noted in Section 6.2 above, net utility revenue is projected to become negative by 2050 though as can be seen in the figure, the magnitude of the net utility revenue is dwarfed by the other benefits of MHD ZEV adoption in Minnesota. By 2050, annual net societal benefits will reach $1.1 billion, $1.5 billion, and $2.1 billion for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios respectively. The cumulative benefits between 2022 and 2050 amount to $9.9 billion, $12.1 billion, and $18.5 billion for the ACT Rule, MHD ZEV MOU, and the Aspirational Scenarios respectively.

Figure 13. Projected Societal Benefits of Minnesota MHD ZEV Adoption



Bars without data labels are less than $0.05 billion. They were excluded to improve readability of the figure.

APPENDIX A

A.1 Generation Mix Assumptions

In the modeling framework, the generation mix and its evolution between 2022 and 2050 contribute to the reduction in emissions associated with electric vehicle adoption. If a generation portfolio is assumed to be a large emitter of greenhouse gases, nitrogen oxides, and particulate matter, the replacement of a conventional vehicle with an ZEV would have a limited impact on the overall state emissions. If generation is predominantly from zero-carbon sources, the impact of each electric vehicle will be greater.

Two generation mixes were used in this modeling: a “business-as-usual” (BAU) grid mix (Figure 14) and decarbonized grid mix (Figure 15). The Baseline, ACT Rule, and MHD ZEV MOU Scenarios used the BAU grid mix while the Aspirational Scenario used the decarbonized grid mix.

As part of its long-term planning, in April 2021, MISO published the MISO Futures Report[16] which developed three scenarios with increasingly ambitious carbon reductions projecting changes in the grid until the end of 2039. Of the three scenarios, Future 1 was chosen as the BAU grid mix assumption since it “incorporates 100 [percent] of utility resource plan (IRP) announcements” and 85 percent of “state and utility goals that are not legislated … to hedge the uncertainty of meeting [the] announced goals and respective timelines.”

The current Minnesota generation mix was used as the starting point for the modeling.[17] To determine a BAU grid for Minnesota, first the evolution of generation capacity within Minnesota needed to be determined. From the current set of generation units within Minnesota, the retirements[18] and additions[19] under the Future 1 Scenario for Minnesota were subtracted and added. To determine the electricity generation from these units, the 2019 capacity factor by fuel type[20] was used. To understand the electricity imports into Minnesota from other parts of MISO, the Future 1 annual demand growth rate (0.60%) was applied to current electricity sales in Minnesota to determine the total demand for future years and from that value the in-state electricity generation was subtracted to leave the needed imports. The average MISO Future 1 generation mix was assumed for the electricity imports. For the final ten years of the analysis, the grid mix gradually increases its share of zero-emitting resources as more coal and natural gas plants go offline.

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[16] MISO Futures Report, (MISO, April 2021, Updated December 2021), https://cdn.misoenergy.org/MISO Futures Report538224.pdf

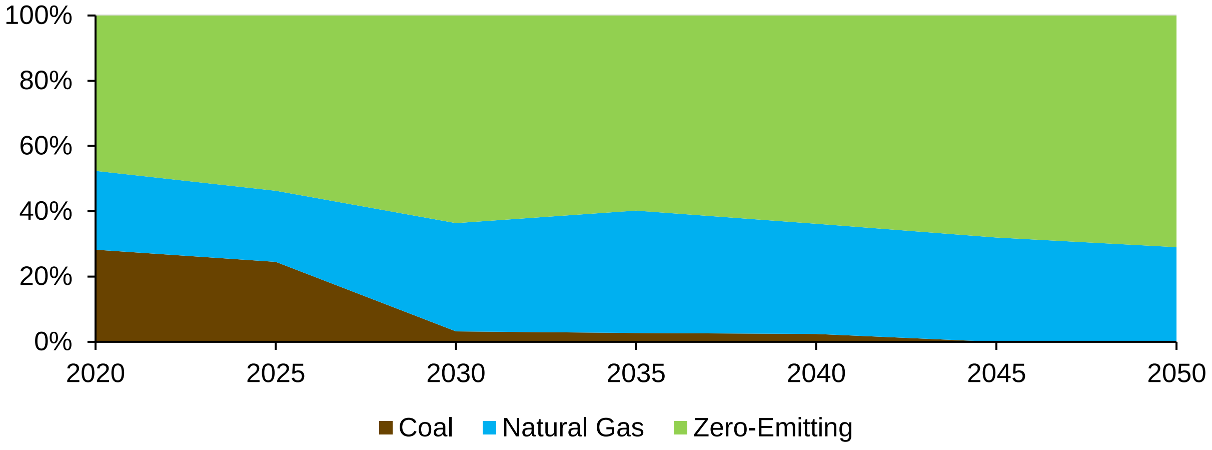
[17] Minnesota Electricity Profile 2020, *State Electricity Profiles* (U.S. Energy Information Administration, U.S. Department of Energy, November 2021), tables 4 and 5, https://www.eia.gov/electricity/state/minnesota/xls/mn.xlsx

[18] Futures Retirements, (MISO, December 2021), https://cdn.misoenergy.org/MISOFutures_Retirements538225.xlsx

[19] Futures Resource Sitting, (MISO, December 2021), https://cdn.misoenergy.org/20211110%20PAC%20Item%2003b%20MISO%20Futures%20Resource%20Siting%20-%20Corrected%20F2%20and%20F3602575.xlsx

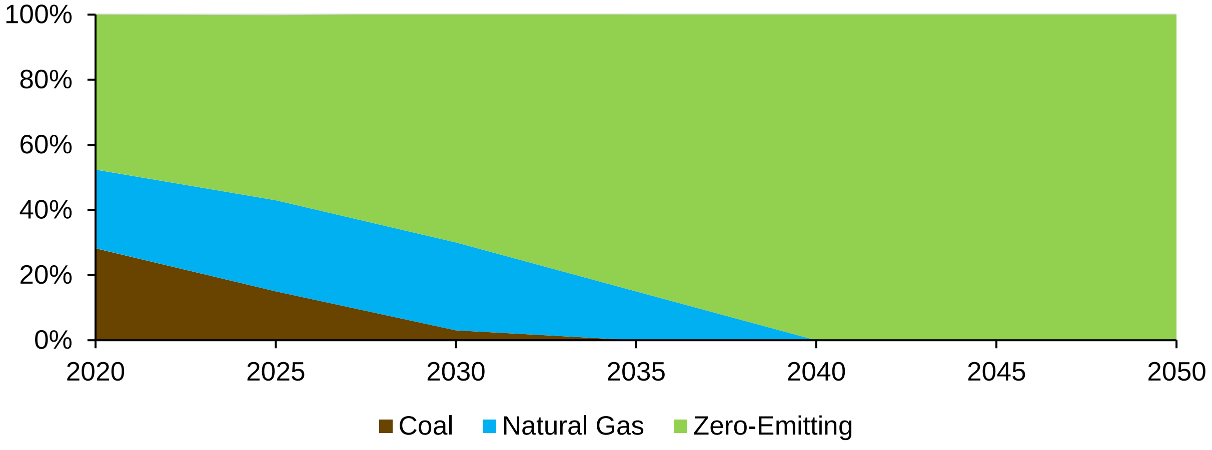
[20] Minnesota Electricity Profile 2019, *State Electricity Profiles* (U.S. Energy Information Administration, U.S. Department of Energy, November 2020), tables 4 and 5, https://www.eia.gov/electricity/state/archive/2019/minnesota/xls/mn.xlsx

Figure 14. Business-As-Usual Grid Mix



Once again, for the decarbonized grid, the current Minnesota generation mix was used as the starting point for the modeling.[21] Then the zero-emitting portion of the grid was increased to reach 100% by 2040 to be aligned with Governor Walz's goal of 100% clean energy in Minnesota by 2040.[22]

Figure 15. Decarbonized Grid Mix



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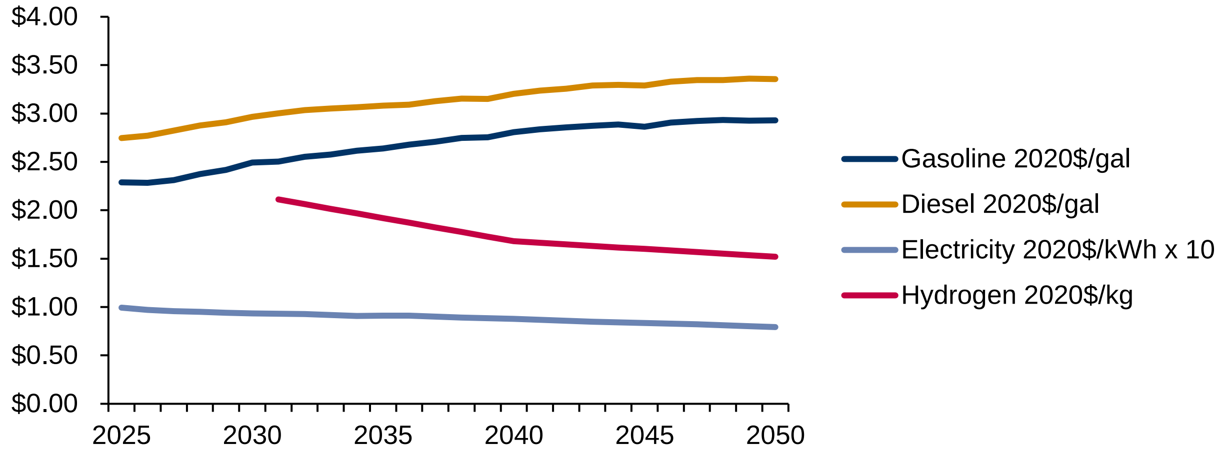
[21] Minnesota Electricity Profile 2020, *State Electricity Profiles* (U.S. Energy Information Administration, U.S. Department of Energy, November 2021), tables 4 and 5, https://www.eia.gov/electricity/state/minnesota/xls/mn.xlsx

[22] Governor Walz, Lieutenant Governor Flanagan, House and Senate DFL Energy Leads Announce Plan to Achieve 100 Percent Clean Energy in Minnesota by 2040, *Press Release,* (Office of Governor Time Walz & Lt. Governor Peggy Flanagan, January 2021). https://mn.gov/governor/news/?id=1055-463873

A.2 Fuel Prices

Figure 16. Minnesota Average Fuel Costs



Gasoline and diesel prices used in this analysis are based on the West North Central regional prices of the EIA's Annual Energy Outlook 2021. These prices take into account long-term trends in fuel prices but do not consider short-term volatility such as being experienced currently.

The electricity price shown in Figure 16 represents an average commercial volumetric electricity rate where utility revenue from commercial electricity sales is divided by commercial electricity. The current Minnesota commercial electricity rate was calculated using EIA Form 861 for electricity sales and revenue by state and sector.[23] They are then adjusted through 2050 based on the EIA's Annual Energy Outlook 2021 projection for electricity prices for the West North Central region.[24] Once again, these are taking into account long-term price trends.

The hydrogen price is based on BloombergNEF's Hydrogen Economy Outlook renewable electrolysis price.[25]

A.3 Individual ZEV-ICE Parity

Shown in Figures 17-20 are the projected lifetime incremental costs for ZEVs compared with combustion vehicles broken out by Class 2B Trucks, Buses, Single-Unit Trucks, and Combination Trucks.

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[23] "Annual Electric Power Industry Report, Form EIA-861 detailed data files," US EIA October 2020, https://www.eia.gov/electricity/data/eia861/.

[24] "Annual Energy Outlook 2021," Reference Case Projections Tables, US Energy Information Administration (EIA), table 57.4, https://www.eia.gov/outlooks/archive/aeo21/tables_ref.php

[25] Hydrogen Economy Outlook, (BloombergNEF, March 2020). https://data.bloomberglp.com/professional/sites/24/BNEF-Hydrogen-Economy-Outlook-Key-Messages-30-Mar-2020.pdf

Figure 17. Projected Lifetime Incremental Costs for Class 2B ZEVs Compared with Combustion Vehicles

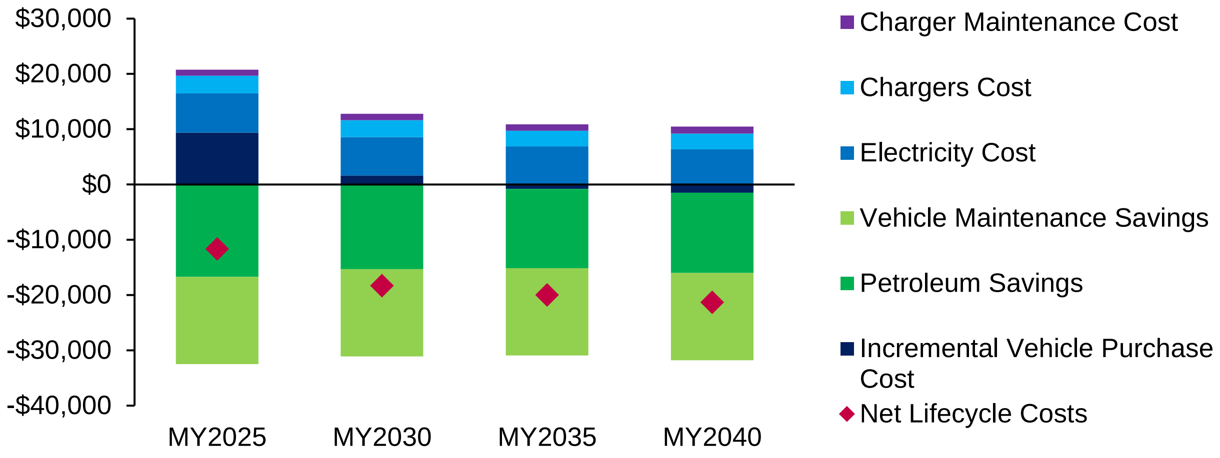

Table 4. Projected Lifetime Incremental Costs for Class 2B ZEVs Compared with Combustion Vehicles

		MY2025	MY2030	MY2035	MY2040
Per New ZEV	**Incremental Vehicle Purchase Cost**	$9,387	$1,615	-$821	-$1,516
	Chargers Cost	$3,178	$3,051	$2,843	$2,843
Per In-use ZEV Discounted Life-time	**Petroleum Savings**	($16,689)	($15,321)	($14,316)	($14,475)
	Electricity Cost	$7,123	$6,968	$6,866	$6,383
	Net Fuel Cost	($9,566)	($8,353)	($7,450)	($8,092)
	Vehicle Maintenance Savings	($15,767)	($15,767)	($15,767)	($15,767)
	Charger Maintenance Cost	$1,091	$1,138	$1,195	$1,228
	Net Lifecycle Costs	($11,677)	($18,316)	($20,000)	($21,303)

Figure 18. Projected Lifetime Incremental Costs for ZEV Buses Compared with Combustion Vehicles

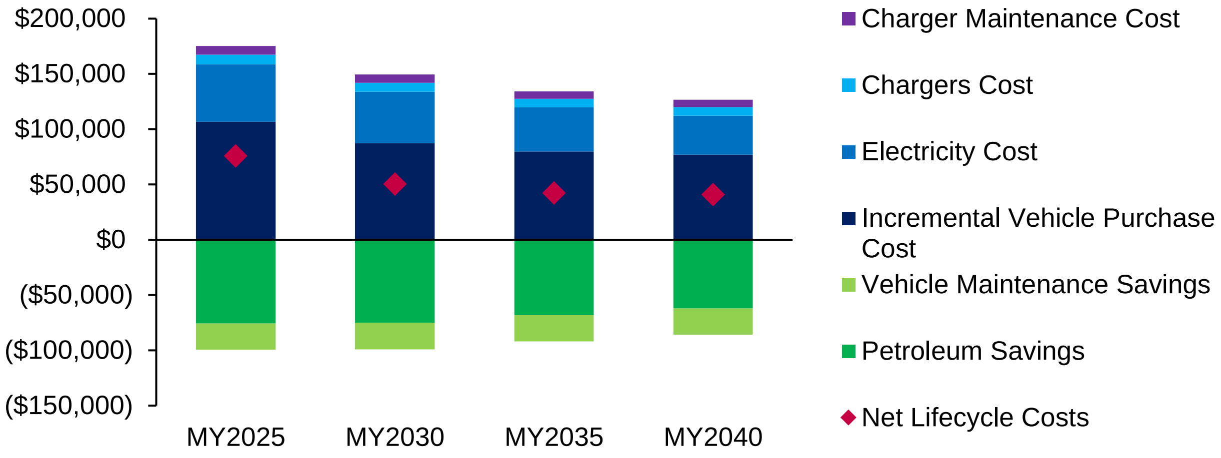

Table 5. Projected Lifetime Incremental Costs for ZEV Buses Compared with Combustion Vehicles

		MY2025	MY2030	MY2035	MY2040
Per New ZEV	**Incremental Vehicle Purchase Cost**	$106,648	$87,372	$79,839	$77,039
	Chargers Cost	$8,556	$8,223	$7,685	$7,685
Per In-use ZEV Discounted Life-time	**Petroleum Savings**	($75,652)	($75,237)	($68,219)	($62,165)
	Electricity Cost	$52,118	$46,427	$39,935	$35,302
	Net Fuel Cost	($23,534)	($28,810)	($28,284)	($26,863)
	Vehicle Maintenance Savings	($23,779)	($23,779)	($23,779)	($23,779)
	Charger Maintenance Cost	$7,849	$7,458	$6,834	$6,679
	Net Lifecycle Costs	$75,740	$50,465	$42,294	$40,760

Figure 19. Projected Lifetime Incremental Costs for ZEV Single-Unit Trucks Compared with Combustion Vehicles

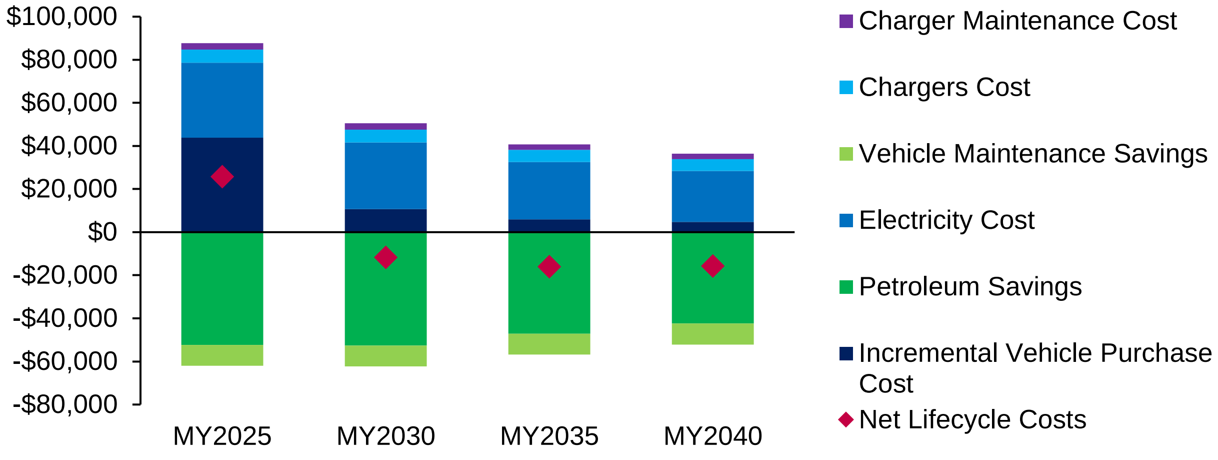

Table 6. Projected Lifetime Incremental Costs for ZEV Single-Unit Trucks Compared with Combustion Vehicles

		MY2025	MY2030	MY2035	MY2040
Per New ZEV	**Incremental Vehicle Purchase Cost**	$43,828	$10,705	$5,977	$4,789
	Chargers Cost	$6,226	$5,978	$5,572	$5,572
Per In-use ZEV Discounted Life-time	**Petroleum Savings**	($52,349)	($52,589)	($47,138)	($42,433)
	Electricity Cost	$34,739	$30,946	$26,618	$23,531
	Net Fuel Cost	($17,610)	($21,643)	($20,520)	($18,903)
	Vehicle Maintenance Savings	($9,694)	($9,694)	($9,694)	($9,694)
	Charger Maintenance Cost	$2,989	$2,840	$2,602	$2,543
	Net Lifecycle Costs	$25,739	($11,815)	($16,063)	($15,692)

Figure 20. Projected Lifetime Incremental Costs for ZEV Combination Trucks Compared with Combustion Vehicles

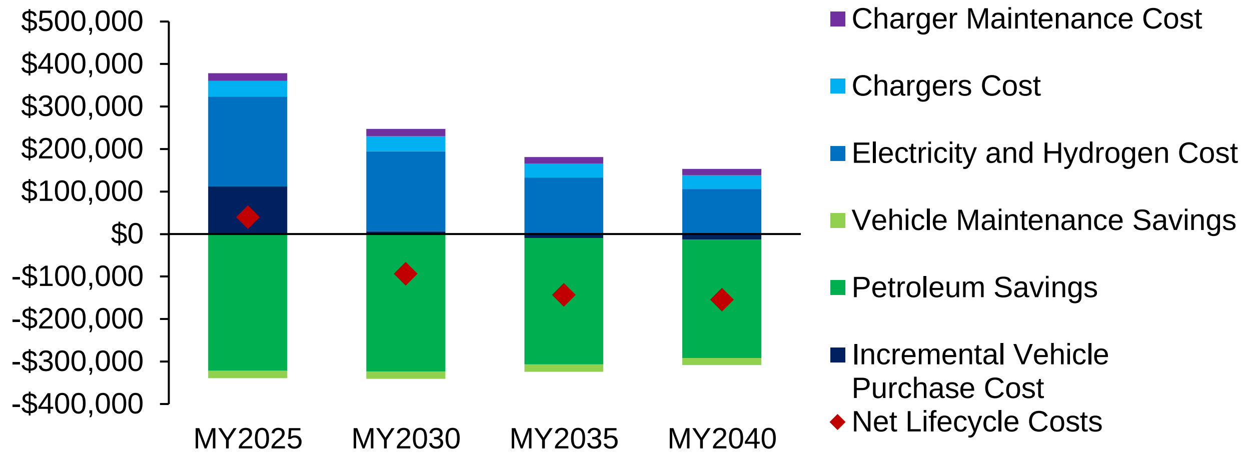

Table 7. Projected Lifetime Incremental Costs for ZEV Combination Trucks Compared with Combustion Vehicles

		MY2025	**MY2030**	**MY2035**	**MY2040**
Per New ZEV	**Incremental Vehicle Purchase Cost**	$111,571	$6,137	-$9,644	-$12,927
	Chargers Cost	$36,641	$34,903	$31,961	$31,961
Per In-use ZEV Discounted Life-time	**Petroleum Savings**	($322,028)	($323,734)	($297,298)	($278,566)
	Electricity and Hydrogen Cost	$212,043	$188,891	$133,093	$106,128
	Net Fuel Cost	($109,985)	($134,844)	($164,205)	($172,438)
	Vehicle Maintenance Savings	($17,199)	($17,199)	($17,199)	($17,199)
	Charger Maintenance Cost	$18,246	$17,335	$15,885	$15,525
	Net Lifecycle Costs	$39,274	($93,668)	($143,201)	($155,078)

A.4 Detailed Charging Infrastructure Costs

Table 8. Projected Annual Cost for Charging Infrastructure

		ACT Rule			MHD ZEV MOU			Aspirational		
		2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
Depot Chargers	**Purchase**	$23	$43	$46	$25	$52	$86	$32	$80	$86
	Installation	$10	$21	$23	$11	$25	$42	$14	$39	$42
	Maintenance	$4	$25	$46	$5	$28	$64	$6	$39	$77
	Total	**$37**	**$90**	**$115**	**$41**	**$105**	**$192**	**$52**	**$159**	**$205**
Public Chargers	**Purchase**	$18	$30	$33	$22	$44	$75	$26	$68	$75
	Installation	$10	$18	$20	$11	$27	$45	$13	$41	$45
	Maintenance	$3	$16	$30	$4	$20	$46	$4	$24	$47
	Total	**$31**	**$64**	**$82**	**$36**	**$90**	**$166**	**$43**	**$133**	**$167**
	Grand Total	**$68**	**$154**	**$197**	**$77**	**$195**	**$358**	**$95**	**$292**	**$371**

A.5 Cumulative Climate and Air Emissions Reductions

Table 9. Cumulative Emission Reductions Compared to Baseline

	ACT Rule			MHD ZEV MOU			Aspirational		
	2030	**2040**	**2050**	**2030**	**2040**	**2050**	**2030**	**2040**	**2050**
GHG (mill MT)	0.80	12.12	39.83	1.19	13.83	50.35	1.43	24.52	91.43
NOx (MT)	2,003	26,510	85,456	3,177	31,528	112,668	3,574	44,972	163,499
PM (MT)	24	238	768	38	286	1,010	46	632	2,321

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Brazil
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China
Colombia
France
Germany
Ghana
Guyana
Hong Kong
India
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Ireland
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The Netherlands
New Zealand
Peru
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