California Clean Trucks Program

An Analysis of the Impacts of Low NOx and Zero-Emission Medium- and Heavy-Duty Trucks on the Environment, Public Health, Industry, and the Economy

ERM

Acknowledgments

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This report was developed by ERM for the Natural Resources Defense Council and the Union of Concerned Scientists.

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Key Takeaways

- Accelerating the 100 percent ZEV sales date from 2040 to 2036 results in an increase of **more than 130,000 Class 2b to 8 ZEVs in 2050.** This leads to an increase in cumulative (2022 to 2050) **net societal benefits of $9.9 billion** due to reduced greenhouse gases (GHGs), improved air quality, higher utility net revenue, and fleet savings.
- These ZEVs would reduce cumulative (2020 to 2050) emissions of:
  - CO_2e by 24 million MT
  - NOx by over 30,000 MT
  - $PM_{2.5}$ by 1,040 MT
- Even with 100 percent ZEV sales by 2036, the Governor's goal outlined in E.O. N-79-20 of 100 percent zero-emitting medium- and heavy-duty vehicles (M/HDV) by 2045 would not be met—in 2045 more than **750,000 medium- and heavy-duty vehicles driving on California roads are not ZEVs**, roughly a third of all M/HDVs.
- Addressing emissions from out-of-state (OOS) vehicles remains a challenge. **Nearly 50 percent of all miles** driven by combination trucks in California are by OOS trucks. By 2050, OOS combination trucks account for 75 percent of all M/HDV GHG emissions under the "100% Sales by 2036" scenario.
- The average M/HD ZEV will provide between $48,000 and $84,000 in fuel and maintenance savings over its lifetime depending on model year. By 2040, the average M/HD ZEV will save vehicle owners more than $47,000 in net lifecycle costs over the vehicle's life.
- If the 100 percent ZEV sales requirement begins in 2040, the early accumulation of ZEV credits under the ACT, as fleets meet their in-use requirements, could suppress ZEV sales between 2036 and 2039 causing over 170,000 fewer M/HD ZEV sales compared to when the 100 percent ZEV sales requirement begins in 2036.

Introduction

ERM was commissioned by the Natural Resources Defense Council and the Union of Concerned Scientists to evaluate the costs and benefits of California's adoption of the Advanced Clean Fleets (ACF) regulation and the impact of changing the start date of the 100 percent sales requirement. The analysis examines all on-road vehicles registered in California with greater than 8,501 pounds gross vehicle weight, encompassing vehicle weight classes from Class 2b though Class 8. This is a diverse set of mostly commercial vehicles that includes heavy-duty pickups; school and shuttle buses; sanitation, construction, and other types of work trucks; and freight trucks ranging from local delivery vans to tractor-trailers that weigh up to 80,000 pounds when loaded.

Collectively the California M/HD fleet includes 1.86 million vehicles that annually travel more than 33.7 billion miles and consume 3.7 billion gallons of petroleum-based fuels.

California passed the Advanced Clean Trucks (ACT) regulation in 2020 and the Heavy-Duty Omnibus (NOx Omnibus) regulation in 2021. The ACT requires an increasing percentage of new trucks sold in the state to be ZEVs beginning in the 2024 model year. The percentage of new vehicles that must be ZEV varies by vehicle type, but the required ZEV percentages increase through 2035. Among other things, the NOx Omnibus regulation establishes a 75 percent lower nitrogen oxide (NOx) emissions limit from the engines in new gasoline and diesel trucks sold between model year 2024 and 2026, and a 90 percent lower standard for trucks sold beginning in the 2027 model year. The NOx Omnibus regulation also sets new requirements to ensure in-use heavy-duty vehicles continue to control emissions throughout their useful lives. Combined, the ACT and NOx Omnibus regulations reduce greenhouse gas and criteria pollutant emissions from California's M/HD fleet. However, adoption of the ACF will significantly decrease M/HDV emissions.

In California, M/HD vehicles are currently responsible for a disproportionate amount of pollution from on-road vehicles. Despite making up only 7 percent of the on-road fleet, M/HD vehicles emit an estimated 47.9 million metric tons (MMT) of greenhouse gas (GHG) emissions annually—approximately 27 percent of all GHGs from the on-road vehicle fleet.[1] In California, M/HD vehicles are also responsible for 62 percent of the nitrogen oxide (NOx) and 56 percent of the particulate matter (PM[2]) emitted by on-road vehicles, both of which contribute to poor air quality and resulting negative health impacts in many urban areas, including low-income and communities of color that are often disproportionately affected by emissions from freight movement due to their proximity to transportation infrastructure.

Prior work by ERM (2020) conducted in consultation with the New Jersey Environmental Justice Alliance and members of the Coalition for Healthy Ports NY NJ demonstrated that emissions from diesel trucks and buses produce higher levels of air pollution, which can lead to greater health concerns in populations exposed to diesel emissions.[3] Communities located adjacent to goods-movement infrastructure (e.g., warehouses, intermodal terminals, logistics centers, rail yards, etc.) experience higher levels of truck traffic, both from surrounding thruways and on local streets, which exacerbates health concerns. Since these emissions are local in their effects, policies to reduce transportation emissions from medium- and heavy-duty vehicles can improve the health and well-being of communities in urban areas or around transportation corridors, which are often home to people of color or low income or those who are otherwise vulnerable or disadvantaged. But to ensure reductions in those communities, program requirements on truck manufacturers would need to be accompanied by additional policies designed specifically with these communities in mind.

1 The remainder of emissions are from passenger cars and light trucks. This includes tailpipe emissions and "upstream" emissions from fuel production and transport.

2 In this report all references to PM are particulate matter with mean aerodynamic diameter less than 2.5 microns (PM2.5).

3 MJB&A, *Newark Community Impacts of Mobile Source Emissions: A Community-Based Participatory Research Analysis*, November 2020, http://www.njeja.org/wp-content/uploads/2021/04/NewarkCommunityImpacts_MJBA.pdf.

For the study of California, ERM modeled three scenarios with increasing levels of ambition. Under the least aggressive scenario—adoption of the ACF rule with 100 percent sales requirement for all M/HDV classes starting in 2040—estimated cumulative net societal benefits total $72.1 billion (in constant 2020$) through 2050, compared with the Baseline (ACT) scenario.[4] These net societal benefits include the monetized value of climate and public health benefits resulting from reduced GHG, NOx, and PM emissions in the state, including up to 2,413 fewer premature deaths and 1,880 fewer hospital visits from breathing polluted air. Net societal benefits also include net cost savings to fleets from operating zero-emission trucks, and savings to all residential and commercial electricity customers due to lower electric rates made possible by the additional electricity sales for electric vehicle charging. Under the "100% Sales by 2040" scenario, by 2050 annual cost savings for California fleets are estimated to be $2.1 billion, and annual bill savings for electric utility customers in the state could reach an estimated $728 million. [5] The California Air Resources Board (CARB) found the cumulative benefits of adopting the ACF are $61.7 billion in health benefits and between $9.5 and $37.4 billion in social cost of carbon benefits.[6]

The most aggressive policy scenario (ACF rule with 100 percent sales requirement for all M/HDV classes starting in 2036) results in cumulative net societal benefits through 2050 increasing to more than $82.1 billion and an estimated 2,647 fewer premature deaths and 2,067 fewer hospital visits. In 2050, estimated annual fleet cost savings also increase to $2.4 billion, and electric customer annual bill savings increase to an estimated $771 million.

Policy Scenarios

This report summarizes the projected environmental and economic effects of California adopting policies requiring manufacturers to sell a greater number of M/HDV low- and no-emission vehicles over the next 30 years. Three specific scenarios, representing increasing levels of ambition, were evaluated. See Figure 1 for the estimated ZEV sales under each of the scenarios shown below.

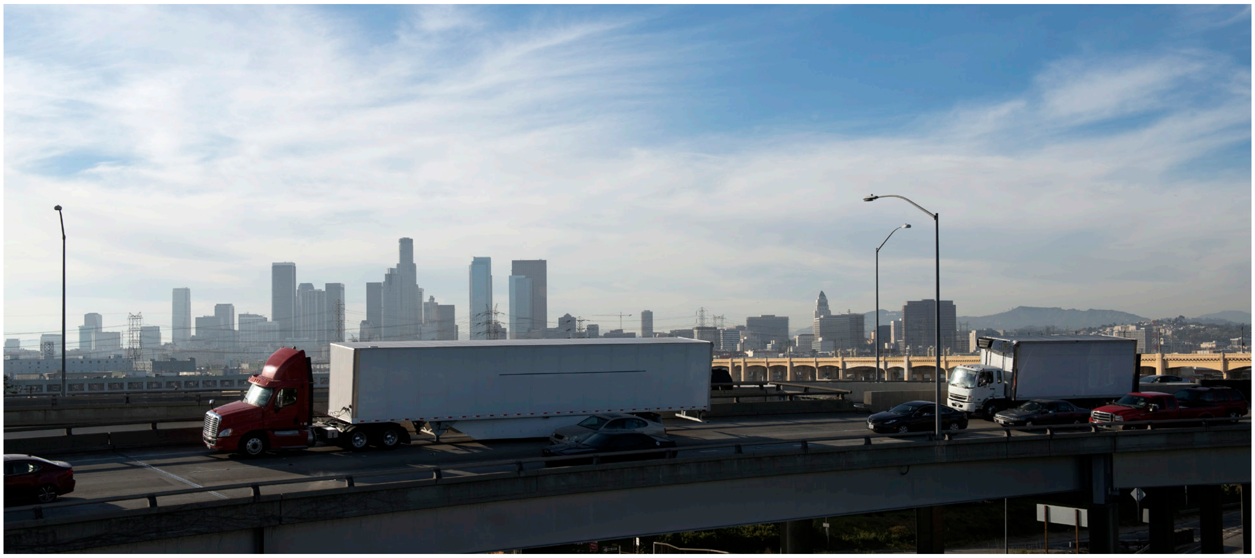
- **100% Sales by 2036 by 2040:** California adopts the ACF with a sales requirement for all M/HDV classes reaching 100 percent by 2040. This scenario is consistent with the draft regulatory language currently proposed. As can be seen in Figure 1, the ZEV sales under this scenario decline between 2036 and 2039. During the first decade of the ACT and ACF, fleet owners buy ZEVs above the ACT manufacturers requirement to meet their in-use ACF fleet requirements, causing manufacturers to accumulate ZEV credits. This allows manufacturers to sell fewer ZEVs from 2036 to 2039 once fleet owners have met their in-use requirements. Once the 100 percent sales mandate begins, manufactures are required to only sell ZEVs regardless of any credits they have accumulated causing ZEV sales to rise once again.
- **100% Sales by 2036 by 2036 Except Combination Trucks:** California adopts the ACF with a 100 percent sales requirement for combination trucks (CTs) in 2040, but all other M/HDV classes would have to meet a 100 percent sales requirement starting in 2036.
- **100% Sales by 2036 by 2036:** California adopts the ACF with a 100 percent sales requirement for all M/HDV classes beginning in 2036.

4 All values cited in this report are in constant 2020$, unless otherwise stated.

5 The modeling tools used for this analysis could not apportion these estimated benefits to individual communities within California.

6 "Advanced Clean Fleets Regulation: Standardized Regulatory Impact Assessment," California Air Resources Board, May 18, 2022.

While the analysis the California Air Resources Board (CARB) conducted assumes a share of vehicles migrate out of California and the ZEVs that migrate out will not produce any benefits, this analysis still includes those benefits. This causes the estimated impact of the ACT in this analysis to be higher than it is in CARB's analysis. While this is also true for the ACF, it is to a lesser extent since a portion of the ACF applies to in-use vehicles and the regulation is not met if those vehicles migrate out of the state. This causes the benefits of adopting the ACF in this analysis to seem smaller than they are in CARB's analysis when compared to the ACT.



All three of these California policy scenarios are compared with a baseline "business-as-usual" scenario which includes California's adoption of the ACT and the NOx Omnibus regulations. It should be noted that the Baseline (ACT) scenario differs from CARB's ACT due to their ZEV projections accounting for vehicle migration. CARB assumes varying percentages of Class 4 to 8 vehicles migrate out of the state and non-ZEV vehicles migrate in to replace them, thus reducing the number of in-state ZEVs. While these ZEVs may migrate out of the state, they are still providing climate benefits to Californians and air quality and fleet savings benefits to the residents of the states the vehicles end up in.

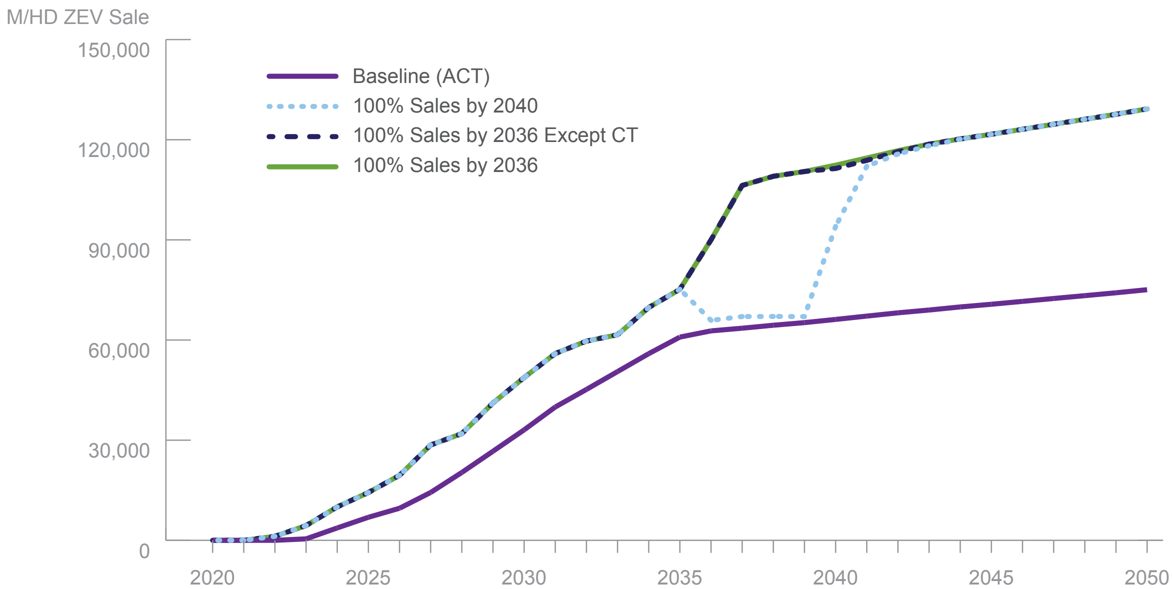
The analysis assumes that M/HD annual vehicle population in California will continue to grow by approximately 1.0 percent annually through 2050, as projected by the most recent California Air Resources Board's Emission Factors Model (EMFAC2021), as the economy and population continue to grow. The modeled policy scenarios do not include freight system enhancements or mode shifting to slow the growth of, or reduce, M/HD truck miles; this would be expected to provide additional emission reductions.

This study was conducted using vehicle population, model year sales, vehicle miles traveled, and tailpipe emission factors from EMFAC. The climate and air quality impacts of each policy scenario were estimated on the basis of changes in M/HD 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 used by ZEVs.

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). To evaluate air quality impacts, the analysis estimated changes in total nitrogen oxide (NOx) and particulate matter (PM) emissions and resulting changes in ambient air quality and health metrics such as premature deaths, hospital visits, and lost workdays.

The economic analysis estimated the change in annual M/HD fleet-wide spending on vehicle purchase, charging/fueling infrastructure to support ZEVs, vehicle fuel, and vehicle and infrastructure maintenance under each scenario. Currently ZEVs are more expensive to purchase than equivalent gasoline and diesel vehicles, but they have lower fuel and maintenance costs. Over time the incremental purchase cost of ZEVs is also projected to fall. Technologies required to meet the more stringent NOx standards of the NOx Omnibus Rule are also projected to increase purchase costs for compliant vehicles.

Figure 1 Annual Zero-Emission Vehicle Sales in Scenarios



The analysis also estimated the impact of each scenario on California's electric utilities, including the total state change in power demand (kW) and energy consumption (kWh) for M/HD EV charging, as well as the additional revenue and net revenue that would be received by the state's electric utilities for providing this power. On the basis of projected utility net revenue, the analysis estimates the potential effect on state electricity rates for residential and commercial customers.

In addition, the analysis estimated the total number of vehicle chargers that will be required to support the increase in M/HD EVs under each scenario—both depot-based chargers and shared public chargers—compared with the existing charging network in the state.

For a full description of the modeling approach and sources of assumptions used for this analysis, see the report: *Clean Trucks Analysis: Costs & Benefits of State-Level Policies to Require No- and Low-Emission Trucks, Technical Report—Methodologies and Assumptions*, May 2021 *(*https://mjbradley.com/clean-trucks-analysis*)*.

The California electric grid mix and energy cost assumptions used can also be found in the Appendix to this report.

California Results

The sections below detail the results of the California Clean Trucks analysis, beginning with a description of the current California M/HDV fleet and the projected fleet under each modeled policy scenario. This is followed by a summary of the environmental and public health benefits of each scenario and the economic impacts of the modeled fleet transitions.

California M/HD Vehicle Fleet

Table 1 summarizes the current M/HD fleet in California, broken down by the four major vehicle types used to frame the Clean Trucks analysis.

Table 1 Current California M/HD Fleet

Vehicle Type		No. of Vehicles	Annual VMT (billion miles)	Annual Fuel (million gallons)
Heavy-Duty Pickup and Van **Class 2b**		955,700	10.8	575
Bus **Class 3–8**		53,032	0.5	64
Single-Unit Work and Freight Truck **Class 3–8**		626,754	9.2	1,119
Combination Truck **Class 7–8**		210,634	13.2	1,913
TOTAL		**1,846,120**	**33.7**	**3,671**

Approximately 52 percent of the in-use M/HD fleet are Class 2b vehicles (8,500–10,000 in gross vehicle weight rating, GVWR), which are mostly heavy-duty pickup trucks and vans.[7] These vehicles account for 32 percent of annual M/HD miles and 16 percent of annual fuel use. Approximately 3 percent of the fleet are buses, which account for 2 percent of annual VMT and 2 percent of annual fuel use. This includes school buses and intercity/charter coach buses.[8] Thirty-four percent of the fleet are single-unit freight and work trucks, which account for 27 percent of annual VMT and 30 percent of annual fuel use. These vehicles come in a wide variety of sizes (Class 3–8) and have a wide variety of uses, from vans and box trucks used to deliver freight, to sanitation and construction trucks, to boom-equipped utility trucks. Only 11 percent of the fleet are combination truck-tractors, but these vehicles account for 39 percent of annual VMT and 52 percent of annual fuel use, since approximately two-thirds of these vehicles are used primarily for long-distance freight hauling and typically log many more daily and annual miles than other M/HD vehicles.

Today less than 1 percent of the national M/HD fleet is powered by electricity or alternative fuels (natural gas and propane). Approximately 64 percent of the fleet have diesel engines and 36 percent use gasoline.[9] The largest Class 7 and 8 vehicles are almost all diesel, while almost 50 percent of the smaller Class 2b to 6 trucks have gasoline engines, with most of the remainder diesel.

Figure 2 summarizes the modeled turnover of the California in-use fleet to zero-emission trucks under the three scenarios and the baseline. Fleet turnover to new trucks is based on data from EMFAC2021. Along with the modeled scenarios, the figure also illustrates the total M/HD vehicles projected for California (orange hashed line), which include in-state and out of state vehicles driving on California roads. Finally, the figure shows the number of ZEVs the California Air Resources Board (CARB) projects under the ACT (gray hashed line) and the currently drafted ACF regulation (yellow dotted line which has a 100 percent sales requirement starting in 2040 for all vehicle classes. As mentioned previously, the difference between the CARB ACT and the Baseline (ACT) ZEV trajectories is CARB's accounting for vehicle migration. For vehicle class specific figures, see the Appendix.

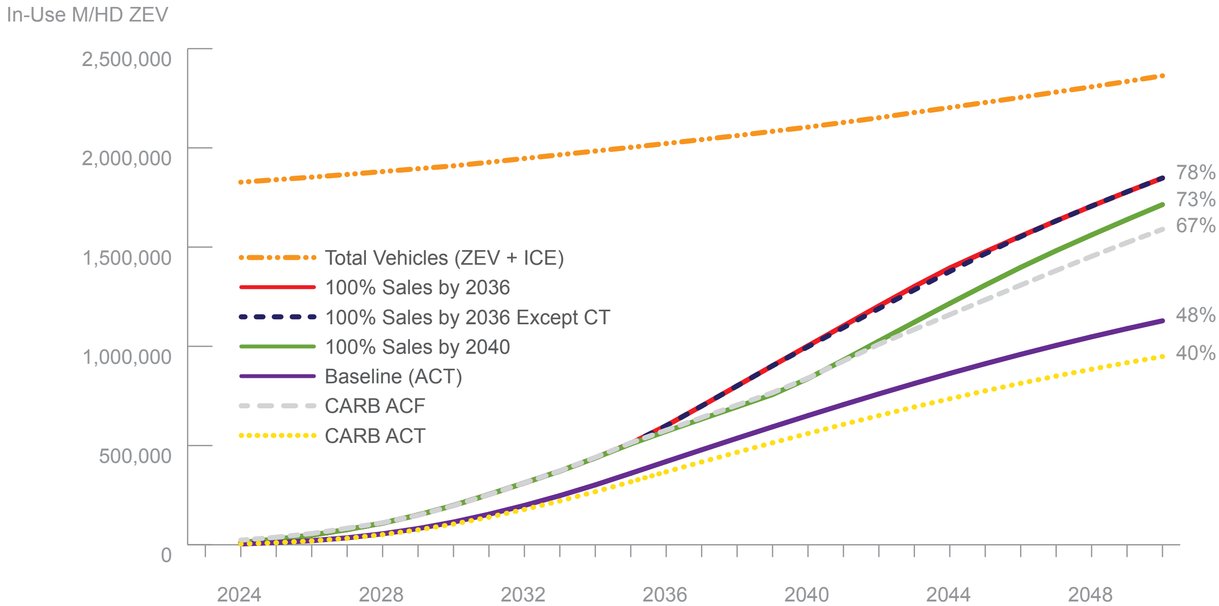
As shown, under the "100% Sales by 2040" scenario, 40 percent of the in-use M/HD fleet will turn over to ZEV by 2040, and 73 percent are ZEV by 2050. Under the "100% Sales by 2036 Except Combination Trucks" scenario, 47 percent of in-use M/HDVs turn over to ZEV by 2040 and 78 percent are ZEV by 2050. Under the "100% Sales by 2036" scenario, 48 percent of the in-use fleet turns over to ZEV by 2040 and 78 percent do so by 2050. By shifting the 100 percent ZEV sales year from 2040 to 2036, California has 133,900 additional M/HD ZEVs on the road in 2050, an 8 percent increase. All of these ZEVs are assumed to be electric vehicles.

7 A very small percentage of these vehicles are large SUVs.

8 Note that the ACF Rule does not include ZEV requirements for transit buses, as these vehicles are covered by a separate Innovative Clean Transit regulation in California.

9 These figures are based on state registration data collected by IHS Markit.

Figure 2 Fleet Zero-Emission Vehicles in Scenarios



Changes in Fleet Fuel Use

Under all modeled scenarios, a significant portion of the California M/HD fleet is assumed to turn over to ZEV trucks and buses. This will result in replacement of petroleum fuels—primarily gasoline and diesel fuel—with electricity.[10]

Under the Baseline (ACT) scenario, total petroleum fuel use by the California M/HD fleet in 2050 is projected to be 3.04 billion gallons. Under the "100% Sales by 2040" scenario, petroleum fuel use in 2050 falls to an estimated 1.78 billion gallons (–41 percent), and cumulative reductions in diesel and gasoline use by the M/HD fleet total 17.3 billion gallons between 2020 and 2050. This petroleum fuel is replaced by 304 million megawatt-hours (MWh) of electricity between 2020 and 2050. Electricity use for M/HD EV charging in 2050 is estimated to be 23.3 million MWh, a 10.6 percent increase to estimated baseline electricity use by California residential and commercial customers that year (220.2 million MWh).

Under the "100% Sales by 2036" scenario, estimated petroleum fuel use by the M/HD fleet in 2050 falls to 1.68 billion gallons (–45 percent), and cumulative reductions in diesel and gasoline use by the M/HD fleet total 19.5 billion gallons between 2020 and 2050. This petroleum fuel is replaced by 340 million MWh of electricity between 2020 and 2050. Electricity use for M/HD EV charging in 2050 is estimated to be 25.3 million MWh, an 11.5 percent increase to estimated baseline electricity use by California residential and commercial customers that year.

10 A small number of M/HD trucks and buses in California currently use natural gas.

Public Health and the Environment

The modeled policy scenarios produce significant reductions in NOx, PM, and GHG emissions from the M/HD fleet, even after accounting for the emissions from producing the electricity needed to power ZEVs. NOx and PM reductions will improve air quality resulting in public health benefits from reduced mortality and hospital visits.

Air Quality Impacts

The emission estimates include tailpipe, petroleum production, and electricity production emissions for NOx and PM as well as brake-wear emissions for PM. Due to regenerative braking, ZEVs are expected to have a 50 percent reduction in brake-wear PM emissions compared to ICE vehicles. Figures 3 and 4 show estimated annual M/HD fleet NOx and PM emissions, respectively, under the Baseline (ACT) scenario and the modeled scenarios. Under the Baseline (ACT) scenario, annual M/HD fleet NOx emissions are projected to fall by 48 percent and annual fleet PM emissions are projected to fall 21 percent through 2045, as the current fleet turns over to new, low-NOx gasoline and diesel trucks. Annual NOx and PM emissions are then projected to start rising again around 2040 as annual fleet VMT continues to grow.

Figure 3 Projected M/HD Fleet NOx Emissions

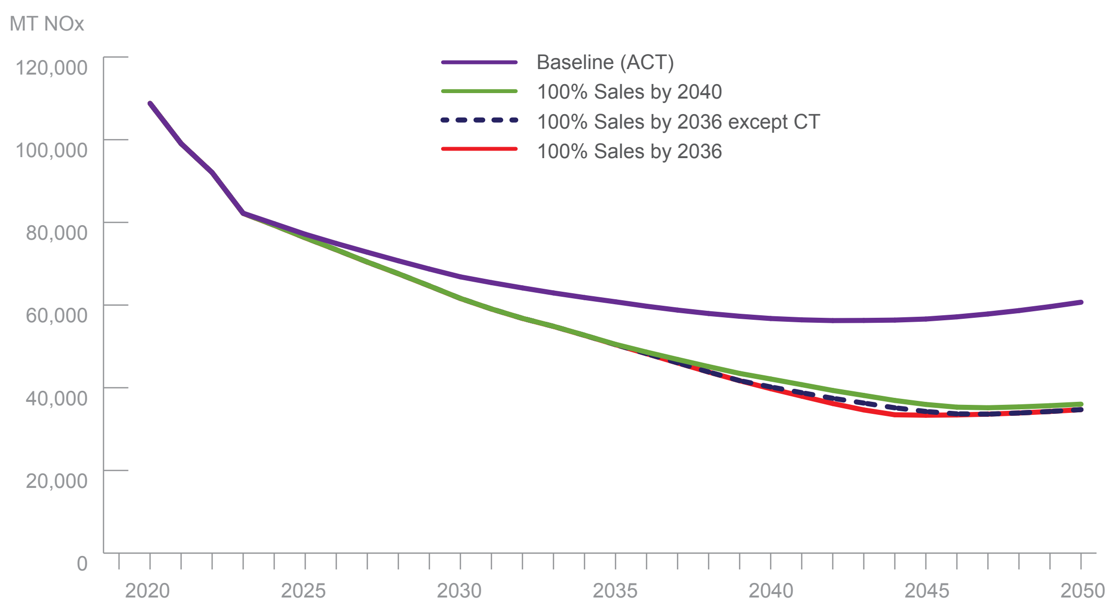
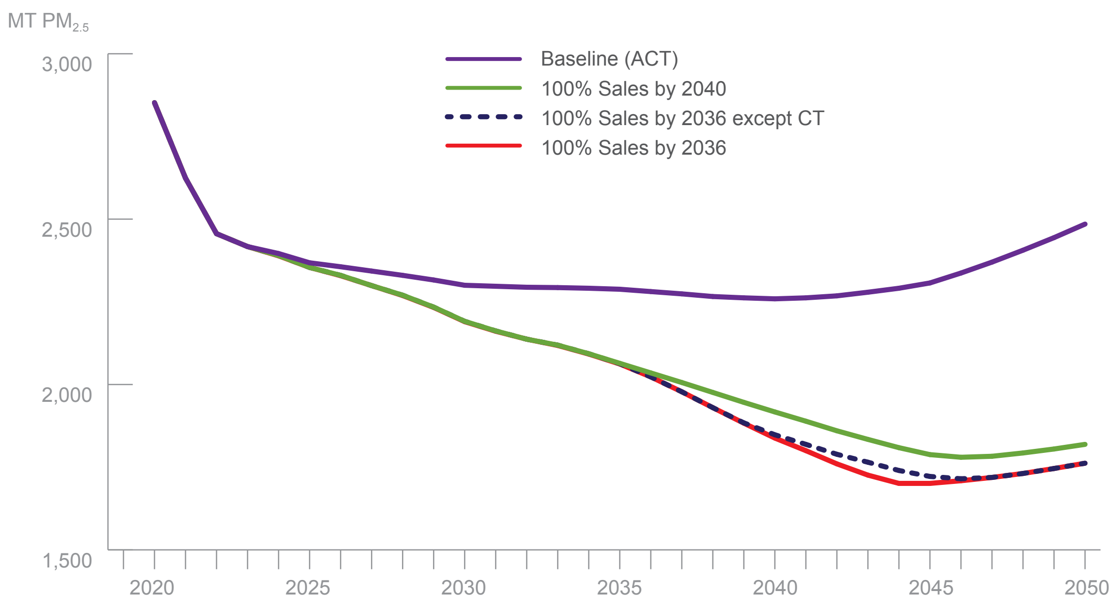


Figure 4 Projected M/HD Fleet PM Emissions



As shown in Figures 3 and 4, the 2050 emission levels are dramatically lower for all scenarios compared to 2020 levels. The "100% Sales by 2036" scenario, for example, contributes to reductions that are 68 percent lower in nitrogen oxide (NOx) and 38 percent lower in PM in 2050 compared to 2020 levels.

Compared with the baseline, by 2050 the "100% Sales by 2040" scenario is estimated to reduce annual fleet NOx and PM emissions by 41 percent and 27 percent, respectively, as diesel and gasoline trucks are replaced with electric vehicles. By 2050, compared to the Baseline (ACT) annual NOx and PM emissions are projected to be 43 percent and 29 percent, respectively, lower than under the baseline under the "100% Sales by 2036 Except Combination Trucks" and "100% Sales by 2036" scenarios. Since these two scenarios have the same vehicle population in 2050, they also have the same emissions in 2050.

Over the next 30 years, cumulative NOx and PM emission reductions from the ACF regulation with a 100 percent ZEV sales requirement in 2040 (compared with the Baseline (ACT) scenario) total 330,300 metric tons (MT) and 7,980 MT, respectively. Additional cumulative NOx and PM reductions under the "100% Sales by 2036 Except Combination Trucks" scenario are estimated at 22,700 MT and 400 MT, respectively, over the same time. Cumulative NOx and PM emission reductions from the most aggressive scenario ("100% Sales by 2036") are projected to total 30,100 MT and 1,040 MT more than under the "100% Sales by 2040" scenario, respectively.

Public Health Benefits

The reduced annual NOx and PM emissions under the scenarios will lower ambient particulate levels in the air, which will reduce the negative health effects on California residents breathing in these airborne particles.[11] 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. Estimated cumulative reductions in these health outcomes in California under the modeled scenarios are shown in Table 2; these benefits were estimated using the U.S. Environmental Protection Agency's CO-Benefits Risk Assessment (COBRA) Health Impacts Screening and Mapping Tool.

Table 2 Cumulative Public Health Benefits of Scenarios, 2020–2050

Health Metric	100% Sales by 2040	100% Sales by 2036 except CT	100% Sales by 2036	Difference Between 100% Sales by 2040 and 2036
Avoided Premature Deaths	2,413	2,593	2,647	+233
Avoided Hospital Visits[a]	1,880	2,025	2,067	+186
Other Health Incidences Avoided (millions)[b]	1.93	2.08	2.13	+0.19
Monetized Value, 2020$ (billions)	$27.4	$29.4	$30.1	+$2.7

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.

The monetized value of cumulative public health benefits under the "100% Sales by 2040" scenario over the next 30 years totals more than $27.4 billion. Moving the 100 percent ZEV sales requirement to 2036 for all M/HDV categories except combination trucks would increase the monetized value of cumulative net public health benefits to $29.4 billion. The monetized value of cumulative public health benefits under the "100% Sales by 2036" scenario totals $30.1 billion through 2050.

Climate Benefits

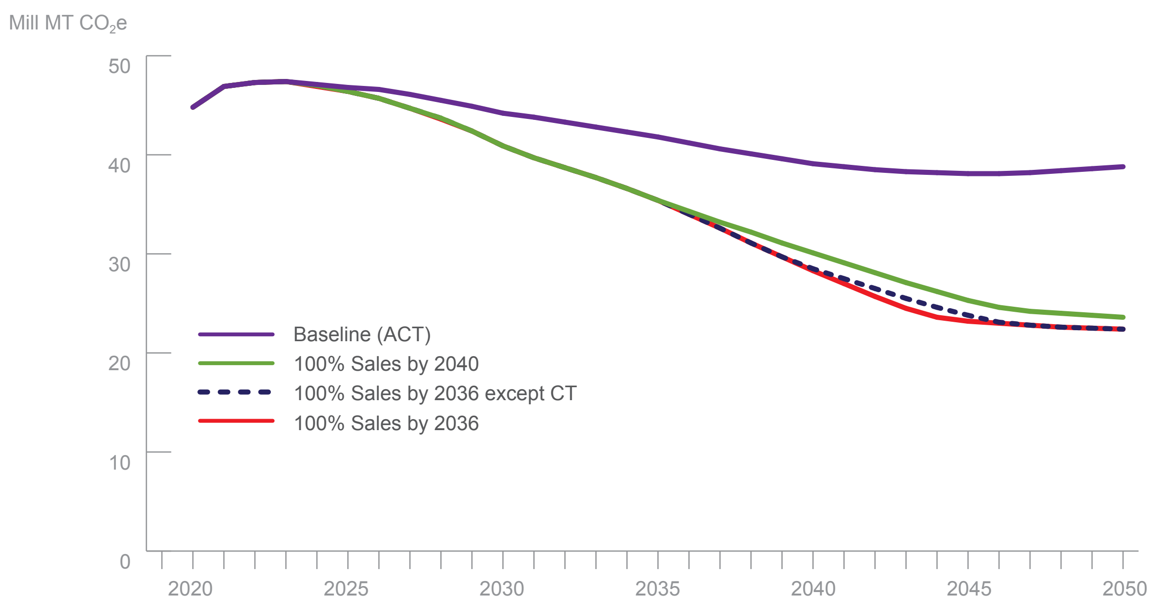
Figure 5 illustrates estimated annual M/HD fleet GHG emissions under the Baseline (ACT) scenario and the modeled scenarios. As shown, under the Baseline (ACT) scenario, annual M/HD fleet GHG emissions are projected to fall by 16 percent through 2050 as the current fleet turns over to new, more efficient gasoline and diesel trucks that meet more stringent California and EPA new engine and vehicle emission standards, as well as the adoption of ZEVs under the Baseline (ACT) scenario.

11 PM is directly emitted to the atmosphere from combustion sources as solid particles. NOx is emitted from combustion sources as a gas but contributes to the formation of secondary particles via chemical reactions in the atmosphere. Both direct and secondary particles have negative health effects when taken into the lungs.

Compared with the baseline, by 2050 the "100% Sales by 2040" scenario is estimated to further reduce annual fleet GHG emissions by 42 percent, as more diesel and gasoline trucks are replaced with electric vehicles.

The "100% Sales by 2036" scenario has the lowest fleet emissions due to replacement of more gasoline and diesel trucks and buses with ZEVs by 2050, when annual fleet GHG emissions are estimated to be 46 percent lower than baseline emissions.

Figure 5 Projected M/HD Fleet GHG Emissions



Over the next 30 years, cumulative GHG emission reductions under the "100% Sales by 2040" scenario (compared with the Baseline (ACT) scenario) total 204 million MT. Cumulative GHG emission reductions from the "100% Sales by 2036" scenario (compared with the baseline) are projected to total 228 million MT. These estimates of GHG reductions from each policy scenario account for reductions in petroleum fuel use (gasoline, diesel fuel) by the M/HD fleet, the decreased upstream emissions from gasoline and diesel production, as well as increased emissions from electricity production to fuel EVs that will replace gasoline and diesel trucks and buses.

Using the social cost of greenhouse gases as estimated by the federal government's Interagency Working Group, these estimated cumulative GHG reductions have a monetized value of $15.7 billion for the "100% Sales by 2040" scenario, and $17.7 billion for the "100% Sales by 2036" scenario.[12] The social value of GHG reductions represents the monetary value of the net harm to society associated with the impacts of incremental

12 For the social cost values used, see Lowell, Dana et al. Clean Trucks Analysis: Costs & Benefits of State-Level Policies to Require No- and Low-Emission Trucks, Technical Report—Methodologies & Assumptions. M.J. Bradley & Associates. June 10,2021. https://mjbradley.com/clean-trucks-analysis.

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.[13]

By moving the 100 percent sales year from 2040 to 2036, cumulative GHG emissions are reduced by 24.2 MMT between 2020 and 2050, a 12 percent increase in reductions.

The assumed California grid mix for electricity generation each year is shown in the Appendix. For all scenarios, this analysis uses a business-as-usual (BAU) grid mix projected by the Integrated Planning Model (IPM). In 2020, California's grid mix is 1.4 percent coal-fired generation, 46.8 percent natural gas–fired generation, and 51.7 percent "zero-emitting" generation sources.[14] By 2050 the zero-emitting portion of the BAU grid mix increases to 96.9 percent while the natural gas-fired generation drops to 1.6 percent and the coal-fired generation stays steady at 1.5 percent.

Economic Impacts

This section summarizes projected economic impacts of the modeled scenarios, including changes in annual operating costs for California fleets; impacts to California electric utilities and their customers; net societal benefits; and macroeconomic effects on jobs, wages, and gross domestic product from the transition to low-NOx and zero-emission trucks and buses. This section also estimates the required public and private investment in electric vehicle charging infrastructure to support the electric M/HD fleet under each scenario.

Costs and Benefits to Fleets

For all modeled scenarios, this analysis estimated annual incremental costs associated with purchase and use of M/HD ZEVs compared to baseline conventional vehicles with combustion engines operated on petroleum fuels (gasoline, diesel). These costs include the incremental purchase cost of the new ZEVs added each year (instead of new combustion vehicles), the cost of installing the charging and hydrogen fueling infrastructure required by these new ZEVs, and net fuel and maintenance costs for all ZEVs in the fleet, both those newly purchased each year, and those purchased in prior years and still in use.

Net fuel costs include reductions in purchases of diesel fuel and gasoline (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.

13 The Interagency Working Group developed GHG social cost estimates using a range of discount rates. These values are based on the average 3 percent discount rate, which is in the middle of the range of estimated values. The monetized value of cumulative GHG reductions under each policy scenario would be 72 percent lower if using the lowest published social cost values, and three times greater if using the highest published values.

14 For this analysis, coal-fired generation includes oil and biomass. Zero-emitting sources include nuclear and renewable sources such as wind, solar, and hydropower.

Figure 6 Projected Lifetime Incremental Costs for California ZEVs Compared with Combustion Vehicles

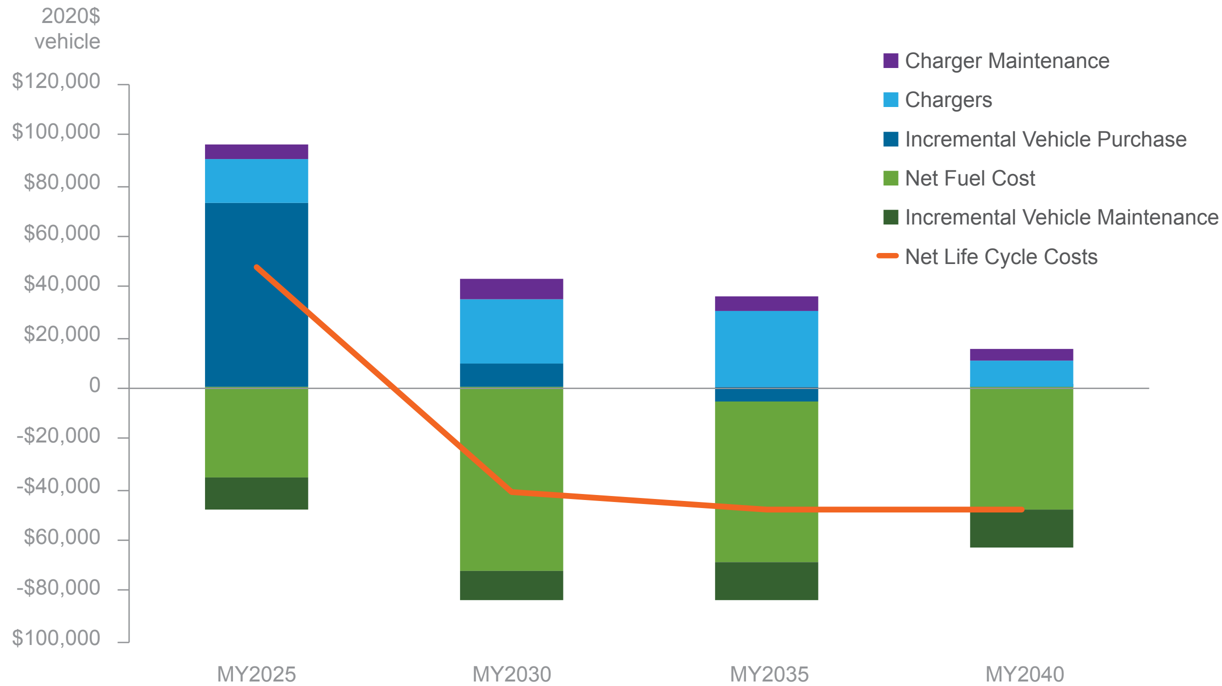


Figure 6 shows projected average lifetime incremental costs for new ZEVs purchased in California compared with lifetime costs for combustion vehicles purchased in the same model year; the bars show fleet average values for all Class 2b–8 ZEVs purchased each year under the "100% Sales by 2036" scenario. 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.

As shown, the average M/HD ZEV in California is projected to produce between $48,000 and $84,000 in discounted fuel and maintenance cost savings over its lifetime depending on the model year of the vehicle. For ZEVs purchased in the very near term, this savings may not be enough to offset the projected incremental cost of vehicle purchase and fueling infrastructure for some ZEVs, resulting in net increased lifetime costs compared with those of combustion vehicles. 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 over $47,000 in discounted lifetime net savings (2020$) compared with the costs of an equivalent combustion vehicle.

It is important to reiterate that the values in Figure 6 are fleet average values, which mask a significant amount of variability across vehicle types and among different fleets of the same vehicle type. Also note that the utility impact analysis (in the next section) indicates that the cost of providing power to charge M/HD EVs is lower than expected utility revenue under current rate structures. This suggests that California could consider changes to rates that would not only be fairer for fleets, but also lower electricity costs for M/HD EV charging, thus reducing net fleet operating costs further than estimated here. However, this would reduce the potential benefits that would accrue to other ratepayers from M/HD vehicle charging (see discussion below).

M/HD ZEVs in some fleets will likely achieve lifetime cost parity with combustion vehicles much earlier than 2030, while others may lag. In addition, this analysis, and the values shown in Figure 6, assume no government incentives for vehicle purchase or development of fueling infrastructure. If existing and potential incentives are considered, or policies such as improved electricity rates for fleets, then actual net costs to fleets will be lower, resulting in cost parity sooner. The California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program (HVIP) provides significant funding to purchase M/HD ZEVs. Through 2021, HVIP supported more than 1,580 fleet purchasers with over $600 million.[15]

Electric Utility Impacts

Current annual electricity sales to residential and commercial customers in California total 200 million MWh and are projected to grow to 220 million MWh in 2050.[16]

Under the "100% Sales by 2040" scenario, additional annual electricity sales for M/HD EV charging are estimated to total 4.8 million MWh in 2030, rising to 23.3 million MWh in 2050. This incremental load represents 2.3 percent and 10.6 percent of the total electricity demand in 2030 and 2050, respectively. Incremental monthly peak charging demand under this scenario is estimated at 1,350 MW in 2030, rising to 7,480 MW in 2050.

Under the "100% Sales by 2036" scenario, incremental peak charging demand is estimated at 1,350 MW in 2030, rising to 8,250 MW in 2050, and annual incremental electricity sales are estimated to be 4.8 million MWh in 2030, rising to 25.3 million MWh in 2050 (2.3 percent and 11.5 percent of the total electricity demand, respectively).

This analysis estimated the revenue that California electric utilities would receive from these incremental electricity sales, the marginal generation and transmission costs of providing this power, and the net revenue that utilities would earn (net revenue = revenue – marginal cost). The estimated marginal cost includes costs associated with procuring the necessary additional peak generation and transmission capacity to serve the load ($/MW) as well as marginal generation and transmission energy costs ($/MWh).

Figure 7 summarizes estimated annual utility net revenue from M/HD EV charging under the modeled scenarios. Under the "100% Sales by 2040" scenario, annual utility net revenue is projected to be $167 million in 2030, rising to $476 million in 2040 and $728 million in 2050. Under the "100% Sales by 2036" scenario, utility net revenue is projected to be $167 million in 2030, rising to $540 million in 2040 and $771 million in 2050.

In general, a utility's costs to maintain its distribution infrastructure increase each year with inflation, and these costs are passed on to utility customers in accordance with rules established by the California Public Utility Commission via periodic increases in residential and commercial electric rates. However, projected utility net revenue from increased electricity sales for M/HD EV charging would lower distribution rates ($/kWh), since fixed annual distribution system costs would be spread over a larger base of energy sales.

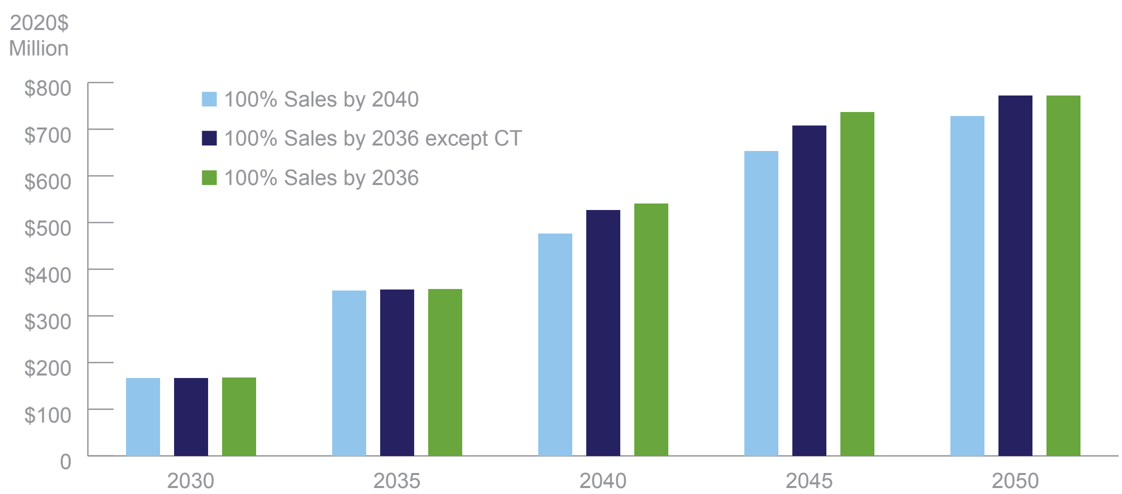
This analysis indicates that under the "100% Sales by 2036" scenario, by 2050, incremental utility net revenue from M/HD EV charging could potentially reduce average residential and commercial electricity rates in California by as much as 2.5 percent ($0.0068/kWh in 2020$). This could save the average California household $46 per year and the average commercial customer $426 per year on their electricity bills (2020$).[17]

15 "Building the Green Economy to Meet Climate Goals," *California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Program*, accessed on 21 June 2022, https://californiahvip.org/impact/.

16 This growth assumption is from the EIA 2021 Annual Energy Outlook. It does not include sales to large industrial customers.

17 Figures are based on average annual electricity use of 6,758 kWh per housing unit and 62,260 kWh per commercial customer in California.

Figure 7 Projected Annual Utility Net Revenue From M/HD EV Charging



Required Public and Private Investments

Using a detailed charging model that considers typical daily usage patterns for different vehicle types, this analysis assumes that most M/HD ZEVs in California will use overnight charging at their place of business, though about 10 percent will need to rely on a publicly accessible network of higher-power chargers.[18] The exception are combination trucks, 70 percent of which are assumed to require high-power public chargers since they are used primarily for long-haul freight operations.

Table 3 summarizes estimated charging infrastructure required to support M/HD electric trucks and buses under the scenarios.

Table 3 Projected Charging Infrastructure Required for Scenarios

Metric		**"100% Sales by 2040"**			**"100% Sales by 2036"**		
		2035	**2045**	**2050**	**2035**	**2045**	**2050**
In-Use Charge Ports	Depot	73,237	227,558	373,870	75,672	365,409	488,189
	Public 150 kW	783	2,058	3,720	823	3,801	5,205
	Public 500 kW	7,879	16,499	18,845	7,898	17,302	18,853
Cumulative Investment, 2020$ (billion)	Depot	$1.15	$2.72	$3.97	$1.15	$3.18	$4.43
	Public	$2.5	$5.40	$7.40	$2.5	$5.56	$7.56

18 See the methodology report for a detailed discussion of M/HD EV charging needs.

Depot chargers will need to be 10–50 kW per port depending on vehicle type. The smaller 150 kW public chargers are needed primarily to support single-unit freight trucks, while the higher-capacity 500 kW public chargers are needed mostly for combination trucks.

As of June 2022, there were 14,059 publicly accessible charging stations in California with a total of 7,298 direct current fast-charging (DCFC) ports (>50 kW).[19] Roughly half of these DCFC ports are Tesla superchargers that currently can be used only by Tesla owners.[20] In California, there are only 3,732 DCFC ports fully available to any vehicle.

Future public charging station sites will need to consider ease of access for M/HD vehicles, given their sheer size and maneuverability. M/HD vehicles are significantly larger than light-duty vehicles and cannot utilize most charging stations currently available since they are small parking spaces designed for passenger cars or light trucks. Charging stations designed for M/HD vehicles will require fundamental differences including the ability to "drive-through" the station as well as have high capacity DCFC ports to minimize vehicle downtime. Siting of these charging stations near major freight routes and industrial zones will also be a key element to their success.

Under the "100% Sales by 2040" scenario, California's fleet owners will have to invest an average of $159 million per year (2020$) between 2025 and 2050 to purchase and install depot-based charging infrastructure. The government and private investors will need to invest an average of $296 million per year over the same time period to build out a publicly accessible charging network across the state to serve the EV M/HD truck fleet.

Under the "100% Sales by 2036" scenario, fleet investments in depot charging infrastructure from 2025 to 2050 will need to increase to an average of $177 million per year, and public and private investments in the public charging network will need to rise to an average of $303 million per year.

Net Societal Benefits

The net societal benefits from the modeled California scenarios include the monetized value of public health and climate benefits, net cost savings for fleets, and net utility revenue from electricity sales for EV charging.

Figure 8 presents projected cumulative net societal benefits under the "100% Sales by 2040", "100% Sales by 2036 Except Combination Trucks", and "100% Sales by 2036" scenarios. Under all three scenarios, near-term fleet costs are higher than fleet costs under the baseline.[21] However, after approximately 2030, all scenarios show annual net societal benefits, despite net fleet costs, due to growing utility net revenue in addition to public health and climate benefits. After approximately 2035, there is an annual net savings in fleet costs from operating ZEVs instead of diesel and gasoline trucks, and net societal benefits grow quickly.[22]

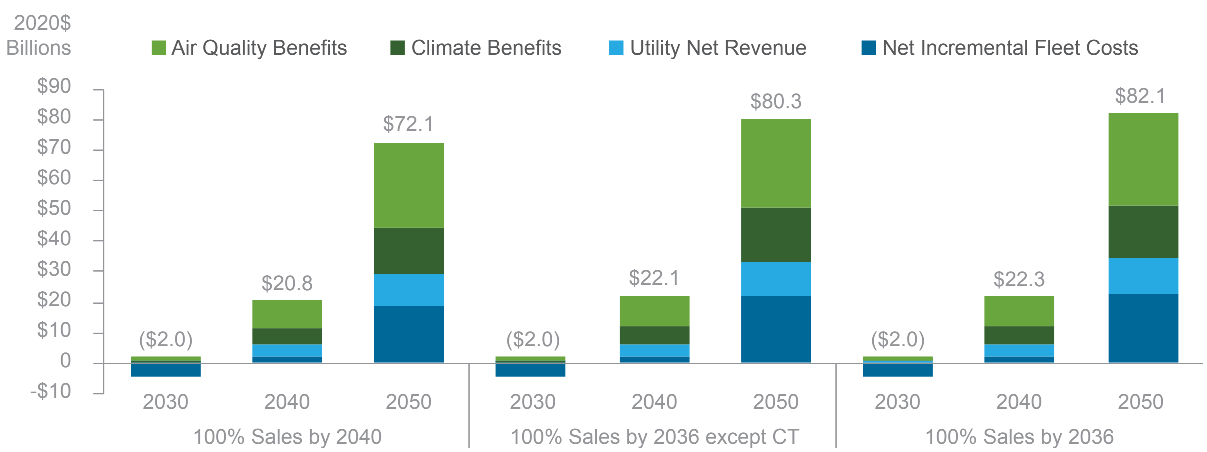
19 These numbers are from the U.S. Department of Energy's Alternative Fuel Data Center public charger database.

20 https://www.businessinsider.com/tesla-elon-musk-chargers-supercharger-network-2021-11

21 If an individual truck owner finances a vehicle, it would better equalize payments for increased vehicle price and fuel savings, resulting in a better balancing of cash flow. On a net fleet-wide basis, however, the cost of financing reduces total net fleet savings.

22 Note that fleet-wide annual net savings under the scenarios lag average ZEV life-cycle cost parity to combustion vehicles by about 5 years. This is because even after life-cycle cost parity is achieved, most ZEVs will still have higher up-front purchase costs (vehicle plus charger) than combustion vehicles; these higher costs are then paid back over the next few years via fuel and maintenance cost savings.

Figure 8 Projected Cumulative Net Societal Benefits by Scenario



Under the "100% Sales by 2040" scenario, by 2050 annual net societal benefits are estimated to be $6.2 billion, including $2.1 billion in net fleet savings and $728 million in utility net revenue. Cumulative estimated societal net benefits under this scenario total $72.1 billion between 2020 and 2050.

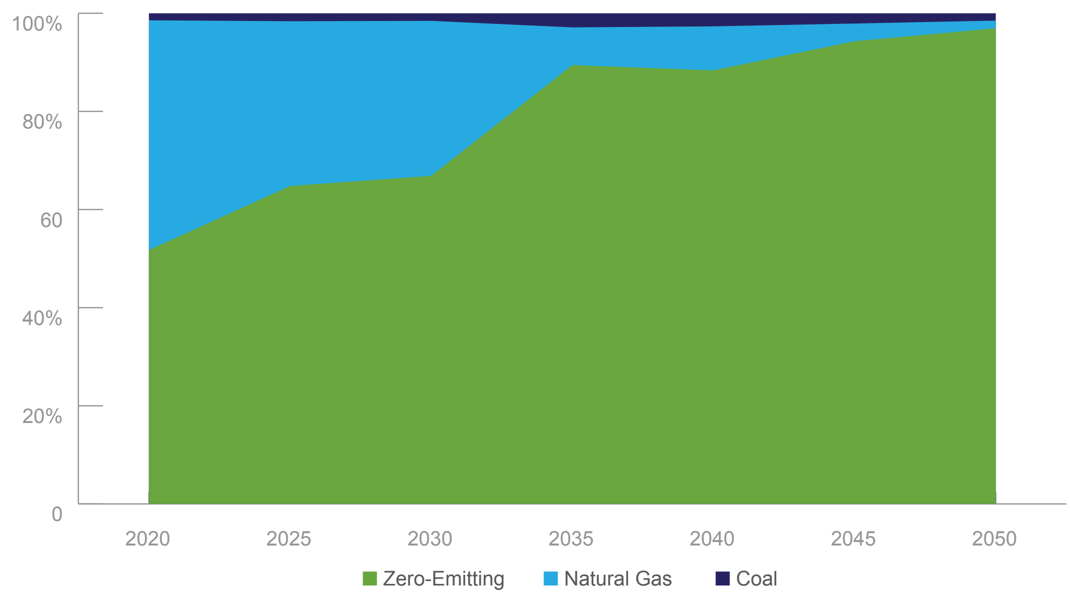
Under the "100% Sales by 2036 Except Combination Trucks" scenario, by 2050 annual net societal benefits are estimated to be $6.8 billion, including $2.4 billion in net fleet savings and $771 million in utility net revenue. Cumulative estimated societal net benefits under this scenario total $80.3 billion between 2020 and 2050.

Under the "100% Sales by 2036" scenario, 2050 annual net societal benefits are the same as "100% Sales by 2036 Except Combination Trucks" scenario but since 100 percent in-use, in-state combination trucks is achieved earlier, cumulative estimated societal net benefits under this scenario are higher, totaling $82.1 billion between 2020 and 2050.

By moving the 100 percent sales year from 2040 to 2036, net cumulative benefits are estimated to be increased by $9.9 billion and annual benefits in 2050 are increased by $580 million.

APPENDIX A: California Energy Assumptions and Supplemental Material

Figure A1 California Business-as-Usual Grid Mix Assumptions



These business-as-usual grid mix assumptions were applied to all scenarios.

Table A1 M/HDV In-Use ZEVs Population

M/HDV In-Use ZEVs (thousand)	2025	2030	2035	2040	2045	2050
Baseline (ACT)	7	68	216	393	558	700
100% Sales by 2040	28	198	508	838	1,308	1,714
100% Sales by 2036 except CT	28	198	511	998	1,467	1,848
100% Sales by 2036	28	198	511	1,002	1,476	1,848
Total M/HDV Fleet (ZEV + ICE)	1,840	1,909	2,003	2,105	2,229	2,363

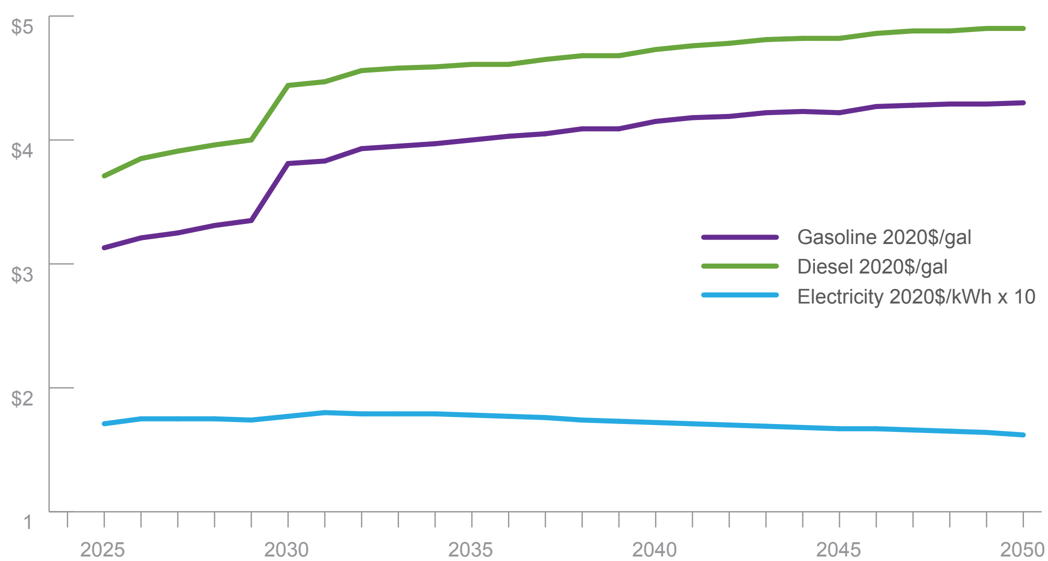
Table A2 Net Incremental Fleet Benefits

2020$ (million)	2025	2030	2035	2040	2045	2050
100% Sales by 2040	($620)	($102)	$594	$1,105	$1,611	$2,130
100% Sales by 2036 except CT	($620)	($102)	$602	$1,297	$1,987	$2,435
100% Sales by 2036	($620)	($102)	$603	$1,313	$2,069	$2,435

Table A3 Average California Household and Commercial Customer Electric Bill Savings in 2050

2020$	Household	Commercial Customer
100% Sales by 2040	$44	$402
100% Sales by 2036 except CT	$46	$426
100% Sales by 2036	$46	$426

Figure A2 California Average Fuel Costs



Report-Specific Methodology

California-specific changes to ERM's State-level methodology are detailed in the following section. For a full description of the modeling approach and sources of assumptions used for these state analyses, see the report: *Clean Trucks Analysis: Costs & Benefits of State-Level Policies to Require No- and Low-Emission Trucks, Technical Report—Methodologies and Assumptions*, May 2021 (https://mjbradley.com/clean-trucks-analysis).

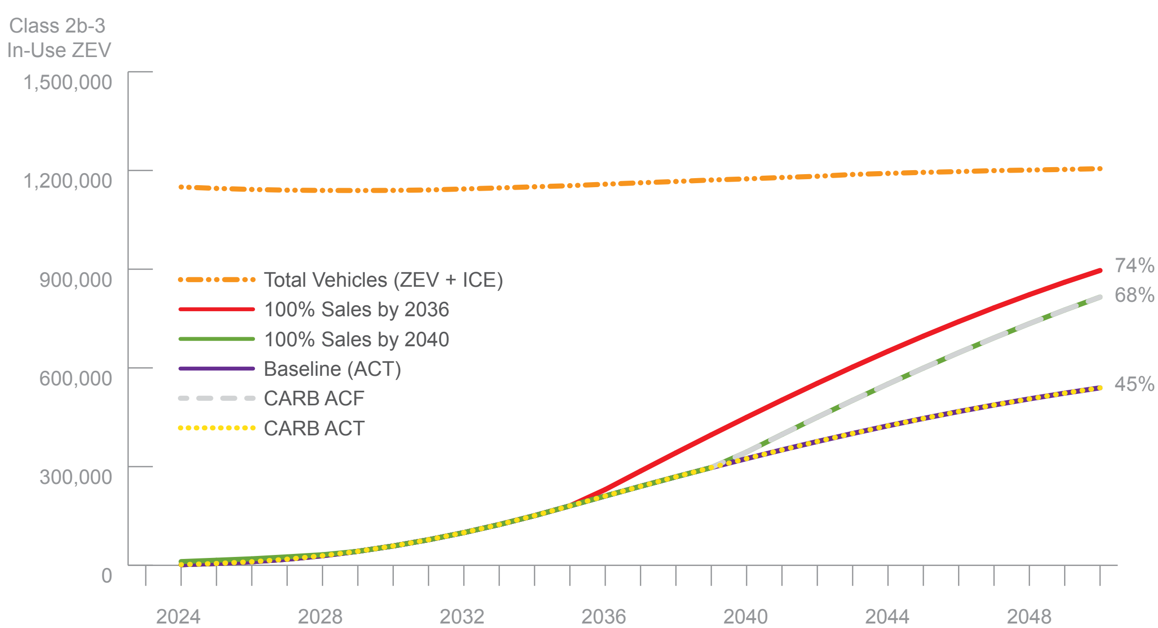
This analysis used the most recent version of California Air Resources Board's (CARB's) Emission Factors Model (EMFAC2021) to determine the vehicle population, vehicle miles traveled, annual turnover, fuel efficiency, and emission factors for each year from 2020 to 2050.

As part of the analysis, ERM modeled the impact of CARB's proposed Advanced Clean Fleet (ACF) rule. The ACF has two components that were modeled: in-use vehicle requirements for public, federal, and large fleets and a 100 percent manufacturer's sales requirement. Not all M/HDV in California are covered by fleet requirements and the percentage covered differs by vehicle class: 12 percent of Class 2b to 3, 53 percent of Class 4 to 8 vocational vehicles, and 68 percent of Class 7 to 8 tractors or combination trucks.

The fleet requirements separate M/HDVs into three groups, with the easiest to electrify in Group 1 (e.g. box trucks and vans) and the more challenging vehicles to electrify in Group 3 (e.g. sleeper cab tractors). A consequence of the fleet requirements is to increase ZEV sales earlier, exceeding the manufacturers' sales mandate set out by CARB's ACT and allowing manufacturers to accumulate credits. Once each required fleet has replaced all their ICE vehicles with ZEVs, the ZEV sales could fall below the ACT level as manufacturers exercise their credits.

To model the in-use fleet requirements, ERM acquired CARB's projections for in-use M/HD ZEVs from their ACF presentation on May 2, 2022. These projections were used as the basis for the development of the ACF scenarios The main difference between this study and CARB's assessment is this analysis assumes vehicles do not migrate out of state. While some ZEVs may migrate out of California, the benefits of those ZEVs are still being realized in other US locations. Because the 100 percent sales mandate imposes a penalty for ICE vehicles sold, this analysis assumed no previously created ZEV credits could be exercised starting with the model year where the 100 percent sales mandate began.

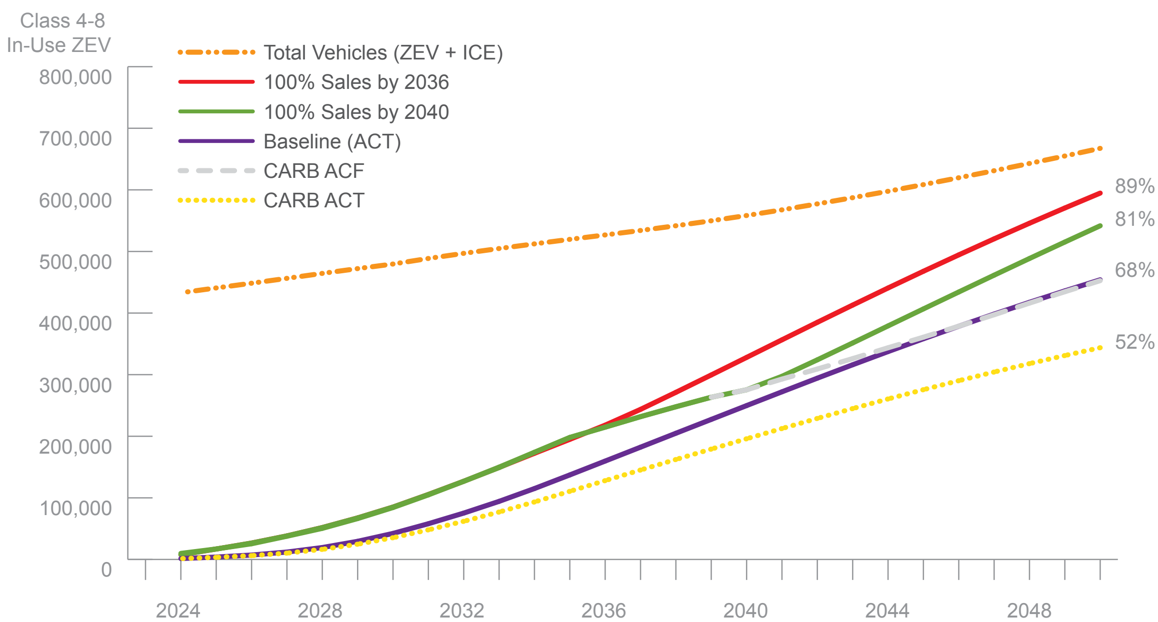
Figure A3 Fleet Zero-Emission Class 2b to 3 Vehicles in Scenarios



CARB assumes no migration for Class 2b to 3 vehicles and as a result, the projection of ZEVs used in this analysis is identical to CARB's ZEV population projection for their ACT and ACF analyses. Only a small percentage of Class 2b to 3 vehicles are part of large, federal, or public fleets. This results in virtually no impact of the in-use fleet requirements on the Class 2b to 3 ZEV population. The ACF projections follow the same trajectory as the ACT projections until the 100 percent sales requirement year.

When ZEV sales reach 100 percent by 2036 instead of 2040, there is an additional 80,800 Class 2b to 3 ZEVs on the road in California in 2050, a 10 percent increase.

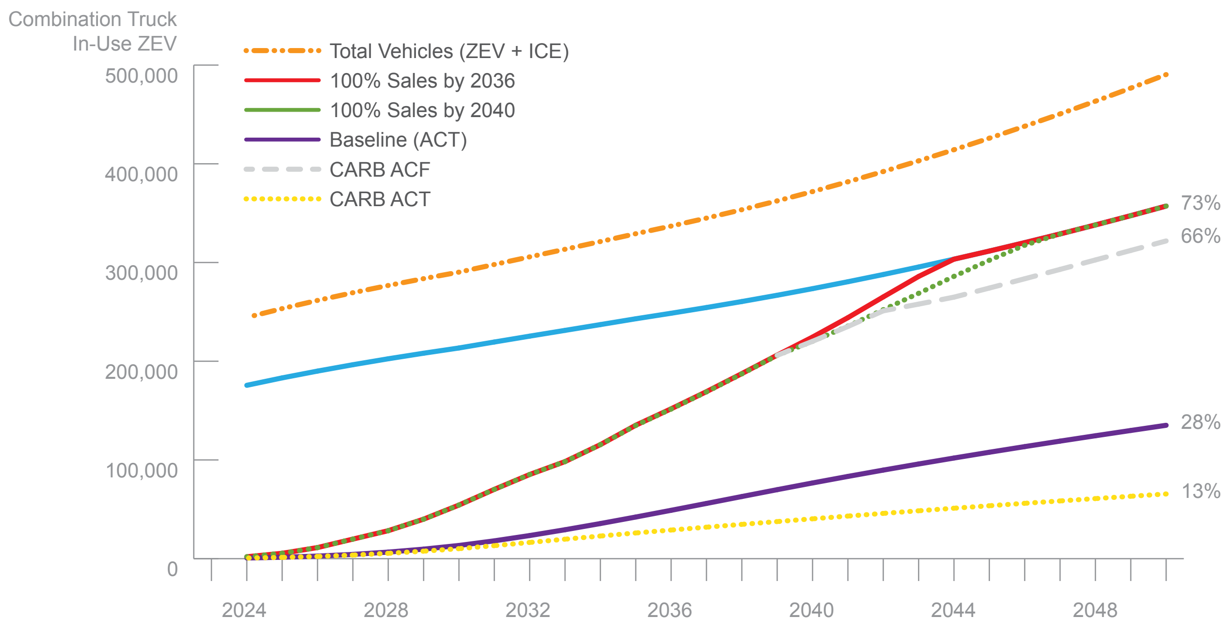
Figure A4 Fleet Zero-Emission Class 4 to 8 Vocational Vehicles in Scenarios



CARB assumes a small share of Class 4 to 8 Vocational vehicles migrate out-of-state and roughly half are part of fleets covered by the in-use ZEV requirements. When the 100 percent sales requirement starts in 2040, ZEV sales drop below the ACT sales percentage during 2036 to 2039 as fleets have already met their in-use requirements and manufacturers use the ZEV credits they accumulated. When the 100 percent sales requirement begins in 2036, this drop is avoided.

The 2036 100 percent sales requirement also increases the number of Class 4 to 8 Vocational ZEVs on the road in California by 53,000 vehicles in 2050, a 10 percent increase.

Figure A5 Fleet Zero-Emission Combination Trucks in Scenarios



Roughly two-thirds of California combination trucks are part of large, federal, public, or drayage fleets. This drives early purchasing of ZEVs. CARB assumes a large percent of combination trucks migrate out-of-state. The large difference in the CARB ACT and Baseline (ACT) ZEV population projection is due to this migration.

In-state combination trucks reach 100 percent in-use ZEV by 2044 when the sales requirement reaches 100 percent in 2036—3 years earlier than the "100% Sales by 2040" scenario. The number of combination truck ZEVs plateaus due to out-of-state (OOS) vehicles. OOS vehicles make up roughly one-quarter of the combination truck population driving on California roads but account for nearly half of all miles driven by combination trucks in California.

As shown in Figure A6, OOS combination trucks currently account for 22 percent of all M/HDV GHG emissions, but under the "100% Sales by 2036" scenario, by 2050, OOS combination trucks will account for 75 percent of GHG emissions.

Figure A6 GHG Emissions Under “100% Sales by 2036” Scenario by Vehicle Category