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POTENTIAL BENEFITS OF THE U.S. PHASE 3 GREENHOUSE GAS EMISSIONS REGULATION FOR HEAVY-DUTY VEHICLES

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EXECUTIVE SUMMARY

To align with the goals of the Paris Agreement, the United States has pledged to reduce economy-wide greenhouse gas (GHG) emissions by 50%–52% by 2030 compared to 2005 levels and to net zero by 2050. Researchers have estimated that to achieve the 2030 target, tank-to-wheel carbon dioxide emissions of light- and heavy-duty vehicles will need to decrease by 29%–40% from 2019 to 2030. Medium- and heavy-duty vehicles (MHDVs) account for one-third of CO_2 emissions from on-road vehicles and will need to achieve substantial emission reductions by 2030 and reach near-zero emissions by 2050 to meet U.S. climate goals.

The industry has begun to pivot to rapidly decarbonize. Major MHDV manufacturers, including Daimler, Ford, Navistar, and Volvo, have committed to increasing their share of zero-emission vehicle (ZEV) sales; these commitments range from 50%–67% of MHDV sales by 2030 to 100% of sales by 2035, 2039, or 2040. In parallel, major companies, including Amazon, DHL Group, FedEx, Ingka Group, and Walmart, have committed to electrifying their MHDV fleets, with zero-emission targets ranging from 50% to 100% of fleet operations by 2030.

Yet, current federal GHG standards are insufficient to deliver the full emission reductions necessary to meet the Paris Agreement commitments. In March 2023, the U.S. Environmental Protection Agency (EPA) will release a proposal to revise its GHG standards, providing a unique opportunity to put the MHDV sector on a trajectory compatible with U.S. climate goals.

This study presents several possible scenarios for the standards, estimates each scenario's potential to align with U.S. climate goals, and quantifies the associated air quality and health benefits through 2050. The policy scenarios detailed below are constructed using varying levels of improvements in internal combustion engine (ICE) vehicle efficiency beyond 2027, and projected ZEV deployment.

- The **Regulatory baseline** scenario considers the effects of the Advanced Clean Trucks rule (ACT), adopted by seven states, and the Innovative Clean Transit rule adopted in California on ZEV deployment. No ICE vehicle efficiency gain is assumed beyond 2027.
- The **Potential market growth** scenario corresponds with a 51% GHG reduction target in 2030 from the adopted model year (MY) 2027 standard. The scenario assumes ZEV deployment based on currently adopted state policies and federal incentives in the Inflation Reduction Act. It includes a 39% ZEV sales share in 2030 for Class 4–8 MHDVs and 16% for long-haul tractors. No ICE vehicle efficiency improvement is assumed beyond 2027.
- The **National ACT** scenario corresponds with a 55% GHG reduction target in 2030 from the adopted MY 2027 standard. The scenario considers the pace of ZEV deployment resulting from extending the ACT rule to all states. This results in a ZEV sales share of 41% for Class 4–8 MHDVs and 16% for long-haul trucks in 2030. This scenario additionally factors in the California Advanced Clean Fleets rule requirement of 100% ZEV sales in all MHDV segments in 2040. ICE vehicle efficiency is assumed to improve up to 25% beyond 2027 for tractors, and up to 31% for vocational trucks.
- The **U.S. NDC** scenario corresponds with a 63% GHG reduction target in 2030 from the adopted MY 2027 standard. The scenario assumes ZEV deployment is aligned with the U.S. NDC commitments. This also aligns with California's Advanced Clean

Fleets (ACF) rule, applied nationwide. This scenario results in ZEV sales shares of 55% for Class 4–8 MHDVs and 40% for long-haul trucks in 2030. ICE vehicle efficiency is assumed to improve up to 25% beyond 2027 for tractors, and up to 31% for vocational trucks.

Figure ES1 shows the projections of tank-to-wheel CO_2 emissions from both light-duty and heavy-duty vehicles through 2050 under the various scenarios. The shaded area represents the range of emissions reduction needed to align with the U.S. NDC 2030 target.

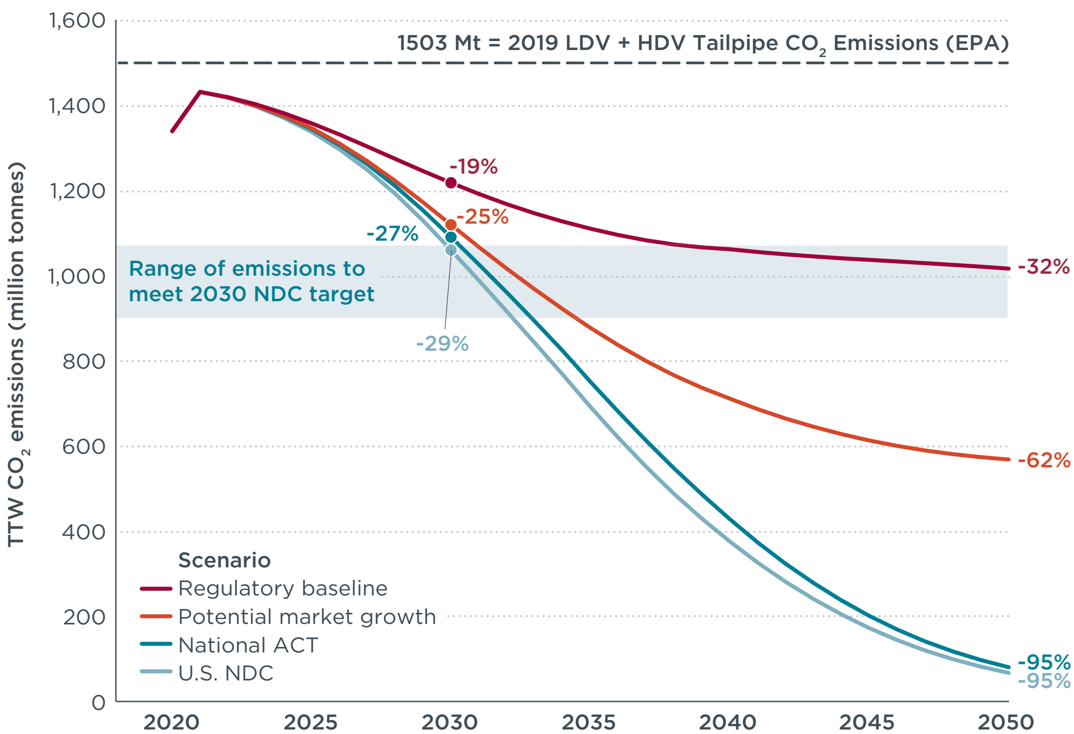

Figure ES1. Tank-to-wheel CO_2 emissions from light- and heavy-duty vehicles and percent change from 2019 level.

Table ES1 shows the degree to which each of these policy scenarios would deliver the emissions reductions needed to meet U.S. climate goals in 2030 and 2050. It also compares the stringency of each scenario with existing federal and state policies and summarizes the level of ZEV uptake and ICE improvements achieved under each scenario in 2030. Finally, it shows the overall reduction in GHG targets for MHDVs that would be consistent with achieving these ZEV sales shares and ICE efficiency improvements.

Table ES1. Key elements of policy scenarios for the Phase 3 GHG standards for medium- and heavy-duty vehicles

Criteria	Potential market growth	National ACT	U.S. NDC
2030 NDC target 29% to 40% GHG reduction	**No** 25% reduction in 2030	**No** 27% reduction in 2030	**Yes** 29% reduction in 2030
2050 NDC target net-zero GHG emissions in 2050	**No** 63% reduction in 2050	**Closely aligned** 95% reduction in 2050	**Closely aligned** 95% reduction in 2050
Alignment with existing policies	ZEV uptake based on existing state policies and IRA incentives	Aligned with the ACT rule, adopted by seven states	Aligned with California's proposed ACF rule
ZEV sales share in 2030	39%, Class 4–8 16%, long-haul tractors	41%, Class 4–8 16%, long-haul tractors	55%, Class 4–8 40%, long-haul tractors
ICE efficiency beyond 2027	No improvement after 2027	22% to 31% vs. to 2027 Phase 2 standard	22% to 31% vs. to 2027 Phase 2 standard
GHG target in 2030 % reduction from 2027 Phase 2 standard	51%	55%	63%

Only the U.S. NDC scenario aligns with the nation's 2030 GHG reduction commitment, yielding a 29% reduction compared to 2019. Both the National ACT and U.S. NDC scenarios are closely aligned with the 2050 net-zero target, yielding 95% emission reductions. Yet, both scenarios are not equivalent. Early action under the U.S. NDC scenario avoids an additional 900 megatonnes of cumulative tank-to-wheel CO_2 emissions by 2050 compared to the National ACT scenario. This CO_2 reduction can avoid a cumulative discounted social cost of $407 billion. In addition to climate benefits, reduced exposure to harmful pollutant emissions resulting from these policy scenarios could deliver cumulative undiscounted social welfare benefits over the regulatory baseline of $8.7 billion (Potential market growth), $16.7 billion (National ACT), and $22.9 billion (U.S NDC).

From the results outlined above, we draw the following conclusions:

» **Currently adopted regulations for MHDVs are not sufficient to align the sector with U.S. climate commitments**. In the Potential market growth scenario, the combined effects of EPA's current Phase 2 GHG standards, California's ACT regulation (also adopted in six other states), and IRA incentives are not sufficient to align with the 2030 and 2050 commitments made by the United States under its NDC.

» **Fully aligning the U.S. MHDV sector with climate goals would require a 55% ZEV sales share in 2030, including a 40% ZEV sales share for long-haul tractors.** These levels of ZEV uptake are in line with sales commitments already made by major truck and bus manufacturers. Major MHDV fleets have also committed to achieving even faster rates of ZEV deployment for their operations.

» **Alongside electrification, there is potential to achieve additional cost-effective GHG emission reductions from ICE vehicle efficiency improvements**. Cost-effective ICE vehicles improvements of up to 25% for tractors and 31% for vocational trucks can be achieved beyond 2027. More stringent GHG emission reduction targets can be met by a combination of ZEV uptake and ICE improvements.

» **Stringent GHG standards could deliver billions of dollars in health and climate social benefits, with a large share of health benefits occurring in communities that meet environmental justice criteria.** An accelerated transition to ZEVs could avoid up to $231 billion in discounted social costs of CO_2. Additionally, the acceleration transition could help avoid $22.9 billion in health benefits, with 40% of these benefits occurring in communities that meet at least one environmental justice criterion, an approach that is consistent with the Federal government's Justice40 initiative.

» **Strong, additional actions by government and industry are needed to build out the necessary charging infrastructure and ramp up ZEV manufacturing capacity.** The rapid rates of electrification in the scenarios shown here, including the Potential market growth scenario, will require additional actions beyond the federal GHG standards.

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INTRODUCTION

The U.S. nationally determined contribution (NDC) to align with the climate goals of the Paris Agreement sets targets to reduce economy-wide greenhouse gas (GHG) emissions by 50%–52% by 2030 compared to 2005 levels. Researchers estimate that reducing tank-to-wheel CO_2 emissions of light- and heavy-duty vehicles by 29%–40% in 2030 compared to 2019 levels is consistent with achieving the U.S. NDC commitment (Orvis et al., 2022; Zhao et al., 2022). Class 4–8 vehicles currently represent only 5% of the on-road vehicle stock in the United States but accounted for 32% of on-road CO_2 emissions in 2020 (United States Environmental Protection Agency, 2022; U.S. EPA, 2022a).[1] Aligning the transportation sector with climate goals therefore requires significant reductions in GHG emissions from medium- and heavy-duty vehicles (MHDVs).

Two main avenues exist to reduce the GHG emissions of MHDVs: increasing the efficiency of internal combustion engine (ICE) vehicles and deploying zero-emission vehicles (ZEVs). A previous ICCT analysis finds that there is significant remaining potential to improve the efficiency of ICE vehicles with cost-effective technology (Buysse et al., 2021). The main areas for technology improvement in ICE vehicles include engine and transmission efficiency, weight reduction, aerodynamics, and tire rolling resistance. In addition, several regulatory developments support the progressive deployment of zero-emission MHDVs. Major MHDV manufacturers and fleets in North America are also committed to accelerating ZEV deployment, which is supported by several new Federal incentive programs.

There is a need for binding federal regulation to sustain and accelerate the transition initiated by state laws and federal incentives. The U.S. Environmental Protection Agency's (EPA) greenhouse gas (GHG) emission standards were last updated in 2016, when zero-emission MHDVs were not considered a viable option for large-scale decarbonization of the sector. Since this time, extensive knowledge has been gathered regarding the performance and costs of zero-emission truck and bus technology, and on the policy and energy market conditions required to make ZEVs cost-competitive with their diesel counterparts (Sharpe & Basma, 2022; Slowik et al., 2023; Xie et al., 2023). As a result, zero-emission sales have begun to grow in some sectors, primarily buses, and medium-duty trucks and vans (Buysse, 2022).

The targets set out by the current Phase 2 program for model years 2021 through 2027 only capture projected efficiency gains for ICE vehicles. Zero-emission vehicles are rewarded via Advance Technology Multipliers, a supercrediting mechanism designed to support market creation at early stages, but the program does not include binding targets for production of such vehicles. Phase 2 targets mandate GHG reductions of 19%–27% for tractor trucks in 2027, and 10%–24% for vocational vehicles, relative to a 2017 baseline. In conjunction with currently adopted state-level ZEV policy, those targets are not expected to deliver the range of GHG emissions reduction needed to align the road transport sector with the U.S. NDC target.[2]

1 Medium-duty vehicles have gross vehicle weights ratings between 14,000 lbs and 16,000 lbs for Class 4, between 16,001 lbs and 19,500 lbs for Class 5, and between 19,501 lbs and 26,000 lbs for Class 6. Heavy-duty vehicles have gross vehicle weight ratings between 26,001 lbs and 33,000 lbs for Class 7, and above 33,000 lbs for Class 8.

2 A detailed summary of the Phase 2 GHG standards is available in Sharpe et al. (2016).

A proposal for Phase 3 GHG standards will be released in early 2023, providing a singular opportunity to set a trajectory for MHDV decarbonization in line with climate goals at the national level.

In this paper, we estimate the targets for the upcoming Phase 3 GHG standards for Class 4–8 HDVs that are needed to align the sector with U.S. climate goals. We first present updated estimates of post-2027 efficiency improvement potential for ICE vehicles and explore several scenarios for ZEV deployment based on different levels of potential regulatory stringency. We then estimate the CO_2 emission reduction, air pollution, and health benefits of each level of stringency. Finally, we describe potential options for GHG emission reduction targets and ZEV production requirements, as well as the potential design of key modalities of the regulation to ensure its effectiveness.

OVERVIEW OF ZEV POLICY AND MARKET DEVELOPMENTS

In November 2022, the United States signed a global memorandum of understanding under the Global Commercial Vehicle Drive to Zero initiative, pledging to pursue at least 30% zero-emission MHDV sales by 2030 and 100% by 2040 (Global Commercial Vehicle Drive to Zero, 2021).

Several regulatory developments currently support an accelerated transition to ZEVs in the MHDV segment. At the state level, California's Advanced Clean Trucks (ACT) rule—also adopted in Washington, Oregon, New York, New Jersey, Massachusetts, and Vermont—requires zero-emission vehicles to comprise increasing percentages of MHDV sales (Buysse & Sharpe, 2020). Under the ACT rule, sales requirements for Class 7–8 tractor trucks increase from 5% in 2024 to 40% in 2035. For Class 4-8 rigid trucks, sales requirements increase from 9% in 2024 to 75% in 2035. California has also adopted the Innovative Clean Transit (ICT) rule, requiring 100% zero-emission transit bus purchases in 2029, and has proposed the Advanced Clean Fleets (ACF) rule, which includes various ZEV adoption requirements for fleets alongside a 100% zero-emission sales requirement in 2040 (California Air Resources Board, n.d., 2022).

The federal government has also introduced several incentive programs to support the ZEV industry under the Inflation Reduction Act and the Infrastructure Investment and Jobs Act (U.S. Congress, 2022a, 2022b). These include a Qualified Commercial Clean Vehicle Tax Credit of up to $40,000 for commercial ZEV purchases, an extension of the Alternative Fuel Vehicle Refueling Property Tax Credit, and grant funding to support charging infrastructure, municipal fleets, and battery manufacturing. The combination of state-level requirements and federal incentives is projected to greatly reduce ZEV technology costs and spur near-term ZEV market growth, particularly for Class 4–5 trucks and buses. ICCT projects that incentives introduced by the Inflation Reduction Act will result in an estimated ZEV sales share of 39%–48% for all MHDVs, with Class 4–7 rigid trucks, refuse trucks, and transit buses exceeding 50% (Slowik et al., 2023).

The automotive industry is also committed to producing increasing numbers of zero-emission MHDVs. Table 1 summarizes commitments from major manufacturers in North America to produce zero-emission vehicles. In parallel, the logistics industry is also committed to reducing emissions from its transport operations, and major operators have made ambitious voluntary commitments to transition an increasing share of their MHDV fleets to ZEVs, as show in Table 2.

Table 1. Zero-emission MHDV production commitments from major North American truck manufacturers

Manufacturer	Commitment
Daimler Truck	100% sales of CO_2-neutral vehicles in driving operation (tank-to-wheel) in Europe, North America, and Japan by 2039; Up to 60% HD ZEV sales in 2030. (Daimler Truck, 2019, 2022)
Ford	67% zero-emission commercial vehicle sales by 2030 in Europe, 100% by 2035 (Ford Motor Company, 2022)
Navistar	50% zero-emission sales by 2030, 100% by 2040 (Navistar, 2022)
Volvo Trucks	50% sales of electric trucks by 2030 globally, 70% in Europe; 100% fossil fuel free vehicle global sales by 2040 (Volvo Trucks, 2022)

Table 2. Zero-emission MHDV fleet commitments from major North American logistics operators

Fleet owner	Commitment
Amazon	50% CO_2-neutral shipments by 2030 globally (Amazon, 2019)
DHL Group	60% electric last-mile delivery fleet by 2030 globally (Deutsche Post DHL Group, 2021)
FedEx	50% zero-emission parcel pickup and delivery vehicle purchase by 2025, 100% by 2030 100% zero-emission parcel pickup and delivery fleet by 2040 globally (FedEx, 2021)
Ingka Group	100% zero-emission customer deliveries and services by 2025 globally 100% zero-emission medium- and heavy-duty vehicles fleet by 2040 in OECD markets, China and India (IKEA, n.d., 2022)
Walmart	100% zero-emission vehicle fleet, including long-haul trucks, by 2040 globally (Walmart, 2020)

There is little incentive to decarbonize long-haul trucks and limited ZEV deployment is expected even with federal subsidies. Yet, long-haul trucks currently account for 60% of HDV CO_2 emissions in the United States, and fast decarbonization of this segment is needed to align with climate goals for the MHDV sector. In addition, ZEV requirements like those in the ACT rule do not exist in 43 states, which represent 79% of the national MHDV stock (United States Environmental Protection Agency, 2022). While market conditions generally suggest a favorable economic case for ZEV adoption as the total cost of ownership gap with diesel vehicles is reduced, achieving this level of deployment will require fleets to navigate other barriers such as limitations in manufacturing production volumes, access to upfront capital, infrastructure installation, and operational constraints. In addition, the expiration of the Inflation Reduction Act incentives in 2032 could significantly slow down the transition to ZEVs, as was experienced in other markets. For example, sales of ZE-MHDVs in China have fallen significantly since 2016 due to the withdrawal of production subsidies that same year (Mao et al., 2023).

There is therefore a need for binding federal regulation triggering high levels of ZEV deployment to sustain and accelerate the transition initiated by state laws and federal incentives. This can be achieved with the forthcoming Phase 3 GHG standards.

PROJECTED PACE OF DEPLOYMENT OF ZERO-EMISSION VEHICLES

The deployment of zero-emission MHDVs has primarily been regulated at the state level to date, led by California's ACT rule. The U.S. EPA's forthcoming Phase 3 GHG standards could be the first federal regulation to drive substantial ZEV deployment for MHDVs. To inform these standards, we explore a range of national ZEV deployment scenarios, shown in Figure 1. Detailed sales share projections for the four policy scenarios are provided in Table A1 in the Appendix.

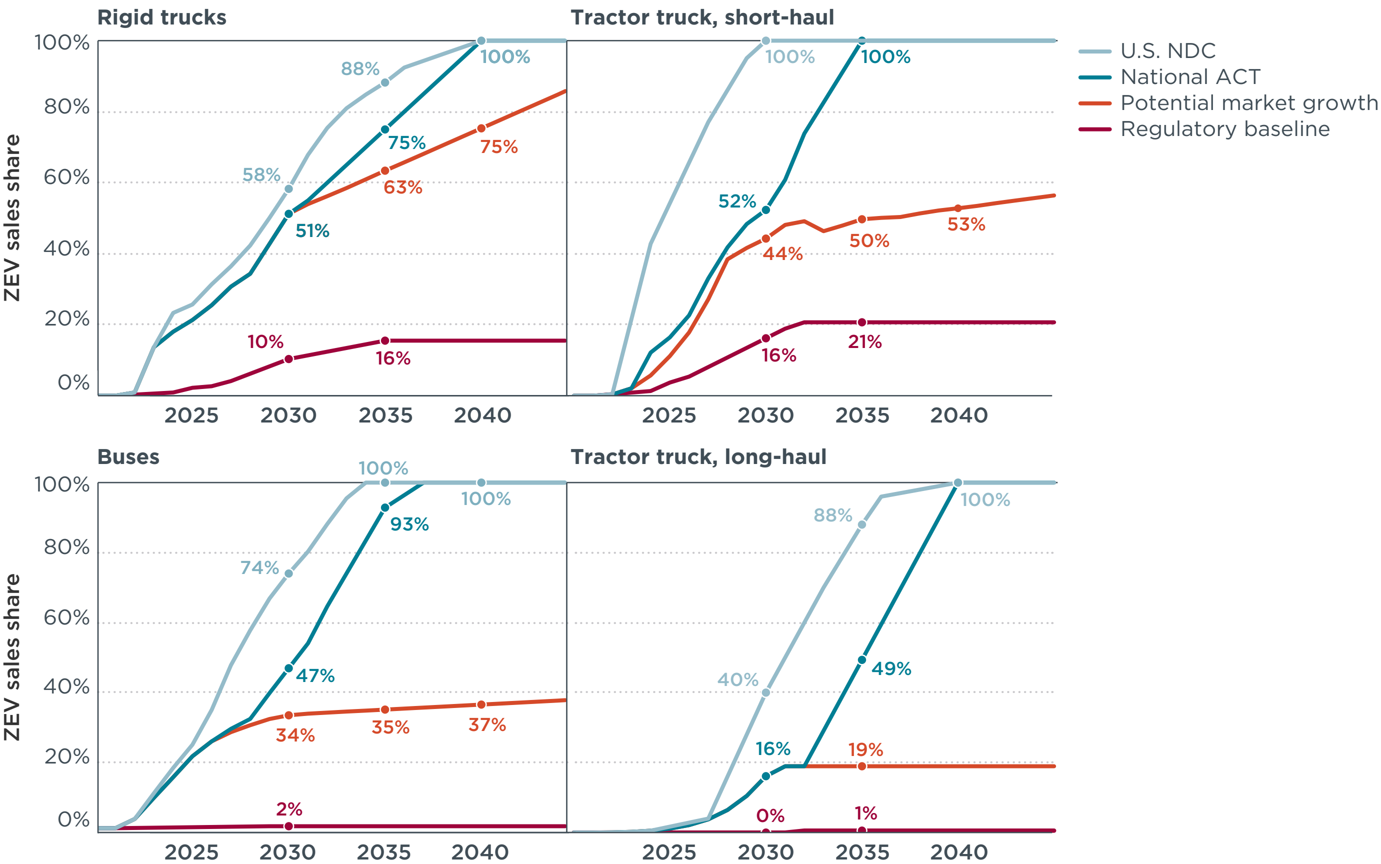

Figure 1. ZEV sales shares by deployment scenario for key market segments. Data labels show sales shares in 2030, 2035, and 2040. The ZEV sales share for short-haul tractor trucks under the Potential market growth scenario corresponds to the phase-out of Inflation Reduction Act incentives in 2032 (Slowik et al., 2023).

The ZEV deployment scenarios used in this analysis are defined as follows:

» **Regulatory baseline:** The baseline scenario includes current ACT rule and ICT rule adoption in California, and ACT rule adoption in Massachusetts, New Jersey, New York, Oregon, Vermont, and Washington.

» **Potential market growth:** Projected ZEV deployment is based on market conditions in combination with state ACT rule adoption and federal subsidies under the Inflation Reduction Act. ZEV projections are drawn from the "moderate" scenario described in detail in Slowik et al. (2023) through 2035, but assume no deceleration in ZEV sales shares for long-haul trucks after 2032. Projections are linearly extrapolated through 2045 based on growth from 2031 to 2035.

» **National ACT:** ZEV deployment for trucks is aligned in stringency with the ACT rule or potential market growth, whichever is higher. ZEV deployment for transit buses is aligned in stringency with ICT rule requirements with a 3-year lag, reaching 100% ZEV sales in 2032. Additionally, shuttle and school buses reach 100% ZEV sales in 2035, followed by coach buses in 2037. Other ZEV sales would reach 100% by 2040.

» **U.S. nationally determined contribution (NDC):** Ambitious ZEV deployment is as close as feasible to achieving CO_2 emissions reduction in line with the U.S. NDC commitment of achieving economy-wide GHG emission reductions of 50%–52% by 2030 compared to 2005 levels (The White House, 2021). ZEV deployment is aligned in stringency with California's market leading proposed ACF regulation and current ICT rule, which is considered as stringent as feasible. School buses, which are not subject to either regulation, reach 100% ZEV sales in 2034, five years after transit buses.

The ZEV scenarios are defined by market segment based on aggregated MOVES source types and weight classes.[3] We model ZEV deployment consistent with ACT rule requirements for rigid and tractor trucks across these market segments, based on assessments of commercial readiness for each MOVES source type in Buysse (2022), International Council on Clean Transportation (2022), and Slowik et al. (2023). For rigid trucks, ZEV deployment occurs earlier for Class 4–5 trucks and refuse trucks and later for Class 6–7 and other Class 8 trucks. For tractor trucks, ZEV deployment is assumed to be exhausted by the short-haul segment before deployment in the long-haul segment.

We model ZEV deployment consistent with the stringency of the proposed ACF regulation across each market segment by weighting ZEV requirements in the applicable regulatory categories: drayage, state and local fleets, and high priority and federal fleets. Public fleet purchase requirements and new drayage registry requirements are treated directly as ZEV sales shares. The proposed ACF requirements include 100% ZEV additions to the state drayage registry beginning in late 2023 and, for state and local fleets, 50% ZEV purchases starting in 2024 and increasing to 100% in 2027 (California Air Resources Board, 2022).

High priority and federal fleet milestones contained in the proposed ACF rule are converted to ZEV sales shares that, based on stock turnover in ICCT's Roadmap model, result in modeled ZEV stock shares that closely match the ACF stock milestones. Proposed stock milestones are staggered by market segment: box trucks, vans, and buses (Class 4-8) would be required to complete a full fleet transition to ZEVs in 2035, followed by work trucks and day cab tractors (Class 7-8) in 2039, and sleeper cab tractors (Class 8) in 2042. All market segments reach 100% ZEV sales by or before 2040.

3 The U.S. EPA's motor vehicle emissions simulator (MOVES) is an emissions model that estimates emissions of criteria air pollutant and greenhouse gases for mobile sources, including MHDVs, classified by source types (United States Environmental Protection Agency, 2022). Details on MHDV source types are presented in the Appendix.

PROJECTION OF COST-EFFECTIVE EFFICIENCY TECHNOLOGY POTENTIAL FOR INTERNAL COMBUSTION ENGINE VEHICLES

There remains significant potential to cost-effectively improve the efficiency and GHG emissions performance of ICE vehicles beyond 2027. This potential should be considered when setting the stringency of the upcoming Phase 3 standards.

In 2021, the ICCT assessed the cost-effective efficiency technology potential of diesel ICE vehicles through 2035 for two HDV segments: a Class 8 high roof sleeper cab tractor truck and a Class 6–7 multipurpose vocational truck (Buysse et al., 2021). The study identified efficiency technology packages, assessed their emissions reduction potential in the U.S. EPA's greenhouse gas emissions model (GEM), and conducted a cost analysis to estimate the cost effectiveness of each technology package. Priority was given to technologies that would achieve the greatest GHG emission reductions at the lowest cost. We also estimated the payback period—i.e., the time it takes for fleets to recoup the increase in technology costs with fuel savings—for each technology package.

For this study, we update the 2021 analysis and extend it to all HDV segments currently covered by mandatory GHG standards under the Phase 2 program. These include Class 7 and Class 8 day cab and sleeper cab tractor trucks, and vocational vehicles in the following classes: light heavy-duty (Class 4–5), medium heavy-duty (Class 6–7), and heavy heavy-duty (Class 8). We apply the technology packages that were assessed to reach payback within two years in the 2021 study to all tractor classes and all vocational classes. This two-year payback reflects the nature of the trucking market, in which a large percentage of fleets—particularly for-hire trucking companies—tend to have ownership cycles of four to six years. Taking the lower end of this range, a two-year payback would allow a fleet to recoup its investment in the first half of a vehicle's life and receive a return on investment during the final two years of ownership (Buysse et al., 2021).

Mild-hybridization is expected to reach payback after 1.8 years for Class 6–7 vocational trucks. However there is currently no indication that the industry is investing in this technology beyond stop-start technology and 48-V systems for improved accessory performance, which is already captured separately in this analysis. Therefore, we conservatively excluded mild hybridization from the analysis, though it could be an option for further reducing ICE fuel consumption.

Table 5 and Table 4 show the efficiency technology improvements we model for low-cost compliance in 2027 and beyond for tractor trucks and vocational vehicles. Unless specified otherwise, all technology improvements are in line with Buysse et al. (2021). For heavy-haul tractors, the technology potential is adapted to mostly non-highway operation. We assume peak engine efficiency to remain at 49% beyond 2027, no direct drive and a final drive ratio of 3.7, and no predictive cruise control. Class 8 diesel vocational trucks already rely on 49% peak engine efficiency to comply with 2027 standards, hence there are lower improvements thereafter.

Table 3. Projections of 2027 low-cost compliance and post-2027 efficiency technology improvements for ICE tractor trucks.

Technology area	Class 7–8 tractor trucks	
	ICCT 2027 low-cost compliance	ICCT post-2027 potential
Engine peak break thermal efficiency	49%	55%
Transmission	Top gear direct drive 2.7 final drive ratio	
Drive axle efficiency	95%	97%
Axle configuration	6x2	
Weight reduction vs. GEM default	300 lbs	1,940 lbs (day cabs) 1,990 lbs (sleeper cabs)
Aerodynamics	Bin V CdA (4.4-5.5 m2)	Bin VI CdA (4.1-5.2 m2)
Tire rolling resistance coefficient	Level 3 (4.9 drive / 5.0 steer)	Level 5 (4.0 drive / 4.1 steer)
Predictive cruise control Efficiency improvement	0%	3%
Reduced accessory load Efficiency improvement	1%	1.5%
Extended idle reduction Efficiency improvement	4%	
Automatic tire inflation system Efficiency improvement	1.2%	

Table 4. Projections of 2027 low-cost compliance and post-2027 efficiency technology improvements for ICE vocational vehicles.

Technology area	Class 4–8 vocational vehicles	
	ICCT 2027 low-cost compliance	ICCT post-2027 potential
Engine peak break thermal efficiency	43% (diesel) 39% (gasoline)	49% (diesel) 44% (gasoline)
Transmission	Advanced shift strategy 3%-6% efficiency improvements	
Stop-start technology	No	Yes
Drive axle efficiency	89%	97%
Axle configuration	4x2 (Class 4–7) 6x4 (Class 8)	
Weight reduction vs. GEM default	0 lbs	850 lbs (Class 4–5) 1,080 lbs (Class 6–7) 1,580 lbs (Class 8)
Aerodynamics CdA delta vs. GEM default	0 m^2	0.2 m^2 (Class 4–5) 0.5 m^2 (Class 6–8)
Tire rolling resistance coefficient	Level 5v (6.2 steer / 6.2 drive)	Level 7v (4.8 steer / 4.8 drive)
Reduced accessory load Efficiency improvement	0%	2.1%
Automatic tire inflation system Efficiency improvement	0.9%	

Table 5 shows the resulting projections in post-2027 efficiency gains. The post-2027 percentage efficiency improvement potential is calculated relative to the 2027 regulatory targets, conservatively assuming no ZEV adoption. If any of these segments realizes ZEV adoption before 2027, the 2027 EPA standard would be achieved with less efficiency gains for ICE vehicles, and the additional remaining ICE potential would be higher than shown here.

Table 5. Post-2027 efficiency gains in ICE heavy-duty vehicles.

Class	Type	2027 EPA regulatory target	ICCT post-2027 ICE potential	Post-2027 efficiency ICE improvement potential
Tractor trucks		gCO_2/ton-mile	gCO_2/ton-mile	Efficiency improvement
Class 7 tractor	**Low roof**	96.2	72.5	25%
	Mid roof	103.4	78.6	24%
	High roof	100.0	76.4	24%
Class 8 tractor (day cab)	**Low roof**	73.4	56.2	23%
	Mid roof	78.0	60.2	23%
	High roof	75.7	58.9	22%
Class 8 tractor (sleeper cab)	**Low roof**	64.1	48.6	24%
	Mid roof	69.6	53.2	24%
	High roof*	64.3	49.7	23%
Heavy-haul tractor		48.3	43.6	10%

Vocational vehicles		gCO_2/ton-mile		gCO_2/ton-mile		Efficiency improvement	
		Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline
Class 4–5	**Urban**	367	413	280	316	24%	24%
	Multi-purpose	330	372	249	278	25%	25%
	Regional	291	319	212	226	27%	29%
Class 6–7	**Urban**	258	297	191	222	26%	25%
	Multi-purpose*	235	268	172	195	27%	27%
	Regional	218	247	153	170	30%	31%
Class 8	**Urban**	269	297	226	222	16%	25%
	Multi-purpose	230	268	199	195	14%	27%
	Regional	189	247	160	170	15%	31%

* A full cost-effectiveness analysis of the various efficiency technology packages was performed for those HDV segments in Buysse et al. (2021).

Based on these ICE efficiency projections, we model four policy scenarios for ICE vehicle greenhouse gas emissions. Each ICE scenario corresponds to a similar level of ambition in our four ZEV deployment scenarios. The ICE scenarios are defined with the following reductions in ICE vehicle GHG emissions, as shown in Table 5:

» **Regulatory baseline:** Current Phase 2 standards, including Advanced Technology Credit multipliers through model year 2027

» **Potential market growth:** Phase 2 standards with an updated model year 2027 standard as proposed by EPA in March 2022 (U.S. EPA OAR, 2022)

» **National ACT:** ICCT's projection of post-2027 efficiency technology potential is achieved in 2036. Efficiency improves linearly between 2027 and 2036

» **U.S. nationally determined contribution (NDC):** ICCT's projection of post-2027 efficiency technology potential improves linearly and is achieved in 2036.

We assume that ICE efficiency does not backslide, or decrease over time, regardless of reductions in the stringency of the standard for ICE vehicles due to sales of ZEVs.

POLICY OPTIONS FOR THE DESIGN OF THE PHASE 3 GHG STANDARDS

The Phase 3 GHG standards for heavy-duty vehicles are a unique opportunity to leverage the emissions reduction potential of ICE vehicle efficiency improvements and ZEV deployment, as explored in the policy scenarios defined in this study. Regulatory targets, compliance provisions, and flexibilities can be designed in a way that best supports the deployment of ZEVs while still incentivizing cost-effective emissions reduction technology for ICE vehicles.

The regulatory targets are the major element of the standards. The U.S. EPA has the option to either cover zero-emission and ICE vehicles in a single set of regulatory targets, or separately. We consider the following two approaches for setting targets for the Phase 3 GHG standards:

- **Single combined averaging set.** With this option, ZEVs are counted in the GHG emission reduction targets, and the standards comprise a single set of targets. Targets factor in both projected improvements in ICE vehicle efficiency and projected deployment of ZEVs. There is therefore no requirement for manufacturers to produce ZEVs, provided they comply with the standards with ICE vehicle efficiency gains.
- **Dual averaging sets.** Alternatively, the U.S. EPA could require manufacturers to meet a zero-emission standard for a specified percentage of production, in addition to GHG standards for ICE vehicles. This standard would require a vehicle to be powered by an electric motor and without an internal combustion engine, resulting in no tailpipe emissions of GHGs. Both standards would be distinct, and compliance with both standards would be assessed separately. The stringency of the GHG standards would be based on projections of ICE vehicle efficiency gains only, while the zero-emission standard would reflect projections of ZEV deployment. More details on the dual averaging sets approach can be found in Minjares and Hannon (2022).

Table 6, Table 7, and Table 8 show the stringency of the single combined averaging sets that would align with the Potential market growth, National ACT and U.S. NDC scenarios. Equivalent stringency level calculations under a dual averaging sets approach are included in the Appendix. Target sets are aggregated for day cab tractor trucks, sleeper cab tractor trucks, and both diesel and gasoline vocational trucks. Detailed targets for each GEM segment covered by the Phase 2 standards can be found in the Appendix. Custom chassis vehicles, including buses, refuse trucks and motor homes, are not covered by mandatory GHG standards in the Phase 2 program, hence, we do not present them here.

Table 6. GHG standards in line with the Potential market growth scenario under a single-averaging set approach for model years 2027–2050.

Class	GHG standards in line with the Potential market growth scenario, single-averaging set (gCO_2/ton-mile)													
	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Class 7-8 day cab tractor trucks	57.0	48.2	45.7	43.6	40.6	39.8	42.0	40.7	39.3	39.0	38.8	38.1	37.4	36.9
Class 8 sleeper cab tractor trucks	61.9	60.2	57.6	54.0	52.2	52.2	52.2	52.2	52.2	52.2	52.2	52.2	52.2	52.2
Class 4-8 vocational trucks (diesel)	179.2	170.0	148.3	126.5	119.4	113.6	107.7	101.4	95.0	88.9	82.8	76.5	70.3	64.1
Class 4-8 vocational trucks (gasoline)	219.3	207.9	174.3	140.3	130.6	122.6	114.7	107.0	99.3	91.5	83.7	76.0	68.2	60.5

Table 7. GHG standards in line with the National ACT scenario under a single-averaging set approach for model years 2027–2050.

Class	GHG standards in line with the National ACT scenario, single-averaging set (gCO_2/ton-mile)													
	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Class 7-8 day cab tractor trucks	52.4	44.5	38.5	34.7	27.8	18.1	11.7	5.7	0.0	0.0	0.0	0.0	0.0	0.0
Class 8 sleeper cab tractor trucks	61.9	58.8	54.9	50.1	47.2	45.9	39.1	32.6	26.4	20.5	15.4	10.2	5.1	0.0
Class 4-8 vocational trucks (diesel)	179.2	165.1	140.0	116.1	104.1	90.0	76.7	64.1	52.4	40.6	30.5	20.3	10.2	0.0
Class 4-8 vocational trucks (gasoline)	219.3	201.0	162.7	126.4	108.9	88.5	69.5	51.7	35.2	26.9	20.1	13.4	6.7	0.0

Table 8. GHG standards in line with the U.S. NDC scenario under a single-averaging set approach for model years 2027–2050.

Class	GHG standards in line with the U.S. NDC scenario, single-averaging set (gCO_2/ton-mile)													
	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Class 7-8 day cab tractor trucks	17.9	10.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Class 8 sleeper cab tractor trucks	61.8	52.8	44.1	35.8	29.1	22.7	16.5	11.3	6.2	2.0	1.5	1.0	0.5	0.0
Class 4-8 vocational trucks (diesel)	163.5	146.6	122.0	98.6	73.7	54.8	41.5	32.3	24.7	15.7	11.8	7.9	3.9	0.0
Class 4-8 vocational trucks (gasoline)	202.0	178.4	144.6	112.5	78.0	52.8	36.2	25.5	15.8	6.5	4.9	3.2	1.6	0.0

The design of the Phase 2 GHG emission standards also involves other regulatory elements, including compliance provisions and flexibilities. The Averaging, Banking and Trading (ABT) program in place in the Phase 2 standards allows manufacturers to accumulate credits or debts if they achieve over- or under-compliance after averaging emissions across vehicle groups within each averaging set. Manufacturers are allowed to bank credits and debts for later use—credits can be carried forward up to five years and deficits up to 3 years—and to trade them with other manufacturers. This element of the regulation has proven valuable in giving manufacturers additional flexibility to meet the standards.

In previous iterations of the standards, the U.S. EPA has set GHG emission reduction targets in three-year intervals. Given the additional flexibility introduced by the ABT program, the U.S. EPA could consider setting annual targets for the Phase 3 program.

CO_2 EMISSIONS AND OIL CONSUMPTION REDUCTION BENEFITS OF THE POLICY SCENARIOS

Researchers have estimated that reducing tank-to-wheel CO_2 emissions of light- and heavy-duty vehicles by 29% to 40% in 2030 compared to 2019 levels is consistent with achieving the U.S. economy-wide NDC (Orvis et al., 2022; Zhao et al., 2022).To compare our modeling results to these estimates, we additionally model emissions from light-duty vehicles (LDVs) based on a previous ICCT analysis, assuming 67% EV uptake by 2030, and a fleet average GHG emissions reduction of 23% in 2030 compared to 2020 (Slowik & Miller, 2022).

We estimate fleetwide tank-to-wheel CO_2 emissions associated with each scenario for ZEV deployment and ICE efficiency using ICCT's Roadmap model (International Council on Clean Transportation, 2022a). Table 9 shows the cumulative tank-to-wheel CO_2 emissions from Class 4–8 vehicles between 2027 and 2050 under each scenario. Under the Regulatory baseline scenario, 49% of those emissions originate from combination long-haul trucks, which therefore represent the most important sector to decarbonize. ICCT's scenarios would reduce cumulative tank-to-wheel CO_2 emissions from Class 4–8 vehicles from 9.3 Gt in the Regulatory baseline scenario to 7.5 Gt (Potential market growth), 4.9 Gt (National ACT), and 4.0 Gt (U.S. NDC).

Table 9. Cumulative tank-to-wheel CO_2 emissions from Class 4-8 vehicles, 2027–2050 (million tonnes).

	Regulatory baseline	Potential market growth	National ACT	U.S. NDC
Buses	481	380	236	191
Class 4-8 rigid trucks	2,328	1,333	967	849
Class 7-8 short-haul trucks	1,657	1,227	744	455
Class 8 long-haul trucks	4,605	4,282	2,686	2,229
Other Class 4-8 HDVs	271	271	228	228
All Class 4-8 vehicles	**9,343**	**7,493**	**4,861**	**3,953**

Table 10 shows the change in cumulative tank-to-wheel CO_2 emissions compared to the Regulatory baseline scenario. For Class 4–8 vehicles, GHG standards enforcing emission reductions in line with the U.S. NDC scenario could avoid 5.4 Gt of CO_2 emissions between 2027 and 2050 compared to the Regulatory baseline scenario. Aligning with the National ACT and Potential market growth scenarios could avoid 4.5 Gt and 1.8 Gt of CO_2 emissions, respectively.

In terms of truck segments, the most significant reductions in the National ACT and U.S. NDC scenarios come from combination long-haul trucks (1.9 Gt and 2.4 Gt, respectively), while the Potential market growth scenario delivers far less benefits for this segment (0.3 Gt). The additional nearly 1 Gt benefit from the U.S. NDC scenario over the National ACT scenario comes principally from combination long-haul trucks (0.5 Gt), followed by combination short-haul trucks (0.3 Gt).

Table 10. Change in cumulative tank-to-wheel CO_2 emissions from Class 4-8 vehicles from baseline scenario, 2027–2050 (million tonnes).

	Regulatory baseline	Potential market growth	National ACT	U.S. NDC
Buses	0	-101	-245	-290
Class 4-8 rigid trucks	0	-995	-1,362	-1,480
Class 7-8 short-haul trucks	0	-430	-913	-1,201
Class 8 long-haul trucks	0	-324	-1,919	-2,376
Other Class 4-8 HDVs	0	0	-43	-43
All Class 4-8 vehicles	**0**	**-1,849**	**-4,481**	**-5,390**

We further assess how those emission reductions from Class 4–8 vehicles compare with the U.S. NDC targets for 2030 and 2050 when combined with our projections of LDV emissions. Figure 2 shows our projections of annual tank-to-wheel CO_2 emissions from light- and heavy-duty vehicles between 2019 and 2050 under each scenario, and the percentage change achieved in 2030 and 2050 relative to the U.S. EPA's 2019 baseline of 1,503 Mt. A similar figure with HDV-only projections can be found in the Appendix.

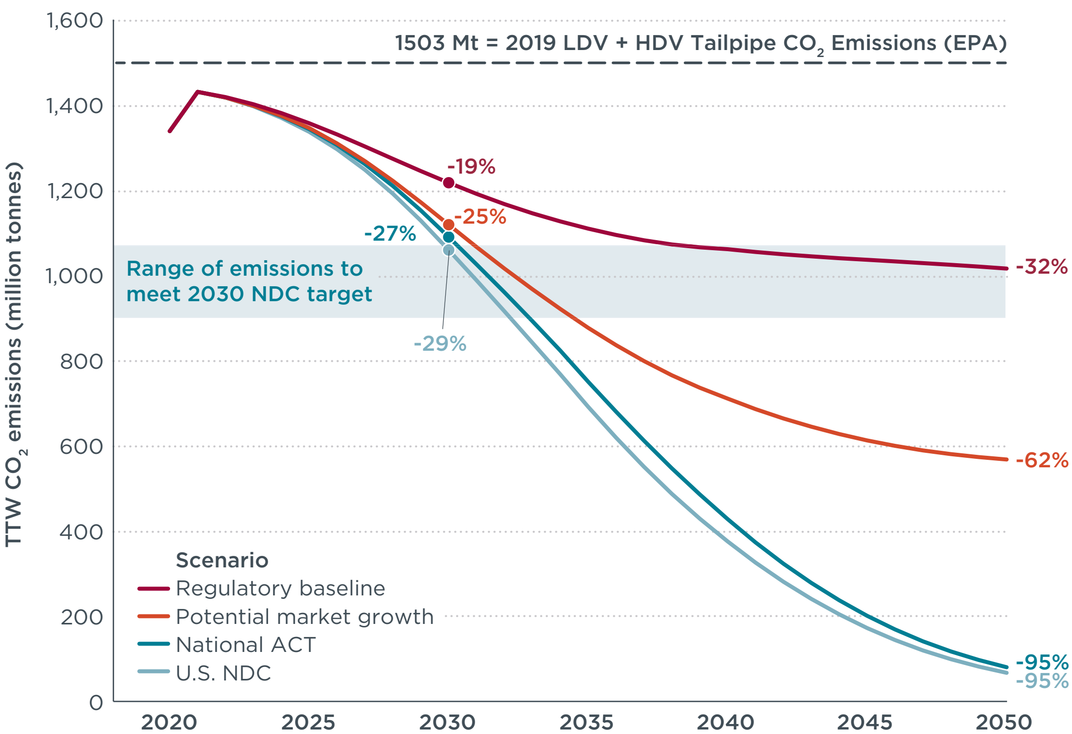

Figure 2. Tank-to-wheel CO_2 emissions from light- and heavy-duty vehicles and percent change from 2019 level.

In the Regulatory baseline scenario, a 19% reduction of LDV and HDV emissions compared to 2019 is achieved by 2030, which is well short of the range of emissions estimated to meet the NDC target in 2030. The U.S. NDC scenario, in combination with ambitious LDV GHG standards (see Appendix D), could achieve a 29% CO_2 emissions reduction in 2030 compared to 2019—this is within the range of emissions needed to achieve the 2030 economy-wide NDC target. The Potential market growth and National ACT scenarios yield CO_2 reductions of 25% and 27% in 2030, falling just outside of this range.

In addition to committing to the 2030 target, the U.S. has also pledged to achieve net-zero GHG emissions by 2050. The regulatory baseline and potential market growth scenarios achieve 32% and 62% CO_2 reductions by 2050, respectively, which falls well short of the 2050 net-zero target. Both the National ACT and U.S. NDC scenarios could achieve 95% reductions in annual emissions by 2050 compared to 2019, although delayed action with the National ACT scenario compared to the U.S. NDC scenario leads to an additional nearly 1 Gt CO_2 of cumulative tank-to-wheel emissions by 2050.

Stringent GHG emission standards also have the potential to significantly reduce oil demand from Class 4–8 vehicles. Table 11 shows the energy consumption savings in ICE vehicles that would result from each scenario between 2027 and 2050 in million tonnes of oil equivalent (Mtoe). We estimate that the scenarios could reduce U.S. fossil fuel energy demand by 500 Mtoe (Potential market growth), 1,400 Mtoe (National ACT) and 1,700 Mtoe (U.S. NDC) between 2027 and 2050 compared to the Regulatory baseline scenario.

Table 11. Estimate of reduced fossil fuel energy demand savings (in million tonnes of oil equivalent), between 2027 and 2050, under the four policy scenarios.

	Regulatory baseline	Potential market growth	National ACT	U.S. NDC
Buses	0	-29	-68	-82
Class 4-8 Rigid Trucks	0	-250	-349	-382
Class 7-8 Short-haul Trucks	0	-139	-295	-388
Class 8 Long-haul Trucks	0	-109	-644	-798
Other Class 4-8 HDVs	0	-10	-18	-18
All Class 4-8 vehicles	0	-536	-1,374	-1,667

Note: 1 Mtoe corresponds to 42 PJ

CLIMATE AND HEALTH SOCIAL BENEFITS OF THE POLICY SCENARIOS

An accelerated transition to zero-emission MHDVs supported by stringent Phase 3 GHG standards could also deliver significant social benefits by reducing air pollution and mitigating climate impacts. This section provides an estimate of the social benefits of reduced CO_2 emissions and the health benefits of reduced exposure to harmful pollutant for all policy scenarios.

We estimate the avoided social damages from reduced CO_2 emissions for each scenario. Estimates are calculated from current Federal guidance on the interim social cost of CO_2 from the Interagency Working Group on Social Cost of Greenhouse Gases (2021), with social costs ranging from $18 to $116 per metric ton of CO_2 for the years 2027–2050. We also calculate the central estimates reported in the draft EPA technical report in 2022, with social costs ranging from $219 to $308 per metric ton of CO_2 for the years 2027–2050 (U.S. EPA, 2022b). The EPA values reflect advances in scientific literature and are higher than current official federal estimates, mostly due to a lower discount rate, updated damage functions, climate models capturing a wider range of scenarios, and the pricing of risk (Rennert & Prest, 2022).

The cumulative avoided social cost of the reduction in CO_2 emissions from 2027 to 2050 for a range of discount rates are presented in Table 12. The policy scenarios could result in $79 billion (Potential market growth scenario), $190 billion (National ACT scenario), and $231 billion (U.S. NDC scenario) in avoided social costs due to reduced CO_2 emissions based on the central estimate from current federal guidance. Based on the values from the EPA draft report, the central estimates are approximately 4 times as high, with estimated cumulative avoided social costs up to $348 billion (Potential market growth scenario), $841 billion (National ACT scenario), and $1,016 billion (U.S. NDC scenario).

Table 12. Estimated cumulative avoided social cost of avoided tank-to-wheel CO_2 emissions relative to the regulatory baseline from 2027 to 2050.

	Discount rate	Potential market growth scenario	National ACT scenario	U.S. NDC scenario
Social benefits based on 2021 federal guidance	5%	$19 billion	$46 billion	$56 billion
	3% (central estimate)	$79 billion	$190 billion	$231 billion
	2.5%	$122 billion	$293 billion	$355 billion
Social benefits based on 2022 EPA draft technical report	2% (central estimate)	$348 billion	$841 billion	$1,016 billion

Additionally, using ICCT's FATE model, we assess the potential of each policy scenario to reduce the number of premature deaths due to exposure to harmful pollutants, as compared to the Regulatory baseline scenario (International Council on Clean Transportation, 2021). The baseline assumes control of nitrogen oxide (NO_x) emissions in ICE vehicles in line with the requirements of the U.S. EPA's recently adopted rule on HDV emissions (Final Rule and Related Materials for Control of Air Pollution from New Motor Vehicles, 2022). Starting in model year 2027, the rule requires MHDVs to adhere to a maximum of 35 milligrams per horsepower-hour of NO_x emissions under the Federal Test Procedure and the Supplemental Emission Test procedure, and a maximum of 50 milligrams per horsepower-hour under the Low Load Cycle. These emission standards are applicable for an extended useful life: 270,000 miles or equivalent years/hours of operation for diesel Class 4–5 vehicles; 350,000 for Class 6–7 vehicles; and 650,000 miles for Class 8 vehicles.

The stringent NO_x emission regulations incorporated in the regulatory baseline means that a significant number of premature deaths have already been avoided before we evaluate the additional benefits of Phase 3 GHG standards. However, more stringency in terms of ZEV deployment will allow for additional reduction in premature deaths due to lower pollutant emissions. Figure 3 shows a median estimate alongside lower and upper bounds for the number of additional cumulative premature deaths avoided in each scenario between 2027 and 2045.[4] The Potential market growth scenario could avoid an estimated 1,500 cumulative premature deaths over the period 2027–2045, the National ACT scenario could avoid around 2,900 cumulative premature deaths, and the U.S. NDC scenario could avoid around 3,800 cumulative premature deaths.

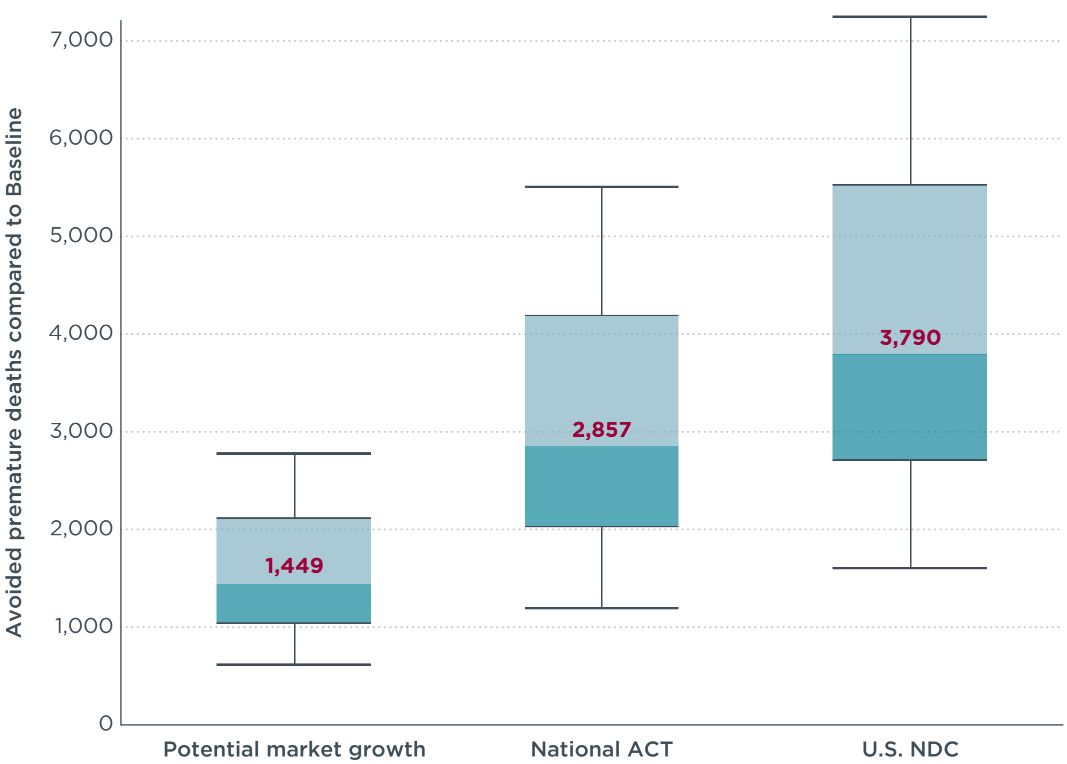

Figure 3. Avoided premature deaths between 2027 and 2045 due to reduced exposure to pollutant emissions in each policy option, relative to the regulatory baseline. The data labels indicate the median estimate for each scenario.

The monetary value of these health benefits is calculated by applying value of statistical life estimates from Viscusi & Masterman (2017) and projected changes from Jin et al. (2021). These benefit calculations are based on avoided premature mortality and do not include avoided morbidities, such as new asthma cases and other health impacts. Considering a 5% discount rate for benefits from avoided premature deaths between 2027 and 2045, the cumulative median estimated benefits are $8.7 billion for

4 We assess health benefits between 2027 and 2045 (instead of 2050) to be consistent with the estimates in the regulatory impact assessment of the U.S. EPA's rule on HDV emissions.

the Potential market growth scenario, $16.7 billion for the National ACT scenario and $22.9 billion for the U.S. NDC scenario, relative to the Regulatory baseline scenario. These benefits are on top of the large health-related benefits of EPA's NO_x standard, which EPA estimates to be $200 billion from 2027 through 2045 (U.S. EPA, 2023). For context, 22,000 premature deaths were estimated to be related to transportation in the United States in 2015, equivalent to $210 billion in welfare loss; 43% of these damages have been attributed to on-road diesel vehicles (Anenberg et al., 2019).

We further assess how each policy scenario would impact air quality for communities that meet select environmental justice (EJ) criteria based on NO_x and $PM_{2.5}$ tailpipe emission reductions under each level of stringency. Those population groups are defined using criteria in EPA's Climate and Economic Justice Screening tool. The definitions and populations of communities meeting each EJ criteria can be found in the Appendix (Council on Environmental Quality, 2022).

The spatial analysis to quantify benefits to various communities uses the Intervention Model for Air Pollution, a reduced-complexity model (Tessum et al., 2017a). Due to reduced modeling accuracy for later years up to 2050, we examine the annual benefits in 2035 as opposed to cumulative benefits in the period 2027–2050. Under this approach, the annual monetary health benefits from avoided premature deaths are about 50% higher than the 2035 central estimate from the FATE model. These differences are likely attributable to a combination of differences in resolution, different concentration-response functions for modeling health impacts of ambient $PM_{2.5}$, and model uncertainty for particulate nitrate (Paolella et al., 2018; Tessum et al., 2017b). This analysis highlights the relative differences for various population groups under each scenario. More details on the methodology can be found in International Council on Clean Transportation (2022).

Table 13 shows the annual health benefit estimates for each scenario in 2035, over the Regulatory baseline scenario, for population groups meeting select EJ criteria. We find over 40% of benefits in each scenario are projected to occur in communities that meet at least one of the selected EJ criteria. This is consistent with the Biden administration's Justice40 Initiative, which sets a goal of 40% of benefits from Federal investments in a number of categories, including climate change, clean energy and energy efficiency, and clean transit, go to communities that are marginalized, underserved, and overburdened by pollution (The White House, 2022). For communities that meet at least one of the selected EJ criteria, the Potential market growth scenario could prevent $120 million in health damages, the National ACT scenario could prevent $226 million, and the U.S. NDC scenario could prevent $390 million in annual health damages in 2035, relative to the Regulatory baseline scenario.

Table 13. Annual health benefits of each policy scenario over the Regulatory baseline scenario for populations meeting various EJ criteria in 2035, in million US$.

Indicator	Potential market growth scenario		National ACT scenario		U.S. NDC scenario	
	Meets criterion	All others	Meets criterion	All others	Meets criterion	All others
Disadvantaged	78.7	196	149	369	252	617
High ambient $PM_{2.5}$ exposure	3.2	271	6.0	512	19.4	850
High diesel particulate exposure	7.0	268	12.5	506	22.7	847
High traffic	4.9	270	9.0	509	20.7	849
High rates of air pollution-related disease	47.8	227	90.8	427	145	724
High proportion of low-income households	93.8	181	178	340	295	574
High proportion of people of color	71.9	203	134	385	243	627
Meets any criteria	120	154	226	292	390	479
Total (48 states and Washington, DC)	**$274.6 million**		**$518.2 million**		**$869.4 million**	

At the national level, additional annual health benefits in 2035 from the U.S. NDC scenario compared to the baseline would be $869 million, a 68% increase in benefits from the National ACT scenario, and a 217% increase in benefits from the Potential market growth scenario. All groups designated as disadvantaged experience even larger benefits as the stringency level increases, with additional benefits from the U.S. NDC scenario being 60%–223% higher than those from the National ACT scenario, and 203%–506% higher than those from the Potential market growth scenario. The largest increases in health benefits are for populations exposed to high ambient $PM_{2.5}$ and high levels of traffic. Detailed results by state are in the Appendix.

CONCLUSIONS

The United States has committed to ambitious economy-wide decarbonization, requiring deep GHG emission reductions in the medium- and heavy-duty vehicles sector. The Phase 3 GHG standards are an opportunity to provide unique binding regulation at the federal level to support the transition to zero-emission MHDVs and align the sector with climate goals. For the standards to drive the expected level of ZEV penetration, GHG reduction targets should also account for potential improvements in ICE vehicle efficiency.

Currently adopted policies at the national and state level would only drive an 8% ZEV sales share for Class 4–8 vehicles in 2030, increasing to 11% in 2040, failing to deliver the emissions reductions needed to meet the targets of the U.S. NDC. The Potential market growth, National ACT, and U.S. NDC scenarios in this study result in 2030 ZEV sales shares of 39%, 41%, and 55%, respectively. In addition, cost-effective ICE vehicle efficiency gains in the National ACT and U.S. NDC scenarios are estimated to be up to 25% for tractor trucks and 31% for Class 4-8 vocational vehicles beyond 2027. Table 14 summarizes the stringency of GHG standards that would align with each scenario in 2030 and 2036, using a single combined averaging set for ICE vehicles and ZEVs.

Table 14. GHG standard stringency levels that would align with ICCT's policy scenarios in 2030 and 2036, using a single combined averaging set for ZEVs and ICE vehicles.

	GHG standards, single combined averaging set (gCO_2/ton-mile)					
	Potential market growth		National ACT		U.S. NDC	
Class	2030	2036	2030	2036	2030	2036
Class 7-8 day cab tractor trucks	43.6	39.0	34.7	0.0	0.0	0.0
Class 8 sleeper cab tractor trucks	54.0	52.2	50.1	20.5	35.8	2.0
Class 4-8 vocational trucks (diesel)	126.5	88.9	116.1	40.6	98.6	15.7
Class 4-8 vocational trucks (gasoline)	140.3	91.5	126.4	26.9	112.5	6.5

Our scenarios could lead to up to 5.4 gigatonnes of CO_2 emission savings between 2027 and 2050 compared to the regulatory baseline, most of which would come from tractor trucks. Fossil fuel energy savings of up to 1,700 million tonnes of oil equivalent could be achived in the same period. Only the U.S. NDC scenario aligns with the 2030 NDC target, while both the National ACT and U.S. NDC scenarios would lead to a 95% CO_2 emissions reduction by 2050 compared to 2019 levels and would closely align with the 2050 NDC target. Earlier ZEV deployment with the U.S. NDC scenario would deliver an additional 0.9 gigatonne of CO_2 emission savings compared to the National ACT scenario.

The scenarios could deliver up to $407 billion in social cost avoided from CO_2 between 2027 and 2050. Additionally, the scenarios could deliver up to $22.9 billion of health benefits from avoided premature mortality at the national level between 2027 and 2045, due to reduced exposure to harmful pollutant concentrations. At least 40% of those benefits would occur in communities that meet at least one environmental justice criterion as defined by the EPA.

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APPENDIX A: ZEV DEPLOYMENT BY MOVES SOURCE TYPE

Table A1. ZEV sales share projections by MOVES source type for the four policy scenarios in 2025, 2030, 2035, and 2040

Segment and class	2021 share	Regulatory baseline				Potential market growth				National ACT				U.S. NDC			
		2025	2030	2035	2040	2025	2030	2035	2040	2025	2030	2035	2040	2025	2030	2035	2040
Rigid truck Class 4–5	<1%	3%	12%	19%	19%	31%	61%	73%	84%	31%	61%	90%	100%	34%	65%	96%	100%
Rigid truck Class 6–7	<1%	2%	11%	17%	17%	22%	55%	70%	84%	22%	55%	81%	100%	27%	60%	92%	100%
Rigid truck Class 8	<1%	1%	7%	10%	10%	9%	34%	43%	53%	9%	34%	49%	100%	15%	48%	75%	100%
Refuse truck	0%	3%	13%	19%	19%	19%	63%	74%	84%	19%	63%	92%	100%	19%	63%	92%	100%
Tractor truck, short-haul	0%	4%	16%	21%	21%	11%	44%	50%	53%	16%	52%	100%	100%	54%	100%	100%	100%
Tractor truck, long-haul	0%	0%	0%	1%	1%	1%	16%	19%	19%	1%	16%	49%	100%	2%	40%	88%	100%
Other bus Class 6–8	<1%	0%	0%	0%	0%	17%	29%	31%	33%	17%	29%	77%	100%	25%	76%	100%	100%
School bus Class 6–8	1%	1%	1%	1%	1%	24%	32%	33%	34%	24%	51%	100%	100%	24%	66%	100%	100%
Shuttle bus Class 4–5	1%	1%	1%	1%	1%	28%	35%	37%	37%	28%	54%	100%	100%	36%	84%	100%	100%
Transit bus Class 6–8	5%	7%	10%	10%	10%	23%	53%	55%	57%	23%	77%	100%	100%	23%	100%	100%	100%
Motor homes Class 4–8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	100%	0%	0%	50%	100%
All Class 4–8 vehicles	<1%	2%	8%	11%	11%	15%	39%	48%	56%	16%	41%	73%	100%	22%	55%	87%	100%

APPENDIX B: STRINGENCY LEVEL OF SINGLE COMBINED AVERAGING SETS FOR DETAILED GEM SEGMENTS THAT WOULD ALIGN WITH EACH OF THE POLICY SCENARIOS

Table B1. GHG standards in line with the Potential market growth scenario under a single-averaging set approach for model years 2027–2050

Class	Type	Market aligned GHG standard with a single-averaging set (gCO_2/ton-mile)													
Tractor trucks		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Class 7 tractor	**Low roof**	66.9	56.6	53.7	51.2	47.7	46.7	49.3	47.8	46.2	45.9	45.6	44.7	44.0	43.4
	Mid roof	72.3	61.1	57.9	55.3	51.5	50.4	53.2	51.6	49.9	49.5	49.3	48.3	47.4	46.8
	High roof	71.5	60.4	57.3	54.7	50.9	49.9	52.7	51.1	49.4	49.0	48.7	47.8	46.9	46.3
Class 8 tractor (day cab)	**Low roof**	51.4	43.5	41.2	39.4	36.6	35.9	37.9	36.7	35.5	35.2	35.1	34.4	33.8	33.3
	Mid roof	54.9	46.4	44.0	42.0	39.1	38.3	40.4	39.2	37.9	37.6	37.4	36.7	36.0	35.6
	High roof	54.5	46.0	43.7	41.7	38.8	38.0	40.1	38.9	37.6	37.3	37.1	36.4	35.8	35.3
Class 8 tractor (sleeper cab)	**Low roof**	59.4	57.7	55.2	51.8	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
	Mid roof	64.7	62.9	60.2	56.4	54.5	54.5	54.5	54.5	54.5	54.5	54.5	54.5	54.5	54.5
	High roof	61.7	60.0	57.4	53.8	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0	52.0
Heavy-haul tractor		48.2	46.8	44.8	42.0	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6	40.6
Vocational vehicles – diesel		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Light heavy-duty	**Urban**	234.3	222.2	183.6	144.5	133.7	125.0	116.4	108.2	100.1	91.7	83.4	75.1	66.9	58.6
	Multi-purpose	209.8	199.1	164.4	129.5	119.8	111.9	104.2	96.9	89.7	82.1	74.7	67.3	59.9	52.5
	Regional	179.8	170.5	140.9	110.9	102.6	95.9	89.3	83.1	76.8	70.4	64.0	57.7	51.3	44.9
Medium heavy-duty	**Urban**	184.0	173.1	144.3	114.6	105.6	98.1	90.7	83.6	76.7	69.4	62.3	55.1	48.0	40.9
	Multi-purpose	169.1	159.1	132.6	105.3	97.1	90.2	83.4	76.9	70.5	63.8	57.2	50.7	44.2	37.6
	Regional	156.0	146.8	122.4	97.2	89.6	83.2	76.9	70.9	65.0	58.9	52.8	46.8	40.7	34.7
Heavy heavy-duty	**Urban**	190.4	182.5	176.3	170.9	166.7	163.7	159.7	153.6	147.3	142.4	137.1	131.4	125.9	120.5
	Multi-purpose	169.7	162.7	157.1	152.4	148.6	145.9	142.4	136.9	131.3	126.9	122.2	117.1	112.2	107.4
	Regional	140.4	134.6	130.0	126.0	122.9	120.7	117.8	113.2	108.6	105.0	101.1	96.9	92.8	88.8
Vocational vehicles – gasoline		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Light heavy-duty	**Urban**	261.3	247.9	204.8	161.2	149.2	139.4	129.8	120.7	111.7	102.3	93.0	83.8	74.6	65.3
	Multi-purpose	231.1	219.2	181.1	142.6	131.9	123.3	114.8	106.8	98.8	90.5	82.3	74.1	66.0	57.8
	Regional	192.1	182.2	150.5	118.5	109.6	102.5	95.4	88.7	82.1	75.2	68.4	61.6	54.8	48.0
Medium heavy-duty	**Urban**	214.6	201.9	168.3	133.6	123.2	114.4	105.8	97.6	89.4	81.0	72.6	64.3	56.0	47.7
	Multi-purpose	193.1	181.7	151.4	120.3	110.9	103.0	95.2	87.8	80.5	72.9	65.4	57.9	50.4	42.9
	Regional	174.7	164.4	137.0	108.8	100.3	93.1	86.1	79.4	72.8	65.9	59.1	52.4	45.6	38.8
Heavy heavy-duty	**Urban**	218.6	209.5	202.3	196.2	191.4	187.8	183.3	176.3	169.0	163.4	157.3	150.8	144.4	138.3
	Multi-purpose	196.7	188.5	182.1	176.6	172.2	169.1	165.0	158.6	152.1	147.1	141.6	135.7	130.0	124.5
	Regional	177.9	170.5	164.7	159.7	155.8	152.9	149.2	143.5	137.6	133.0	128.1	122.8	117.6	112.6

Table B2. GHG standards in line with the National ACT scenario under a single-averaging set approach for model years 2027–2050

Class	Type	National ACT aligned GHG standard with a single-averaging set (gCO_2/ton-mile)													
Tractor trucks		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Class 7 tractor	**Low roof**	61.5	52.2	45.2	40.7	32.6	21.2	13.8	6.7	0.0	0.0	0.0	0.0	0.0	0.0
	Mid roof	66.4	56.4	48.9	44.0	35.3	22.9	14.9	7.2	0.0	0.0	0.0	0.0	0.0	0.0
	High roof	65.7	55.7	48.2	43.3	34.7	22.5	14.6	7.1	0.0	0.0	0.0	0.0	0.0	0.0
Class 8 tractor (day cab)	**Low roof**	47.3	40.2	34.8	31.4	25.2	16.4	10.6	5.2	0.0	0.0	0.0	0.0	0.0	0.0
	Mid roof	50.5	42.9	37.2	33.5	26.9	17.5	11.4	5.5	0.0	0.0	0.0	0.0	0.0	0.0
	High roof	50.1	42.5	36.8	33.1	26.5	17.2	11.2	5.4	0.0	0.0	0.0	0.0	0.0	0.0
Class 8 tractor (sleeper cab)	**Low roof**	59.4	56.4	52.6	48.1	45.3	44.1	37.6	31.3	25.4	19.7	14.8	9.8	4.9	0.0
	Mid roof	64.7	61.4	57.4	52.5	49.4	48.1	41.0	34.2	27.7	21.5	16.2	10.8	5.4	0.0
	High roof	61.7	58.5	54.6	49.8	46.8	45.5	38.7	32.2	26.0	20.2	15.1	10.1	5.0	0.0
Heavy-haul tractor		48.2	48.2	46.2	43.5	40.2	38.2	37.7	32.4	27.4	22.4	17.7	13.2	8.8	4.4
Vocational vehicles – diesel		**2027**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**
Light heavy-duty	**Urban**	234.3	214.6	170.9	129.5	109.9	86.8	65.4	45.5	27.1	20.7	15.5	10.3	5.2	0.0
	Multi-purpose	209.8	192.3	153.2	116.2	98.6	78.0	58.8	40.9	24.4	18.6	14.0	9.3	4.7	0.0
	Regional	179.8	165.5	132.5	101.1	86.2	68.6	52.1	36.5	22.0	16.9	12.7	8.4	4.2	0.0
Medium heavy-duty	**Urban**	184.0	167.4	134.8	103.3	89.6	74.7	60.8	47.7	35.6	27.2	20.4	13.6	6.8	0.0
	Multi-purpose	169.1	153.8	123.7	94.7	82.0	68.4	55.5	43.5	32.4	24.7	18.6	12.4	6.2	0.0
	Regional	156.0	142.0	114.4	87.7	76.0	63.5	51.6	40.6	30.2	23.1	17.3	11.6	5.8	0.0
Heavy heavy-duty	**Urban**	190.4	179.1	169.6	161.2	153.4	142.7	132.3	122.2	112.4	87.9	65.9	43.9	22.0	0.0
	Multi-purpose	169.7	159.5	150.9	143.4	136.4	126.7	117.4	108.3	99.6	77.8	58.3	38.9	19.4	0.0
	Regional	140.4	132.2	125.3	119.2	113.6	105.8	98.2	90.9	83.7	65.6	49.2	32.8	16.4	0.0
Vocational vehicles – gasoline		**2027**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**
Light heavy-duty	**Urban**	261.3	239.3	190.7	144.6	122.6	96.9	73.0	50.8	30.3	23.1	17.3	11.5	5.8	0.0
	Multi-purpose	231.1	211.8	168.9	128.1	108.8	86.1	64.9	45.2	27.0	20.6	15.5	10.3	5.2	0.0
	Regional	192.1	176.7	141.4	107.8	91.9	73.1	55.4	38.8	23.3	17.9	13.5	9.0	4.5	0.0
Medium heavy-duty	**Urban**	214.6	195.1	157.0	120.2	104.1	86.8	70.5	55.3	41.2	31.4	23.6	15.7	7.9	0.0
	Multi-purpose	193.1	175.4	140.9	107.8	93.2	77.6	62.9	49.3	36.6	27.9	20.9	13.9	7.0	0.0
	Regional	174.7	158.9	127.8	97.9	84.8	70.7	57.4	45.1	33.6	25.6	19.2	12.8	6.4	0.0
Heavy heavy-duty	**Urban**	218.6	202.4	188.7	176.4	164.9	150.5	136.8	123.7	111.2	84.9	63.7	42.4	21.2	0.0
	Multi-purpose	196.7	182.0	169.4	158.2	147.7	134.6	122.1	110.2	98.9	75.3	56.5	37.7	18.8	0.0
	Regional	177.9	164.8	153.7	143.7	134.4	122.7	111.5	100.8	90.7	69.2	51.9	34.6	17.3	0.0

Table B3. GHG standards in line with the U.S. NDC scenario under a single-averaging set approach for model years 2027–2050

Class	Type	U.S. NDC aligned GHG standard with a single-averaging set (gCO_2/ton-mile)													
Tractor trucks		2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Class 7 tractor	Low roof	21.1	12.5	4.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mid roof	22.7	13.5	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	High roof	22.5	13.3	4.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Class 8 tractor (day cab)	Low roof	16.2	9.6	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Mid roof	17.3	10.3	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	High roof	17.1	10.2	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Class 8 tractor (sleeper cab)	Low roof	59.2	50.6	42.3	34.4	27.9	21.8	15.9	10.8	6.0	1.9	1.5	1.0	0.5	0.0
	Mid roof	64.5	55.1	46.1	37.5	30.5	23.8	17.4	11.8	6.6	2.1	1.6	1.1	0.5	0.0
	High roof	61.6	52.5	43.9	35.6	28.9	22.5	16.4	11.1	6.2	2.0	1.5	1.0	0.5	0.0
Heavy-haul tractor		48.1	41.5	35.0	28.7	23.6	18.6	13.7	9.5	5.3	1.7	1.3	0.9	0.4	0.0
Vocational vehicles - diesel		2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Light heavy-duty	Urban	218.5	191.6	153.6	117.6	78.8	50.9	32.9	22.0	11.8	2.6	1.9	1.3	0.6	0.0
	Multi-purpose	195.8	171.7	137.7	105.4	70.7	45.7	29.6	19.7	10.6	2.3	1.7	1.2	0.6	0.0
	Regional	167.7	147.8	119.2	91.7	61.8	40.2	26.2	17.6	9.6	2.1	1.6	1.1	0.5	0.0
Medium heavy-duty	Urban	153.9	139.1	114.8	91.6	66.3	47.5	34.6	24.8	15.6	7.2	5.4	3.6	1.8	0.0
	Multi-purpose	141.5	127.8	105.4	83.9	60.7	43.5	31.7	22.6	14.2	6.5	4.9	3.3	1.6	0.0
	Regional	130.5	118.0	97.4	77.7	56.3	40.4	29.4	21.0	13.3	6.1	4.6	3.0	1.5	0.0
Heavy heavy-duty	Urban	187.4	169.9	147.3	126.1	104.1	85.9	71.3	61.4	55.3	42.8	32.1	21.4	10.7	0.0
	Multi-purpose	167.0	151.3	131.1	112.1	92.5	76.3	63.3	54.5	49.0	37.9	28.4	18.9	9.5	0.0
	Regional	138.1	125.4	108.8	93.3	77.1	63.7	53.0	45.7	41.2	31.9	23.9	16.0	8.0	0.0
Vocational vehicles - gasoline		2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Light heavy-duty	Urban	243.8	213.8	171.4	131.2	87.9	56.8	36.8	24.5	13.2	2.9	2.2	1.4	0.7	0.0
	Multi-purpose	215.6	189.2	151.8	116.3	78.0	50.5	32.7	21.8	11.8	2.6	1.9	1.3	0.6	0.0
	Regional	179.2	157.8	127.2	97.8	65.9	42.9	27.9	18.7	10.2	2.2	1.7	1.1	0.6	0.0
Medium heavy-duty	Urban	179.5	162.1	133.7	106.5	77.1	55.2	40.2	28.7	18.0	8.3	6.2	4.1	2.1	0.0
	Multi-purpose	161.5	145.8	120.1	95.5	69.0	49.3	35.9	25.6	16.0	7.3	5.5	3.7	1.8	0.0
	Regional	146.1	132.0	108.9	86.8	62.8	45.0	32.7	23.4	14.7	6.7	5.1	3.4	1.7	0.0
Heavy heavy-duty	Urban	215.0	192.1	163.9	138.0	111.9	90.7	73.8	62.2	54.7	41.3	31.0	20.7	10.3	0.0
	Multi-purpose	193.5	172.7	147.2	123.7	100.2	81.1	65.8	55.4	48.6	36.7	27.5	18.3	9.2	0.0
	Regional	175.1	156.4	133.5	112.4	91.2	73.9	60.1	50.7	44.6	33.7	25.3	16.9	8.4	0.0

Class	U.S. NDC aligned GHG standard with a single-averaging set (gCO_2/ton-mile)													
2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	
Day cab tractor trucks	17.9	10.6	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sleeper cab tractor trucks	61.8	52.8	44.1	35.8	29.1	22.7	16.5	11.3	6.2	2.0	1.5	1.0	0.5	0.0
Vocational trucks (diesel)	163.5	146.6	122.0	98.6	73.7	54.8	41.5	32.3	24.7	15.7	11.8	7.9	3.9	0.0
Vocational trucks (gasoline)	202.0	178.4	144.6	112.5	78.0	52.8	36.2	25.5	15.8	6.5	4.9	3.2	1.6	0.0

APPENDIX C: STRINGENCY LEVEL OF DUAL AVERAGING SETS THAT WOULD ALIGN WITH EACH OF THE POLICY SCENARIOS

Table C1. GHG standards for ICE vehicles that would align with the Potential market growth, National ACT, and U.S. NDC scenarios, with dual averaging sets, for model years 2027–2050

Class	Type	GHG standards for ICE vehicles with dual averaging sets (gCO_2/ton-mile)													
Tractor trucks		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Class 7 tractor	**Low roof**	91.9	89.8	87.6	85.4	83.3	81.1	78.9	76.8	74.6	72.5	72.5	72.5	72.5	72.5
	Mid roof	99.2	96.9	94.6	92.3	90.1	87.8	85.5	83.2	80.9	78.6	78.6	78.6	78.6	78.6
	High roof	98.1	95.7	93.3	90.9	88.5	86.1	83.7	81.3	78.8	76.4	76.4	76.4	76.4	76.4
Class 8 tractor (day cab)	**Low roof**	70.6	69.0	67.4	65.8	64.2	62.6	61.0	59.4	57.8	56.2	56.2	56.2	56.2	56.2
	Mid roof	75.4	73.7	72.0	70.3	68.6	66.9	65.2	63.5	61.8	60.2	60.2	60.2	60.2	60.2
	High roof	74.8	73.0	71.2	69.5	67.7	65.9	64.2	62.4	60.6	58.9	58.9	58.9	58.9	58.9
Class 8 tractor (sleeper cab)	**Low roof**	61.7	60.3	58.8	57.3	55.9	54.4	53.0	51.5	50.1	48.6	48.6	48.6	48.6	48.6
	Mid roof	67.2	65.7	64.1	62.5	61.0	59.4	57.8	56.3	54.7	53.2	53.2	53.2	53.2	53.2
	High roof	64.2	62.6	61.0	59.4	57.8	56.2	54.6	52.9	51.3	49.7	49.7	49.7	49.7	49.7
Heavy-haul tractor		48.3	48.3	48.3	47.9	47.2	46.5	45.7	45.0	44.3	43.6	43.6	43.6	43.6	43.6
Vocational vehicles – diesel		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Light heavy-duty	**Urban**	367.0	362.0	349.0	336.1	323.1	310.2	297.2	284.3	271.3	258.3	258.3	258.3	258.3	258.3
	Multi-purpose	330.0	324.4	312.9	301.5	290.0	278.5	267.0	255.6	244.1	232.6	232.6	232.6	232.6	232.6
	Regional	287.8	279.2	270.7	262.2	253.7	245.1	236.6	228.1	219.6	211.0	211.0	211.0	211.0	211.0
Medium heavy-duty	**Urban**	254.0	245.6	237.3	229.0	220.6	212.3	204.0	195.6	187.3	179.0	179.0	179.0	179.0	179.0
	Multi-purpose	233.5	225.6	217.8	209.9	202.1	194.2	186.3	178.5	170.6	162.8	162.8	162.8	162.8	162.8
	Regional	215.4	208.4	201.4	194.3	187.3	180.3	173.2	166.2	159.2	152.1	152.1	152.1	152.1	152.1
Heavy heavy-duty	**Urban**	258.1	253.2	248.3	243.4	238.5	233.6	228.7	223.8	218.9	214.0	214.0	214.0	214.0	214.0
	Multi-purpose	230.0	225.6	221.0	216.5	212.0	207.5	203.0	198.4	193.9	189.4	189.4	189.4	189.4	189.4
	Regional	189.0	186.9	183.5	180.1	176.7	173.3	169.9	166.4	163.0	159.6	159.6	159.6	159.6	159.6
Vocational vehicles – gasoline		**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**
Light heavy-duty	**Urban**	413.0	403.8	389.4	375.0	360.6	346.2	331.8	317.4	303.0	288.6	288.6	288.6	288.6	288.6
	Multi-purpose	369.9	357.4	344.9	332.4	319.9	307.5	295.0	282.5	270.0	257.5	257.5	257.5	257.5	257.5
	Regional	307.4	298.2	288.9	279.7	270.4	261.2	251.9	242.7	233.4	224.2	224.2	224.2	224.2	224.2
Medium heavy-duty	**Urban**	296.3	286.3	276.4	266.4	256.4	246.5	236.5	226.6	216.6	206.7	206.7	206.7	206.7	206.7
	Multi-purpose	266.6	257.4	248.1	238.9	229.6	220.4	211.1	201.9	192.6	183.4	183.4	183.4	183.4	183.4
	Regional	241.2	233.1	225.0	217.0	208.9	200.8	192.8	184.7	176.6	168.6	168.6	168.6	168.6	168.6
Heavy heavy-duty	**Urban**	296.3	286.3	276.4	266.4	256.4	246.5	236.5	226.6	216.6	206.7	206.7	206.7	206.7	206.7
	Multi-purpose	266.6	257.4	248.1	238.9	229.6	220.4	211.1	201.9	192.6	183.4	183.4	183.4	183.4	183.4
	Regional	241.2	233.1	225.0	217.0	208.9	200.8	192.8	184.7	176.6	168.6	168.6	168.6	168.6	168.6

Table C2. Share of production of vehicles to comply with a zero-emission standard to align with the Potential market growth scenario

Class	Potential market growth scenario aligned share of production to comply with a zero-emission standard													
	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Rigid truck Class 4–5	38%	41%	51%	61%	64%	67%	69%	71%	73%	76%	78%	80%	82%	84%
Rigid truck Class 6–7	28%	32%	43%	55%	58%	61%	64%	67%	70%	73%	75%	78%	81%	84%
Rigid truck Class 8	26%	29%	32%	34%	35%	37%	38%	41%	43%	45%	47%	49%	51%	53%
Refuse truck	35%	45%	54%	63%	66%	68%	70%	72%	74%	76%	78%	80%	82%	84%
Tractor truck, short-haul	27%	38%	42%	44%	48%	49%	46%	48%	50%	50%	50%	51%	52%	53%
Tractor truck, long-haul	4%	6%	10%	16%	19%	19%	19%	19%	19%	19%	19%	19%	19%	19%
Other bus Class 6–8	25%	28%	29%	29%	30%	30%	30%	31%	31%	32%	32%	32%	33%	33%
School bus Class 6–8	30%	31%	32%	32%	33%	33%	33%	33%	33%	34%	34%	34%	34%	34%
Shuttle bus Clas 4–5	34%	35%	37%	35%	36%	36%	36%	36%	37%	37%	37%	37%	37%	37%
Transit bus Class 6–8	32%	35%	44%	53%	53%	54%	54%	54%	55%	55%	56%	56%	56%	57%
Motor home	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table C3. Share of production of vehicles to comply with a zero-emission standard to align with the National ACT scenario

Class	National ACT scenario aligned share of production to comply with a zero-emission standard													
	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Rigid truck Class 4–5	38%	41%	51%	61%	66%	72%	78%	84%	90%	92%	94%	96%	98%	100%
Rigid truck Class 6–7	28%	32%	43%	55%	59%	65%	70%	76%	81%	85%	89%	92%	96%	100%
Rigid truck Class 8	26%	29%	32%	34%	36%	39%	42%	45%	49%	59%	69%	79%	90%	100%
Refuse truck	35%	45%	54%	63%	67%	73%	79%	85%	92%	93%	95%	97%	98%	100%
Tractor truck, short-haul	33%	42%	48%	52%	61%	74%	83%	91%	100%	100%	100%	100%	100%	100%
Tractor truck, long-haul	4%	6%	10%	16%	19%	19%	29%	39%	49%	59%	70%	80%	90%	100%
Other bus Class 6–8	25%	28%	29%	29%	30%	41%	53%	65%	77%	88%	100%	100%	100%	100%
School bus Class 6–8	30%	31%	41%	51%	61%	70%	80%	90%	100%	100%	100%	100%	100%	100%
Shuttle bus Class 4–5	34%	35%	45%	54%	63%	72%	82%	91%	100%	100%	100%	100%	100%	100%
Transit bus Class 6–8	41%	53%	65%	77%	88%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Motor home	0%	0%	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

Table C4. Share of production of vehicles to comply with a zero-emission standard to align with the U.S. NDC scenario

Class	U.S. NDC scenario aligned share of production to comply with a zero-emission standard													
	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Rigid truck Class 4–5	43%	48%	56%	65%	75%	83%	89%	92%	96%	99%	99%	100%	100%	100%
Rigid truck Class 6–7	38%	44%	52%	60%	70%	78%	83%	87%	92%	96%	97%	98%	99%	100%
Rigid truck Class 8	27%	33%	41%	48%	56%	63%	69%	73%	75%	80%	85%	90%	95%	100%
Refuse truck	35%	45%	54%	63%	67%	73%	79%	85%	92%	93%	95%	97%	98%	100%
Tractor truck, short-haul	77%	86%	95%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Tractor truck, long-haul	4%	16%	28%	40%	50%	60%	70%	79%	88%	96%	97%	98%	99%	100%
Other bus Class 6–8	52%	62%	69%	76%	79%	89%	99%	100%	100%	100%	100%	100%	100%	100%
School bus Class 6–8	41%	49%	58%	66%	75%	83%	92%	100%	100%	100%	100%	100%	100%	100%
Shuttle bus Class 4–5	59%	66%	75%	84%	94%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Transit bus Class 6–8	61%	81%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Motor home	0%	0%	0%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%

APPENDIX D: PROJECTIONS OF LDV AND HDV CO_2 EMISSIONS

Projected LDV ZEV uptake and CO_2 emissions were modeled using ICCT Roadmap, using assumptions in line with Slowik and Miller (2022). Figure D1 illustrates LDV assumptions through 2030.

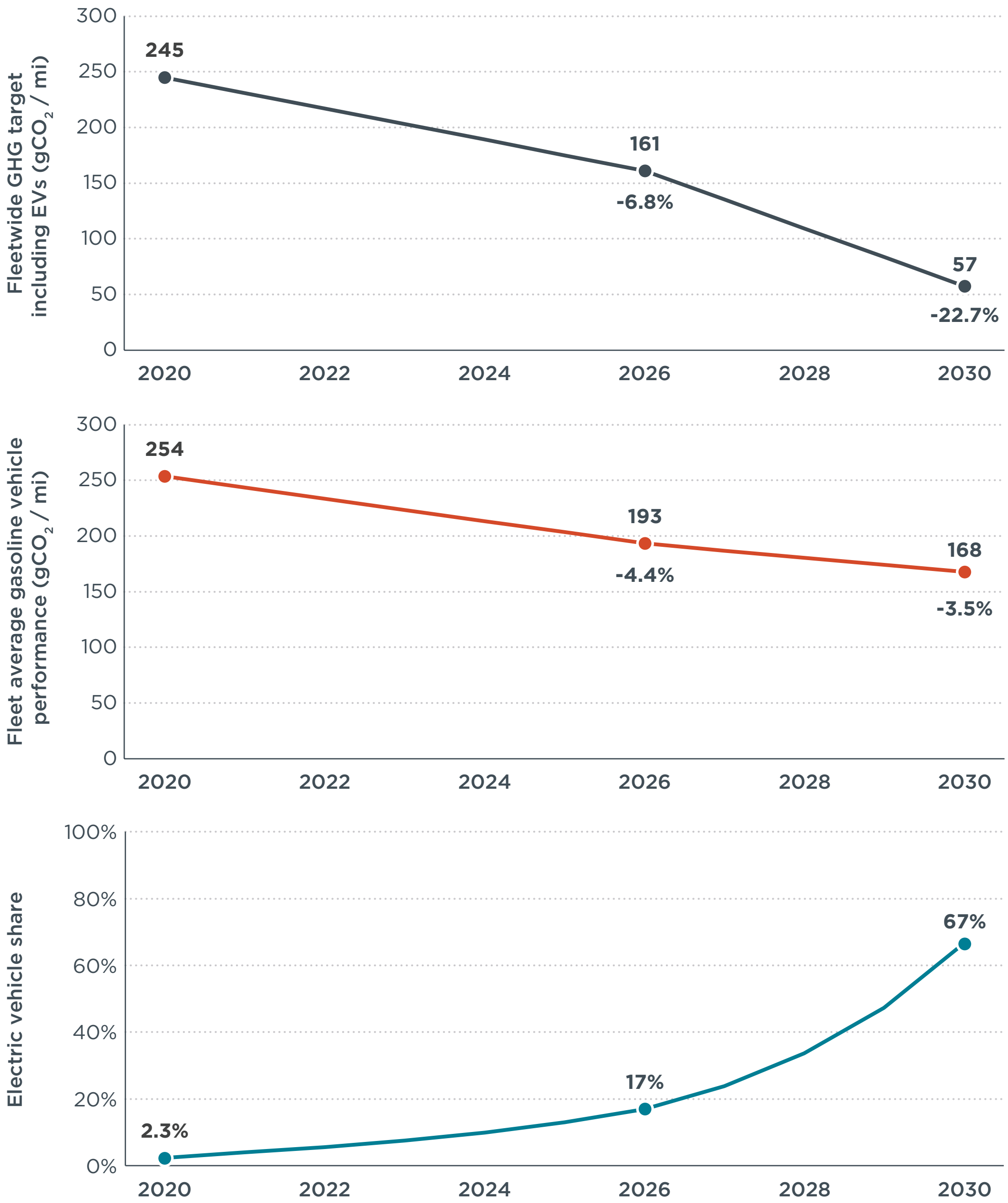

Figure D1. Stringency of model year 2030 LDV GHG targets assumed in this analysis

Figure D2 and Figure D3 show our projections of HDV and LDV tank-to-wheel CO_2 emissions separately through 2050. Figure D2 also shows the percentage change in HDV CO_2 emissions from 2019 levels in 2030 and 2050.

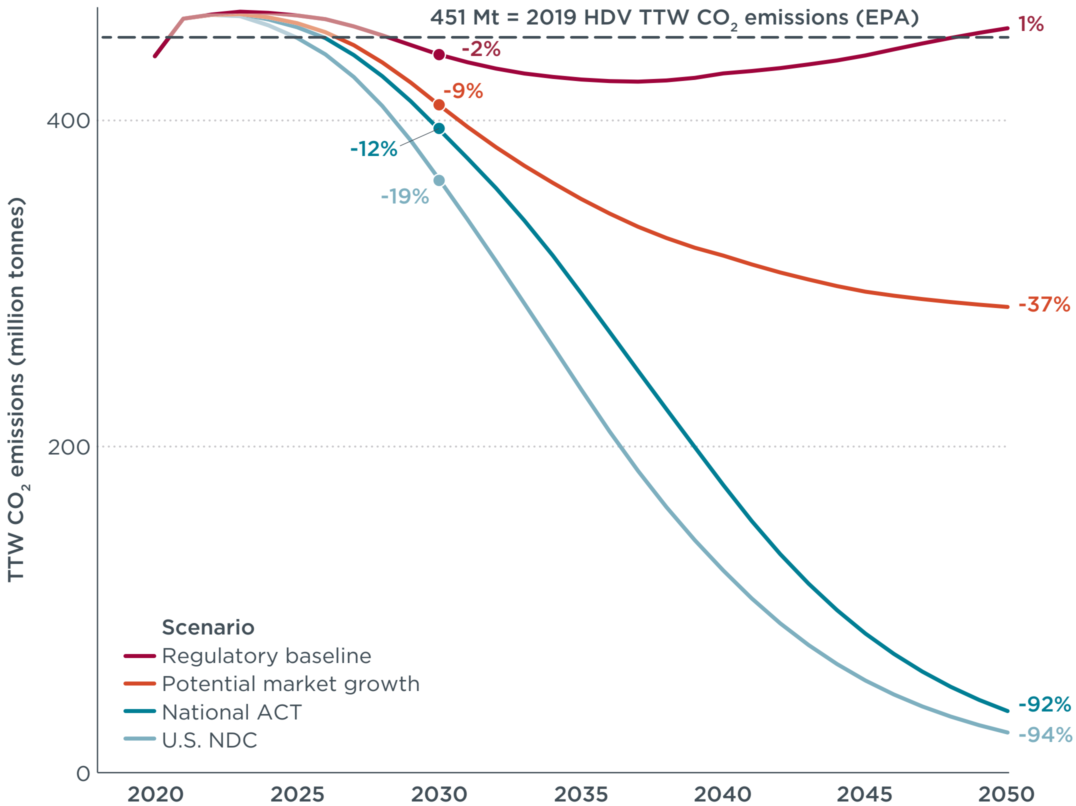

Figure D2. Tank-to-wheel CO_2 emissions from heavy-duty vehicles and percent change from 2019 level. Class 2b-8 vehicles are included in this figure.

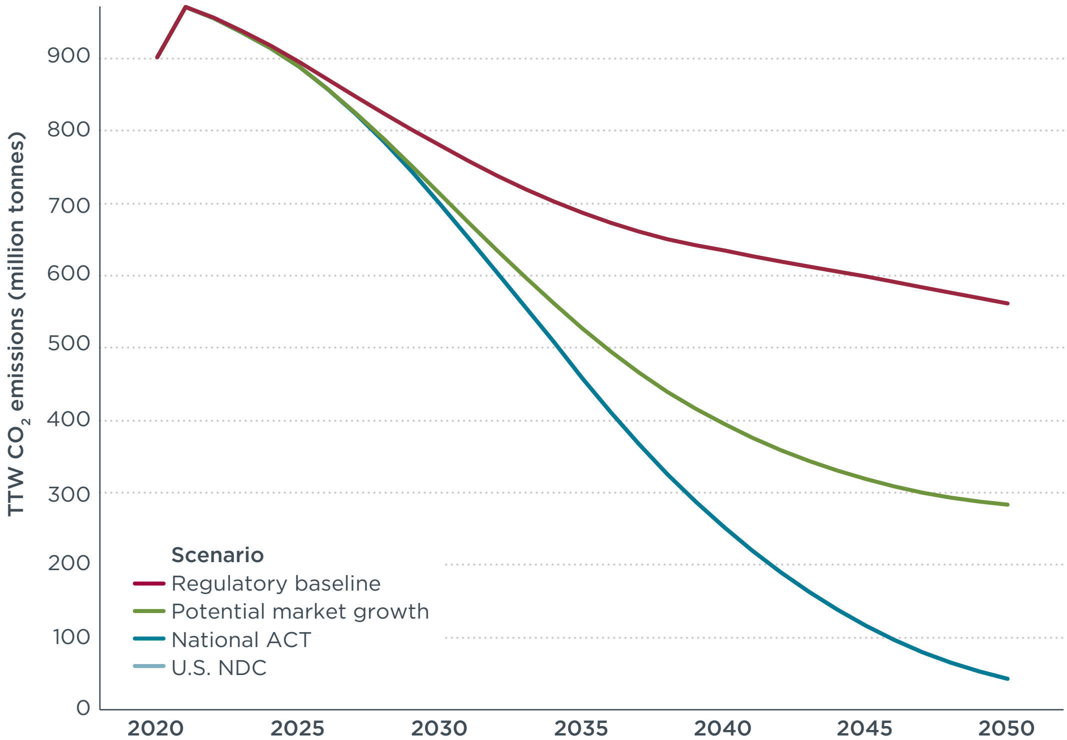

Figure D3. Tank-to-wheel CO_2 emissions from light-duty vehicles. National ACT and U.S. NDC scenario assumptions are the same for light-duty vehicles.

APPENDIX E: POPULATION GROUPS MEETING ENVIRONMENTAL JUSTICE CRITERIA

The population groups meeting each environmental justice criteria are defined in the Climate and Economic Justice Screening Tool (Council on Environmental Quality, 2022) as follows:

» **Disadvantaged:** Communities that are both overburdened in terms of environmental or climate indicators and underserved socioeconomically. This is not limited to impacts from transportation.

» **High diesel particulate exposure:** Communities at or above the 90th percentile for diesel particulate matter exposure in the United States and above the threshold for socioeconomic indicators.

» **High traffic:** Communities at or above the 90th percentile for traffic proximity and volume and above the threshold for socioeconomic indicators.

» **High ambient PM2.5 exposure:** Communities at or above the 90th percentile for PM2.5 in the air on an annual average basis and above the threshold for socioeconomic indicators.

» **High rates of air pollution related diseases:** Communities at or above the 90th percentile for asthma, diabetes, heart disease, or low life expectancy and above the threshold for socioeconomic indicators.

» **High proportion of low-income households:** Communities at or above the 65th percentile for low income versus all others. Low income is defined as households with a household income at or below 200% of the Federal poverty level.

» **High proportion of people of color:** Communities at or above the 65th percentile for percent people of color, defined as Latinos of any race and non-Latino, non-white people.

» **Meets any criteria:** Communities that meet any of the criteria above.

Table E1 presents the population of communities meeting each criterion.

Table E1. Population of communities meeting environmental justice criteria (48 states and Washington DC)

Indicator	Total population (millions)		Share of population	
	Meets criterion	All others	Meets criterion	All others
Disadvantaged	90.0	232.5	27.9%	72.5%
High ambient $PM_{2.5}$ exposure	12.3	310.2	3.8%	96.2%
High diesel particulate exposure	12.3	310.3	3.8%	96.2%
High traffic	11.1	311.4	3.4%	96.6%
High rates of air pollution related disease	42.6	279.9	13.2%	86.8%
High proportion of low-income households	100.3	222.2	31.1%	68.1%
High proportion of people of color	112.8	209.7	35.0%	65.0%
Meets any criteria	152.4	170.1	47.3%	52.7%

APPENDIX F: PER CAPITA HEALTH BENEFITS OF POLICY OPTIONS FOR ENVIRONMENTAL JUSTICE POPULATIONS, BY STATE

Figure F1 shows the state-by-state annual monetary health benefits in 2035 delivered by each scenario for populations meeting any EJ criteria (Table 12), as compared to the Regulatory baseline scenario.

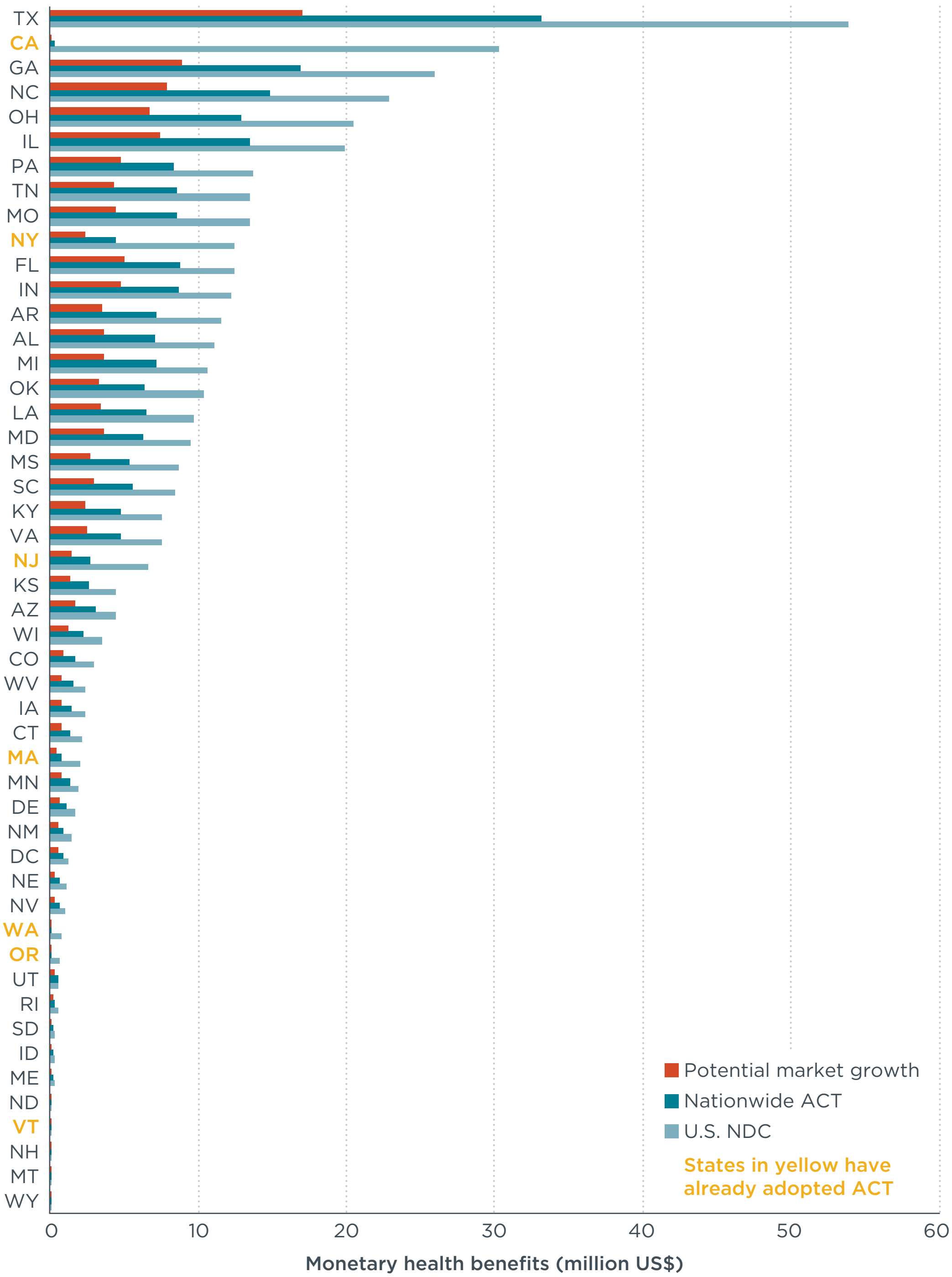

Figure F1. Annual monetary health benefits of the Potential market growth, National ACT, and U.S. NDC scenarios over the current regulatory baseline for populations meeting any environmental justice criteria in 2035, by state

In states that have not adopted California's ACT rule, the U.S. NDC scenario results in 54% higher benefits for communities meeting any EJ criteria than the National ACT scenario when compared to the baseline. We assume that states that have adopted ACT would have similar outcomes under the National ACT scenario, though residents of New York, New Jersey, Massachusetts, and Vermont experience some additional benefit due to reduced pollution from neighboring states. Benefits for communities meeting any EJ criteria from the Potential market growth scenario are approximately half of the benefits from the National ACT scenario for all states.

For all scenarios, the states with the largest per-capita benefits for EJ populations are largely in the Midwest and South. Communities meeting EJ criteria in Arkansas, Indiana, Missouri, Delaware, Oklahoma, Kansas, and North Carolina all show health benefits that are more than double the national average for all scenarios. In all of these states, people of color are currently disproportionately exposed to $PM_{2.5}$ from diesel trucks (Tessum et al., 2021).