EDF
ENVIRONMENTAL DEFENSE FUND®
Finding the ways that work

THE OPPORTUNITY FOR NEAR-TERM ELECTRIFICATION OF MEDIUM- AND HEAVY-DUTY VEHICLES

MAY 2022

1. Executive Summary

The Biden Administration has an opportunity right now to jumpstart the nation's transition to a zero-emitting fleet of medium- and heavy-duty trucks and buses. Greater federal investments and policies including protective emissions standards are urgently needed. Our nation's commercial vehicles are significant contributors to the climate crisis. And the diesel emissions from these trucks and buses harm the health of all Americans and can be deadly to many, especially those in low-income communities and communities of color that are more often located near truck routes and hubs. New standards for medium- and heavy-duty vehicles can reduce pollution by ensuring higher sales of zero emitting vehicles (ZEVs) in the near term. The transition to a zero-emitting commercial sector will strengthen our nation's security while advancing environmental justice, saving trucks, fleets and shippers money, and strengthening American manufacturing jobs.

The Environmental Protection Agency (EPA) recently proposed updated pollution standards for model year (MY) 2027-2029 medium- and heavy-duty vehicles and engines. The proposal assumes only a very modest, 1.5 percent level of ZEV deployment, though EPA has sought comment on how it might strengthen the standards to further reduce pollution and substantially increase ZEVs. Greater ZEV deployment is warranted – many classes and segments of medium- and heavy-duty vehicles are ready for electrification – the technology is available, the costs are falling rapidly and are already competitive with diesel, and manufacturers are investing billions of dollars to deliver more and improved models at a rapid pace.

In this report, EDF presents information and analysis that demonstrates the overall feasibility, including adequate lead time and reasonable cost, of EPA standards that, by 2029, ensure 40 percent of all new class 4-8 single unit trucks and short haul tractors and 80 percent of new school and transit buses are zero-emitting. We then estimate the emissions reductions, health benefits and economic and health related savings of EPA finalizing performance-based pollution standards that would ensure ZEV deployment consistent with these goals. The MY2027-2029 standards are an essential first step in ensuring that all new medium- and heavy-duty vehicle sales be ZEVs by 2035. The administration must also use all available tools, including infrastructure investments and government purchasing power to reward manufacturers who immediately accelerate freight ZEVs in communities afflicted by harmful truck pollution.

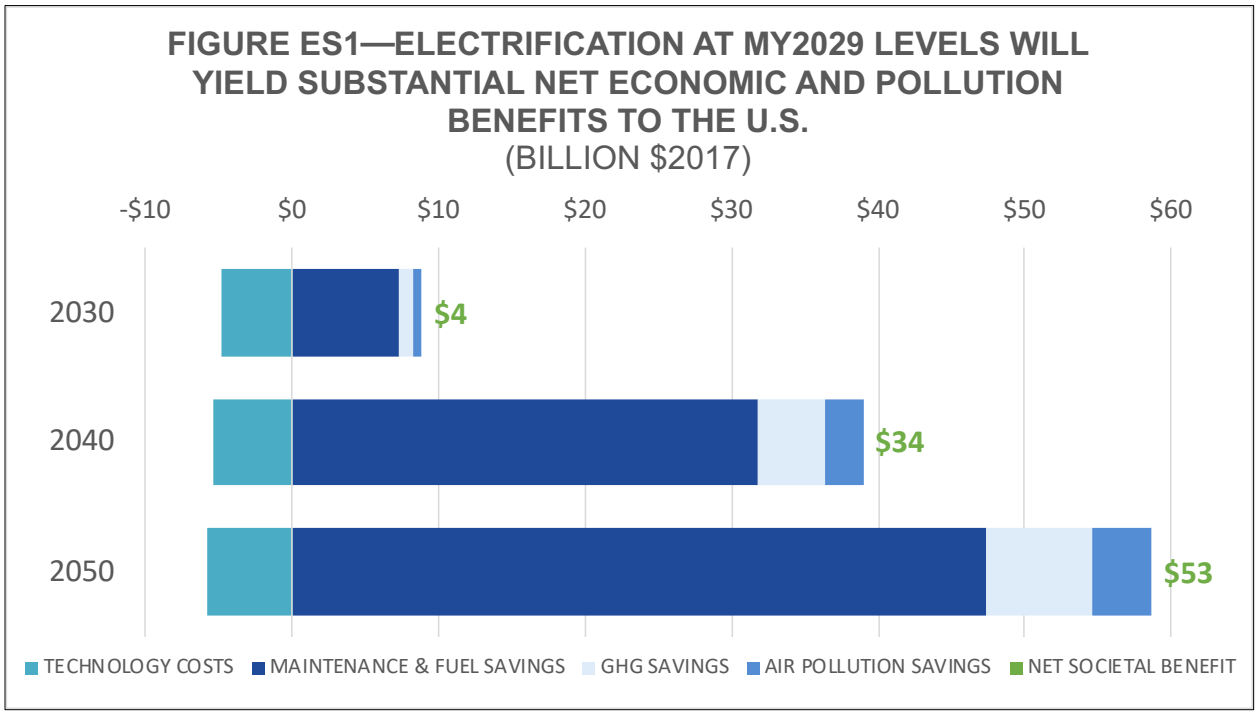
Numerous recent studies confirm that eliminating tailpipe emissions from 40 percent of Class 4-8 single unit trucks and short haul tractors and 80 percent of school and transit buses by 2029 is both technically feasible and cost-saving.[1] EDF analysis shows that advancing ZEVs at this rate would:[2]

- Avoid 85 – 114 million metric tons of greenhouse gas (GHG) emissions every year by 2040 and **more than 1.6 billion tons of GHG emissions through 2050**, eliminating 46 percent of emissions from those segments by 2050.

- Significantly reduce ozone forming nitrogen oxide **(NO_x) pollution by 840,000 – 2.2 million tons through 2050** – pollution that disproportionately impacts people of color and lower income neighborhoods.

- **Prevent as many as 7,500 – 9,600 premature deaths** through 2050.

- Provide our nation with up to $34 billion in economic benefits annually in 2040 with a **cumulative savings of more than $650 – 680 billion by 2050.**



The following sections discuss our analysis in more detail.

2. Protecting the health of all communities

The health burden from truck and bus pollution is substantial, causing adverse health impacts in utero, in infants and children, and in adults and the elderly – with those who live closest to our nation's roads and highways, ports, distribution centers, freight depots, and other well-known sources of truck pollution facing the greatest harms.[3] EPA has estimated that 72 million people live within 200 meters of a truck freight route, and relative to the rest of the population, people of color and those with lower incomes are more likely to live near truck routes.[4]

Despite making up only about 4 percent of vehicles on the road,[5] the buses, trucks, and tractor trailers that distribute our people and goods are the largest contributor to ozone-forming oxides of nitrogen (NOx) emissions from all highway vehicles and will be one of the largest mobile source contributors to ozone in 2025.[6] They are also responsible for a significant amount of health-harming fine particulate matter ($PM_{2.5}$) and more than 420 million tons of climate pollution – more than a quarter of all transportation sector emissions and more than the entire country of Australia.[7]

It is estimated that more than 15,000 Americans die prematurely every year as a result of the motor vehicle pollution on our roads and highways.[8] As a result of housing discrimination and

other unjust policies, communities of color and low-income communities constitute a higher percentage of the population near our roads and highways and therefore suffer disproportionately from this harmful pollution.[9] According to the American Lung Association's 2022 State of the Air report, people of color are more than three and a half times more likely to breathe the most polluted air when compared to white people.[10] A report by Moving Forward Network found that, on average, Asian and Black Americans are exposed to PM2.5 pollution that is 56 and 44 percent higher, respectively, than white Americans.[11] And an EDF analysis of the Bay Area in California found that neighborhoods with higher percentages of residents of color experienced double the rate of asthma from nitrogen dioxide (NO_2) –a pollutant often used as a marker for transportation-related pollution.[12]

Heavy-duty diesel vehicle emissions are often identified as among the largest source of disparity, disproportionally affecting racial-ethnic minorities across geographies and demographics.[13] A recent analysis by The Real Urban Emissions (TRUE) Initiative finds that people of color living in New York City are exposed to 5 percent more $PM_{2.5}$ attributable to diesel trucks operating in the city than average, while non-Latino white residents are exposed to 10 percent less.[14] TRUE concludes, "[t]hese inequities in air pollution exposure contribute to racial disparities in health outcomes."[15]

Recent work using satellite data to assess the health burdens from NO_2 pollution in 52 cities found diesel traffic is the dominant source of disparities—across race, ethnicity, and income—and that a 62 percent reduction in on-road diesel traffic would decrease these inequalities by 37 percent, noting that heavy-duty diesel vehicle emissions, specifically, contribute to the majority of these NO_2 inequalities.[16]

Analysis by scientists at EDF, Harvard Chan School of Public Health and University of North Carolina, using state of the art fine scale air quality modelling and health impact assessment methods, found that electrification of medium- and heavy-duty diesel vehicles will have significant benefits in New York City at a census tract scale.[17] Full electrification of the sector in New York area would prevent $2.4 billion in health damages every year by 2040 (248 deaths, 173 childhood asthma emergency department (ED) visits), much of it directly due to the NO_2 reduction health benefits. Ensuring all new sales of medium- and heavy-duty vehicles by 2040 would provide half of these benefits. Many minority and low-income neighborhoods with high baseline asthma ED visits also have elevated diesel truck and bus traffic and pollution and therefore face disproportionate impacts. Census tracts with 97 percent minority populations bear > 35 percent of total childhood asthma ED visits attributable to medium- and heavy-duty vehicles, despite being only 19 percent of the population. This also means that disadvantaged populations in NYC will potentially experience significant benefits of medium- and heavy-duty electrification. Up to 68 percent of childhood asthma ED visits reduced will be accrued in census tracts with >85 percent minority populations if full electrification takes place by 2040.

Heavy-duty vehicles are also responsible for significant NOx, $PM_{2.5}$, and black carbon emissions around ports, railyards, distribution centers, airports, and other places where trucks congregate and idle.[18] Warehouses and distribution centers where trucks pull in and out, and often idle, are also concentrated sources of risk. Again, many discriminatory policies have led to the siting of these facilities near communities of color who face higher rates of underlying health conditions

as a result of the cumulative burden from air pollution and other factors.[19] In Houston's Fifth Ward, diesel trucks that come and go from the cluster of metal recyclers and concrete processing plants, drive up NO_2 levels by 48 percent relative to the rest of the city. Residents are largely people of color (more than 90 percent), 40 percent live below the federal poverty line and life expectancy is almost a decade lower than the rest of the region (69 compared to 78 years).[20]

Commercial diesel trucks also take an especially heavy toll on neighborhoods along their routes. A years-long study in Canada confirms large trucks to be the greatest contributors to black carbon emissions near major roadways.[21] A study in Oakland, California found that transportation-related air pollution (*e.g.,* black carbon and NOx) was much higher—in some cases double—on a freeway that is a designated truck route (I-880) compared to another freeway in the same city where trucks are prohibited (I-580).[22] Another study near the Port of Oakland also found that black carbon levels measured along truck routes were higher compared to measurements at most other sites, including those near industrial facilities, other highways and on residential streets.[23] Studies have combined these fine scale assessments with electronic health records in the health care systems serving the population in Oakland (Sutter Health and Kaiser Permanente) and find that these elevated levels of NO_2 and black carbon are associated with higher rates of cardiovascular events,[24] asthma emergency room visits and hospitalizations,[25] as well as adverse pregnancy outcomes.[26] Estimated effects of NO_2 and black carbon on preeclampsia were highest among non-Latina Black mothers.

A shift to zero emitting medium- and heavy-duty vehicles–including rapid deployment in communities long overburdened by this pollution–is a critically important step our nation can take to save lives and bring cleaner air to all communities.

3. Investments and Market Advancements

Momentum for electric vehicle development and production is accelerating rapidly, both globally and in the United States. Numerous recent studies highlight key automaker commitments and deployments, the dynamic and growing market for ZEVs, and the opportunity for new American jobs. States and business coalitions are taking the lead in supporting the industry in its transition to electrification.

President Biden has also signaled his support for a zero-emitting transportation system through the signing of two executive orders and an infrastructure bill. In the *Executive Order on Strengthening American Leadership in Clean Cars and Trucks*, President Biden set a goal that 50 percent of new passenger vehicles sold by 2030 are ZEVs and directed EPA to undertake a series of rulemakings to reduce pollution from light, medium- and heavy-duty vehicles, beginning with model year 2027.[27] A second executive order set goals for the federal government to achieve 100 percent ZEV fleet acquisition by 2035 (including medium- and heavy-duty vehicles), and 100 percent light-duty ZEV fleet acquisitions by 2027.[28] President Biden also signed the $1.2 trillion Infrastructure Investment and Jobs Act (IIJA) in 2021, which passed with bi-partisan support in both the U.S. House and Senate. It allocates more than $19 billion toward the medium- and heavy-duty sector, a significant portion of which can be used for ZEV purchases.[29] IIJA also includes $7.5 billion for grant programs administered by U.S. Department of Transportation

(DOT) for EV charging infrastructure and provides new funding to support ZEV school buses, with priority given to underserved and overburdened communities.[30]

Vehicle manufacturers and fleets are making substantial economic and employment investments in a ZEV future

ERM recently released its fifth *Electric Vehicle Market Update*, which tracks the current status and projected growth of the U.S. electric vehicle industry.[31] The April 2022 report found robust growth indicators for the electric vehicle sector just since the last update was published one year prior. Medium- and heavy-duty vehicle manufacturers and fleets are making substantial commitments to zero-emitting vehicles. Daimler Trucks North America, the leading manufacturer of class 8 trucks in the U.S., has committed to offering only carbon-neutral trucks in the U.S. by 2039,[32] and expects that by 2030, as much as 60 percent of its sales will be ZEVs.[33] Volvo Group, owner of the Mack truck brand, has set a goal of having 100 percent of its truck and bus sales be zero-emission by 2040.[34] Navistar recently said it believes that 50 percent of its sales will be electric by 2030 and 100 percent by 2040.[35] Both FedEx and Walmart have committed to transition their entire global truck fleets to ZEVs by 2040.[36]

According to ERM, the labor market is also benefiting from the transition to electrification. Manufacturers have announced new investments in the United States of almost $2 billion in medium and heavy-duty assembly plants, investments that will support approximately 15,000 new direct U.S. jobs over the next decade.[37]

The numbers of electric trucks and buses already on the roads is growing, in part because of the increased selection of model availability. According to CALSTART, as of December 2021, 1,215 Class 2b through Class 8 ZEVs had been deployed in the United States across over 163 fleets.[38] CALSTART has developed an interactive online tool that tracks available and soon-to-be-available medium- and heavy-duty zero-emission trucks (ZETs).[39] In 2019, there were only 20 models of Class 2b-8 ZETs available for purchase in the United States. Today there are more than 400 models available across all classes and CALSTART estimates that could increase to 544 total models by the end of 2022. EPA also conducted an analysis of the manufacturer-supplied end-of-year production reports and found that out of the 380 BEVs certified in MY 2020, a total of 177 unique makes and models were available for purchase by 52 producers in Class 3-8.[40] For example, General Motors launched a new business unit, BrightDrop, in January 2021 that focuses on electric first-to-last-mile delivery trucks. FedEx signed an agreement reserving 2,500 delivery vans and is working with BrightDrop to add up to 20,000 more vehicles in coming years.[41] UPS and DHL ordered 950 electric trucks and 63 delivery vans, respectively, from Workhorse[42] and Amazon has ordered 100,000 zero-emitting vehicles from Rivian.[43]

Leading businesses have also recognized the importance of pollution standards and complementary policies in hastening ZEV deployment. The Zero Emission Transportation Association (ZETA) – a coalition of major businesses including electric vehicle manufacturers, power companies, and many others – has urged adoption of ambitious policies to support medium- and heavy-duty electrification, including multi pollutant standards under the Clean Air Act.[44] The National Zero-Emission Truck (ZET) Coalition is a group of America's biggest truck equipment manufacturers, suppliers and key stakeholders, such as Cummins, Daimler,

PACCAR, Eaton, Tesla and Rivian, advocating for federal charging and refueling infrastructure and increased federal investments and incentive programs to help drive the near-term production of ZEV trucks and buses in the United States.[45] And the European Automobile Manufacturers Association – which includes Scania, Daimler Truck AG, Ford Trucks and Volvo Group, among others – together with the Potsdam Institute for Climate Impact Research, has pledged that by 2040 all new commercial vehicles sold must be fossil free.[46]

State policies are further accelerating ZEV deployment

California and other states around the nation are paving the way for ZEVs and creating a strong foundation for the federal government to move forward with protective emissions standards. In September 2020, California Governor Gavin Newsom announced a bold plan for the state to achieve 100 percent zero emitting passenger vehicle sales by 2035 and 100 percent zero emitting freight trucks and buses for all feasible operations by 2045, while accelerating mobilization of zero emitting vehicles in urban and community applications to address environmental injustice.[47]

In June 2020, California adopted the world's first zero-emission truck rule. The Advanced Clean Truck (ACT) rule will require manufacturers to start selling new heavy-duty ZEVs by 2024 and require 55 percent of class 2b – 3 truck sales, 75 percent of class 4 – 8 straight truck sales, and 40 percent of truck tractor sales to be zero-emission by 2035 at the latest.[48] This landmark rule is expected to prevent more than 900 premature deaths, save the state economy up to $12 billion over the next 20 years and create thousands of new jobs by 2035.[49]

Importantly, California also adopted more protective heavy-duty low NO_x emissions standards to help the state meet national ambient air quality standards and vital state public health and environmental justice goals. In August 2020, California adopted the Heavy-Duty Engine and Vehicle Omnibus Regulation, which substantially tightens the NOx emission standard for on-road heavy-duty engines by 75 percent beginning in 2024 and ramping up to 90 percent in 2027.[50] Once fully phased in by 2031, the rule is expected to reduce harmful NOx emissions in California by more than 23 tons per day – the equivalent of taking 16 million light-duty cars off the road in 2031. The emissions reductions will result in 3,900 avoided premature deaths and 3,150 avoided hospitalizations statewide over the life of the rule (2024 – 2050), and lead to estimated statewide health benefits of approximately $36.8 billion.[51]

In November 2021, Oregon became the first state outside of California to adopt both the ACT rule and the Heavy-Duty Omnibus rule, which will apply to model years 2025 and beyond.[52] Four other states – New Jersey, New York, Washington and Massachusetts – have all adopted the Advanced Clean Trucks rule.[53] These states, together with California and Oregon are estimated to contain more than 20-percent of the national fleet of medium- and heavy-duty trucks.[54] And many other states, including Connecticut,[55] Colorado and Maine are currently contemplating adoption of the ACT rule.

As part of its statewide strategy to reduce transportation emissions, California is also developing the Advanced Clean Fleets regulation, which aims to accelerate the market for zero-emission trucks and buses by requiring fleets that are well suited for electrification to transition to ZEVs.[56] The regulation would set requirements for new ZEV sales as well as in-use fleet composition,

and would apply to fleets performing drayage operations, public agencies, federal governments, and high-priority fleets.

The draft regulation includes setting a requirement that all new medium- and heavy-duty vehicle sales be ZEVs starting in 2040 – a target that is faster than that finalized in the ACT rule – and proposed to help contribute to the state's goal of carbon neutrality by 2045 and the Governor's executive order that 100 percent of medium- and heavy-duty vehicles where feasible be ZEVs by 2045. Under the draft regulation, public fleets would be required to purchase 100 percent ZEVs by 2027; all new drayage trucks would be ZEVs beginning in 2024 and by 2035 every drayage truck on the road would be a ZEV; and high priority and federal fleets would be required to meet ZEV targets as a proportion of their total fleet. The Air Resources Board (ARB) will hold additional public workshops on the draft regulation in May 2022.[57]

In addition to state rulemakings, a diverse collection of seventeen states and the District of Columbia joined a multi-state initiative to advance and accelerate the market for electric medium- and heavy-duty vehicles.[58] Together, the signatories account for 35 percent of the nation's medium- and heavy-duty fleet.[59] The voluntary initiative set a target of 30 percent of new truck and bus sales being ZEV by 2030 and 100 percent ZEV sales by 2050 with an emphasis on the need to accelerate and prioritize deployment in disadvantaged communities. The agreement could result in an estimated reduction of up to 740 million barrels of oil by 2045, which is equivalent to more than 300 million metric tons of CO_2 pollution.[60] A more recent report from ICCT estimates a cumulative emissions reduction of 646 million metric tons of CO2 from 2020-2050.[61]

These state initiatives are imperative because they drive the adoption of ZEV technology and help alleviate statewide pollution burdens. However, heavy-duty vehicles and their pollution do not always stay within state borders. For example, over half of the heavy-duty vehicle miles traveled in California are by federally certified vehicles that are not required to meet California's more protective standards.[62] A durable EPA medium- and heavy-duty greenhouse gas and NOx rule will further encourage the investments needed to transition to a fully zero-emitting medium- and heavy-duty fleet.

4. ZEV costs are nearing parity with gasoline and diesel vehicles

Many commercial truck and bus segments are primed for a near term transition to electrification – the technology has been proven and the benefits outweigh the costs now or in the very near term. A recent study conducted by Roush Industries for Environmental Defense Fund evaluated both the upfront and ongoing costs of electrifying several types of medium and heavy-duty vehicles that are commonly used in urban areas, including transit buses, school buses, garbage trucks, shuttle buses and delivery trucks.[63] These vehicles tend to be concentrated in urban areas where average trip distances are shorter and health and pollution impacts are of most concern, making them particularly important opportunities for early electrification deployment.

The analysis evaluated the cost of electrifying these medium- and heavy-duty market segments and projected incremental vehicle costs of BEVs over diesel vehicles at the time of purchase and the total cost of ownership (TCO) of BEVs in the 2027- 2030 timeframe. The analysis concludes

that BEVs are cost competitive with diesel vehicles in all vehicle segments examined, and in most cases at the time of purchase in 2027.

As shown in Figure 1, when considering upfront purchase price alone, by 2027, the electric freight trucks and buses examined will be incrementally less expensive than their combustion engine counterparts in all categories except shuttle buses (which are close to price parity). Incremental vehicle costs were determined by identifying the major components in a diesel-powered vehicle that would be eliminated in a BEV (delete costs), as well as identifying components that must be added to a vehicle for electrification.

As state and federal greenhouse gas and low NOx regulations continue to become more protective, technology will be developed to improve fuel economy and reduce emissions in diesel vehicles, adding costs to their systems. In contrast, further technology development of EV components such as batteries, motors, and power electronics will lower the costs of these items, leading to their cost parity or advantage over diesel powertrains as early as 2027.

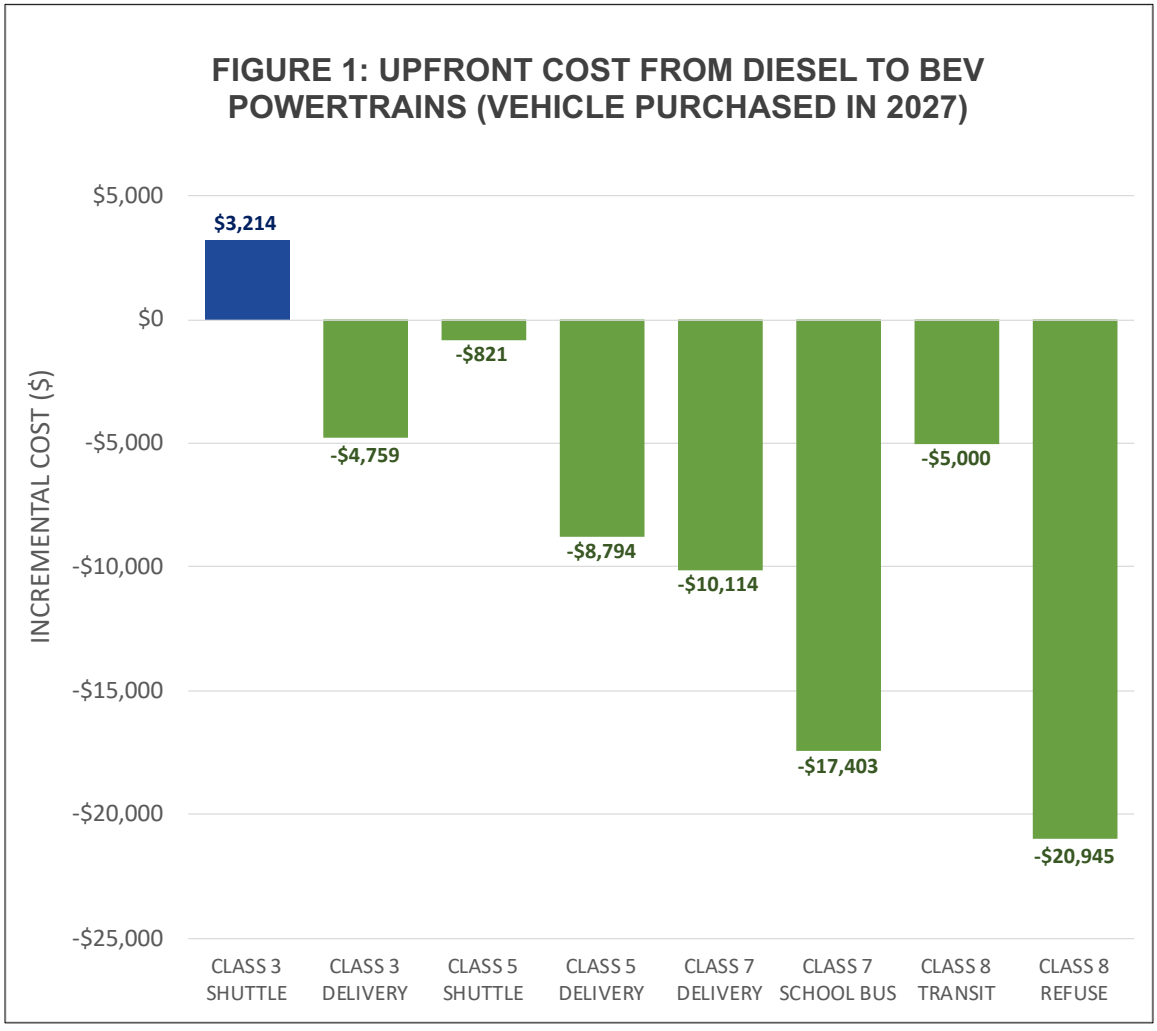


Figure 1 shows that in almost every case, electric vehicles are projected to have lower upfront costs than their diesel counterparts as early as 2027.

Total cost of ownership (TCO), which is important to fleet customers, represents all capital expenditures related to a vehicle that an owner will incur over the vehicle's life. TCO considers purchase price, maintenance, energy, and charging infrastructure costs over the life of the vehicle. The Roush study concluded that for vehicles purchased in 2027, electric vehicle costs will be less than internal combustion vehicles costs over the life of the vehicle – largely because maintenance and energy costs will be lower (Figure 2). The cost savings will also be more than enough to overcome any added costs from charging infrastructure. Charging infrastructure costs are expected to decline in the future as a result of increasing availability, advancing technology, and optimized charging strategies, which could further reduce the TCO for EVs.

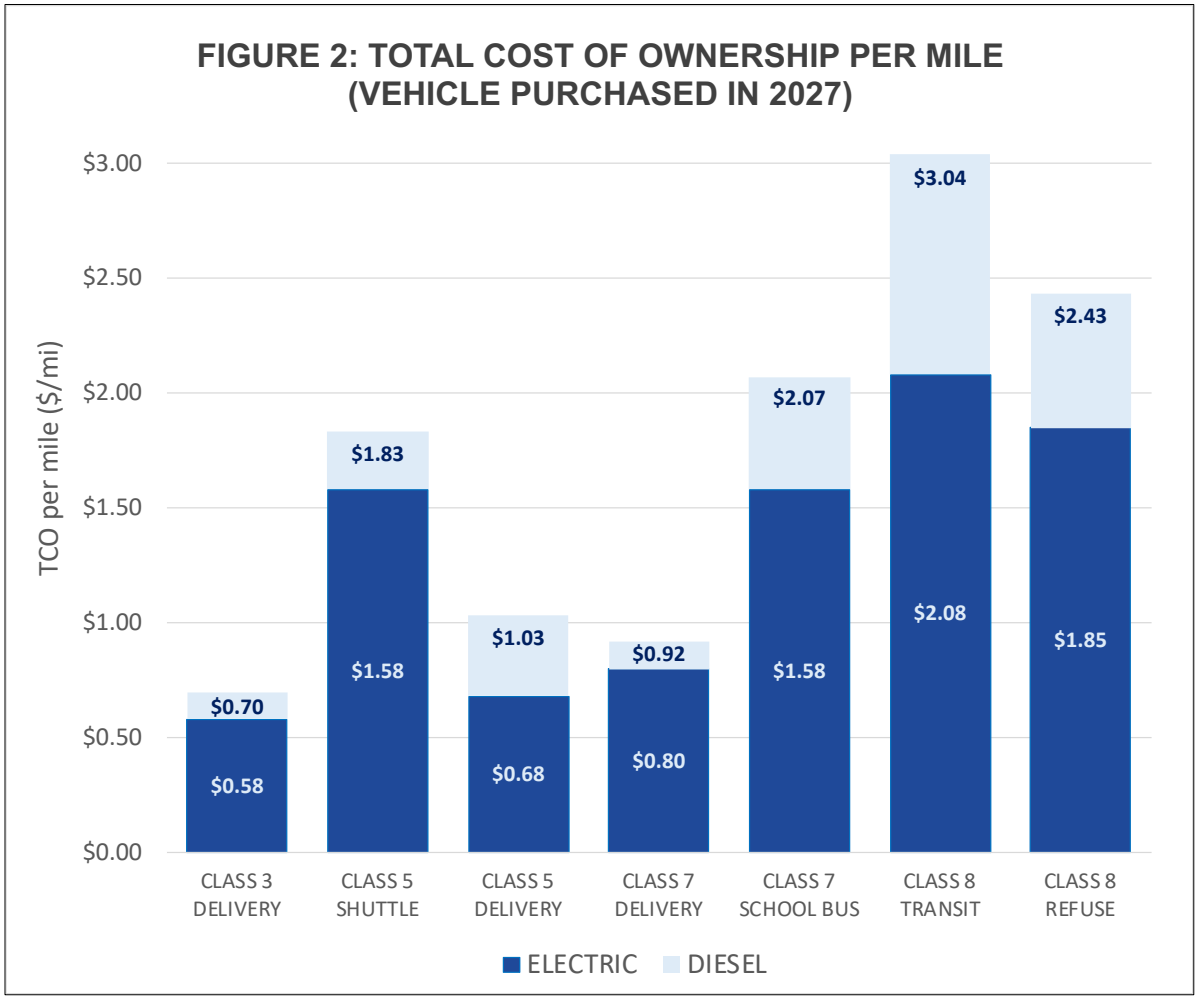


Figure 2 shows that in all segments, the cost of owning a BEV purchased in 2027 will be less than a diesel counterpart over the life of the vehicle.

Finally, Roush concluded that TCO parity will occur at the time of purchase in 2027 for many segments or very quickly for others (Table 1). These TCO projections reflect Roush's original analysis that used a fuel cost of $3.25 per gallon. In a study update, Roush used EIA's high projection for 2027-2030 of $4.90 per gallon, which is much closer to today's prices. At that fuel price the TCO parity occurs a year earlier for a couple of classes.[64] These results support the

immediate move to electrification for vehicle segments that operate primarily in urban settings where vehicle trips are shorter and the burden from harmful emissions is greatest.

	TABLE 1–TOTAL COST OF OWNERSHIP (TCO) PARITY (VEHICLE PURCHASED IN 2027)			
	CLASS	SEGMENT	BATTERY SIZE kWh	TIME TO TCO PARITY
	CLASS 8	REFUSE HAULER	200	IMMEDIATE
	CLASS 8	TRANSIT BUS	400	1 YEAR
	CLASS 7	SCHOOL BUS	60	IMMEDIATE
	CLASS 7	DELIVERY TRUCK	100	3 YEARS
	CLASS 5	DELIVERY TRUCK	150	IMMEDIATE
	CLASS 3–5	SHUTTLE BUS	200	2 YEARS
	CLASS 3	DELIVERY VAN	100	2 YEARS

Roush's findings have been confirmed in other recently released reports. The National Renewable Energy Lab (NREL) looked at all classes and segments of medium- and heavy-duty vehicles and concluded that with continued improvements in vehicle and fuel technologies, ZEVs can reach TCO parity with diesel vehicles as early as 2026 for some applications and no later than 2035 for all segments, including long-haul trucks.[65] The study also concludes that 42 percent of all medium- and heavy-duty truck sales and 100 percent of bus sales will be ZEVs by 2030.

While Roush did not study Class 8 short haul (day cab) tractors, this segment is also ripe for near-term electrification. These tractors pull trailers and typically drive less than 250 miles per day, returning to a hub each night where they could charge. NREL estimates that these tractors will reach TCO parity with their diesel counterparts by 2025.[66] And a recent study by the North American Council for Freight Efficiency (NACFE) concluded that a BEV short haul tractor purchased today will save more than $9,000 annually on fuel costs compared to a diesel truck.[67]

Cost parity projections are also being confirmed by leading heavy-duty truck and bus manufacturers. Navistar noted recently that long haul trucks will meet cost parity with diesel by 2027 with all other heavy-duty vehicles reaching cost parity before 2025.[68] Daimler anticipates total cost of ownership of its BEVs to reach parity with traditional diesel vehicles by 2025.[69]

Another report developed by M.J. Bradley & Associates for Environmental Defense Fund shows a large and growing opportunity to expand America's zero-emission freight trucks and buses. The report evaluates four factors in assessing the readiness of zero-emitting medium and heavy-duty vehicles in different applications – the availability of electric models from manufacturers, the requirements for charging, the ability of electric models to meet operating requirements, and the business case for zero-emitting vehicles. It finds that many market segments have favorable ratings across at least three of these categories, which indicates strong potential for near-term zero-emitting vehicle deployment. These market segments, which represent about 66 percent of the current in-use fleet, include heavy-duty pickups and vans, local delivery and service trucks and vans, transit and school buses, Class 3 to 5 box trucks, Class 3 to 7 stake trucks, dump trucks and garbage trucks. Similarly, a ZEV applicability spreadsheet created by California's ARB and the Truck and Engine Manufacturers Association (EMA) shows that dozens of medium- and heavy-duty vehicle segments in Class 3-8 already met all of the criteria for immediate electrification in 2019.[70]

Market sources clearly show that the medium- and heavy-duty industry has embraced zero-emitting vehicle technology and momentum is growing. Numerous vehicle classes and segments are ready for electrification today to help launch the industry toward zero tailpipe emissions. Strong and durable federal emissions standards are needed to signal our nation's steadfast commitment to reducing truck emissions and support the industry in its transition to ZEVs.

5. National pollution standards must achieve significant penetration of ZEVs in the near term

EPA is considering pollution standards under the Clean Air Act that could ensure substantially greater adoption of medium- and heavy-duty ZEVs in the near term. As noted above, many classes of medium- and heavy-duty vehicles, including delivery vans, short-haul box trucks, refuse haulers, shuttle vehicles, and transit and school buses, are already cost-effective segments for electrification with more models reaching purchase and TCO parity within the next few years.

EDF has conducted analysis examining the climate, air pollution, health and monetized impacts that would result from electrifying vehicles in several medium- and heavy-duty market segments, in the 2027-2029 timeframe. While these segments present the most cost-effective near-term opportunity for reductions, it will be equally important for other segments, including long-haul tractors, to transition to electrification as soon as possible because of their significantly high emissions, high vehicle miles traveled and lower fuel economy.

Methodology

Our analysis assumes by model year 2029:

- 40 percent of new Class 4-8 single unit truck sales will be BEVs,
- 40 percent of new Class 8 short haul (day cab) tractor sales will be BEVs, and
- 80 percent of new transit and school bus sales will be BEVs.

Table 2 below shows the assumed ramp up to 2029 for each vehicle category. The analysis assumes BEV sales will be held constant at MY2029 levels thereafter.

TABLE 2: BEV SALES UNDER SCENARIO MODELED

MODEL YEAR	CLASS 4–8 SINGLE UNIT TRUCKS CLASS 8 DAY CABS	TRANSIT AND SCHOOL BUSES
2026 AND EARLIER	0%	0%
2027	13%	25%
2028	27%	50%
2029 AND BEYOND	40%	80%

The analysis estimates the health, environmental and economic impacts against a baseline that utilizes default vehicle sales and usage from EPA's MOVES3 model. Baseline emissions have been adjusted to account for proposed Option 1 NOx and PM standards in EPA's recent proposal for heavy-duty engine and vehicle standards[71] as well as EPA's projected medium- and heavy-duty BEV sales (taken from AEO2018).[72] Only those emissions from the four vehicle segments listed in Table 2 are included in the analysis. Fuel prices – including gasoline, diesel and electricity rates – are taken from the High Oil Price case of the Annual Energy Outlook (AEO) 2022. Upstream fossil fuel emission factors are taken from the recent EPA final rulemaking for light-duty model year 2023-2026 GHG standards.[73,74] Upstream electricity emissions in 2025 are based on GREET2020 estimates, linearly reduced to zero in 2035 per President Biden's plan for the nation to be 100 percent renewable by 2035.[75]

The estimated vehicle, maintenance and electric charging costs are based on the Roush report conducted for EDF and a DOE report from NREL.[76] The impact of emissions on public health is based on the findings of EPA's analysis presented as part of its proposed rulemaking.[77]

Case for near-term electrification of modeled medium- and heavy-duty vehicles

Based on technological feasibility, cost, lead time and other market forces it is reasonable that performance-based pollution standards would help to ensure that 40 percent of all new class 4-8 single unit trucks and short haul tractors and 80 percent of school and transit buses are zero-emitting by 2029.

Most Class 4-8 single unit trucks, Class 8 day-cab tractors, and school and transit buses are suitable for near-term electrification due to generally modest daily mileage and energy demand per vehicle, as well as the ability of most vehicles in the segments to utilize home base charging. We do not include sleeper cab-equipped tractors in our analysis because they are used in long-haul operations and are more likely to require a public charging network, making them more difficult to electrify in the 2027-2029 timeframe. In the truck segments encompassed in our analysis, 60 – 80 percent of existing highway vehicles are estimated to be highly suitable for

electrification with current technology, and these percentages are expected to increase by 2029 due to improvements in battery technology that will increase range and reduce vehicle weight.[78]

The U.S. medium- and heavy-duty electric vehicle market has significantly expanded in the past three years, with the addition of more variety of vehicle models available from a greater number of manufacturers, such that sufficient electric vehicle options will be available in the 2027 – 2029 time. In the past, most ZEVs were produced by small manufacturers; there are now larger companies that dominate the diesel and gasoline truck market entering the ZEV market and making significant investments to expand ZEV production capacity. This trend is expected to continue as ZEV demand increases due to reductions in ZEV life-cycle costs, ZEV-focused federal funding under the Bipartisan infrastructure law, existing policies in California and other states that require minimum levels of ZEV sales, and announced fleet ZEV purchase commitments from private companies and government agencies. A recent analysis commissioned by EDF indicates that baseline medium- and heavy-duty ZEV sales, absent any additional standards or supporting federal policy, could account for half or more of the scenario modeled in this analysis.[79]

Navistar and Daimler Trucks North America – which together account for about 37 percent of Class 4 – 8 truck sales – both project 50 – 60 percent of their sales volume will be ZEVs by 2030.[80] These companies are already preparing to meet similar levels of demand as those that would result from protective, performance-based standards consistent with the above-described 2029 ZEV goals. Accordingly, these company projections reinforce our analysis and underscore that there is ample lead time to meet national performance-based standards that ensure this level of ZEV deployment.

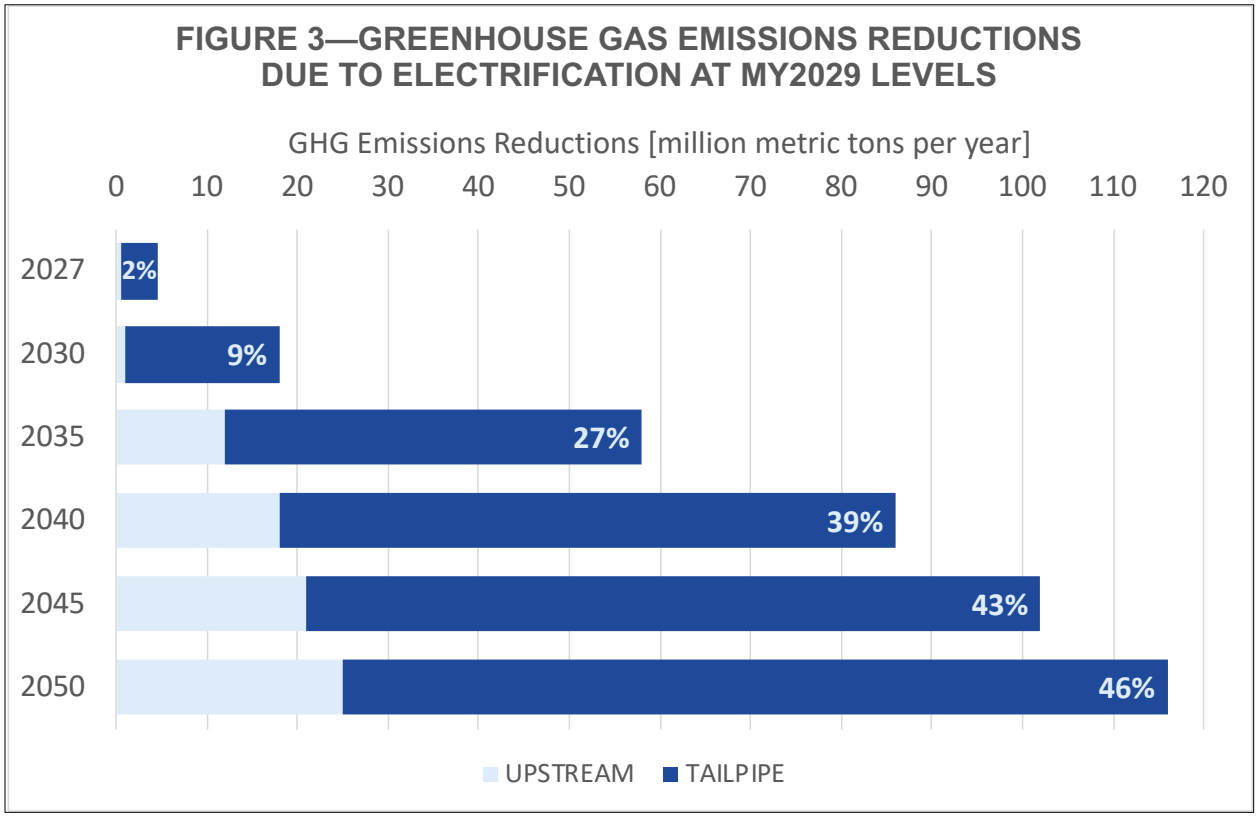
One factor likely driving Navistar and Daimler's projections of high ZEV sales growth is a rapidly improving business case for medium- and heavy-duty electrification, due to projected reductions in battery and component costs and increasing availability of charging infrastructure. As noted earlier, numerous recent studies project life cycle cost parity - or even purchase cost parity - between ZEV and diesel/gasoline trucks and buses in the 2025 – 2028 timeframe. And both Navistar and Daimler stated recently that they anticipate their heavy-duty ZEV vehicles reaching life-cycle cost parity with diesel before or by 2025.[8182]Achievement of cost parity with traditional vehicles will drive ZEV demand beyond early adopters, to a greater number of fleets that are primarily focused on the bottom line.

Ensuring that 40 percent of new Class 4-8 single unit trucks and short haul tractors and 80 percent of buses are ZEVs by 2029 is reasonable and readily achievable and will result in significant emissions reductions, health benefits and billions of dollars saved, as shown in our results below.

6. Results

National pollution standards for new medium- and heavy- duty vehicles have the opportunity to deliver significant climate, health and economic benefits by reducing greenhouse gas and other harmful air pollutants, including carbon dioxide (CO_2), NO_x, fine particulates, air toxics and other health-harming pollutants.

As shown in Figure 3, standards that drive the early electrification of Class 4-8 single unit trucks, day cabs and transit and school buses have the potential to eliminate nearly 60 million metric tons of GHG emissions annually in 2035, 85 million tons in 2040 and 115 million tons every year by 2050, relative to no federal action. Between now and 2050, standards that achieve the above-described goals will eliminate more than 1.6 billion tons of climate pollution, which is 46 percent of GHG emissions from the vehicle segments modeled. If we assume that all of these segments reach 100 percent new ZEV sales by 2035, we would see far greater emissions benefits. Similarly, requiring even a small portion of long-haul tractor sales to be ZEVs over the next decade would result in dramatic reductions due to the high fuel use by that segment.

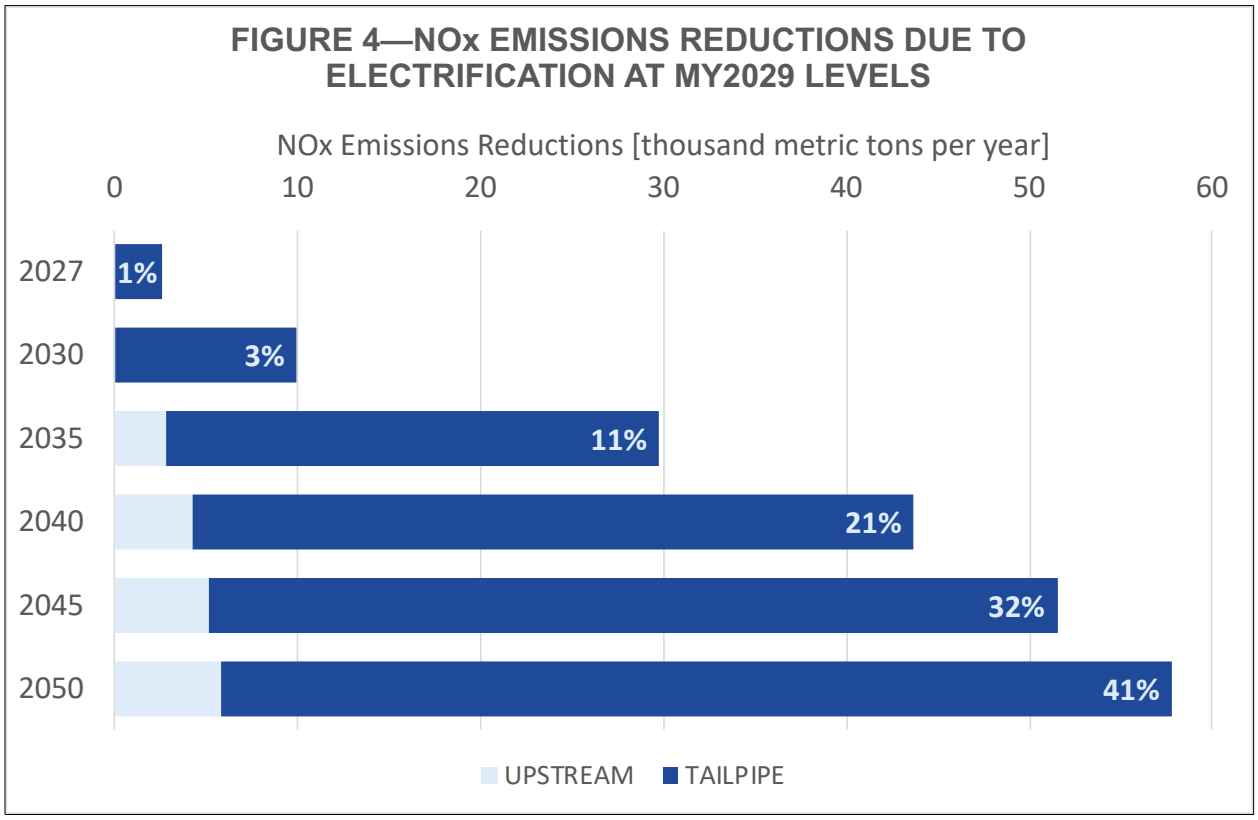


Protective standards would also deliver significant reduction in ozone-forming nitrogen oxides (NOx), health-harming particulates and sulfur oxides (SOx), especially in communities near busy truck routes.

As Figure 4 shows, standards that achieve the above-described ZEV goals would reduce NO_x emissions by nearly 30,000 tons per year in 2035, more than 43,000 tons annually by 2040 and nearly 60,000 tons annually by 2050. In total, the standards will eliminate more than 840,000 tons and 41 percent of NOx emissions from the modeled vehicle segments alone by 2050. These reductions are incremental to EPA's proposed Option 1 NOx emissions standards. The emissions benefits of early electrification would increase dramatically to a total NOx reduction of nearly 2.2 million tons by 2050 if compared to the existing NOx standards.[83] NO_x contributes to the

formation of fine particles and ground level ozone, both of which are associated with adverse health effects, including premature death.[84]

Standards that drive electrification of urban vehicles would also reduce fine particulate matter by a total of 14,000 tons and SOx emissions by 87,000 tons by 2050.

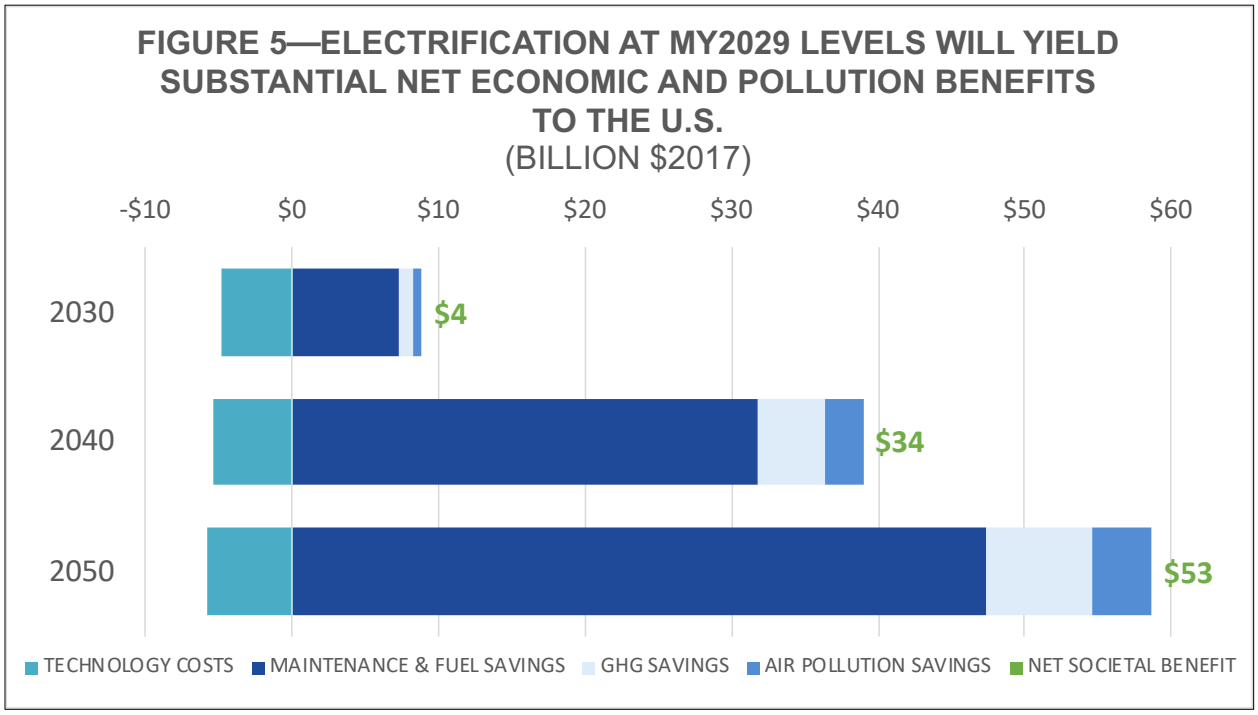


We translated these pollution reductions into health benefits using EPA's latest assessment of the impact of NOx and PM emissions described in EPA's recent proposal.[85] Table 3 shows that emissions standards that drive early electrification of some medium- and heavy-duty vehicles segments would result in an estimated 390 fewer premature deaths and more than 32,000 fewer lost workdays each year by 2040. By 2050, a total of more than 7,500 fewer Americans will have died prematurely. And if compared to existing NOx standards, the impact of electrification could prevent as many as 9,600 premature deaths by 2050.

TABLE 3: ELECTRIFICATION AT MY 2029 LEVELS YIELD SIGNIFICANT REDUCTIONS IN HEALTH IMPACTS			
INCIDENCES	**2040**	**2050**	**TOTAL THRU 2050**
PREMATURE MORTALITY			
Average Long Term PM–Related	394	542	7,591
Short Term PM– and Ozone–Related	8.9	11.6	172.6
NON–FATAL HEART ATTACKS			
Peters et al. (2001)	279	383	5,396
Others*	30	42	585
CARDIAC ARREST	217	302	4,159
ASTHMA SYMPTOMS	28,385	38,132	558,655
TOTAL RESPIRATORY SYMPTOMS	8,836	12,277	169,586
EMERGENCY ROOM VISITS AND HOSPITAL ADMISSIONS	335	458	6,486
ACUTE BRONCHITIS	340	471	6,543
LOST WORK DAYS	32,561	44,753	69,861
*Equal-weights pooling of these studies: Pope III et al. (2006); Sullivan et al. (2005); Zanobetti et al. (2009); and Zanobetti and Schwartz (2006)			

To evaluate the economic impacts of eliminating pollution from new vehicles sold by 2029, we monetized the benefits of the GHG emissions reductions and ambient ozone and PM-related health benefits to society and added it to the total vehicle, maintenance and fuel cost savings.[86] Figure 5 summarizes the substantial aggregate benefits to the nation, relative to no federal action. The annual benefits are an estimated $4 billion in 2030 and jump to as high as $34 billion in 2040 and nearly $53 billion in 2050. In total, eliminating tailpipe pollution from the segments modeled would save the nation more than $650 billion – or up to $680 billion assuming today's NOx standards. Again, these dramatic economic and health savings are the result of just a portion of the medium- and heavy-duty fleet starting to electrify over the next 7 years. The

impact of 100 percent new ZEV sales across all vehicle segments would push these benefits into the trillions of dollars.



7. Conclusion

Performance-based pollution standards that ensure the early electrification of Class 4-8 single unit trucks, day cabs and transit and school buses would have substantial benefits for all Americans. These standards would avoid at least 85 million metric tons of greenhouse gas emissions every year by 2040 and a total of more than 1.6 billion tons by 2050. They would likewise significantly reduce ozone forming pollution by more than 43,000 tons annually by 2040 and 840,000 in total through 2050 – pollution that disproportionately burdens people of color and lower income communities. The standards would prevent more than 7,500 premature deaths through 2050. Adopting national multipollutant standards for this subset of medium- and heavy-duty vehicles would save Americans up to $34 billion annually by 2040 and $650 billion cumulatively by 2050. Following these pollution standards with a national program that drives 100 percent new ZEV sales of all medium- and heavy-duty vehicles by 2035 would result in even greater benefits, including trillions of dollars in economic savings to our nation.

[1] *See e*g. Vishnu Nair, Sawyer Stone, Gary Rogers, Sajit Pillai. 2022. *Medium and Heavy-Duty Electrification Costs for MY 2027- 2030*, Roush Industries for Environmental Defense Fund. http://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf; Muratori, Matteo et al. "Decarbonizing Medium- and Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis." NREL Transforming Energy. March 2022. https://www.nrel.gov/docs/fy22osti/82081.pdf.

[2] These estimated benefits ranges are calculated as incremental to EPA's proposed Option 1 NOx emissions standards (low end of benefits range) and incremental to today's current NOx emissions standards (high end of benefits range).
[3] *See, e.g.*, Riley, S., Wallace, J., & Nair, P. 2012. Proximity to Major Roadways is a Risk Factor for Airway Hyper-Responsiveness in Adults. *Can. Respir. J., 19*(2):89-95. McConnell, R. et al. 2010. Childhood Incident Asthma and Traffic-Related Air Pollution at Home and School. *Envtl. Health Perspect.,118*(7):1021-6. Huynh, P. et al. 2010. Residential Proximity to Freeways is Associated with Uncontrolled Asthma in Inner-City Hispanic Children and Adolescents, *J. Allergy (Cairo).* Chang, J. et al. 2009. Repeated Respiratory Hospital Encounters Among Children with Asthma and Residential Proximity to Traffic. *Occup. Envtl. Med., 66*(2):90-8. Salam, M.T., Islam, T, & Gilliland, F.D. 2008. Recent Evidence for Adverse Effects of Residential Proximity to Traffic Sources on Asthma. *Curr. Opin. Pulm. Med., 14*(1):3-8.
[4] 87 Fed. Reg. 17451 (March 28, 2022).
[5] H. Christopher Frey. 2018. Trends in onroad transportation energy and emissions. *Journal of the Air&Waste Management Assoc.* Vol. 68, No. 6, 514–563, Table 1. https://www.tandfonline.com/doi/full/10.1080/10962247.2018.1454357
[6] https://www.epa.gov/sites/default/files/2019-08/documents/cti-sae-govt-ind-2019-04-04.pdf
[7] EPA. 2022. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2020, Chapter 3, Table 3-13. https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2020 International Energy Agency, Atlas of Energy. 2020. http://energyatlas.iea.org/#!/tellmap/1378539487
[8] Kenneth F Davidson et al. 2020. The recent and future health burden of the U.S. mobile sector apportioned by source. *Environ. Res. Lett.* 15 (7). https://iopscience.iop.org/article/10.1088/1748-9326/ab83a8/pdf Estimate of "over 20,000" derived using the medians of the upper bound of Krewski and Lepeule's 2011 and 2025 onroad health burden estimates in Table 3 and 4 and assuming a linear reduction over time.
[9] Gregory M. Rowangould. 2013. A census of the US near-roadway population: Public health and environmental justice considerations. *Transportation Research Part D 25*, 59–67. https://www.sciencedirect.com/science/article/pii/S1361920913001107.
[10] American Lung Association. 2022. State of the Air. https://www.lung.org/getmedia/74b3d3d3-88d1-4335-95d8-c4e47d0282c1/sota-2022.pdf
[11] Jimmy O'dea. 2020. *Zero-Emissions Technology for Freight: Heavy-Duty Trucks, Tools to Advocate for Zero-Emissions Technology.* Moving Forward Network. http://www.movingforwardnetwork.com/wp-content/uploads/2020/10/MFN_ZeroEmissionToolkit-1.pdf
[12] EDF. 2021. Air pollution's unequal impacts in the Bay Area. https://www.edf.org/airqualitymaps/oakland/health-disparities
[13] Tessum, C. W., Paolella, D. A., Chambliss, S. E., Apte, J. S., Hill, J. D., Marhsall, J. D. $PM_{2.5}$ polluters disproportionately and systemically affect people of color in the United States. *Sci. Adv.* 7, eabf4491 (2021).
[14] Meyer, M. and Dallman, T., (April 2022). *Air quality and health impacts of diesel truck emissions in New York City and policy implications.* The Real Urban Emissions (TRUE) Initiative. https://www.trueinitiative.org/media/792240/true-nyc-report-fv.pdf
[15] *Id.*
[16] Demetillo, M. A. G., Harkins, C., McDonald, B. C., Chodrow, P. S., Sun, K., & Pusede, S. E. (2021). Space-based observational constraints on NO2 air pollution inequality from diesel traffic in major US cities. *Geophysical Research Letters, 48*, e2021GL09433. https://doi.org/10.1029/2021GL094333
[17] Presentation by Jonathan Buonocore, Chet France, Rick Rykowski, Brian Naess, Komal Shukla, Catherine Seppanen, Dylan Morgan, Frederica Perera, Katie Coomes, Ananya Roy, Sarav Arunachalam. 2022. "Distribution of Air Quality Health Benefits of MHEV policies: New York," University of North Carolina, Harvard Chan School of Public Health, Columbia University Mailman School of Public Health and Environmental Defense Fund.
[18] *E.g.,* MJB Ports of Newark and Elizabeth.
[19] Nardone A, Casey JA, Morello-Frosch R, Mujahid M, Balmes JR, Thakur N. 2020. Associations between historical residential redlining and current age-adjusted rates of emergency department visits due to asthma across eight cities in California: an ecological study. *Lancet Planet Health*. 4(1):e24-e31. Miranda ML, Edwards SE, Keating MH, Paul CJ. 2011. Making the environmental justice grade: The relative burden of air pollution exposure in the United States. *Int J Environ Res Public Health*. 8: 1755-1771. Ihab Mikati, Adam F. Benson, Thomas J. Luben, Jason D. Sacks, Jennifer Richmond-Bryant. April 2018. Disparities in Distribution of Particulate Matter Emission Sources by Race and Poverty Status, *American Journal of Public Health* 108, no. 4: pp. 480-485. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5844406/
[20] https://www.edf.org/airqualitymaps/houston/findings

[21] Wang, J.M., Jeong, C-H., Hillker, N., Shairsingh, K. K., Healy, R. M., Sofowote, U., Debosz, J., Su, Y., McGaughey, M., Doerksen, G., Munoz, T., White, L., Herod, D., Evans, G. J. Near-road air pollution measurements: Accounting for inter-site variability using emission factors. *Environmental Science & Technology,* 2018; 52(16): 9495. DOI: 10.1021/acs.est.8b01914

[22] Joshua S. Apte et. al. 2017. High-Resolution Air Pollution Mapping with Google Street View Cars: Exploiting Big Data. *Environ. Sci. Technol.* 51, 12, 6999-7008. https://pubs.acs.org/doi/10.1021/acs.est.7b00891

[23] Julien J. Caubel et. at. 2019. A Distributed Network of 100 Black Carbon Sensors for 100 Days of Air Quality Monitoring in West Oakland, California. *Environ. Sci. Technol.* 53, 13, 7564-7573. https://pubs.acs.org/doi/10.1021/acs.est.9b00282

[24] Alexeeff, Stacey E., et al. "High-resolution mapping of traffic related air pollution with Google street view cars and incidence of cardiovascular events within neighborhoods in Oakland, CA." *Environmental Health* 17.1 (2018): 1-13.

[25] Alexeeff, S., et al. "Google Street View car measurements of traffic related air pollution within neighborhoods and asthma-related emergency department visits and hospitalizations." *Environmental Epidemiology* 3 (2019): 406-407.

[26] Goin, Dana E., et al. "Hyperlocalized Measures of Air Pollution and Preeclampsia in Oakland, California." *Environmental Science & Technology* 55.21 (2021): 14710-14719.

[27] White House, Executive Order on Strengthening American Leadership in Clean Cars and Trucks, August 5, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/08/05/executive-order-on-strengthening-american-leadership-in-clean-cars-and-trucks/

[28] White House, Executive Order on Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, December 8, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/

[29] Ellen Robo and Dave Seamonds, "Analysis of Alternative Medium- and Heavy-duty Zero-Emission Vehicle Baseline Scenarios," Technical memo by ERM for EDF (May 12, 2022).

[30] Infrastructure Investment and Jobs Act. H.R. 3684 – 117th Congress. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjwmMqwp6P3AhW9kIkEHcENAOcQFnoECAcQAQ&url=https%3A%2F%2Fwww.congress.gov%2Fbill%2F117th-congress%2Fhouse-bill%2F3684%2Ftext&usg=AOvVaw19Oazsvt2IW47UxWolNvve

[31] Rachel MacIntosh, Sophie Tolomiczenko, Grace Van Horn. April 2022. *Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide*, ERM for EDF, Version 6. http://blogs.edf.org/climate411/files/2022/04/electric_vehicle_market_report_v6_april2022.pdf The original report was released in May of 2019.

[32] David Cullen, "Daimler to Offer Carbon Neutral Trucks by 2039," (October 25, 2019). https://www.truckinginfo.com/343243/daimler-aims-to-offer-only-co2-neutral-trucks-by-2039-in-key-markets

[33] Deborah Lockridge, "What Does Daimler Truck Spin-off Mean for North America?," Trucking Info (November 11, 2021). https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america

[34] https://www.oemoffhighway.com/trends/electrification/press-release/21203695/volvo-group-global-volvo-group-focuses-on-electrification-and-emissions-reduction-strategy

[35] Alan Ohnsman, "Big Rigs Going Electric As Navistar, Cummins, Daimler Rev Up Next-Generation Trucks," Forbes (May 13, 2022). https://www.forbes.com/sites/alanohnsman/2022/05/13/big-rigs-going-electric-as-navistar-cummins-daimler-rev-up-next-generation-trucks/?sh=7c007668419d

[36] Fed Ex Newsroom, "FedEx Commits to Carbon-Neutral Operations by 2040," March 3, 2021. https://newsroom.fedex.com/newsroom/Sustainability2021 Doug McMillon, President & CEO, Walmart, "Walmart's Regenerative Approach: Going Beyond Sustainability," September 21, 2020. https://corporate.walmart.com/newsroom/2020/09/21/walmarts-regenerative-approach-going-beyond-sustainability

[37] Rachel MacIntosh, Sophie Tolomiczenko, Grace Van Horn. April 2022. *Electric Vehicle Market Update: Manufacturer Commitments and Public Policy Initiatives Supporting Electric Mobility in the U.S. and Worldwide*, ERM for EDF, Version 6. http://blogs.edf.org/climate411/files/2022/04/electric_vehicle_market_report_v6_april2022.pdf

[38] Baha, Al-Alawi, et al. "The Advanced Technology Truck Index: A U.S. ZET Inventory Report." CALSTART. Jan 2022. https://calstart.org/wp-content/uploads/2022/02/ZIO-ZETs-Report_Updated-Final-II.pdf.

[39] CALSTART's Zero Emission Technology Inventory (ZETI) tool. https://globaldrivetozero.org/tools/zero-emission-technology-inventory/

[40] EPA memorandum from Angela Cullen, Center Director, Assessment and Standards Division to Docket EPA-HQ-OAR-2019-0055, "HD2027 Proposed Changes to Heavy-Duty Greenhouse Gas Emissions," (November 2021).

[41] "BrightDrop Announces Walmart as New EV Customer and Expands Collaboration with FedEx at CES." 5 Jan. 2022. https://media.gm.com/media/us/en/gm/home.detail.html/content/Pages/news/us/en/2022/jan/ces/0105-brightdrop.html

[42] Hanley, Steve, "UPS Places Order For 950 Workhorse N-GEN Electric Delivery Vans." CleanTechnica, 20 June 2018, https://cleantechnica.com/2018/06/20/ups-places-order-for-950-workhorse-ngen-electric-delivery-vans/#:~:text=UPS%20Places%20Order%20For%20950%20Workhorse%20N-GEN%20Electric,to%20UPS%2C%20bringing%20the%20total%20order%20to%201%2C000 ; DHL. "DHL Expands Green Fleet with Addition of New Electric Delivery Vans." 7 Feb 2019, https://www.dhl.com/us-en/home/press/pressarchive/2019/dhl-expands-green-fleet-with-addition-of-new-electric-delivery-vans.html

[43] Andrew J. Hawkins, "Amazon unveils its new electric delivery vans built by Rivian," *The Verge* (Oct. 8, 2020). https://www.theverge.com/2020/10/8/21507495/amazon-electric-delivery-van-rivian-date-specs

[44] https://www.zeta2030.org/

[45] Calstart. 2020. National Zero-Emission Truck Coalition Statement of Principles. https://calstart.org/zet-statement-of-principles-6-17-20/

[46] Joint statement, ACEA and Potsdam Institute for Climate Impact Research, "The Transition to Zero-emission Road Freight Transport," December 2020. https://www.acea.be/uploads/publications/acea-pik-joint-statement-the-transition-to-zero-emission-road-freight-trans.pdf

[47] State of California, Executive Order N-79-20 (September 23, 2020). https://www.gov.ca.gov/wp-content/uploads/2020/09/9.23.20-EO-N-79-20-Climate.pdf

[48] ARB press release, "California takes bold step to reduce truck pollution," (June 25, 2020). https://ww2.arb.ca.gov/news/california-takes-bold-step-reduce-truck-pollution

[49] Jamie Fine, "Report: California's clean truck rule will save the economy billions, eliminate vast amounts of pollution," EDF blog (June 17, 2020). http://blogs.edf.org/energyexchange/2020/06/17/report-californias-clean-truck-rule-will-save-the-economy-billions-eliminate-vast-amounts-of-pollution/#more-20253

[50] ARB press release, "California adopts strong new regulation to further reduce smog-forming pollution from heavy-duty diesel trucks," (August 28, 2020). https://ww2.arb.ca.gov/news/california-adopts-strong-new-regulation-further-reduce-smog-forming-pollution-heavy-duty

[51] *Id.*

[52] Work Truck staff, "Oregon Adopts Clean-Trucks Rules; Other States May Follow," Work Truck (November 18, 2021). https://www.worktruckonline.com/10156330/oregon-leads-convoy-of-states-toward-cleaner-trucks Oregon will see a projected $21.2 billion in net societal benefits, including saving fleet owners over $1 billion annually, preventing 160 premature deaths and avoiding 84,000 respiratory illnesses by 2050 with the adoption of these two rules. Dana Lowell et. al. 2021. Oregon Clean Trucks Program: An Analysis of the Impacts of Zero-Emission Medium- and Heavy-Duty Trucks on the Environment, Public Health, Industry, and the Economy, M.J. Bradley & Associates for the Natural Resources Defense Council and the Union of Concerned Scientists. https://static1.squarespace.com/static/613127fc91a6b76873be6446/t/61561514cf312212c5dceee6/1633031446406/MJ+Bradley_MHD+Clean+Trucks+Report_Oregon+2021.pdf

[53] Laura Bliss, "How Six States Could Transform the U.S. Trucking Industry," Bloomberg (January 26, 2022). https://www.bloomberg.com/news/articles/2022-01-06/how-zero-emission-laws-will-reshape-u-s-trucking

[54] Federal Highway Administration, Highway Statistics 2019, Truck and Truck-Tractor Registrations (2019). https://www.fhwa.dot.gov/policyinformation/statistics/2019/mv9.cfm

[55] With passage of Connecticut Senate Bill 4 in May 2022, which authorizes the state's Department of Energy and Environmental Protection to adopt California medium and heavy-duty motor vehicle standards, Connecticut is expected to join these states soon.

[56] ARB fact sheet, "Advanced Clean Fleets: Accelerating Zero-Emission Truck Markets," (March 3, 2022). https://ww2.arb.ca.gov/sites/default/files/2022-03/ACF%20Fact%20Sheet_ADA.pdf

[57] ARB website, "Advanced Clean Fleets – Meetings and Events," (last accessed May 11, 2022). https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets/advanced-clean-fleets-meetings-events

[58] The current signatories are California, Colorado, Connecticut, Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, Nevada, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and the District of Columbia. "Multi-State Medium- and Heavy-Duty Zero Emission Vehicle Memorandum of Understanding," (July 14, 2020), https://www.nescaum.org/documents/mhdv-zev-mou-20220329.pdf/

[59] Arijit Sen, Ray Minjares, Josh Miller, and Caleb Braun. April 2022. "Benefits of the 2020 Multi-State Medium- and Heavy-Duty Zero-Emission Vehicle Memorandum of Understanding," ICCT Briefing. https://theicct.org/wp-content/uploads/2022/04/md-hd-mou-benefits-apr22.pdf

[60] Emily Wimberger, Hannah Pitt, Kate Larsen, and Maggie Young. 2020. States Pave the Way for a Zero-Emission Vehicle Future, Rhodium Group. https://rhg.com/research/states-zero-emission-vehicles/
[61] Arijit Sen, Ray Minjares, Josh Miller, and Caleb Braun. April 2022. "Benefits of the 2020 Multi-State Medium- and Heavy-Duty Zero-Emission Vehicle Memorandum of Understanding," ICCT Briefing. https://theicct.org/wp-content/uploads/2022/04/md-hd-mou-benefits-apr22.pdf
[62] Letter from Richard W. Corey, ARB Executive Officer to Liane Randolph, ARB Board Chair, "Accelerating California's Transition to Zero-Emission Trucks," (January 10, 2022). https://ww2.arb.ca.gov/sites/default/files/2022-02/ZE%20Trucks%20Board%20Memo_ADA.pdf
[63] Vishnu Nair, Sawyer Stone, Gary Rogers, Sajit Pillai. 2022. *Medium and Heavy-Duty Electrification Costs for MY 2027- 2030*, Roush Industries for Environmental Defense Fund. http://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf
[64] Sawyer Stone, "MD/HD Total Cost of Ownership – High Fuel Cost," Roush Industries for EDF (April 1, 2022).
[65] Muratori, Matteo et al. "Decarbonizing Medium- and Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis." NREL Transforming Energy. March 2022. https://www.nrel.gov/docs/fy22osti/82081.pdf.
[66] Chad Hunter, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birky, and Chen Zhang. 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks, Nation Renewable Energy Lab, Technical Report. https://www.nrel.gov/docs/fy21osti/71796.pdf
[67] North American Council for Freight Efficiency. 2022. Electric Trucks Have Arrived: The Use Case for Heavy-Duty Regional Haul Tractors. https://nacfe.org/heavy-duty-regional-haul-tractors/

[68] Navistar President and CEO, Mathias Carlbaum, presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9-11, 2022).
[69] Deborah Lockridge, "What Does Daimler Truck Spin-off Mean for North America?," Trucking Info (November 11, 2021). https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america
[70] ARB excel spreadsheet, "Advanced Clean Truck Market Segment Analysis," (February 22, 2019). https://ww2.arb.ca.gov/sites/default/files/2019-02/190225actmarketanalysis.xlsx
[71] Public version of MOVES3 (Latest Version of Motor Vehicle Emission Simulator (MOVES) | US EPA), default inputs except for NOx emissions from 2027-2030 MY and 2031 MY+ HDVs reduced by 61% and 65%, respectively and PM emissions from 2027+ MY HDVs reduced by 28%.
[72] EPA, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards; Draft Regulatory Impact Analysis," EPA-420-D-22-001 (March 2022), Table 5-38.
[73] https://www.eia.gov/outlooks/aeo/, Table 12 of the High Oil Price case.
[74] https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-revise-existing-national-ghg-emissions#additional-resources, EPA model runs and files supporting the final rule's benefit-cost analysis. EPA CCEM PostProcessingTool Project FRM (zip) (December 2021), EPA Tool input file: cost_factors_criteria_frm.csv
[75] Grid emissions through 2025 are based on GREET2020 projections. Emissions after 2025 decline linearly until reaching zero in 2035. The benefits of medium- and heavy-duty standards would be substantial even if the transition to 100 percent renewable electrical grid takes until 2050. For example, emission reductions through 2050 would only be reduced by 1% for GHGs, 0.1% for NOx and 0.4% for PM. Likewise, the impacts on pre-mature mortality and monetized health and welfare benefits would only decrease by 1%.
[76] Chad Hunter, Michael Penev, Evan Reznicek, Jason Lustbader, Alicia Birky, and Chen Zhang. 2021. Spatial and Temporal Analysis of the Total Cost of Ownership for Class 8 Tractors and Class 4 Parcel Delivery Trucks, Nation Renewable Energy Lab, Technical Report. https://www.nrel.gov/docs/fy21osti/71796.pdf; Vishnu Nair, Sawyer Stone, Gary Rogers, Sajit Pillai. 2022. *Medium and Heavy-Duty Electrification Costs for MY 2027- 2030*, Roush Industries for Environmental Defense Fund. http://blogs.edf.org/climate411/files/2022/02/EDF-MDHD-Electrification-v1.6_20220209.pdf
[77] EPA, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards; Draft Regulatory Impact Analysis," EPA-420-D-22-001 (March 2022) Chapters 4,5 and 8.
[78] California Air Resources Board, *Public Hearing to Consider the Proposed Advanced Clean Trucks Regulation, Staff Report: Initial Statement of Reasons; Appendix E Zero Emission Truck Market Assessment,* October 2019.
[79] Ellen Robo and Dave Seamonds, "Analysis of Alternative Medium- and Heavy-duty Zero-Emission Vehicle Baseline Scenarios," Technical memo by ERM for EDF (May 12, 2022).
[80] D. Lowell and J. Culkin, *Medium- and Heavy-duty Vehicles: Market Structure, Environmental Impact, and EV Readiness*, M.J. Bradley & Associates, an ERM Group Company, July 202. Presentation by Mathias Carlbaum, Navistar President and CEO, at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 10, 2022).

Deborah Lockridge, "What Does Daimler Truck Spin-off Mean for North America?," Trucking Info (November 11, 2021). https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america

[81] Navistar President and CEO, Mathias Carlbaum, presentation at the Advanced Clean Transportation (ACT) Expo, Long Beach, CA (May 9-11, 2022). Navistar expects cost parity for long-haul tractors by 2027.

[82] Deborah Lockridge, "What Does Daimler Truck Spin-off Mean for North America?," Trucking Info (November 11, 2021). https://www.truckinginfo.com/10155922/what-does-daimler-truck-spin-off-mean-for-north-america

[83] Our analysis assumes EPA finalizes "Option 1" in its proposed Heavy-duty Engine and Vehicle Standards.

[84] Health Effects Institute. 2019. State of Global Air 2019. https://www.stateofglobalair.org/sites/default/files/soga_2019_usa.pdf

[85] EPA, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards; Draft Regulatory Impact Analysis," EPA-420-D-22-001 (March 2022) Chapters 4,5 and 8.

[86] CO2 was valued at $48 per metric ton in 2021, increasing in real terms by roughly 2% per year. See EPA, Technical Support Document, Estimating the Benefit per Ton of Reducing PM2.5 Precursors from 17 Sectors, February 2018. https://www.epa.gov/benmap/estimating-benefit-ton-reducing-pm25-precursors-17-sectors