NOx Emission Reduction Benefits of Future Potential U.S. Mobile Source Regulations

June 2018

Manufacturers of Emission Controls Association
2200 Wilson Boulevard | Suite 310 | Arlington, VA 22201 | (202) 296-4797
www.meca.org

Table of Contents

Executive Summary

In 2015, MECA funded an independent, emission inventory forecast study with ENVIRON (now Ramboll Environ) to better understand the nitrogen oxide (NOx) reduction benefits of future potential tightening of NOx emission standards for both on-road and off-road heavy-duty diesel engines, and aligning federal rules for aftermarket catalytic converters with California. MECA believes that future potential NOx reductions from mobile sources could provide a cost-effective compliance option for states needing to meet the tighter ozone National Ambient Air Quality Standards (NAAQS) finalized by the U.S. EPA in October 2015 (70 parts per billion).

The study forecasted the NOx, as well as volatile organic compound (VOC), particulate matter (PM), and carbon monoxide (CO), emission reduction benefits in 2025, 2030, 2040, and 2050 of the following three potential emission reduction strategies:

- A 90% NOx tightening from on-road heavy-duty trucks below U.S. 2010 standards;
- Approximately 70% NOx tightening from off-road engines below Tier 4 final standards and PM standards equivalent to on-road diesel limits; and
- Aligning federal gasoline aftermarket requirements with the California Air Resources Board's (CARB) 2009 regulation.

The analysis relied on EPA's MOVES2014 for on-road vehicle emissions and the NONROAD2008 model for off-road emissions. To estimate the impacts of new controls, ENVIRON developed by-model-year emissions for on-road vehicles and modified input databases for the NONROAD model for the off-road equipment to develop emissions estimates with and without new potential emission standards. The results of the model runs were used to adjust the EPA 2025 base inventory in EPA's November 2014 Regulatory Impact Analysis.

The results of the NOx reduction benefits if the modeled potential regulations applied to 47 of the 48 contiguous U.S. states and the District of Columbia (excluding California) are summarized in Table ES-1. The potential NOx reductions from the heavy-duty sector are approximately 603 tons/day from on-road trucks and 468 tons/day from off-road equipment in 2050, and potentially 51.5 tons per day from in-use, light-duty passenger cars in 2025.

Table ES-1. On-road and off-road emission reductions (x 1000 tons) by calendar year for 47 CONUS and D.C. (excludes CA) domain from potential emission standards analyzed in this study

Year	On-Road Vehicles				Diesel Off-Road	
	Gasoline Light Duty			Diesel Heavy Duty		
	VOC	CO	NOx	NOx	NOx	PM
2025	12.7	309.3	18.8	50.6	10.7	0.04
2030	8.6	225.6	12.1	129.5	81.5	0.28
2040	6.0	164.1	8.1	220.4	171.1	0.58
2050	6.1	168.9	8.1	265.8	215.3	0.72

EPA has put in place important regulatory programs for reducing NOx emissions and PM emissions from new on-road and off-road diesel engines beginning with the 2007-2010 heavy-duty highway engine emission program, followed by the Tier 4 nonroad diesel emission regulations that have been phased in over the 2008-2015 timeframe. Both of these regulatory programs rely on a systems approach that combines advanced diesel engine technology, exhaust emission control technologies, and the use of ultra-low sulfur diesel fuel to achieve significant reductions in both NOx and PM emissions compared to older technology diesel engines.

Exhaust emission control technologies that have played a major role in complying with EPA's current emission standards for new on-road and nonroad diesel engines include diesel oxidation catalysts (DOCs), diesel particulate filters (DPFs), and selective catalytic reduction (SCR) catalysts. High-efficiency DPFs are already standard equipment on all new light-duty diesel vehicles and on-road heavy-duty diesel trucks sold in the U.S. Similar DPF systems are being used by some manufacturers to comply with EPA's Tier 4 final emission standards for nonroad engines. The significant reductions in diesel particulate emissions that result from the use of filters not only provides health-related benefits but also significant climate change impacts due to the large reduction in black carbon emissions associated with filter operation on diesel engines. Particulate filter technology can also be used as a strategy to reduce the mass and number of particulate emissions from gasoline direct injection (GDI) vehicles to ensure that PM emissions from these powertrains are equivalent to those associated with filtered diesel exhaust.

Further reductions in NOx emissions from new heavy-duty on-road and off-road diesel engines beyond the 2010 on-road and Tier 4 off-road requirements are achievable and cost-effective through the combination of more advanced diesel engines with advanced emission control technologies. The types of technologies that will be deployed to achieve future lower NOx standards include advanced substrates, improved SCR catalysts, SCR catalysts deposited on DPF substrates, more efficient SCR reductant delivery technologies and algorithms, and/or passive NOx adsorber catalysts. Substrate mounting mat materials have also evolved through newer technology generations including innovative, insulating intumescent canning materials that retain heat in the catalyst during periods of engine shutdown or low-temperature operation. The emission reduction benefits achieved through the deployment of these types of technology advances and thermal management strategies will extend to increased NOx conversion during low temperature duty-cycle operations.

In 2015, CARB signaled that they will propose tighter NOx standards for on-road, heavy-duty diesel engines and initiated a demonstration program, co-funded by CARB, MECA, South Coast AQMD, and EPA, at Southwest Research Institute (see: https://www.arb.ca.gov/research/veh-emissions/low-nox/low-nox.htm) to prove out the efficacy of potential technologies to further reduce NOx from heavy-duty and natural gas engines. MECA members provided fully aged exhaust emission control systems for demonstration in this program. The results of the first stage of this program were published in a series of Society of Automotive Engineers (SAE) technical papers in 2017 and 2018 (SAE paper numbers: 2017-01-0954, 2017-01-0956, 2017-01-0958, and 2018-01-0362). Furthermore, these cold-start and low temperature technologies will allow vehicle manufacturers to deploy hybrid systems, stop-start technologies, waste heat recovery, cylinder deactivation, and other powertrain efficiency technologies to improve fuel efficiency while still meeting tighter NOx limits.

Recognizing the critical contribution of NOx from heavy-duty engines, in October 2016, EPA announced as part of its final Phase 2 GHG and fuel-efficiency standards for heavy-duty trucks that it believes the opportunity exists to develop, in close coordination with the California ARB and other stakeholders, a new, harmonized national NOx reduction strategy for heavy-duty on-highway engines. In addition, states in the Ozone Transport Region (OTR) have petitioned EPA to develop tighter standards for this sector in order to help them achieve their ozone reduction goals. Improved NOx reduction technologies are available today to deliver ultra-low NOx emissions from heavy-duty engines. Existing and future ozone nonattainment regions in the U.S. will benefit from these cost-effective NOx reductions to support their state implementation plans (SIPs). (Note: EPA in November 2015 tightened the National Ambient Air Quality Standards for ground-level ozone from 75 parts per billion to 70 ppb.) Engine manufacturers can combine these advanced NOx emission controls with other efficiency technologies to optimize future truck performance to deliver both lower NOx emissions and improved fuel efficiency.

Similarly, further reductions of NOx, hydrocarbon (HC), and CO emissions from the in-use fleet of light-duty gasoline vehicles can be achieved cost effectively by setting tighter federal aftermarket catalytic converter requirements that align performance and durability standards consistent with the standards currently required by California. EPA's current aftermarket converter program requires that a catalytic converter demonstrate specific conversion efficiencies over 25,000 miles of operation or five years. The emission reductions at the end of this durability period must be at least 70% for HCs, 70% for CO, and 30% for NOx below engine-out levels. CARB's regulation requires that higher performance and more durable OBD-compliant aftermarket converter products be used on both non-OBD and OBD-equipped vehicles. Specifically, since 2009, CARB aftermarket converters have been required to achieve a vehicle's original certification limits and be fully compliant with the OBD requirements of the vehicle. These CARB-approved, OBD-compliant aftermarket converters are warranted for 50,000 miles or five years based on the use of an aggressive, high temperature accelerated engine-aging protocol.

The state of New York implemented California's aftermarket converter requirements in January 2014 for California-certified vehicles. In addition, Maine implemented California's requirements on June 1, 2018, for California-certified vehicles (transition period until January 1, 2019, allowing state enforcement discretion).

EPA has not updated its aftermarket converter requirements since 1986 and, with more than three million aftermarket converters sold per year across the U.S. (based on surveys completed by MECA with aftermarket converter manufacturers), significant additional reductions of HC emissions, including toxic HC emissions, and NOx emissions could be achieved with a national aftermarket converter policy that made use of the same higher performance OBD-compliant aftermarket converters available in California, New York, and Maine. For example, CARB estimated that requiring these advanced aftermarket converters in California would result in the reduction of over 36 tons/day of HC+NOx emissions once the new standards were fully implemented. New York, in 2012, estimated reductions of 3.66 tons/day of NOx and HC emissions by adopting the California aftermarket requirements for model year 1993 and newer vehicles. In addition, the Ozone Transport Commission estimated a reduction of 12,000 tons per year (36 tons per day) of NOx and HC emissions from the in-use, light-duty fleet in the Ozone Transport Region through adoption of stricter aftermarket converter standards under a revised federal program.

Introduction

The purpose of the project is to assess total emission reductions of three potential control programs: lower heavy-duty truck standards, lower off-road diesel standards, and aligning federal rules for replacement catalysts with California (i.e. aftermarket catalysts). The analysis provides total emission reduction estimates from these programs through calendar year 2050, when the majority of the fleet would be turned over to these potential new emission standards. Additional detail is provided to allow comparison of reductions from these programs to those included in EPA's recently released Ozone NAAQS proposal (EPA, 2014a).

This analysis relied on EPA's MOVES2014 model for on-road vehicle emissions and the NONROAD2008 model (within the National Mobile Inventory Model, or NMIM, framework) for off-road emissions. These models account for all "on-the-books" regulations, including the recently finalized Tier 3 vehicle standards, and are consistent, but not exactly the same, with the Base Case (i.e. with current emission controls) used in the Ozone NAAQS proposal, in which EPA used a modified version of the MOVES2010 in the RIA analysis that was adjusted to include Tier 3.

To estimate the impacts of new controls, ENVIRON developed by-model-year emissions for on-road vehicles, and modified input databases for the NONROAD model for the off-road equipment to develop emissions estimates with and without new potential emission standards. The models were run to generate 49 state (minus California) emission inventories of NOx, VOC, CO and PM for on-road and off-road mobile sources for calendar years 2025, 2030, 2040, and 2050 for the Base Case and four control scenarios:

- Scenario 1: Diesel heavy-duty truck standards
- Scenario 2: Off-road diesel standards
- Scenario 3: Federal aftermarket catalyst standards for gasoline light duty vehicles
- Scenario 4: All three controls together

The results of the model runs were used to adjust the EPA 2025 base inventory in the RIA (EPA, 2014b). The EPA's RIA 2025 base inventory emissions were forecasted to analysis years 2030, 2040 and 2050 by multiplying the RIA 2025 inventory with the ratio of the models' emission totals for each calendar year to the 2025 model estimates. This is illustrated by equations further below in the analysis.

It is useful to understand the emission reduction estimates in 2025 for a set of county groups used in the Ozone NAAQS proposal to assess controls needed to achieve 70, 65, and 60 ppb ozone standards as provided in the Executive Summary of the RIA.[1] Figure 1 shows counties and states where EPA applied control measures to demonstrate 2025 attainment of alternative ozone standards. These county groups were determined as lists and grouped accordingly. The areas subject to meet the 70 ppb standard include 494 counties that encompass metropolitan areas for Houston,

1 Ozone NAAQS RIA. Accessed at http://www.epa.gov/ttn/ecas/regdata/RIAs/20141125ria.pdf

Baltimore/Washington DC, and New York/New Jersey/Connecticut. For 65 and 60 ppb, the areas include Houston, Dallas, Denver, Chicago/Lake Michigan Shore, and New York and include 2,040 counties for 65 ppb and 2,080 counties for the 60 ppb standard. The coverage difference between the 65 ppb and 60 ppb regions is related to the number of Texas counties exceeding each standard. In this analysis, for purposes of assessing the impact of control scenarios, we assume 60 ppb and 65 ppb regions as equivalent.

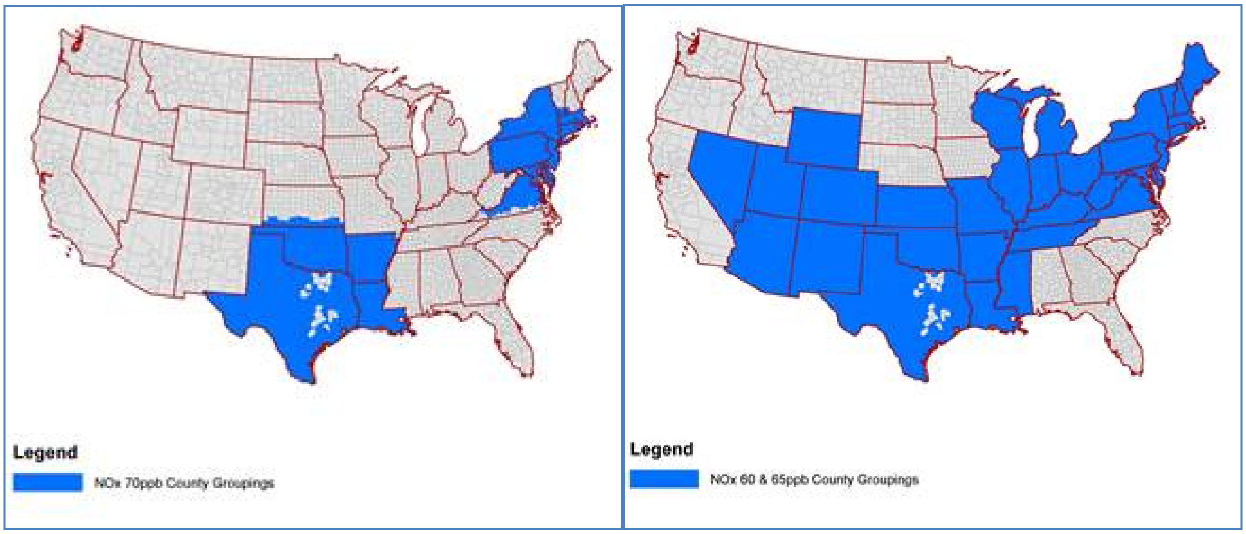

Figure 1. Counties where emission reductions were applied to demonstrate attainment with a 70 ppb (left) and 60 & 65 ppb (right) Ozone Standards in the 2025 Analysis.

The following scope outlines the approach to be used in the development of the emission inventories and reductions from control scenarios.

Baseline 2025 Emissions

The 2025 baseline on-road emissions from the Ozone NAAQS RIA are available on the EPA website[2]. However, only state-level emissions summaries by SCC were published by EPA, thus county-level emissions were estimated in house by disaggregating state-level emissions to county-level using fractions derived from 2025 county-level VMT and vehicle population data[3]. In particular, VMT was used to disaggregate emissions from driving activity on roads (e.g. interstate, arterials, collectors, etc.), while vehicle population data was used to disaggregate parked vehicle emissions (i.e. cold start, evaporation, idling, etc.).

The difference between versions of MOVES2014 used in this analysis and MOVES2010 used in the RIA show that MOVES2014 predicts higher NOx emissions and lower VOC emissions for on-road vehicles as shown in Table 1. The light-duty vehicle emissions were lower and the heavy-duty vehicle emissions higher. The NONROAD2008 model produced emissions close to those reported by EPA (2014a) for 2025.

2 Source: ftp://ftp.epa.gov/EmisInventory/2011v6/ozone_naaqs/reports/

[3] Source: ftp://ftp.epa.gov/EmisInventory/2011v6/ozone_naaqs/2025emissions/

Table 1. Vehicle emissions comparison from the MOVES2014 and EPA RIA inventory for 2025 Base Case.

2025 Emissions	% difference (MOVES2014 – EPA)/EPA			
	VOC	CO	NOx	PM
NATIONAL TOTAL	**-21%**	**-18%**	**21%**	**-13%**
Gasoline-LDVs	-36%	-29%	-21%	-51%
Gasoline-LDTs	-16%	-15%	-2%	-40%
Diesel-HDTs	62%	21%	62%	40%
NONROAD	-3%	-1%	-1%	1%

Note that EPA's baseline emissions come from 2011v6.1 modeling platform and were prepared using the MOVESTier3FRM, a beta version of MOVES similar to MOVES2010b but that includes Tier 3 standard assumptions.

The differences between the EPA RIA (2014a) vehicle emission totals using a modified a version of the MOVES2010 model and those calculated using the default EPA MOVES2014 model could be a result of several factors that have changed. The largest effects appear to be VMT and vehicle age distribution forecasts by vehicle type.

MOVES2014 incorporates changes in vehicle miles traveled (VMT) totals and by vehicle type, as well as differences in age distribution forecasts especially in 2025. MOVES2014 VMT appears to forecast more heavy-duty vehicle VMT and less light-duty vehicles as shown in Table 2.

Table 2. Vehicle miles traveled (VMT) comparison of the MOVES2014 (MVS) and EPA RIA inventory for 2025.

Vehicle Group	EPA MP 2011v6.1	MOVES2014	% (MVS-EPA)/EPA
Gas Passenger Cars	1,561,297,130,708	1,506,028,209,000	-4%
Gas Light Duty Trucks	1,027,215,585,620	1,306,446,330,000	27%
Diesel Heavy Duty Trucks	297,940,996,359	357,297,066,500	20%
TOTAL LDVs + LDTs	2,683,298,716,010	2,923,058,237,607	9%
TOTAL HDVs	408,734,589,206	438,531,116,550	7%

In addition, the age distribution used in MOVES2014 may be different than was used in the EPA RIA. The age distribution forecasts in MOVES2014 significantly shifts to newer light-duty vehicles compared with base year 2012 age distribution as shown in Figure 2. The historic 2012 age distribution was likely used to estimate emissions in the EPA RIA inventory. The 2025 age distribution, used in the MOVES modeling of 2025 emissions, has more nine year old (2017 model year in 2025 calendar year or the newer Tier 3 vehicles) and newer vehicles compared with the 2012 age distribution. In the past, EPA has estimated vehicle emissions modeling using a fixed rather than dynamic age distribution forecasts, and we expected but cannot confirm that the 2012 age distribution reflects that used in the EPA RIA (2014a) inventory. The emissions effect of the forecasted age distribution have significantly more Tier 3 (8 year old and newer vehicles) compared with an assumed fixed age distribution (as characterized by the 2012 default).

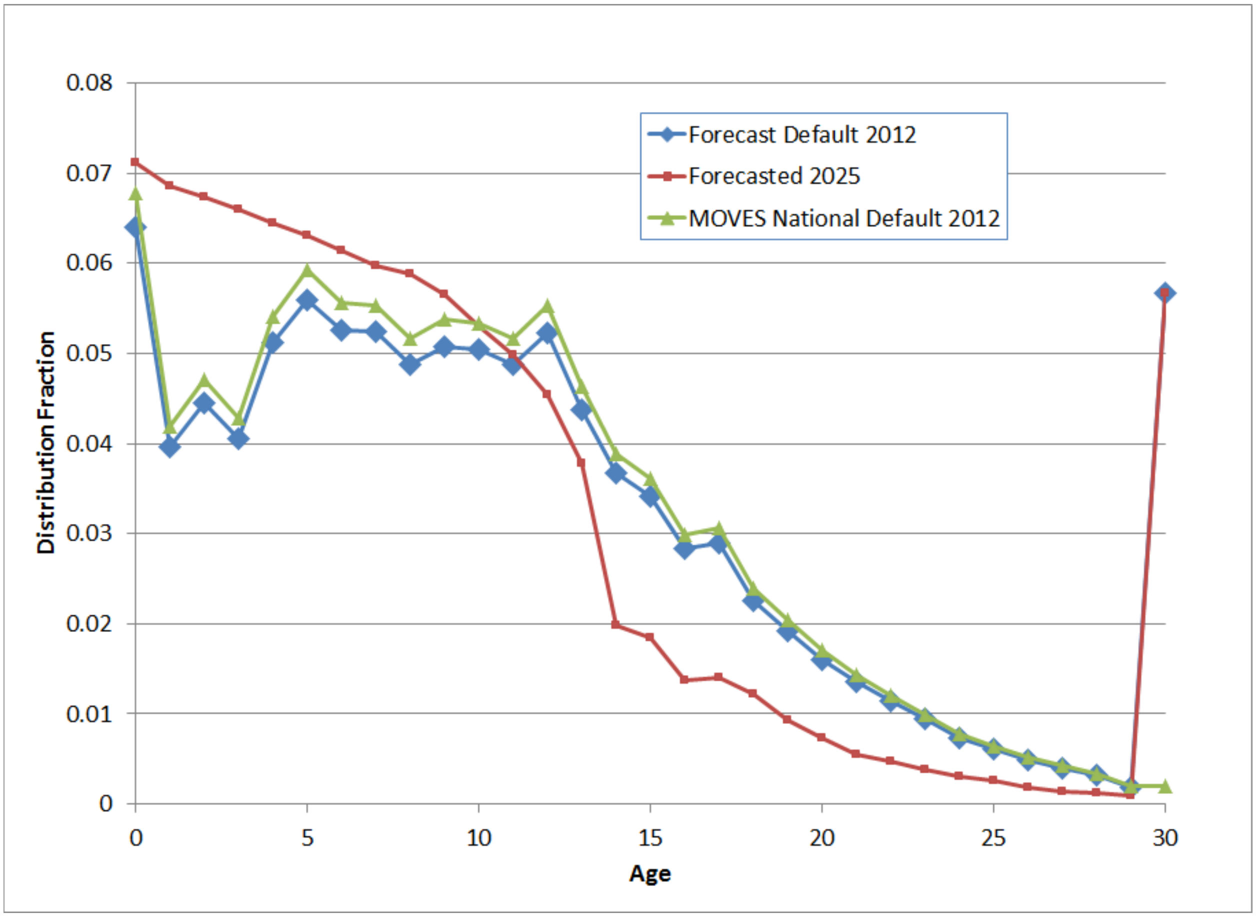

Figure 2. Age distribution forecast for light-duty vehicles (passenger cars) in 2025 starting with the adjusted 2012 default compared with the national 2012 default calendar year distribution.

Figure 3 shows the larger truck age distribution forecast for 2025 compared with the 2012 age distribution. For the heavy-duty trucks, the initial 2012 age distribution (that is likely close to what was used in the EPA RIA inventory) has a large fraction of age 5 – 15 population fraction, and the 2025 forecast reflects that initial age distribution with a large fraction of age 18 – 28 population. The larger fraction of older trucks increases the average emission rates compared with those estimated using a fixed age distribution for trucks.

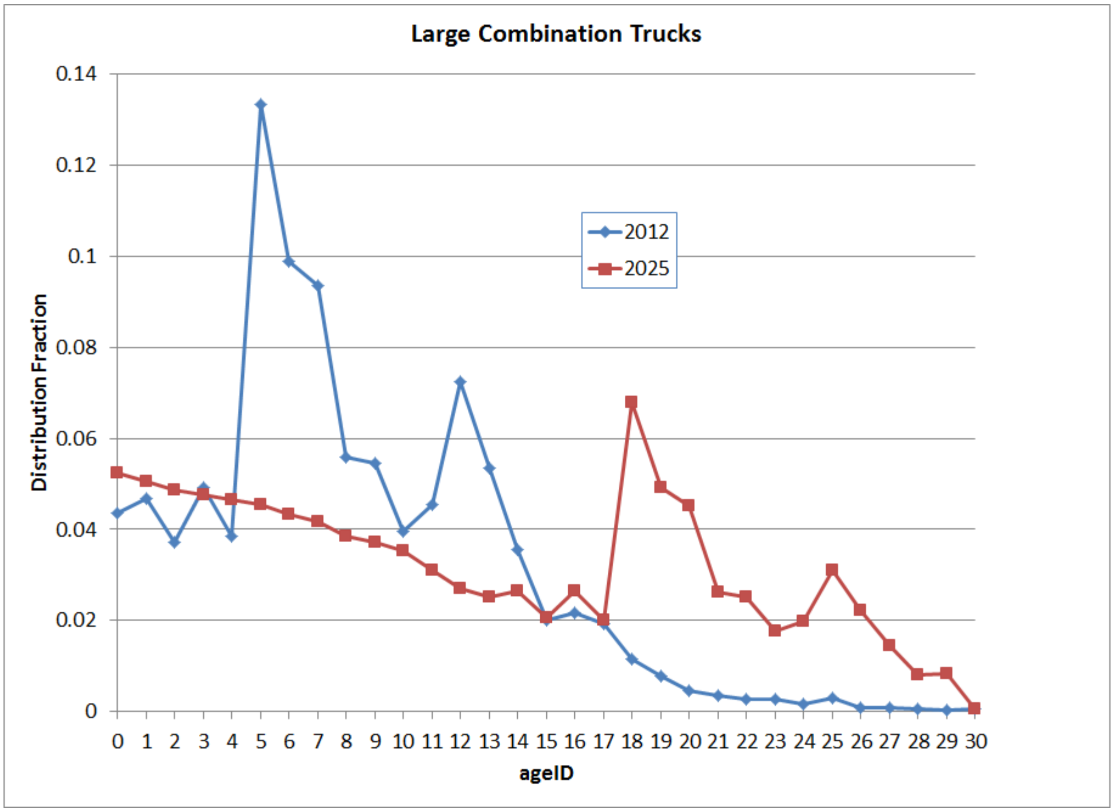

Figure 3. Age distribution forecast for heavy-duty combination truck 2025 compared with the national 2012 default calendar year distribution.

The conclusion of this analysis is outlined below:

- NONROAD2008 emission estimates for 2025 are close to those in EPA RIA (2014a)
- On-Road vehicle NOx emissions in the RIA would have been higher using MOVES2014
  - Light-duty vehicle emissions would have been lower using MOVES2014 for 2025 due to
    - Small increase in VMT forecasted
    - Age distribution for 2025 forecasts more fleet turnover to Tier 3 vehicles
  - Heavy-duty vehicle emission would be higher using MOVES2014 for 2025 due to
    - Diesel heavy duty vehicle VMT 20% higher
    - Age distribution forecasts an older fleet for 2025, especially 2007 and earlier model years

The result of the baseline emission analysis is such that the EPA RIA (2014a) inventory, while reasonably close in total to that estimated using MOVES2014, may understate the importance of heavy-duty vehicles to the NOx inventory.

Potential Emission Standards

The overall goal of this technical analysis is to evaluate emission reductions from on-road and off-road emission standards. The three additional new potential emission standards are:

- Heavy-duty truck diesel engine standard
- Off-road diesel engine standards
- Federal aftermarket catalyst standard

For each measure, we outline the level of standard for all pollutants, model year phase-in, and applicable categories. For aftermarket catalysts, program attributions will include program start, applicable model years, and catalyst replacement rates.

For the heavy duty vehicle engine emission standards, Table 3 shows the potential emission standard in grams per brake horsepower-hours and the phase-in schedule. Overall, we applied the fleet-average NOx reductions by model year to the by model year emissions estimated by MOVES2014 for diesel-fueled heavy duty trucks and buses. It is assumed that the standard reduces running exhaust and start exhaust vehicle emissions.

Table 3. Potential heavy-duty truck diesel engine emission standards.

Model Year	NOx limit (g/bhp-hr)	% Reduction from 2010	Fleet Fraction	Effective Fleet-Average	
				Standard (g/bhp-hr)	NOx Reduction
2021	0.02	90%	25%	0.155	22.5%
2022	0.02	90%	50%	0.11	45.0%
2023	0.02	90%	75%	0.065	67.5%
2024+	0.02	90%	100%	0.02	90.0%

Emission reductions for on-road vehicles relied on MOVES2014 by model year emissions. For example, Figure 4 shows that NOx baseline emissions by model year in 2025 and VMT for heavy duty vehicles reflect the average emission rates in Figure 5 from MOVES.

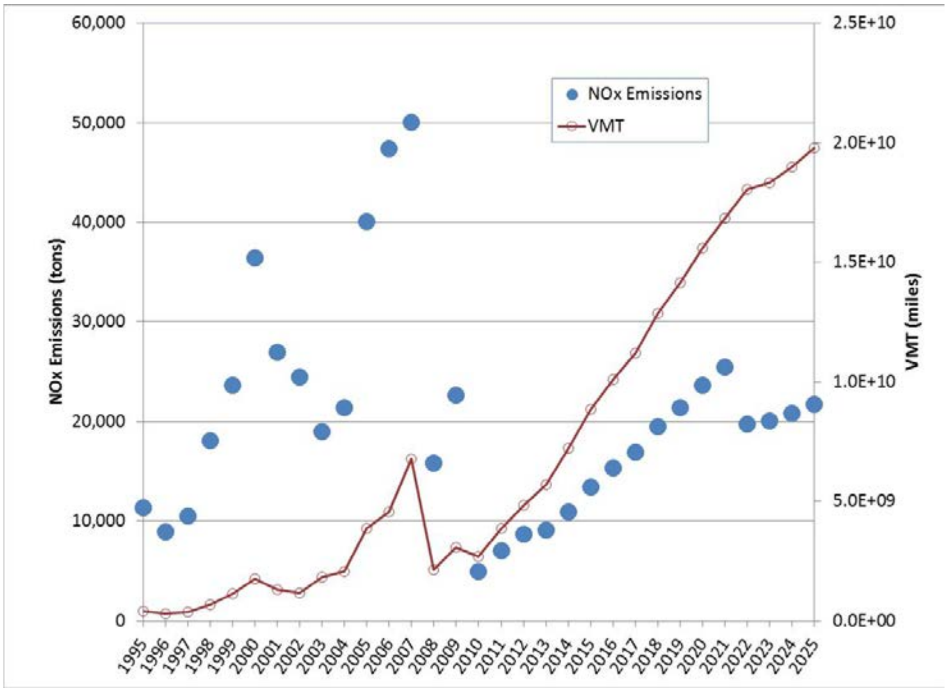

Figure 4. Large combination Class 8 heavy-duty vehicle emissions by model year in 2025.

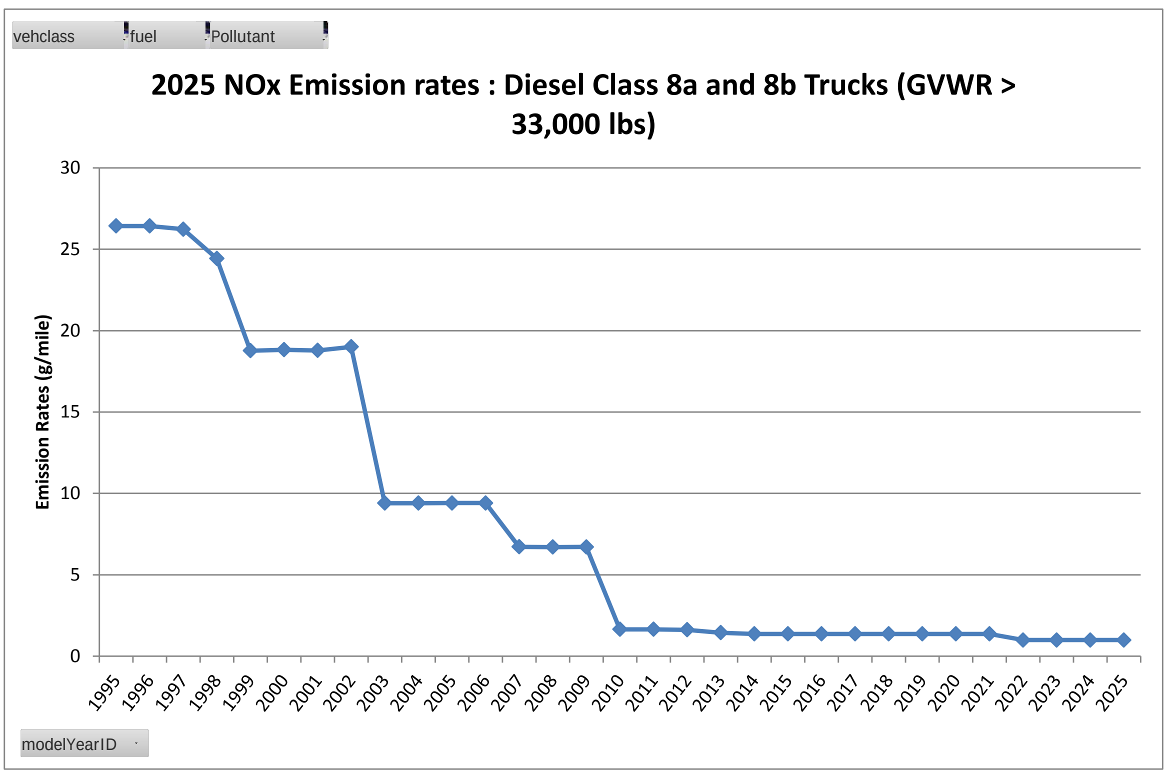

Figure 5. Large combination Class 8 heavy-duty vehicle emissions rates by model year in 2025.

For the off-road diesel standard, the potential emission standard beyond Tier 4 is shown in Table 4 and results in a NOx decrease of about 70% for 75 – 750 hp for the 2026 and 2027 model years and later, and 80% for 25 – 75 hp for model year 2025. The standard also includes an emission reduction of 50% for PM for diesel off-road sources in the 25-75 hp range starting from model year 2025. The emission reductions percentage was applied to the final Tier 4 emission factors in NONROAD to estimate the emissions inventory when including engines meeting the potential emission standard.

Table 4. Potential off-road diesel engine emissions standards.

Model Year	Power range (hp)	Tier 4	Potential New Emission Standard	
		NOx/PM (g/bhp-hr)	NOx Limit (g/bhp-hr)	PM limit (g/bhp-hr)
2025	25-75	3.5 / 0.02	0.7	0.01
2027	75-175	0.3 / 0.01	0.09	0.01
2026	175-750	0.3 / 0.01	0.09	0.01

For the third scenario, a new aftermarket catalysts standard would align federal rules for replacement catalysts with California and reduce NMHC and CO by 65% and NOx by 85% of the affected fleet. The phase-in is expected to result in 1% of the LDV fleet (gasoline cars and light duty trucks) replacing their catalyst per year starting in 2018. By calendar year 2022 it would be fully phased-in and affect the five most recent model years (MY) by 1% to the 5% maximum in 1% increments per year (e.g. in CY2025, 1% of MY2025 fleet would be affected, 2% of MY2024. 3% of MY2023 and so on, up to 5%), so when fully phased-in the standard affects 5% of the fleet older than five years. Because catalysts have a five year warranty, it was assumed that after five years it would be replaced with another aftermarket catalyst. The impacted model years would remain at five years from current calendar year and include all older vehicles as shown in Table 5. It is expected that the standard will affect tailpipe emissions of start exhaust and running exhaust processes.

Table 5. Federal aftermarket catalyst standard phase-in for light-duty vehicles (Resulting emission reductions 65% NMHC, 65% CO, and 85% NOx).

Calendar Year	Impacted Model Years	Fleet Fraction and Model Year	LDV Fleet-wide Reduction		
			NMHC	CO	NOx
2018	2013 and older	1% 2013 and older	0.7%	0.7%	0.9%
2019	2014 and older	2% 2014 and older	1.3%	1.3%	1.7%
2020	2015 and older	3% of 2015 and older	2.0%	2.0%	2.6%
2021	2016 and older	4% of 2016 and older	2.6%	2.6%	3.4%
2022	2017 and older	5% of 2017 and older	3.3%	3.3%	4.3%
2023	2018 and older	5% of 2018 and older	3.3%	3.3%	4.3%
2024	2019 and older	5% of 2019 and older	3.3%	3.3%	4.3%

We estimated the on-road emission reductions using the equations below. The MOVES2014 by model year results for any calendar year were adjusted (% reductions from scenarios 1 and 3 applied to the appropriate model year) to account for the potential new emission standard and summed to estimate a “reduced scenario” MOVES2014 emission inventory. The MOVES2014 without the new standard forms the basis for comparison. Then the ratio of the two MOVES2014 results was applied to the EPA RIA Emission Inventory for 2025. For future year forecasts, the MOVES2014 and NONROAD default growth rates and age distribution expectations were accepted.

Emissions $_{\text{Future Year}}$ = 2025 Base EPA RIA Inventory x (MOVES$_{\text{w/o, Future Year}}$ / MOVES$_{\text{w/o, Year 2025}}$)

Emission Reductions $_{\text{Future Year}}$ = Emissions $_{\text{Future Year}}$ x (1 – MOVES$_{\text{w, Future Year}}$ / MOVES$_{\text{w/o, Future Year}}$)

Where,
MOVES2014$_{w}$ (or NONROAD2008) with new potential standard
MOVES2014$_{w/o}$ (or NONROAD2008) without potential standard

The NONROAD model and emission reductions for off-road engines were approached in the same manner except that the NONROAD model could incorporate the emission standards directly. We developed modified NONROAD input files rather than developing by model year emissions as was accomplished for on-road vehicle emissions. The new engine standard evaluated in this work was included in the NONROAD emission factor and phase-in input files. The modified emission factor input files incorporate the NOx and PM emission factor reduction expected with the new standard. The NOx emission factor reduction is about 80% for 25-75 hp engines and 70% for 75-750 hp engines. The PM emission factors reduction is about 50% under the new standard. The phase-in emission standard input file was modified to include and account for the phase-in schedule of the new standard. The new standard affects engine model years starting in different years for different horsepower ranges. These years and ranges are 2025 and later for 25-75 hp, 2027 and later for 75-175 hp, and 2026 and later for 175-750.

NONROAD2008 was run separately using the default inputs and the modified inputs described above for the years of interest to obtain ratios of baseline to reduced scenario emissions, as well as to obtain growth factors for RIA base case emissions to future years.

Emission Reductions

EPA’s RIA (2014a) analyzed control strategies for various sectors (EGU, non-point, non-road, etc.) that would be necessary in order for county regions to be able to demonstrate attainment to the alternative ozone standards. The NOx emission reductions for 2025 from the RIA are shown in Table 6. In this same table, NOx emission reductions from control scenarios for 2025 presented in the current analysis are shown. Evidently, EPA’s analysis did not include control strategies for on-road sources, thus this additional reduction potential is analyzed here.

Table 6. NOx emission reductions (x 1000 tons) by county groupings for 2025.

Source Category	Reductions from EPA's RIA Control Strategies (EPA, 2014a)			Reductions from Control Strategies in this Study	
	70 ppb Region	65 ppb Region	60 ppb Region	70 ppb Region	65/60 ppb Region
EGU	25	206	232		
Non-EGU Point	210	448	458		
Nonpoint	260	457	459		
Non-road	5	13	13	4	7
On-road Heavy-Duty				14	36
On-road Light-Duty				5	12
Total	**500**	**1124**	**1162**	**24**	**55**

Emission reductions from applying potential off-road diesel engine standards in the RIA base case of 2025 and forecasted baselines for the different county groupings are shown in Table 7. The off-road equipment emission reduction is a result of the new standards described in the section above. The standard begins to become relevant in 2025 with some new engines being required to meet the standard. Because of engine turnover and phase-in, reductions from the new standard increase in later years as a greater percentage of the engine fleet meets the standard. This is illustrated in Table 7, with only a 4 kton/yr of NOx reductions in the 70 ppb domain and a 7 kton/yr reduction in the 65 and 60 ppb domains. In 2030 the reductions for the 70 ppb and 65/60 ppb domains jump to 28 and 56 kton/yr, respectively. The NOx reductions eventually grow in 2050 to 73 kton/yr and 145 kton/yr for the 70 ppb and 65/60 ppb domains, respectively. Similarly for PM, emission reductions expected for 60-65 ppb domain in 2025 are about 30 tons/yr and are estimated to reach around 480 tons/yr in 2050 as the fleet turns over towards newer model years covered by the standard. The off-road PM standard affects the population of smaller off-road sources sized between 25 to 75 hp, and generates a 50% reduction of PM emissions from diesel off-road sources; hence it is expected to achieve a lower percentile reduction over the overall PM total than the NOx diesel off-road standard.

Table 7. Emission reductions (x 1000 tons) by county groupings and calendar year from off-road diesel engine emission standards.

Year	Region	Emission Reductions (x1000 tons)	% Reduction over Total*	Emission Reductions (x1000 tons)	% Reduction over Total*
		NOx	NOx	PM	PM
2025	60/65 ppb	7.4	2.23%	0.03	0.17%
	70 ppb	3.8	2.26%	0.02	0.17%
2030	60/65 ppb	55.7	19.40%	0.19	1.67%
	70 ppb	28.0	19.29%	0.10	1.69%
2040	60/65 ppb	115.7	42.03%	0.39	5.30%
	70 ppb	57.8	41.22%	0.20	5.28%
2050	60/65 ppb	145.2	48.32%	0.48	6.78%
	70 ppb	72.5	47.25%	0.26	6.74%

*Total represents emissions from diesel off-road sources in domain.

Emission reductions from on-road control strategies applied to the RIA baseline and projected baselines are shown in Table 8, by county groupings and vehicle class. Scenario 1 (diesel heavy duty standards) NOx emission reductions increase steadily from 36 kton/yr in 2025 to 190 kton/yr in 2050 for the 60 and 65 ppb domain. As shown in Figure 6, a cumulative increase in emission reductions from calendar year 2025 through 2050 is expected from this standard as the heavy duty fleet turns over to newer model years (beyond MY2024) and sheds older models, making the fleet increasingly covered by the 90% NOx emission reduction standard. For the light duty standard scenario, achievable reductions for VOC in 2025 are nearly 4 kton/yr and decrease to nearly 2 kton/yr in 2050 for the 70 ppb domain. Similarly, NOx reductions in 2025 are 5 kton/yr, and 2 kton/yr in 2050 for the 70 ppb domain.

Table 8. On-road emission reductions (x 1000 tons) by county groupings and calendar year from heavy-duty vehicle and light-duty vehicle potential on-road emission standards.

	On-road Vehicles							
	Gasoline Light Duty						Diesel Heavy Duty	
	VOC		CO		NOx		NOx	
Year	70 ppb	65/60 ppb	70 ppb	65/60 ppb	70 ppb	65/60 ppb	70 ppb	65/60 ppb
2025	3.5	8.3	91.5	210.5	5.3	12.3	14.4	35.8
2030	2.3	5.7	66.8	153.6	3.5	8.0	36.6	92.4
2040	1.6	4.0	48.7	112.0	2.3	5.4	62.1	158.2
2050	1.7	4.0	50.2	115.4	2.4	5.4	74.9	190.8

Reductions from aftermarket catalyst standards decrease over the period of 2025 to 2040 as the LDV fleet turns over and base case emissions for LDV decreases. The turnover-related decrease in LDV base case emissions is apparent in the trend of emissions unaffected by the standard, shown in Figure 6 for NOx and 60-65 ppb domain, and simultaneously implies a smaller pool of emissions affected by the aftermarket catalyst standard since it is capped at 5% of the LDV fleet after 2022.

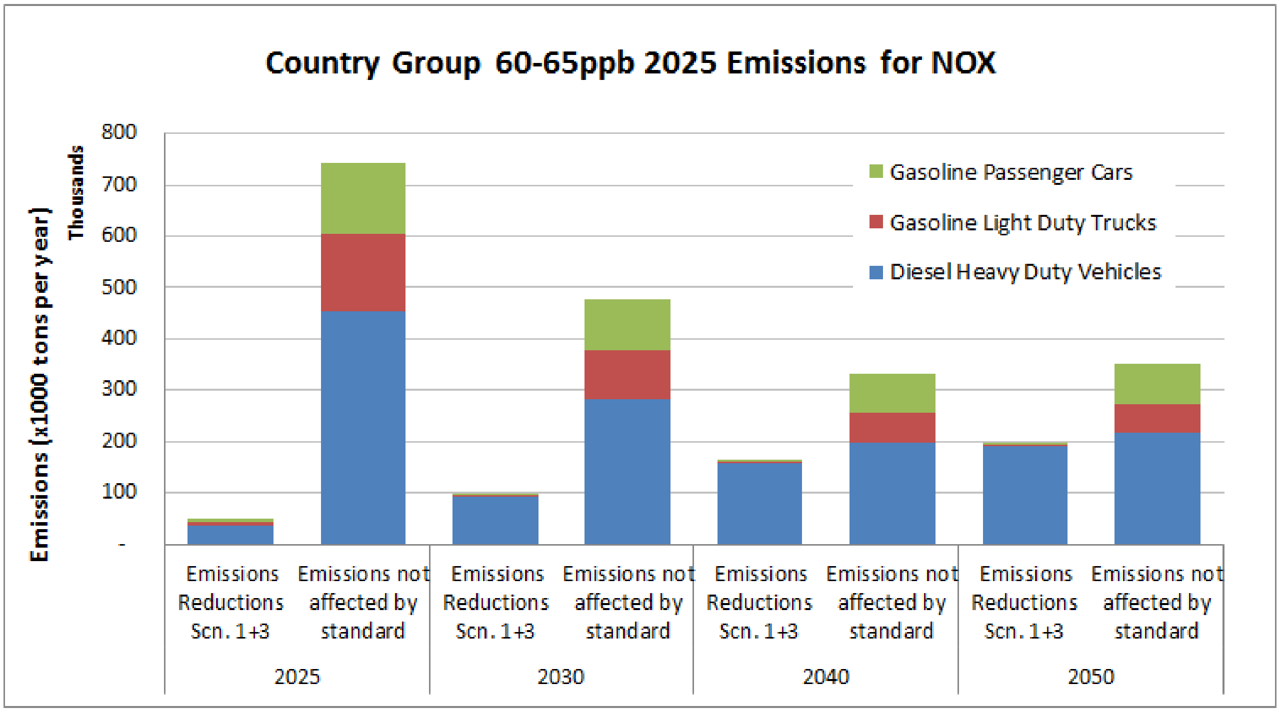

Figure 6. NOx emission reductions and unaffected emissions by calendar year from heavy-duty vehicle and light-duty vehicle potential on-road emission standards for 60-65 ppb domain (in 1000 tons).

Table 9 shows the percentile reduction of on-road emissions for the different vehicle groups affected by Scenarios 1 and 3 standards for the years analyzed. As discussed previously, heavy duty vehicle emissions are reduced increasingly by the diesel engine standard (Scenario 1) as the fleet turns over, achieving a reduction of 7% of HDV emissions in 2025 up to 47% reduction of NOx in 2050. One thing to note is that any of the on-road standards discussed here only affect a fraction of the overall on-road emissions which will vary by vehicle category and pollutant. To illustrate this, on-road and off-road emissions from the RIA Base Case and forecasted 2050 emissions for key vehicle groups and off-road diesel sources are shown segregated by emission process in Table 10. Distribution of the RIA-based on-road emissions by process were assumed similar to those in MOVES2014 2025 and 2050 national default outputs. For off-road, splits of emissions by process were obtained from 2025 and 2050 emissions modeled in NONROAD2008.

Table 9. Percentile emission reductions of vehicle group emissions from analyzed on-road standards, by calendar year.

Vehicle Group	Pollutant	% Emission Reductions from Proposed On-road Controls			
		2025	2030	2040	2050
Diesel Heavy Duty Vehicles	NOx	-7.3%	-24.5%	-44.4%	-46.9%
	CO	0.0%	0.0%	0.0%	0.0%
	VOC	0.0%	0.0%	0.0%	0.0%
Gasoline Light Duty Trucks	NOx	-4.1%	-4.0%	-3.9%	-3.8%
	CO	-3.1%	-3.1%	-3.0%	-2.9%
	VOC	-1.8%	-1.5%	-1.3%	-1.2%
Gasoline Passenger Cars	NOx	-4.0%	-4.0%	-3.8%	-3.8%
	CO	-3.1%	-3.0%	-2.9%	-2.9%
	VOC	-1.6%	-1.5%	-1.3%	-1.3%

Table 10 shows which emission processes are responsible for the majority of VOC and NOx emissions in gasoline light duty vehicles and diesel heavy duty vehicles. As mentioned before, vehicle standards reviewed here are expected to affect running exhaust and start exhaust emissions, which are a predominant segment, particularly start exhaust, of the total VOC and NOx emissions for gasoline LDVs in 2025 and 2050. For diesel heavy duty vehicles, NOx emissions are primarily produced through running exhaust and extended idle exhaust. While running exhaust NOx may be controlled through the proposed standard for heavy duty engines, extended idling NOx emissions are not affected by it. These heavy duty vehicle extended idling emissions are an important portion of the on-road NOx emissions inventory in 2025 and are expected to be proportionally more important in 2050 as running exhaust emissions will tend to decrease as a result of already established standards and fleet turnover. Therefore, extended idling is a relevant source of on-road emissions to be evaluated for future on-road control standards. In terms of off-road, diesel-fueled sources release NOx and VOC emissions through exhaust, whereas in gasoline off-road sources VOCs are emitted through exhaust and evaporative processes and during refueling. Evaporative VOCs represent about 18% of gasoline off-road VOC emissions in 2025, while refueling VOCs represent about 11% of the total. Note that off-road VOC emissions are included in this table for consistency and information; however, they are not relevant to the control strategies analyzed here for off-road sources.

Table 10. On-road and off-road emissions from 2025 RIA base case and 2050 forecast for 65 ppb domain segregated by emission process and fuel/source type.

Vehicle Type	Emission Process	Affected by Scenario Controls (Y/N)	VOC (1000 TPY)		NOx (1000 TPY)	
			2025	2050	2025	2050
Gasoline Light Duty Vehicles	Running Exhaust	Y	35	11	163	59
	Start Exhaust	Y	247	133	140	82
	Evaporative	N	186	143	0	0
	Refueling	N	29	21	0	0
	Other Exhaust (crankcase)	N	4	2	0	0
Diesel Heavy Duty Vehicles	Running Exhaust	Y	17	8	328	207
	Start Exhaust	Y	2	2	5	6
	Extended Idle Exhaust	N	23	24	150	183
	Auxiliary Power Exhaust	N	2	3	7	11
	Refueling	N	7	8	0	0
Diesel Off-road	Exhaust	Y	43	48	333	155
	Evaporative	N	0	0	0	0
	Refueling	N	0	0	0	0
Gasoline Off-road	Exhaust	N	521	607	132	153
	Evaporative	N	129	135	0	0
	Refueling	N	79	104	0	0

Potential Reductions in Other Geographical Domains

Emission reductions from the control strategies previously analyzed were evaluated for other geographical domains of interest to MECA. One of them is the Ozone Transport Region, covered by the Ozone Transport Commission – OTC. The OTC member states include: Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Virginia. Emission reductions were obtained using the same methodology and control factors that for the EPA's RIA County Groupings estimates. Annual reductions estimates for the OTC Domain are shown in Table 11.

Table 11. On-road and off-road emission reductions (x 1000 tons) by calendar year for OTC domain from potential emission standards analyzed in this study.

Year	On-road Vehicles				Diesel Off-road	
	Gasoline Light Duty			Diesel Heavy Duty		
	VOC	CO	NOx	NOx	NOx	PM
2025	2.3	62.8	3.6	8.0	2.1	0.01
2030	1.5	45.9	2.4	20.8	15.3	0.06
2040	1.1	33.7	1.6	35.9	30.7	0.11
2050	1.1	34.7	1.6	43.3	38.3	0.14

In addition, we developed state-wide emission reductions for 47 out of the 48 contiguous states (California was excluded) and the District of Columbia. A summary of area-wide reductions for this domain is shown in Table 12.

Table 12. On-road and off-road emission reductions (x 1000 tons) by calendar year for 47 CONUS and DC (excludes CA) domain from potential emission standards analyzed in this study.

Year	On-road Vehicles				Diesel Off-road	
	Gasoline Light Duty			Diesel Heavy Duty		
	VOC	CO	NOx	NOx	NOx	PM
2025	12.7	309.3	18.8	50.6	10.7	0.04
2030	8.6	225.6	12.1	129.5	81.5	0.28
2040	6.0	164.1	8.1	220.4	171.1	0.58
2050	6.1	168.9	8.1	265.8	215.3	0.72

For perspective, the on-road activity for the RIA 2025 base year inventory is included in Table 13, which shows the vehicle miles traveled and vehicle population for each domain analyzed here. The VMT and population for the smaller domains, 70pbb, 60/65 ppb and OTC, represent 33%, 69%, 23%, respectively, of that in the 47 CONUS + DC domain.

Table 13. On-road activity from EPA's RIA 2025 base case inventory for various geographical domains.

Activity for CY2025	Vehicle Groups	60ppb domain	70ppb domain	CONUS and DC (excludes CA)	OTC
VMT (Million Miles)	Diesel Heavy Duty Vehicles	206,979	84,405	297,941	48,123
	Gasoline Light Duty Trucks	691,304	315,893	1,027,216	206,734
	Gasoline Passenger Cars	1,102,132	543,625	1,561,297	382,024
	TOTAL	**2,000,416**	**943,923**	**2,886,454**	**636,881**
POP (Million Vehicles)	Diesel Heavy Duty Vehicles	9	4	13	2
	Gasoline Light Duty Trucks	62	31	90	21
	Gasoline Passenger Cars	85	41	123	30
	TOTAL	**156**	**76**	**226**	**53**

Summary

This analysis reviewed the potential of emission reductions for two on-road emission control strategies and one control strategy for off-road emissions during analysis years 2025, 2030, 2040, and 2050. Results for the geographic domains relevant to EPA's RIA County groupings are summarized in Table 14. Results suggest that the control strategy for diesel heavy duty vehicle can achieve up to 49% reduction of diesel HDV NOx emissions by 2050, while the maximum reduction for NOx from the light duty vehicle control strategy will likely be achieved at the first couple of years of phase in, capping at 4% of LDV-related NOx emissions in years 2022-2024 and decreasing its impact from there. The off-road diesel control strategy is estimated to achieve a reduction of 48% of diesel off-road NOx emissions by 2050 for the 60-65 ppb domain and a 7% reduction of PM emissions for that same year.

Table 14. On-road and off-road emission reductions (x 1000 tons) by county domains from potential emission standards analyzed in this study.

	On-road Vehicles								Off-road			
	Gasoline Light Duty						Diesel Heavy Duty		Diesel			
	VOC		CO		NOx		NOx		NOx		PM	
Year	70 ppb	65 ppb	70 ppb	65 ppb	70 ppb	65 ppb	70 ppb	65 ppb	70 ppb	65 ppb	70 ppb	65 ppb
2025	3.5	8.3	91.5	210.5	5.3	12.3	14.4	35.8	3.8	7.4	0.0	0.0
2030	2.3	5.7	66.8	153.6	3.5	8	36.6	92.4	28.0	55.7	0.1	0.2
2040	1.6	4	48.7	112	2.3	5.4	62.1	158.2	57.8	115.7	0.2	0.4
2050	1.7	4	50.2	115.4	2.4	5.4	74.9	190.8	72.5	145.2	0.3	0.5

References

Environmental Protection Agency (EPA). 2014a. "Regulatory Impact Analysis of the Proposed Revisions to the National Ambient Air Quality Standards for Ground-Level Ozone," EPA-452/P-14-006, November 2014.

Environmental Protection Agency (EPA). 2014b. "Preparation of Emissions Inventories for the Version 6.1, 2011. Emissions Modeling Platform." November 2014 (http://www.epa.gov/ttn/chief/emch)