

MOVES Inventory Modeling of a Potential Cleaner Trucks Initiative Scenario

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Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

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Executive Summary

The U.S. Environmental Protection Agency (USEPA) announced in November 2018 that the agency would pursue the Cleaner Trucks Initiative (CTI) to update NO_x emissions standards for heavy-duty on-road trucks, and on January 6, 2020, the Administrator signed an Advance Notice of Proposed Rule (ANPR) soliciting pre-proposal comments on the CTI.^{1,*} USEPA's actions are occurring in concert with comparable California regulatory development activities and include the input of affected stakeholders and trade associations.²

To assist in the response to the ANPR request for comments, the Manufacturers of Emission Controls Association (MECA) sponsored Oak Leaf Environmental to complete an emission inventory analysis for a potential CTI scenario. The resulting analysis was conveyed to Alpine Geophysics LLC to complete the photochemical air quality modeling reported in the accompanied reports for the base year of 2028 and the modeled year of 2035. This report documents the emission inventory analysis.

A contiguous United States emissions impact analysis of a hypothetical CTI scenario was completed based on the USEPA aligning their final CTI rule at the same levels as proposed by California Air Resources Board (CARB).[†] The analysis quantified on-road emissions in calendar year 2035 – both with and without the assumed regulatory scenario. The basis for the CTI program modeled was the most recent information – available at project commencement from CARB – the agency's September 26, 2019 workshop proposal – with the understanding that USEPA and CARB are working on a nationally uniform regulatory framework.^{3, 4, ‡}

The modeled CTI scenario covers three key elements:

- More stringent NO_x certification standards,
- Increased certification durability, and
- Anti-backsliding particulate matter (PM) standards.

While the CTI under development is a NO_x-focused control program – as defined by certification standards and more robust in-use testing requirements, the remaining two elements reduce the emissions of other criteria pollutants. All three elements are summarized in Tables ES-1 and ES-2 presenting current and assumed CTI regulatory requirements for exhaust certification standards and durability, respectively.

- Table ES-1 indicates that NO_x emission standards under the CTI scenario become more stringent in 2 phases, commencing with model years (MYs) 2024 and 2027, respectively; the MY2027 standard of 0.02 g/bhp-hr equals a 90

* Numeric superscripts denote References provided at the end of this report.

† The ANPR did not include preliminary regulatory language or specific certification standards for the CTI.

‡ The analysis year of 2035 was chosen to allow as much phase-in of low NO_x trucks meeting the future modeled CTI emission limits while still providing adequate confidence from the air quality perspective. Given that the new truck regulations begin implementation with the 2024 model year and heavy-duty trucks last 20-30 years on the road, the 2035 timeframe represents an intermediate level of CTI truck penetration.

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percent control level over current certification standards. The PM certification requirement of 0.005 g/bhp-hr is a 50 percent reduction meant to ensure that future vehicles continue to maintain the PM levels observed in current engine certifications.

- Table ES-2 indicates that the assumed CTI scenario certification durability requirements represent an increased regulatory useful life of 18 years or up to 850 thousand miles.*

Table ES-1					
Current and Assumed CTI Engine Certification Standards					
	NO_x			PM	
	Current	CTI (2024-26 MY)	CTI (2027+ MY)	Current	CTI (2024+ MY)
FTP Standard (g/bhp-hr)	0.2	0.05	0.02 [†]	0.01	0.005

Table ES-2			
Current and Assumed CTI Engine Certification Durability			
Engine Type	Gross Vehicle Weight Rating (GVWR)	Useful Life (Miles / Years)	
		Current	CTI (2024+ MY)
Heavy-Duty Compression-Ignition (HDCI) Engine	Class 8 (Heavy) GVWR >33,000 lbs.	435,000 / 10	850,000 / 18
	Class 6-7 (Medium) 19,500 < GVWR ≤ 33,000 lbs.	185,000 / 10	350,000 / 18
	Class 3-5 (Light) 10,000 < GVWR ≤ 19,500 lbs.	110,000 / 10	250,000 / 18
Heavy-Duty Spark- Ignition (HDSI) Engine	GVWR >10,000 lbs.	110,000 / 10	250,000 / 18

The foundation of the emission impact analysis was Version 1 of USEPA’s 2016 modeling platform (referred to herein as the “2016v1 Platform”) – a product of the agency’s National Emission Inventory (NEI) efforts. The 2028 calendar year inventory from the 2016v1 Platform was extrapolated to 2035 using the latest on-road vehicle activity data from the Energy Information Agency’s (EIA’s) annual publication Annual Energy Outlook (AEO2019)⁵ and emission rates from the USEPA’s MOVES model.⁶ From the 2016v1 Platform foundation, the two new inventory scenarios were developed as follows.

* Useful life is defined in *miles* or *years*, whichever occurs first in the service life of the engine.

[†] CARB, in the September 26, 2019 workshop proposal, proposed a range for the 2027 model year NO_x standard of 0.015-0.030 g/bhp-hr; the value used in this analysis of 0.02 g/bhp-hr (representing 90 percent control over current certification standards) was the most common proposed control level under discussion. In March 2020, CARB refined their proposal specifically to the 0.02 g/bhp-hr standard.

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- The “**2035 Base Case**” inventory was developed to include an on-road fleet projection to 2035 with no change in the underlying regulatory context.
- The “**2035 Control Case**” inventory was developed to include both the 2035 fleet projection and the impacts of the modeled CTI scenario for those vehicles certified to the assumed CTI standards.

Accordingly, the emission impacts of the CTI scenario as reported in this report are defined by the difference between the 2035 Control Case and 2035 Base Case inventories. Both Base and Control Cases were prepared in file formats suitable for further processing for input into subsequent photochemical air quality modeling.* Emission inventories were prepared by applying both activity and fleet turnover adjustment factors to the 2028 inventory of the 2016v1 Platform. The inventories covered 3,108 counties (or county-equivalents) and contained up to 9,217 emission records per county† – each emissions record contains a single, annual and twelve, monthly emissions estimates.

The 2035 on-road activity projection was completed to estimate vehicles, vehicle miles traveled (VMT) and hoteling hours‡ – the results of which are summarized in Tables ES-3 and ES-4. Activity projections were resolved by county, vehicle type and roadway type.

- Table ES-3 presents the 2035 domain-wide on-road VMT projection. Overall, estimated heavy-duty VMT growth (9.9 percent) is just over 3 times the growth estimated for the light-duty sector (2.9 percent) over the 7-year period. Within the heavy-duty sector, single-unit trucks are the fastest growing segment – 18.8 percent growth estimated from 2028 to 2035.
- Table ES-4 presents a summary of the 2035 domain-wide activity estimates for the on-road heavy-duty sector. In the 48-state region, the activity projection estimated 14 million heavy-duty vehicles on the road in 2035 accumulating 372 billion miles of travel over the course of the year. By 2035, heavy-duty VMT is estimated to represent 10.2 percent of the total on-road VMT.

* Files were prepared in the SMOKE flat-file 2010 format (FF10) as described in this document.

† An emissions record is produced for each unique combination of source category code (SCC), rate type and pollutant. Forty-nine pollutants were modeled. The SCC provides the differentiation by vehicle type, roadway type and emissions process.

‡ “Hoteling hours” are the mandatory rest periods by long-haul trucking personnel when extended engine idling and auxiliary power unit (APU) use occurs.

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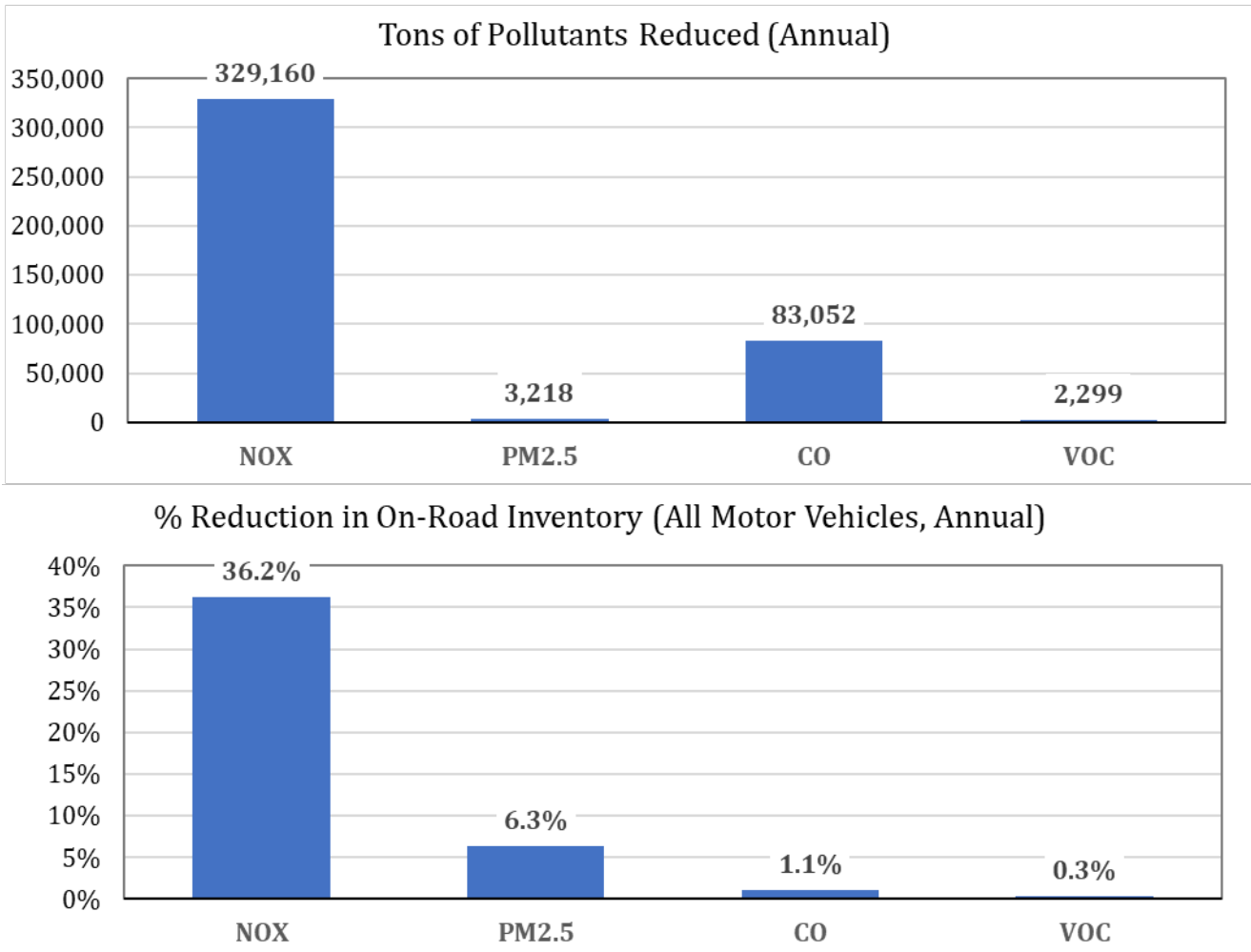
Table ES-3 2035 On-Road VMT, 48-State Total				
Sector	Vehicle Type	VMT (Billion Miles/Year)		2028 to 2035 Growth Rate
		2028	2035	
Light-Duty (GVWR ≤10,000 lbs.)	Passenger Car	1,512	1,552	2.6%
	Truck	1,649	1,701	3.2%
	Motorcycle	21	21	1.0%
	<i>Total Light-Duty</i>	<i>3,181</i>	<i>3,274</i>	<i>2.9%</i>
Heavy-Duty (GVWR >10,000 lbs.)	Single-Unit Truck	127	151	18.8%
	Combination Truck	194	202	4.1%
	Bus	18	20	9.9%
	<i>Total Heavy-Duty</i>	<i>339</i>	<i>372</i>	<i>9.9%</i>

Table ES-4 2035 Heavy-Duty Population and VMT, 48-State Total	
2035 Heavy-Duty Vehicle Population (Millions):	
Single-Unit Trucks	9.8
Combination Trucks	3.2
Buses	1.0
Total Heavy-Duty Vehicles	14.0
2035 Heavy-Duty VMT (Billion Miles/Year):	
Single-Unit Trucks	150.7
Combination Trucks	201.7
Buses	19.8
Total Heavy-Duty Vehicle VMT	372.3
Heavy-Duty VMT as % of Total On-Road VMT	10.2%

Figure ES-1 presents a summary of the emissions impact analysis of the modeled CTI scenario aggregated over 48 states in 2035. The CTI scenario reduces 329 thousand tons of NOx across the domain; the equivalent to a 36.2 percent reduction in the on-road NOx inventory. Moreover, an estimated 83, 3 and 2 thousand tons of CO, PM2.5 and VOC, respectively, could potentially also be eliminated by the program as modeled. These estimated pollutant reductions would be realized because of the more stringent standards and increased certification durability requirements.

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Figure ES-1
Emissions Impact of the Modeled CTI Scenario in 2035, 48-State Total*



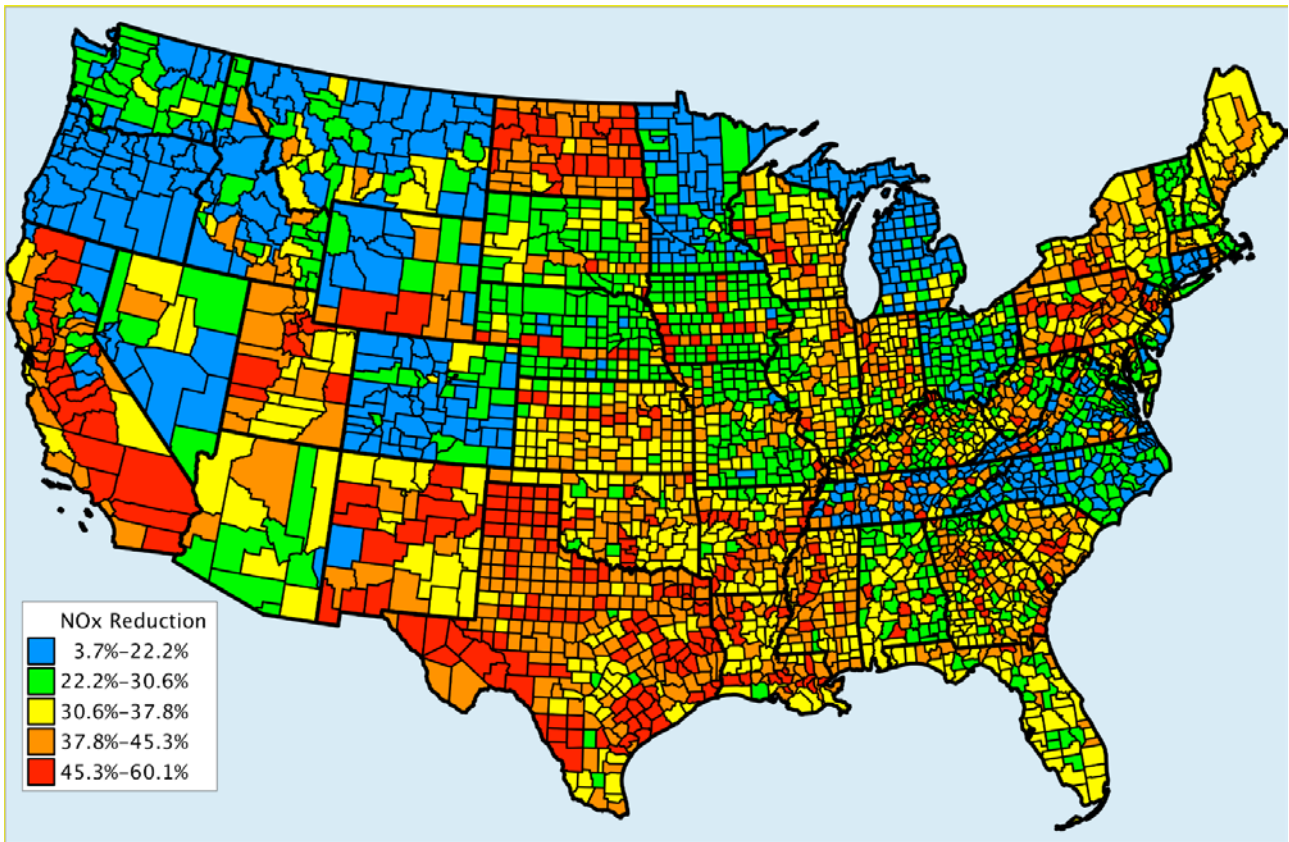
At the county level, the range in NO_x impact – when expressed as a percent reduction in on-road emissions – varies from -3.7 to -60.1 percent. The relative impact of the modeled CTI scenario on NO_x is summarized in Figure ES-2 and Table ES-5. The key predictor of the relative NO_x impact at the county level is the underlying percent of VMT from heavy-duty vehicles in 2035.

- Figure ES-2 presents the annual NO_x impact of the modeled CTI scenario in 2035 at a county-level resolution. The percent benefit is calculated as a reduction in the total on-road NO_x inventory (both light and heavy-duty vehicles). The scale represents quintiles meaning one fifth of the counties examined fall within each color range bin.
- Table ES-5 presents the 10 counties with the largest, estimated annual NO_x reduction (percent) in 2035. A common characteristic of these counties is that they tend to be more rural with one or more major highways located within.

* PM2.5 (particulate matter 2.5 microns or less) includes all directly emitted exhaust plus brake and tire wear.

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**Figure ES-2
NOx Impact of CTI Scenario in 2035 as a Percent Reduction in On-Road Inventory
48-State Modeling Domain, County-Level**



**Table ES-5
Ten Counties with Largest, Annual NOx Reduction (%) in 2035
From Modeled CTI Scenario**

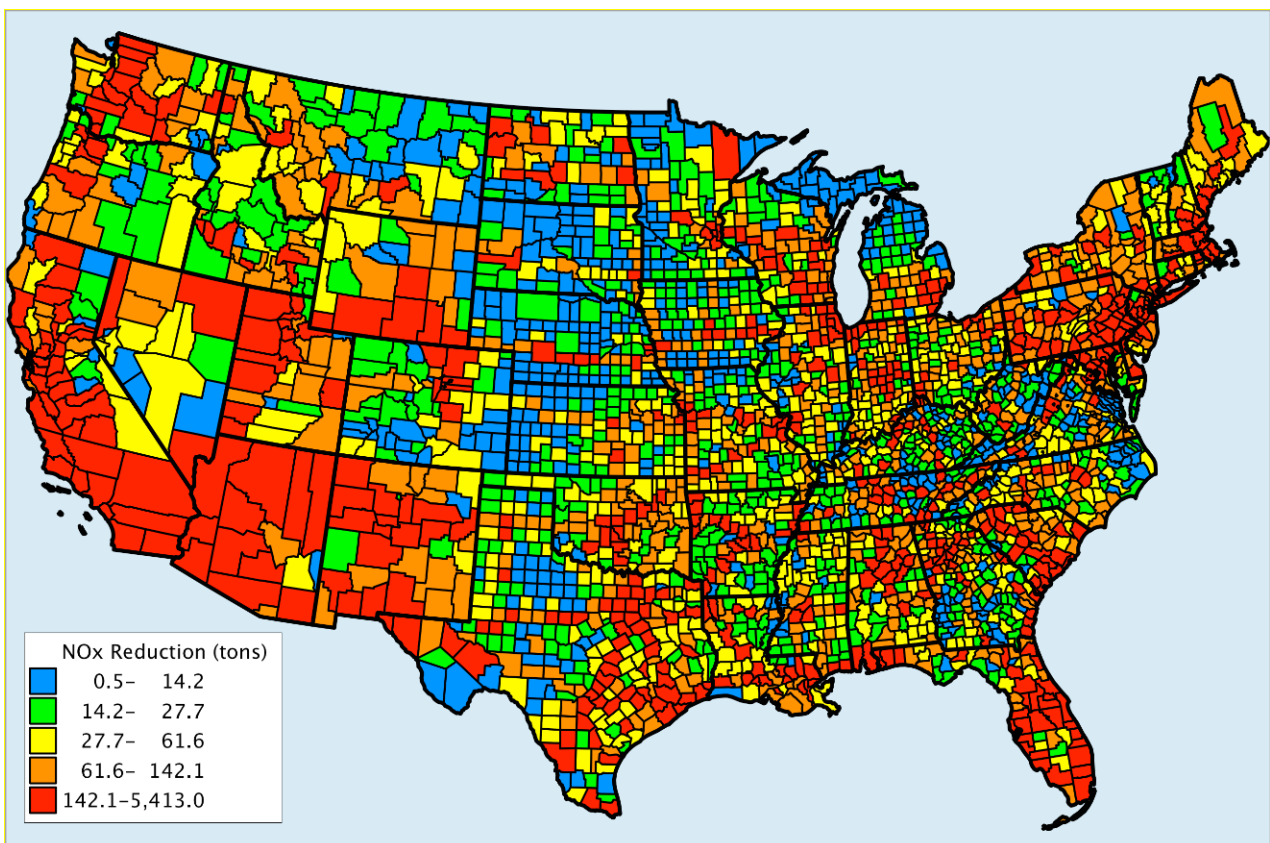
State	County	2035 Annual On-Road NOx Inventory (Light & Heavy-Duty)			
		Base Case (Tons)	Control Case (Tons)	Reduction (Tons)	Reduction (%)
Illinois	Grundy	905.7	361.3	544.4	60.1%
Wisconsin	Jackson	549.7	225.1	324.6	59.1%
Arkansas	St. Francis	528.8	217.6	311.2	58.8%
Texas	Eastland	361.0	151.5	209.4	58.0%
Texas	Reeves	263.1	110.9	152.2	57.9%
California	Merced	1,484.7	627.2	857.5	57.8%
Arkansas	Prairie	240.4	101.6	138.7	57.7%
Texas	Nolan	246.0	104.1	141.8	57.7%
Texas	La Salle	374.6	158.7	216.0	57.6%
Texas	Mitchell	165.0	70.0	95.0	57.6%

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At the county level, the range in NO_x impact – when expressed on an absolute scale – varies from -0.5 to -5,413 tons per year. The absolute impact of the modeled CTI scenario on NO_x is summarized in Figure ES-3 and Table ES-6. The key predictor of the absolute NO_x impact at the county-level is the absolute level of VMT from heavy-duty vehicles in 2035.

- Figure ES-3 presents the annual NO_x impact of the modeled CTI scenario in 2035 at a county-level resolution expressed as annual tons of NO_x reduced. The scale represents quintiles meaning one fifth of the counties examined fall within each color range bin.
- Table ES-6 presents the 10 counties with the largest, estimated annual NO_x reduction (tons) in 2035. A common characteristic of these counties is that they tend to include or be a part of a major metropolitan area. Los Angeles County contains the largest estimated NO_x reduction of 5,413 tons per year.

Figure ES-3
NO_x Impact of CTI Scenario in 2035 (Reduction in Tons per Year)
48-State Modeling Domain, County-Level



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**Table ES-6
Ten Counties with Largest, Annual NO_x Reduction (Tons) in 2035
From Modeled CTI Scenario**

State	County	2035 Annual On-Road NO _x Inventory (Light & Heavy-Duty)			
		Base Case (Tons)	Control Case (Tons)	Reduction (Tons)	Reduction (%)
California	Los Angeles	11,786.1	6,373.1	5,413.0	45.9%
California	San Bernardino	7,607.4	3,467.6	4,139.8	54.4%
California	Riverside	6,256.0	2,895.3	3,360.7	53.7%
California	Kern	4,835.5	2,074.6	2,760.8	57.1%
Texas	Harris	6,690.9	3,962.9	2,728.0	40.8%
Illinois	Cook	7,087.4	4,367.0	2,720.4	38.4%
Utah	Salt Lake	5,217.7	2,826.1	2,391.6	45.8%
Arizona	Maricopa	8,434.2	6,093.7	2,340.5	27.8%
Texas	Dallas	4,930.2	3,061.3	1,868.9	37.9%
California	San Diego	4,309.6	2,592.8	1,716.8	39.8%

In conclusion, the emissions impact analysis of the modeled, federal CTI scenario, set at the limits proposed by CARB in the September 26, 2019 workshop, has been demonstrated to provide substantive NO_x reductions nationally. The 2035 inventory impact analysis, representing only the first 11 model years of more stringent standards, yields an average estimated 36.2 percent reduction or approximately 330,000 tons in the year 2035 in on-road NO_x emissions nationally. Accordingly, the benefits of the modeled CTI scenario would be realized in a relatively short timeframe given the 20 to 30-year service life of heavy-duty on-road trucks and buses. Moreover, because the current USEPA MOVES model does not include all of the NO_x emissions that the CTI proposal would mitigate, it is anticipated that the modeled NO_x benefits are conservative. The real-world NO_x benefits of the modeled CTI scenario are potentially greater than estimated with the current USEPA modeling methods.

The remainder of this report is divided into the following three sections.

- **Background** summarizes key references and material related to the project including the project statement, the modeled CTI scenario, the 2016v1 Platform and the MOVES model.
- **Methods** documents the approach used in the activity forecasts, CTI scenario emission factor development, MOVES modeling and inventory processing.
- **Results** presents tabulated and graphical summaries of the emission impact analysis and fleet projections.

References are included at the end of this report. Key electronic appendices accompanying this report contain additional results reporting.

Background

This discussion of background material includes summaries of the problem statement and the assumptions around a potential federal Cleaner Trucks Initiative (CTI) scenario that would be aligned with the draft proposal presented at the September 26, 2019 California Air Resources Board (CARB) workshop;³ this is followed by summaries of key reference material.

Problem Statement

The project developed two 48-state, contiguous United States domain, emissions inventory databases incorporating a potential heavy-duty CTI scenario that would set national standards for emissions, durability and timeline based on the CARB workshop proposal from September 26, 2019.³ The emissions inventory impact of the national CTI scenario was modeled in calendar year 2035 (CY2035). The databases were prepared in the SMOKE flat-file 2010 format (FF10) – a file format suitable for post-processing into photochemical model ready inventories. The two databases represent (1) the current regulatory case and (2) current regulatory case plus the addition of the CTI scenario; these two are referred to in this document as the **2035 Base Case** and the **2035 Control Case** inventories.

The project's database deliverables were a derivative of the latest U.S. Environmental Protection Agency (USEPA) database for CY2028 (also in FF10 format) available at project commencement referred to herein as the "2016v1 Platform" (and described further below). Two modifications to that database were incorporated as follows.

- 2035 Activity Projection - an on-road activity data extrapolation to CY2035 was completed.*
- Fleet Turnover Analysis – on-road emission factor updates and inventory modeling were completed to evaluate fleet turnover from CY2028 to CY2035. Fleet turnover both with and without the assumed CTI scenario were examined.†

Several quality assurance and quality control (QA/QC) checks were implemented to ensure the correctness of the database development. Those QA/QC checks were also used to support tabulated and graphical summaries of the emission inventory results, as reported in this document.

Basis of Assumptions for the Cleaner Trucks Initiative (CTI) Scenario

CARB completed the agency's 2016 Mobile Source Strategy – a comprehensive strategy to reduce emissions from mobile sources to meet air quality and climate goals over the next fifteen years. The strategy notes that 80% of ozone forming NO_x emissions come from the transportation sector and 32% of transportation sector NO_x is emitted by heavy-duty on-road vehicles. As such, a cornerstone of the strategy, which covers all

* The on-road vehicle activity update was developed from USEPA and EIA resources.

† The emission factor updates and fleet turnover modeling were completed with the EPA MOVES model; MOVES is EPA's model for estimating emissions from on-road vehicles.

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mobile sources, was a new “low-NOx” on-road engine certification proposal that is effectively 90 percent cleaner than today’s current standards. The low-NOx engine proposal would be necessary for California to meet national ambient air quality standards (NAAQS) for ozone pollution. CARB’s proposal would set a California certification standard for in-state trucks, and the agency would also petition the USEPA for a comparable federal standard due to the sizable contribution of out-of-state trucks.⁷

In 2015, CARB initiated a test program at Southwest Research Institute (SwRI) to demonstrate the technical feasibility of meeting a 90% reduction in tailpipe NOx below current standards using advanced engine and aftertreatment controls.* The subsequent technical work at SwRI successfully demonstrated the feasibility of achieving 90% lower NOx emissions, and MECA estimated the cost effectiveness of these mobile source NOx reductions to be in the range of \$1,000 to \$5,000 per ton of NOx reduced.[†]

In 2016, the USEPA responded to the receipt of multiple petitions for new NOx standards and the agency announced in November 2018 that the agency would pursue the Cleaner Trucks Initiative (CTI) to update federal NOx emissions standards for heavy-duty on-road trucks. Most recently, on January 6, 2020, the Administrator signed an Advance Notice of Proposed Rule (ANPR) soliciting pre-proposal comments on the CTI on the merit of meeting a 50% to 90% NOx emission reduction below today’s truck standards.¹ Therefore, the objective of the emission impact analysis set forth in this report and the related air quality modeling, performed by Alpine Geophysics LLC, was to respond to EPA’s request for comment in the ANPRM as to the merits of reducing NOx emissions from heavy-duty trucks by 90%.

USEPA’s actions are occurring concurrently with comparable California regulatory development that started technology feasibility work five years earlier and regulatory discussions in 2018. Public statements made by the USEPA have indicated that the agency is looking to develop a nationally uniform regulatory framework for the heavy-duty on-road vehicles; however, the agency was unable to provide any details of the federal version of the program under development. Given a lack of specifics from USEPA, the basis for the “potential” federal CTI scenario that was modeled in this project was the most recent information – available at project commencement – from CARB given USEPA’s explicit intent of a nationally uniform framework.⁴

To assist in the response to the ANPR request for comments, two companion studies were undertaken to examine the air quality impact of a potential federal CTI scenario in calendar year 2035: Oak Leaf Environmental completed the emission inventory analysis and Alpine Geophysics LLC completed the photochemical air quality modeling of the inventory. This report documents the emission inventory analysis. ‡ The

* The Manufacturers of Emission Controls Association (MECA) partnered with CARB, USEPA and South Coast Air Quality Management District on this test program by providing all of the hardware and some of the funding for screening technology pathways and full useful life aging of hardware. The goals of this test program were to demonstrate the technical feasibility of achieving a 90% lower tailpipe NOx without impacting GHG emissions among other objectives to inform regulatory development.

† SwRI references and the cost-effective determination can be found in MECA’s feasibility study (Reference 11).

‡ The analysis year of 2035 was chosen to allow as much phase-in of low NOx trucks meeting the future modeled CTI emission limits while still providing adequate confidence from the air quality perspective.

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modeled year of 2035 was chosen to allow as much phase-in of low NOx trucks meeting the future modeled CTI emission limits while still providing adequate confidence from an air quality perspective.

The basis for the CTI scenario modeled in this project was the material from CARB’s September 26, 2019 public workshop.³ Overall, the CARB proposal covers three key elements:

- More stringent NOx certification standards,
- Increased certification durability, and
- Anti-backsliding particulate matter (PM) standards.

These three elements are summarized in Tables 1 and 2 presenting current and the assumed CTI regulatory requirements for exhaust certification standards and durability, respectively.

Table 1					
Current and Assumed CTI Engine Certification Standards					
	NOx			PM	
	Current	CTI (2024-26 MY)	CTI (2027+ MY)	Current	CTI (2024+ MY)
FTP Standard (g/bhp-hr)	0.2	0.05	0.02*	0.01	0.005

Table 2			
Current and Assumed CTI Engine Certification Durability			
Engine Type	Gross Vehicle Weight Rating (GVWR)	Useful Life (Miles / Years)	
		Current	CTI (2024+ MY)
Heavy-Duty Compression-Ignition (HDCI) Engines	Class 8 (Heavy) GVWR >33,000 lbs.	435,000 / 10	850,000 / 18
	Class 6-7 (Medium) 19,500 < GVWR ≤ 33,000 lbs.	185,000 / 10	350,000 / 18
	Class 3-5 (Light) 10,000 < GVWR ≤ 19,500 lbs.	110,000 / 10	250,000 / 18
Heavy-Duty Spark- Ignition (HDSI) Engines	GVWR >10,000 lbs.	110,000 / 10	250,000 / 18

Given that the new truck regulations begin implementation in 2024 and heavy-duty trucks last 20-30 years on the road, the 2035 timeframe represents an intermediate level of CTI truck penetration. It is expected that further NOx reductions will be realized beyond the 2035 modelled year as the heavy-duty truck fleet fully turns over to the cleanest technology vehicles. It was felt that full-implementation air quality projection was beyond the scope of this analysis.

* CARB, in the September 26, 2019 workshop proposal, proposed a range for the 2027 model year NOx standard of 0.015-0.030 g/bhp-hr; the value used in this analysis of 0.02 g/bhp-hr (representing 90 percent control over current certification standards) was the most common proposed control level under discussion. In March 2020, CARB refined their proposal specifically to the 0.02 g/bhp-hr standard.

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As shown in Table 1, NO_x emission standards under the modeled CTI scenario become more stringent in 2 phases, commencing with model years (MYs) 2024 and 2027, respectively; the MY2027 standard of 0.02 g/bhp-hr equals a 90 percent control level over current certification standards. The assumed PM certification requirement of 0.005 g/bhp-hr is a 50 percent reduction meant to ensure that future vehicles continue to maintain the PM levels observed in current engine certifications. As shown in Table 2, the assumed certification durability requirements represent an increased regulatory useful life of 18 years or up to 850 thousand miles.*

The following are additional key assumptions incorporated into the evaluation of the potential CTI scenario.

- The proposed regulatory certification standards apply to both compression-ignition (CI) and spark-ignition (SI) engines. As such, fuel types included in the inventory approach are diesel, gasoline, and natural gas.†
- The requirements only apply to heavy-duty engine certifications and would exclude heavy-duty certifications of complete vehicles.‡
- The assumed certification standards of Table 1 were modeled as impacting the in-use emissions of the certification pollutant only (i.e., either NO_x or PM); secondary impacts on other criteria or GHG pollutants (e.g., HC, CO, CO₂, etc.) were not estimated.
- The assumed certification durability standards of Table 2 were modeled as impacting the in-use emissions from all certification criteria pollutants (HC, CO, NO_x, PM) as the increasing useful life results in an extension of the lifetime of emission control equipment.
- Whereas the CARB is proposing explicit extended idling NO_x standards, USEPA noted that they will not follow suit on this one California requirement with the expectation that it is not needed. The agency expects the rigorous in-use testing requirements of the federal CTI under development will mean that engines will meet the California extended idling standard regardless and a separate standard is not needed.⁴

However, it should be noted that there are additional provisions of a future CTI that agencies intend to propose of which we did not explicitly model the emissions consequences. These include the following:

- The newly defined low load certification driving cycle, and

* Useful life is defined in *miles* or *years*, whichever occurs first in the service life of the engine. Useful life is the period during which the engine and emissions control equipment are required to demonstrate compliance with applicable emission standards. The CARB proposal also proposed substantive changes to the “warranty” requirements – the period in which the manufacturer guarantees functioning engine and emissions control equipment.

† USEPA’s MOVES model only includes these 3 fuels in on-road vehicle inventory development.

‡ Most heavy-duty gasoline vehicles between 8,500 and 10,000 lbs. GVWR are certified as complete vehicles and are subject to emissions certification limits expressed on a per-mile basis. The CTI evaluation was applied to engine certified vehicles with >10,000 lbs. GVWR – including both trucks and buses.

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- Revisions to the to the in-use compliance program based on moving-average windows.*

Modeling of the CTI Control Case scenario was done in a manner that was intentionally consistent with existing MOVES methods of the base case. Modeling these provisions would not be possible without some modification to the existing MOVES methods – which fell outside the scope of work. Some of the NO_x emissions from currently certified vehicles that the CTI under development will mitigate are emissions that the model does not yet adequately capture in the underlying MOVES methods. It is expected that once these adjustments are made in future versions of MOVES, the projected emission reductions of any CTI scenario would be greater given the fact that the model currently underestimates real world emissions as reported by testing conducted by CARB and USEPA.† As such, the NO_x reduction reported in this report – in both absolute and relative terms – are conservative.

USEPA’s 2016v1 Platform

The National Emission Inventory is a periodically updated effort of the USEPA in collaboration with state and local agencies to compile a national emission inventory using locally derived data and estimates. It represents the most accurate national compilation of emissions. The current version at the time of this project was Version 1 of the 2016 modeling platform (2016v1 Platform).‡ The inventory evaluation years of the platform are 2016, 2020, 2023 and 2028. The following datasets were utilized.

- The 2028 inventory was used in the development of 2035 Base Case and 2035 Control Case inventories.
- The 2023 and 2028 on-road activity data were used in the 2035 activity projection completed.

The 48-state plus District of Columbia modeling domain of this project covered 3,108 counties (or county-equivalents) and contained up to 9,217 emission records per county§ – each emissions record contains a single, annual and twelve, monthly emissions estimates. There were approximately 19 million emission records in the domain-wide 2035 inventory databases – an identical number of records as the 2028 inventory used in their development. Four fields defined a unique record in these databases: county, SCC, rate type** and pollutant. The databases format was the flat file 2010 (FF10) format of SMOKE.††

* The moving-average windows replaces the current not-to-exceed (NTE) compliance requirements.

† Reference 8 contains USEPA’s assessment of emission factor updates planned for future MOVES revisions.

‡ Version 1 is the third version (after *alpha* and *beta* versions). It is common in the NEI process for successive versions to occur.

§ An emissions record is produced for each unique combination of source category code (SCC), emissions type and pollutant. Forty-nine pollutants were modeled. The SCC provides the differentiation by vehicle type, roadway type and emissions process.

** Three rate type, related to how the 2016v1 Platform relates to MOVES, were defined: rate per distance (RPD), rate per profile (RPP) and rate per vehicle.

†† SMOKE is the name of EPA’s emission inventory processing software.

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The data noted above for the 2016v1 Platform are available here:

<ftp://newftp.epa.gov/Air/emismod/2016/>

The documentation for the 2016v1 Platform is available here:

<http://views.cira.colostate.edu/wiki/wiki/10202>

Documentation of the SMOKE FF10 file format of the 2028 and 2035 emissions inventory databases is available here:

<https://www.cmascenter.org/smoke/documentation/3.7/html/ch08s02.html>.

USEPA's MOVES Model

The MOtor Vehicle Emission Simulator (MOVES) is a periodically updated model that is required for use in official US on-road emission inventory assessments.* The current version available at project commencement was used in this effort, which is MOVES2014b dated December 2018 with the default database dated October 2018.^{6, †}

The MOVES model was executed to simulate the fleet turnover effects from 2028 to both 2035 Base and Control Cases; the results were post-processed to produce a series of relative emissions adjustment factors. Those adjustment factors were applied to develop the 2035 inventories. Key input into the MOVES modeling completed included fleet and activity data from the 2016v1 Platform and project-developed emission rates reflecting the CTI regulatory case.

MOVES Model Review Workgroup

As noted above, the MOVES model is updated regularly and the USEPA has already completed significant updates to both light-duty and heavy-duty emission rate methods. Those updates have been presented and reviewed as part of the MOVES Model Review Workgroup.[‡] Oak Leaf Environmental participates in the workgroup process and is familiar with those updates.[§]

USEPA's emission rate updates will have significant impact on both light-duty and heavy-duty emissions. But the emission rate data tables reflecting those updates, for use in MOVES, will not be made available until the next major update to MOVES or until the next significant regulatory activity occurs. At which point, the updated emission rate databases will become publicly available. While MOVES-ready inputs are not available, the summary material of the workgroup were used in this project to inform how anti-backsliding PM standards would impact emission rates from diesel-powered vehicles.[§]

* With the exception of California as USEPA currently permits the use of a California-developed model for official inventory submissions for that state.

† The on-road emission inventory of the 2016v1 Platform is also based on the use of the MOVES2014b model.

‡ The MOVES Review Work Group was formed under the Mobile Sources Technical Review Subcommittee (MSTRS) and is charged to provide input to EPA via the MSTRS and the Clean Air Act Advisory Committee on specific issues regarding the development of the MOVES model.

§ The PM anti-backsliding standards are directly related to the significant overperformance of current diesel engine certifications relative to the existing PM standard. The anti-backsliding is intended to preserve those PM reductions in the context of future CTI regulatory development.

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It is also noteworthy to recognize that when the USEPA completes a proposed rulemaking of the CTI, the agency may choose to use the latest emission rates from the workgroup. If indeed the case, then the CTI impact analysis of the USEPA would differ significantly from this effort – as the foundational emission rates of the MOVES model would be significantly different.

EIA's Annual Energy Outlook (AEO)

The Energy Information Agency's (EIA's) annual publication *Annual Energy Outlook* (AEO) provided key data for the CY2035 activity extrapolation. AEO is the resource used by USEPA for national on-road activity projections in conjunction with MOVES model input development. In this project AEO provided vehicle and VMT projections at the national level through CY2035 and were incorporated into the activity data extrapolation. The 2019 version, the most recent available at project commencement, was used in this activity extrapolation; the AEO2019 was also used to support the on-road activity projection of the 2016v1 Platform.⁵

Methods

The methods applied to develop two 48-state (contiguous United States) emission inventory databases – the 2035 Base Case and the 2035 Control Case – are described as follows. The individual elements addressed are

- CY2035 activity forecast,
- Emission factor development for modeled CTI scenario
- MOVES inventory modeling, and
- Data processing.

CY2035 Activity Forecast

In current USEPA methods based on MOVES, there are 3 distinct activity bases defined for 2035:

- vehicles,*
- vehicle miles traveled (VMT)[†] and
- hours spent hoteling (long-haul operations only).[‡]

In terms of NO_x emissions from the heavy-duty sector, VMT is the primary activity basis responsible a majority of the inventory, followed by hours hoteling and then vehicles.

The activity forecast was completed in a two-step process.

- The first step was a linear extrapolation of the CY2023 and CY2028 activity data from the 2016v1 Platform out to CY2035. It was performed at the county and SCC level – where the SCC assignment contains the resolution by vehicle, fuel and roadway types.
- The second step was to renormalize the extrapolated results, so that total vehicles and VMT growth rates nationally from 2028 to 2035 match the comparable national rates published by AEO2019. In this process, the same renormalization adjustment to heavy-duty VMT was also applied to hoteling hours (as AEO does not report estimates of hoteling hours), and these 2 activity bases are correlated. The assignment of AEO reported vehicle types were assigned to MOVES vehicle types in accordance with USEPA methods used previously in MOVES input development.⁹ The renormalization step was implemented such that the national growth trend of this forecast matches that of AEO.[§]

* Vehicles are the activity basis used for estimating trip start emissions, trip end evaporative emissions and evaporative emissions occurring while the engine is off.

[†] VMT is the activity basis for estimating stabilized running exhaust emissions and evaporative emissions that occur during operation.

[‡] “Hoteling hours” are the mandatory rest periods by long-haul trucking personnel when extended engine idling and auxiliary power unit (APU) use occurs. Extended idling is the use of the main vehicle engine for climate control and accessories during the rest period.

[§] To complete the national growth reconciliation, the activity forecast was completed for the entire nation before selecting just those results over the modeling domain of 48 states plus the District of Columbia.

Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

The activity forecast was converted into a relative activity adjustment factor (*Activity AF*) defined as follows. The relative adjustment factors were defined at the county and SCC level for each activity basis.

$$\text{Activity AF} = \frac{\text{CY2035 Activity}}{\text{CY2028 Activity}}$$

The result were activity adjustment factors capturing trends at the county, vehicle, fuel and roadway class level – while ensuring that the total national growth trend represents the EIA’s AEO2019. A review of these results showed that the underlying 2016v1 Platform VMT projections did not vary by roadway type, such that the analysis results also did not exhibit any roadway type variation (i.e., the growth rate of a given vehicle and fuel type in a given county was uniform across road types).^{*} The number of unique activity adjustment factors by a basis were as follows.

- 74,733 population adjustment factors (variation by county, vehicle, and fuel)
- 78,481 VMT adjustment factors (variation by county, vehicle, and fuel)
- 3,586 hoteling hours adjustment factors (variation by county, vehicle, fuel, engine versus APU)

Emission Factor Development

Emission factors for the modeled CTI regulatory scenario case were needed to support the 2035 Control Case Inventory evaluation. The development of these addressed the following elements:

- More stringent NOx certification standards,
- Increased certification durability, and
- Anti-backsliding particulate matter (PM) standards.

The emission rate data were developed in the format required by the MOVES model. The approach taken emulated that of the USEPA used in past efforts to estimate emission rates reflective of specific certification standards and durability requirements while relying on other CTI scenario-specific information.^{10, 11, 12}

It is important to state that there are no explicit engine certification standards that exist as input parameters into MOVES. As such, the modeled certification values are not directly useable as model input; emission rates reflective of the assumed CTI regulatory context were developed for use in MOVES. Addressing changes in the underlying regulatory context was handled as a series pre-processing steps and requires an understanding of the fundamental emission factor development method of the USEPA. Whereas, certification limits are specific to a standard duty cycle, standard ambient conditions and standard vehicle preconditioning, those limits are converted into

^{*} The QA/QC review also discovered unusual vehicle population estimates for Pima County, AZ in the 2016v1 Platform; the values for the two years 2023 and 2028 were visibly inconsistent. These suspect data were confirmed with the EPA as originating from different sources. For Pima County, the 2028 to 2035 VMT growth rate estimated was also applied to the vehicle population data to derive the 2035 population estimate for this county.

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representative in-use emission rates covering the full range of operation and conditions over the vehicle's entire service life.

The input exhaust rates of MOVES are modal in-use exhaust emission factors (mass emissions per unit time) defined by specific operating modes, vehicle types and vehicle ages. The underlying method and data record are fully separate by fuel type and vehicle regulatory class; thirteen combinations of fuel and regulatory class emission rates are impacted by the modeled CTI scenario.

The modeled emission factor development included the following elements.

- Emission rates were updated for the 3 emissions processes of running exhaust, startup exhaust and extended idling exhaust.
- Emission rates covered the MOVES input species of hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), elemental carbon (EC) and non-elemental-carbon particulate matter (non-EC PM).
- The emission rates factored in the assumed CTI warranty and useful life assumptions in a manner consistent with USEPA methods.¹⁰
- NO_x emission rates incorporated the 2 phases of the assumed CTI shown in Table 1. The basis for incorporating new standards followed the method employed by USEPA to adjust for the most recent set of SI and CI standards in MOVES.¹⁰ For SI engines (i.e., gasoline engines), there was little in the background source material to estimate how future CTI scenario NO_x standards would impact startup and running exhaust distinctly. Equivalent reductions were applied uniformly across both startup and running exhaust processes in the application of the modeled CTI NO_x standards.
- For diesel engines only, a PM exhaust reduction (applied to both EC and non-EC PM) was applied for the anti-backsliding standards of the CTI scenario. A review of the MOVES workgroup materials show that current PM rates are 47 percent below what MOVES currently predicts – this is the specific PM reduction that the assumed anti-backsliding standards intends to retain. The reduction of 47% was applied to EC and non-EC PM emission rates for certified engines.*

The emission factor analysis yielded 86,816 updated emission rates formatted for use in MOVES to address all the regulatory classes, fuel types, operating modes, age bins and model years needed to model the potential CTI scenario in 2035.

* Because subsequent air quality modeling of the CTI regulatory case was planned as follow-on to this project, it was important for the PM emission rates to accurately reflect the expected emission levels. This reduction was applied only to diesel-fueled CTI-certified engines; a comparable analysis of PM emission rates from gasoline vehicles showed that current MOVES model assumptions agree well with recent exhaust measurements.

Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

MOVES Inventory Modeling

The MOVES model was applied in “inventory mode” to generate inventories for three scenarios: 2028 Base,* 2035 Base and 2035 Control. The MOVES modeling was completed to generate fleet turnover adjustment factors (*Fleet Turnover AF*) to be applied in the data processing of this effort as shown below.

$$\text{Fleet Turnover } AF_{Base} = \frac{MOVES_{2035 \text{ Base}}}{MOVES_{2028 \text{ Base}}}$$

$$\text{Fleet Turnover } AF_{Control} = \frac{MOVES_{2035 \text{ Control}}}{MOVES_{2028 \text{ Base}}}$$

The MOVES modeling was completed at the “national domain scale” – meaning fleet turnover estimates are national average.† National-scale modeling of fleet turnover is a sound approach for the inventory evaluation of the heavy-duty sector – for which fleet characteristics are more uniform nationally and activity is often interstate in nature.‡ The modeling assumptions employed in the application of MOVES included the following.

- The fleet and activity input were developed from the aggregate over the 48-state domain of the 2028 inventory of the 2016v1 Platform.§
- Modeling included all 12 months individually as well as both weekdays and weekends.
- Modeling of evaporative emissions performed on an hourly time resolution and a daily time resolution for all other processes.
- All available pollutants were included.
- MOVES Output was reported at the SCC level so that results could differentiate vehicle types, emission process, roadway type and fuel types.

The MOVES output data was post-processed before adjustment factors could be calculated. Data were processed to address the differences in how SCCs and pollutants are defined (between MOVES and the 2016v1 Platform) as follows.

* The 2028 Base Case is a simulation of CY2028 under the current regulatory context used as a point of comparison to the 2028 inventory of the 2016v1 Platform.

† Because much of the spatial variation of input parameters would remain the same between CY2028 and CY2035 – including county-level speeds, operating characteristics, ambient conditions – a county-level analysis of fleet turnover contains considerable redundancy (and would also require significant resources). Notably, the critical difference between the two years (2028 and 2035) is properly capturing fleet turnover, and fleet turnover impacts of each emissions process are effectively similar when expressed in relative terms across a wide variety of modeling conditions.

‡ While national-scale modeling of fleet turnover introduces more uncertainty in the light-duty sector, which exhibits more variation in the local fleet age distribution, it is also not credible to suggest that forecasting local light-duty age distributions 15 years forward can be completed accurately.

§ This input covered vehicles, VMT, hours hoteling and vehicle age distribution. The 2028 fleet and activity data were used for both 2028 and 2035 modeling in order to capture the fleet turnover and recognizing that activity adjustment factors are applied externally to the MOVES-based fleet turnover adjustments.

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- The SCC of MOVES is mapped to two fields of the 2016v1 Platform – SCC and rate type. The SCC schemes of MOVES and the 2016v1 Platform are distinct in how the emissions process is identified. This mapping accounted for the correct assignment of emissions process between the MOVES modeling and the platform database.
- Of the 50 pollutants of the 2016v1 Platform, 44 had a direct equivalent reported by MOVES. The remaining 6 pollutants of the platform had to be calculated by addition and or subtraction of 2 or more MOVES-reported pollutants.

From this analysis, about 113 thousand fleet turnover adjustment factors were estimated for each of the Base and Control Cases – representing 9,437 unique SCC, rate type and pollutant combinations reported for each of the 12 months.

Inventory Processing

The inventory database processing consisted of the conversion of the 2016v1 platform CY2028 database over to the 2035 Base Case and the 2035 Control Case. The conversion was completed by the application of the adjustment factors, whose development is described above, as follows.

$$2035 \text{ Base Case} = 2028_{2016v1 \text{ Platform}} \times \text{Fleet Turnover } AF_{\text{Base}} \times \text{Activity } AF$$

$$2035 \text{ Control Case} = 2028_{2016v1 \text{ Platform}} \times \text{Fleet Turnover } AF_{\text{Control}} \times \text{Activity } AF$$

The 2028 inventory contained approximately 19 million emissions records, where each record included an annual and 12 monthly emissions totals. Four fields defined a unique record (county, SCC, rate type and pollutant). The processing included the following elements.

- The assignment of an activity adjustment factor (and which activity basis to apply) to a given record was determined from the combination of county, SCC and rate type.
- The assignment of a fleet turnover adjustment factor to a given record was determined from the combination of SCC, rate type and pollutant.
- Monthly emissions were determined by the application of activity and fleet turnover factors; annual emissions were determined by the sum of the 12 months.

The resulting 2035 Base Case and the 2035 Control Case databases created were transferred to MECA electronically.

Results

Results presented in this section include tabulated and graphical summaries of the potential CTI modeled emission impact analyses for a national scenario set at the limits proposed by CARB in the September 26, 2019 workshop. Fleet projections are included at various geographic levels. Additional results are provided in electronic appendices as noted in the discussions below. Results are grouped by these topics.

- National and state summaries
- CY2035 activity forecast
- Emissions impact analysis – tons
- Emissions impact analysis – percent scale
- Final Remarks

National and State Summaries

Figures 1 and 2 present a summary of the modeled CTI emissions impact and key heavy-duty vehicle fleet statistics for the 48-state domain and for an example state (Ohio), respectively. Electronic **Appendix A** contains a complete set of results for all 48 states plus the District of Columbia presented in the format of Figure 2.

For the 48-state total (Figure 1), key results include the following.

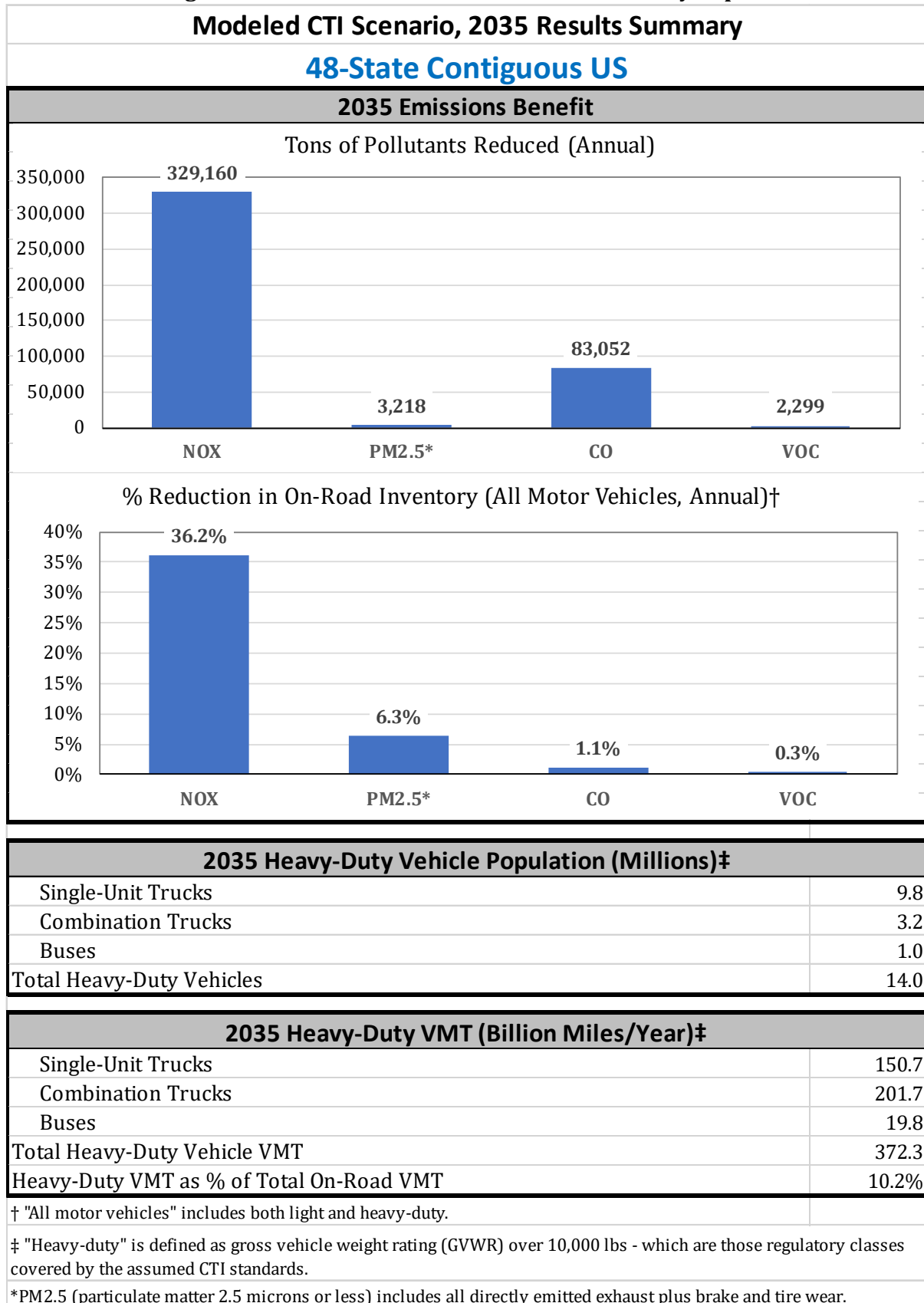
- There are an estimated 14 million heavy-duty vehicles on the road in 2035 accumulating 372 billion miles of travel over the course of the year. By 2035, heavy-duty VMT is estimated to represent 10.2 percent of the total on-road VMT.
- The modeled scenario of the CTI would reduce 329 thousand tons of NO_x across the domain; the equivalent to a 36.2 percent reduction in the on-road NO_x inventory in 2035. Moreover, an estimated 83, 3 and 2 thousand tons of CO, PM_{2.5} and VOC, respectively, are also eliminated by the program. These estimated pollutant reductions are realized because of the more stringent standards and increased certification durability requirements.

For Ohio (Figure 2), key results include the following.

- There are an estimated 402 thousand heavy-duty vehicles on the road in 2035 accumulating 9.2 billion miles of travel over the course of the year. By 2035, heavy-duty VMT is estimated to represent 7.0 percent of the total on-road VMT. Ohio ranks at #11 and #14 highest (out of 49) in terms of HD vehicles and VMT, respectively, estimated to occur within the state in 2035.
- The modeled CTI scenario reduces 7,865 tons of NO_x across the state; the equivalent to a 27.9 percent reduction in the on-road NO_x inventory in 2035. Moreover, an estimated 2,088, 83 and 56 tons of CO, PM_{2.5} and VOC, respectively, are also eliminated by the program. Ohio ranks at #14 highest (out of 49) in terms of total tons of NO_x benefit estimated to occur within the state in 2035.

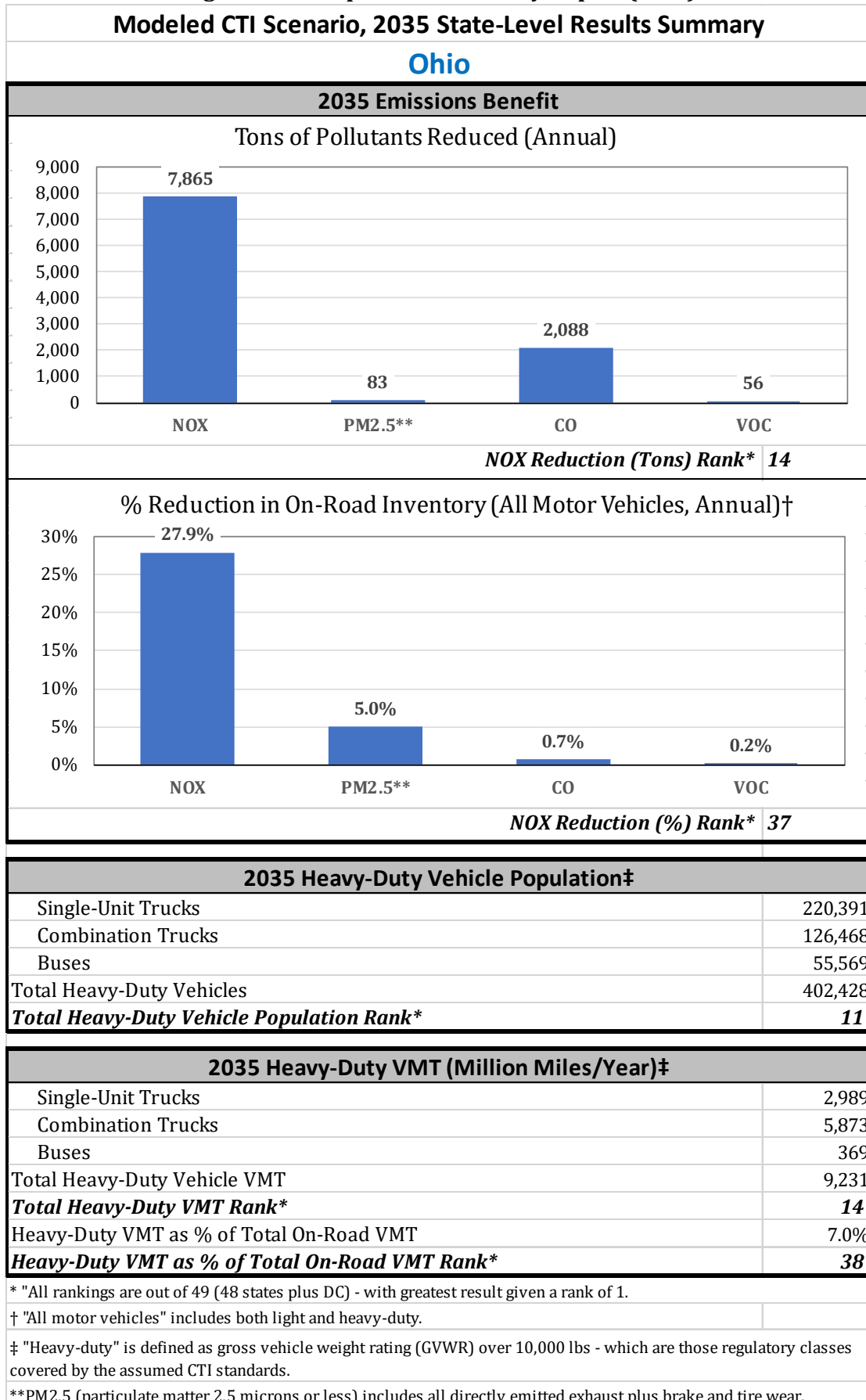
Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

Figure 1 – 48-State Modeled CTI Scenario Summary Impact



Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

Figure 2 - Example State Summary Impact (Ohio)



CY2035 Activity Forecast

There were 3 distinct activity bases defined for 2035:

- vehicles,
- vehicle miles traveled (VMT) and
- hours spent hoteling (long-haul operations only).

Tables 3 through 5 present the 48-state summary of the 2035 activity forecast for each activity type. Electronic **Appendix B** to this report provides comparable state-level activity reporting.

- Table 3 presents the 48-state on-road vehicle projection. Overall, estimated heavy-duty vehicle population growth (9.5 percent) is just over 4 times the growth estimated for the light-duty sector (2.4 percent) over the 7-year period. Within the heavy-duty sector, single-unit trucks are the fastest growing segment – 11.6 percent growth estimated from 2028 to 2035.
- Table 4 presents the 48-state on-road VMT projection. Overall, estimated heavy-duty VMT growth (9.9 percent) is just over 3 times the growth estimated for the light-duty sector (2.9 percent) over the 7-year period. Within the heavy-duty sector, single-unit trucks are the fastest growing segment – 18.8 percent growth estimated from 2028 to 2035. Across vehicle types, VMT growth is marginally higher than vehicle growth of the same vehicle types – indicating that annual mileage accumulation rates per vehicle are estimated to increase.
- Table 5 presents the 48-state long-haul trucking hoteling hours projection. Overall, there is a 4.1 percent estimated growth in hoteling hours over 7 years. Much of the growth in hoteling hours is met by increased APU usage (15.3 percent growth); whereas, extended idling of the main engine use remains relatively constant (0.2 percent growth).

Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

Table 3				
2035 On-Road Vehicle Population, 48-State Total				
Sector	Vehicle Type	Million Vehicles		2028 to 2035 Growth Rate
		2028	2035	
Light-Duty (GVWR ≤10,000 lbs.)	Passenger Car	129.4	131.3	1.4%
	Truck	143.9	148.6	3.2%
	Motorcycle	8.9	9.0	1.2%
	<i>Total Light-Duty</i>	<i>282.2</i>	<i>288.9</i>	<i>2.3%</i>
Heavy-Duty (GVWR >10,000 lbs.)	Single-Unit Truck	8.7	9.8	11.6%
	Combination Truck	3.0	3.2	4.0%
	Bus	0.9	1.0	7.3%
	<i>Total Heavy-Duty</i>	<i>12.7</i>	<i>14.0</i>	<i>9.5%</i>

Table 4				
2035 On-Road VMT, 48-State Total				
Sector	Vehicle Type	VMT (Billion Miles/Year)		2028 to 2035 Growth Rate
		2028	2035	
Light-Duty (GVWR ≤10,000 lbs.)	Passenger Car	1,512	1,552	2.6%
	Truck	1,649	1,701	3.2%
	Motorcycle	21	21	1.0%
	<i>Total Light-Duty</i>	<i>3,181</i>	<i>3,274</i>	<i>2.9%</i>
Heavy-Duty (GVWR >10,000 lbs.)	Single-Unit Truck	127	151	18.8%
	Combination Truck	194	202	4.1%
	Bus	18	20	9.9%
	<i>Total Heavy-Duty</i>	<i>339</i>	<i>372</i>	<i>9.9%</i>

Table 5			
2035 Long-Haul Trucking Hoteling Hours, 48-State Total			
Vehicle Type	Hoteling (Million Hours/Year)		2028 to 2035 Growth Rate
	2028	2035	
Extended Idling (Main Engine)	350.5	351.3	0.2%
Auxiliary Power Unit (APU)	122.9	141.7	15.3%
<i>Total Hoteling</i>	<i>473.4</i>	<i>492.9</i>	<i>4.1%</i>

Emissions Impact Analysis – Tons

Figure 3 shows that the state-level annual NOx benefit of the modeled CTI scenario in 2035 tracks with the amount of heavy-duty VMT in each state in that year. Both NOx benefit (tons) and VMT (10⁶ Miles) are shown on an identical scale in Figure 3, and the fact that benefit tracks VMT matches expectation. On average over the domain, 0.87 tons of benefit were estimated per million miles of HD VMT. Texas has the largest VMT at an estimated 39,821 million miles per year; California has the largest benefit, under this scenario, at an estimated 34,872 tons per year.

Figure 3. State-Level Annual NOx Benefit (Tons) and VMT in 2035
48-State Modeling Domain, Modeled CTI Scenario

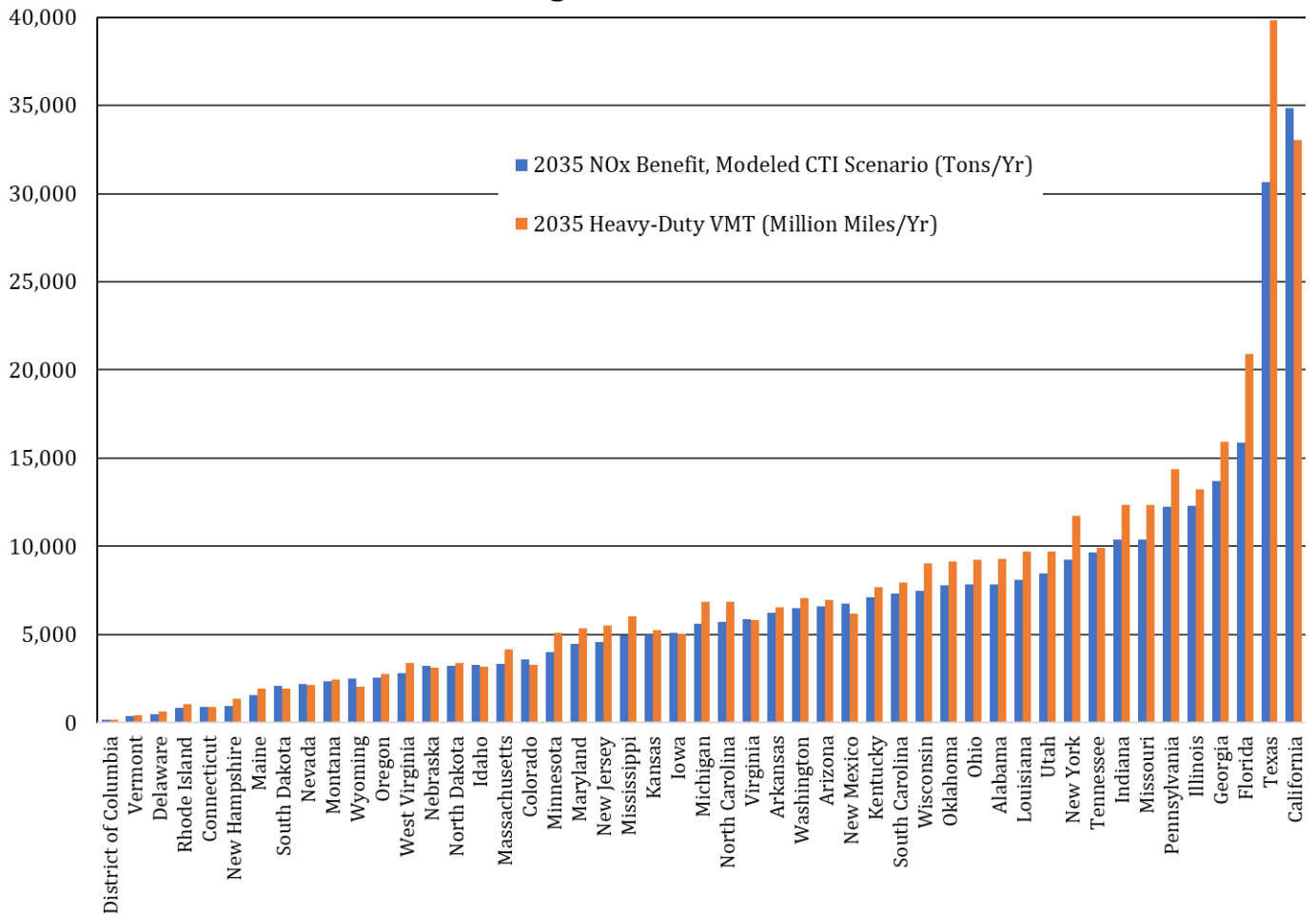
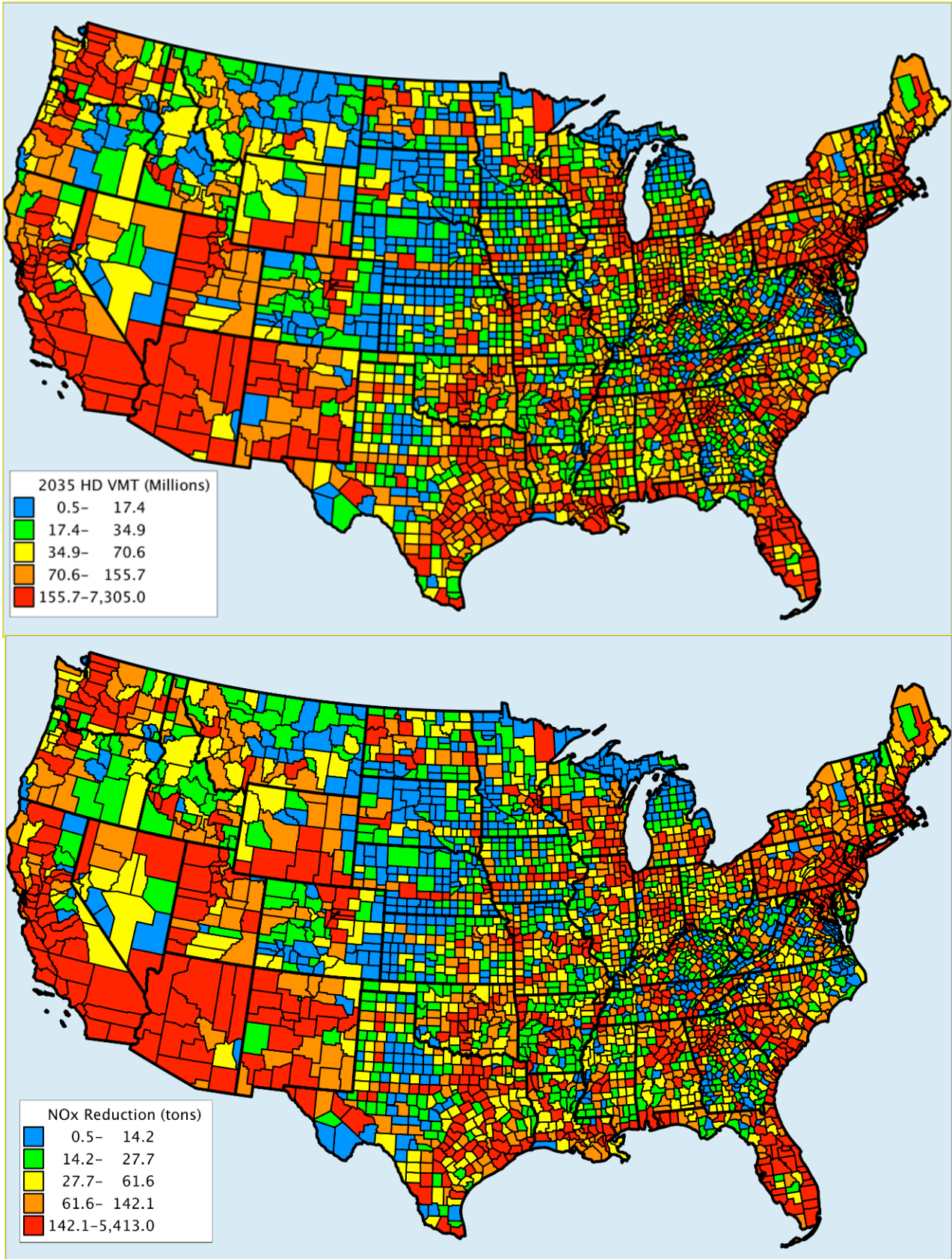


Figure 4 presents county-level annual NOx benefit of the modeled CTI scenario in 2035 along with heavy-duty VMT. Again, the heavy-duty VMT and NOx benefit (tons) have a similar spatial distribution. Los Angeles County is estimated to contain the highest heavy-duty VMT and NOx benefit of 7.3 billion miles and 5,413 tons, respectively. The scale represents quintiles meaning one fifth of the counties examined fall within each color range bin, and the counties nearly line up in identical quintiles for both NOx benefit and VMT.

Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

Figure 4 – County-Level VMT and Annual NOx Benefit (Tons) in 2035 48-State Modeling Domain, Modeled CTI Scenario

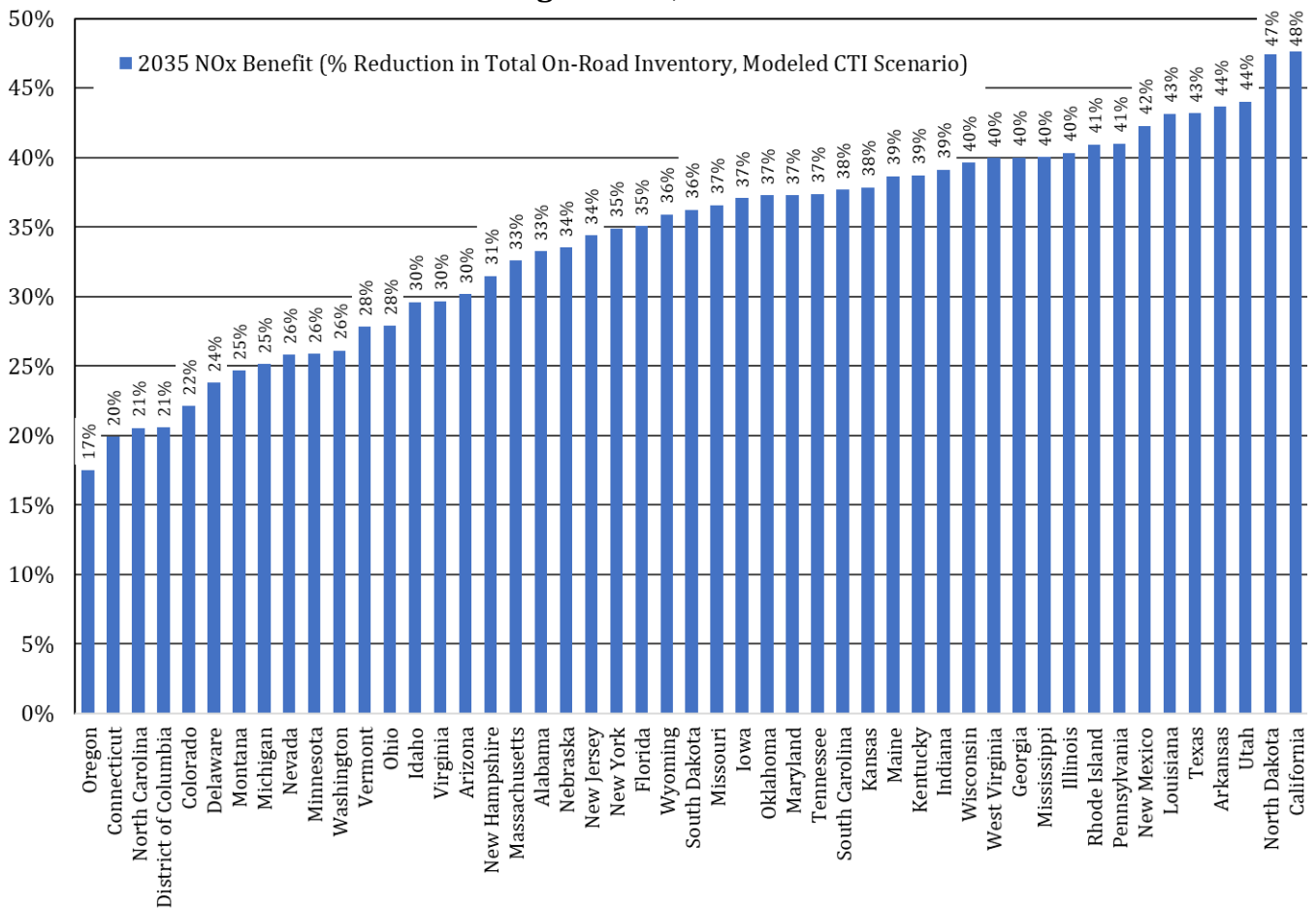


Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

Emissions Impact Analysis – Percent Scale

Figure 5 presents the relative, annual NO_x benefit of the modeled CTI scenario in 2035, sorted in rank order. The percent benefit is estimated as a reduction in the total on-road NO_x inventory (both light and heavy-duty vehicles). When examining the assumed CTI scenario on a percent benefit scale, the reduction in emissions ranges from 17 to 48 percent from Oregon to California, respectively. For comparison, the 48-state domain average assumed CTI scenario NO_x benefit in 2035 is a 36 percent reduction in annual on-road NO_x emissions.

**Figure 5 – Annual NO_x Benefit (Percent Reduction in On-Road Inventory) in 2035
48-State Modeling Domain, Modeled CTI Scenario**



A key parameter impacting the percent NO_x benefit of the assumed CTI scenario (as shown in Figure 5) is the share of VMT coming from heavy-duty vehicles. Figure 6 presents the relative, annual NO_x benefit of the assumed CTI scenario in 2035, sorted in rank order. There is a significant range in VMT share from the heavy-duty sector observed from 3 percent (Connecticut) to 29 percent (North Dakota). For comparison, the 48-state average share of VMT from heavy-duty vehicles is 10.2 percent.

Figure 6
Heavy-Duty VMT Share by State, 2035

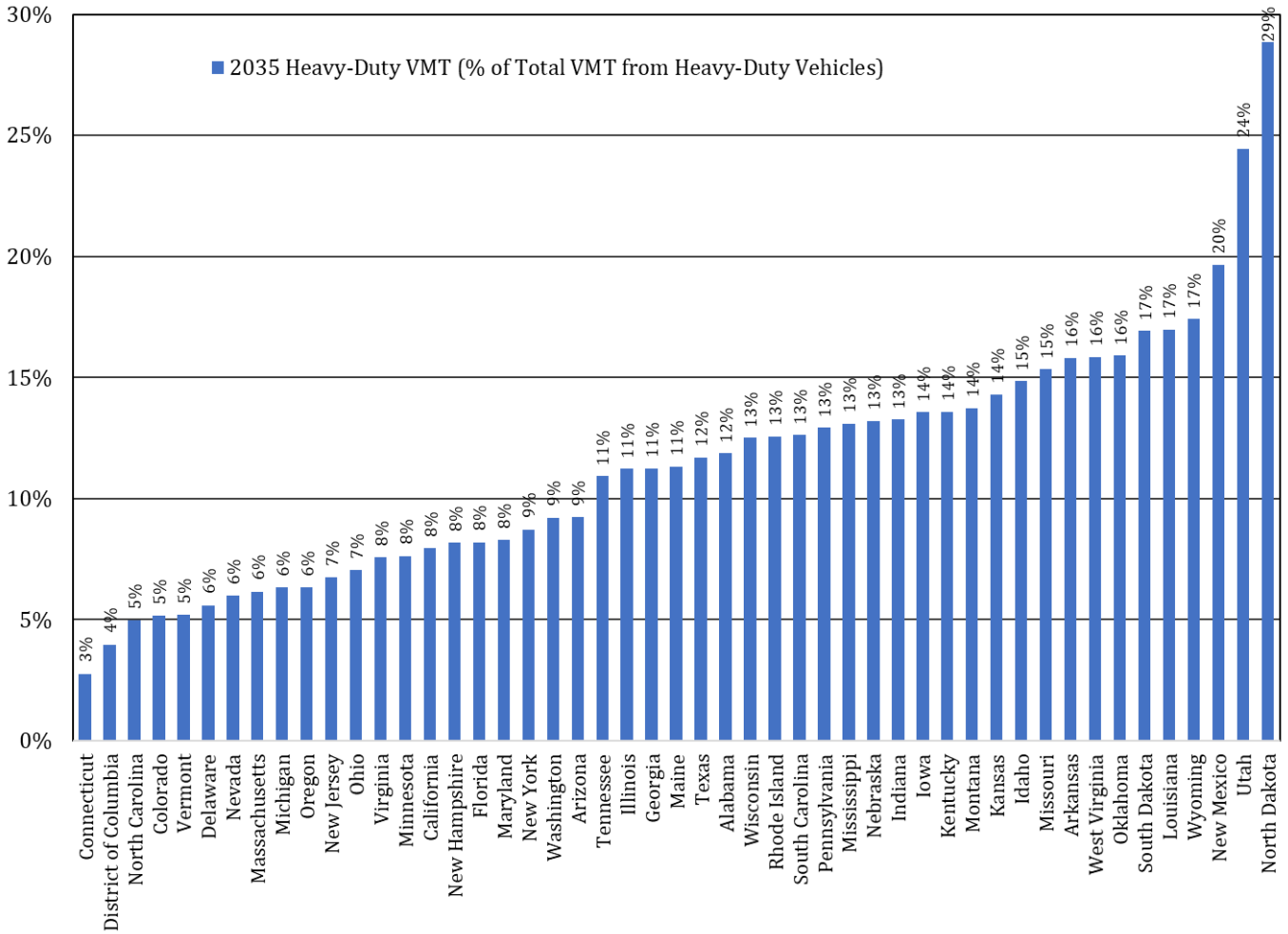


Figure 7 presents the relative, annual NOx benefit of the potential CTI scenario in 2035 at a county-level resolution. The percent benefit is estimated as a reduction in the total on-road NOx inventory (both light and heavy-duty vehicles). The range in benefit, by county, is between 4 and 60 percent. Table 6 presents the 10 counties with the largest, estimated annual NOx reduction (percent) in 2035. A common characteristic of these counties is that they tend to be more rural with one or more major highways located within.

Modeling Inventory of Potential Heavy-Duty Cleaner Trucks Initiative Scenario

Figure 7 – Annual NOx Benefit (Percent Reduction in On-Road Inventory) in 2035
48-State Modeling Domain, County-Level, Modeled CTI Scenario

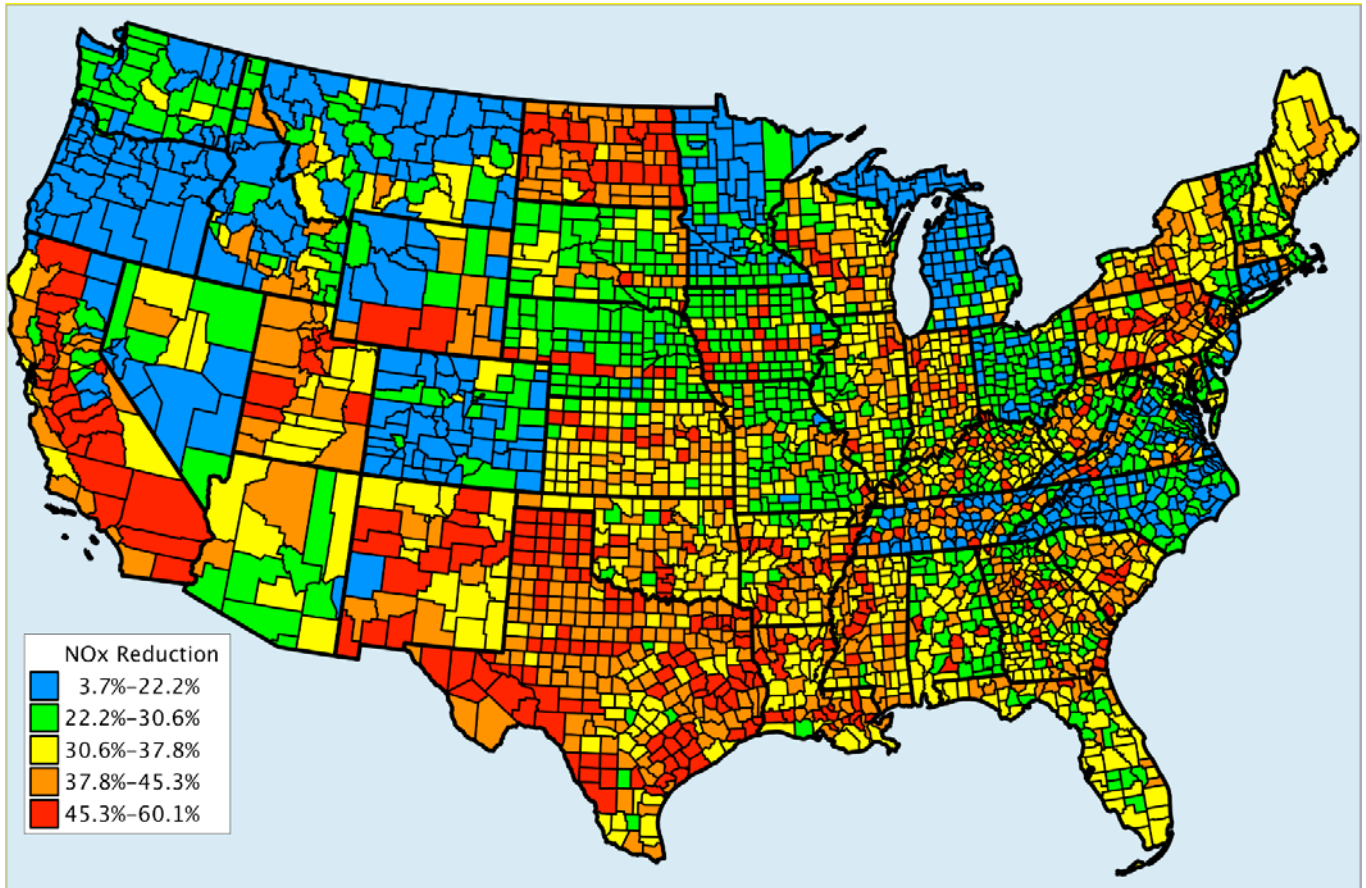


Table 6
Ten Counties with Largest, Annual NOx Reduction (%) in 2035
From Modeled CTI Scenario

State	County	2035 Annual On-Road NOx Inventory (Light & Heavy-Duty)			
		Base Case (Tons)	Control Case (Tons)	Reduction (Tons)	Reduction (%)
Illinois	Grundy	905.7	361.3	544.4	60.1%
Wisconsin	Jackson	549.7	225.1	324.6	59.1%
Arkansas	St. Francis	528.8	217.6	311.2	58.8%
Texas	Eastland	361.0	151.5	209.4	58.0%
Texas	Reeves	263.1	110.9	152.2	57.9%
California	Merced	1,484.7	627.2	857.5	57.8%
Arkansas	Prairie	240.4	101.6	138.7	57.7%
Texas	Nolan	246.0	104.1	141.8	57.7%
Texas	La Salle	374.6	158.7	216.0	57.6%
Texas	Mitchell	165.0	70.0	95.0	57.6%

Summary Conclusions

The emissions impact analysis of the modeled, federal CTI scenario, set at the limits proposed by CARB in the September 26, 2019 workshop, has been demonstrated to provide substantive NO_x reductions nationally. The 2035 inventory impact analysis, representing only the first 11 model years of more stringent standards, yields an average estimated 36.2 percent reduction or approximately 330,000 tons in the year 2035 in on-road NO_x emissions nationally. Accordingly, the benefits of the modeled CTI scenario would be realized in a relatively short timeframe given the 20 to 30-year service life of heavy-duty on-road trucks and buses. Moreover, because the current USEPA MOVES model does not include all of the NO_x emissions that the CTI proposal would mitigate, it is anticipated that the modeled NO_x benefits are conservative. The real-world NO_x benefits of the modeled CTI scenario are potentially greater than estimated with the current USEPA modeling methods.

References

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- 12 "Staff White Paper. California Air Resources Board Staff Current Assessment of the Technical Feasibility of Lower NOx Standards and Associated Test Procedures for 2022 and Subsequent Model Year Medium-Duty and Heavy-Duty Diesel Engines," California Air Resources Board, April 18, 2019.