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FINAL REPORT: CONTROL OF OZONE PRECURSOR EMISSIONS IN THE GREAT LAKES REGION

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LIST OF ABBREVIATIONS

AESS	Auto Engine Start Stop
AIM	Architectural, Industrial, and Maintenance
CARB	California Air Resources Board
CI	Compression-ignition
CMAQ	Congestion Mitigation and Air Quality
CO	Carbon monoxide
CORE	Clean Off Road Equipment Voucher Incentive Project
CTG	control technique guideline
CTI	Cleaner Trucks Initiative
DEF	diesel exhaust fluid
DERA	Diesel Emission Reduction Act
DTF	Diesel Technology Forum
ECA	Emission Control Area
EDF	Environmental Defense Fund
EF	emission factors
EGR	exhaust gas recirculation
EMFAC	EMission FACtors model
EPA	United States Environmental Protection Agency
ERIG	Emissions Reduction Incentive Grants
FAST	Fixing America's Surface Transportation Act
FF	failure frequency
FI	failure increase
g/mile	grams per mile
GVWR	gross vehicle weight rating
HC	hydrocarbons
HDDT	heavy duty diesel truck
HDT	heavy-duty truck
HDV	heavy-duty vehicle
Hp	horsepower
I/M	inspection and maintenance
ICS	Illinois Compiled Statutes
IMO	International Maritime Organization
LADCO	Lake Michigan Air Directors Consortium
LCFS	Low Carbon Fuel Standard
MIL	malfunction indication light
MJO	Multi-Jurisdictional Organization

MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MOVES	MOtor Vehicle Emissions Simulator
MTA	Metropolitan Transit Authority
MY	model year
NAA	nonattainment area
NAAQS	National Ambient Air Quality Standard
NEDC	Northeast Diesel Collaborative
NEI	national emission inventories
NMHC	non-methane hydrocarbon
NOx	nitrogen oxides
OBD	on-board diagnostics
OGV	ocean-going vessels
OTB	on-the-books
OTC	Ozone Transport Commission
OTW	on-the-way
PDTR	Port Drayage Truck Registry
PM	particulate matter
ppb	parts per billion
RBLC	RACT/BACT/LAER Clearinghouse
RIA	regulatory impact analysis
RPD	rate-per-distance
RSD	remote sensing devices
SCC	source category code
SCR	selective catalytic reduction
SI	spark-ignition
SIP	State Implementation Plan
SORE	small off-road engines
TERP	Texas Emissions Reduction Plan
Tg	teragrams
TM&M	tampering, mal-maintenance, and malfunction
TxDOT	Texas Department of Transportation
VCP	volatile chemical products
VMT	vehicle miles traveled
VOC	volatile organic compound

EXECUTIVE SUMMARY

The purpose of this study is to identify and evaluate nitrogen oxides (NOx) and volatile organic compound (VOC) emissions reduction potential for anthropogenic sources in the LADCO region. The goal is to identify strategies for lowering ground-level ozone concentrations in counties that are designated nonattainment for the 2015 ozone National Ambient Air Quality Standard (NAAQS).

The study includes 1) analysis of ozone precursor emission controls for emission sources included in national emission inventories such as the 2016v1 Modeling Platform[1] and 2) analysis of ozone precursor emission inventories and emission controls for emission sources underrepresented in national emission inventories.

Sources Included in National Emission Inventories

Ramboll developed a master list of over 300 candidate control measures applicable to LADCO region point, nonpoint, and mobile emission sources. Control measures on the master list were screened based on potential emission reductions, cost effectiveness and other factors to develop a shortlist of candidate control measures. In collaboration with LADCO and member states, several source categories and control measures with the potential to reduce substantial ozone precursor emissions were further evaluated (see Table ES-1). Point source categories were not considered for further analysis in this study because point source emission control analyses are expected to be performed on an as-needed basis by state/region specific agency staff. Detailed analysis of source categories and control measures "Prioritized for Analysis" may be found in Section 4.0. Source categories and control measures "Prioritized for Analysis in Subsequent Study" are not addressed herein; analysis of these source categories is expected to be the subject of future study.

Table ES-1. Ozone precursor control measures selected for evaluation.

Source Category	Control Measure
Prioritized for Analysis	
Locomotives	Anti-idling
	Engine Rebuilds
	Engine Replacements
Harbor Craft	Engine Repowers
	Engine Replacements
Gasoline Non-road Small Off-road Equipment	Opt-in to California SORE[a] Regulation
Heavy-duty Trucks (HDTs)	Anti-idling
	Anti-tampering for diesel-fueled HDTs
Diesel Non-road	Anti-idling
	Enhanced fleet turnover to Tier 4 engines
	Enhanced electrification
Prioritized for Analysis in Subsequent Study	
Architectural, Industrial, and Maintenance (AIM) Coatings	Opt-into more stringent rules (e.g., California, Ozone Transport Commission (OTC)[b])
	UV/EB-cured coatings

[1] https://www.epa.gov/air-emissions-modeling/2016v1-platform, Accessed online October 2020.

Source Category	Control Measure
Volatile Consumer/Commercial Products	Opt-into more stringent rules (e.g., California, OTC)
Commercial Marine	Vessel speed reductions
	Shoreside power
	Retrofits
	Alternative fuels
Water Heaters	Natural gas heater replacement
	Low NOx water heaters

[a] small off-road engines
[b] Ozone Transport Commission

Table ES-2 shows emission reduction and cost effectiveness for the source categories and control measures evaluated herein. Control measures with the potential to reduce the largest amount of LADCO-wide emissions are 1) Opting-into California's proposed regulation for gasoline small off-road engine equipment, 2) HDT tampering detection and enforcement, and 3) HDT short term idling restrictions. The most cost-effective control measures are estimated to have no net cost per ton of ozone precursor emissions reduced: 1) locomotive idle limiting or shut-off devices and 2) non-road diesel construction and industrial equipment anti-idle rule. Further information on these source categories and control measures, including emission reductions by state and nonattainment area (NAA); a description of each emission source category; and discussion of regulatory history, geographic applicability, seasonal applicability, schedule, implementation feasibility, and public acceptance are provided in Section 4.0.

Table ES-2. LADCO-wide emission reductions and cost effectiveness estimates for evaluated source categories and control measures.

Control Measure	LADCO-wide Emission Reduction (TPY)		Cost Effectiveness ($/ton)	
	NOx	VOC	NOx	VOC
Locomotives				
Rebuilds	433	-	$1,000 - $2,000	-
Replacements	305	-	$10,000 - $20,000	-
Idle limiting or shut-off devices	3,242	-	$0 [a]	-
Harbor Craft				
Rebuilds/Replacements	3,081	-	$500 - $5,000	-
Gasoline Small Off-Road Engine Equipment				
Opt-in to California SORE Proposed Regulation	8,895	54,918	$39,600-62,400	$6,400-10,100
HDTs				
Tampering Detection and Enforcement	19,416	-	$10,360 - $15,700	-
Short-term Idling Restrictions	9,214	1,441	$270	$1,730
Non-Road Diesel Construction and Industrial Equipment				
Fleet Turnover to Tier 4	2,061	-	$19,394	-
Electrification	2,705	-	$45,573	-
Alternative Fuel Engines	648	-	$13,264	-

Control Measure	LADCO-wide Emission Reduction (TPY)		Cost Effectiveness ($/ton)	
	NOx	VOC	NOx	VOC
Anti-idle Rule	1,926	-	$0	-
Emission Specifications in Government Contracts	880	-	$15,141	-

[a] Locomotive-idle-reduction technology has a reported capital cost of $40,000 per device and cost effectiveness of $1,500 to $5,000 per ton of NOx. Capital costs are offset by fuel cost savings up to $20,000 per year.

Sources Underrepresented in National Emission Inventories

Ramboll reviewed national emission inventories (e.g., base and future year emission inventories included in the 2016v1 Modeling Platform) to determine whether there are sources for which emissions may be underrepresented. In consultation with LADCO, we developed a revised LADCO region emission inventory for heavy-duty diesel trucks (HDDT) and volatile chemical products (VCP) source categories. The revised HDDT emission inventory includes additional emissions from tampering and mal-maintenance and vehicle operation at low speeds. The VCP emission inventory was revised based on a recent study which indicates potential undercounting of VCP-related emissions in national emission inventories. We also identified potential emission control options for additional emissions from HDDTs and VCPs. We estimated potential additional emissions in the LADCO region of close to 75,000 tons per year of NOx from HDDTs and over 1.3 million tons of VOC from VCPs in 2026.

Potential control measures to reduce these additional HDDT and VCP emissions are also provided for as follows:

- HDDTs
  - Failure identification and repair
  - Freight route planning
- VCPs
  - Facility-based emission controls
  - Product-based emission controls based on OTC model programs and California regulations

1.0 INTRODUCTION

1.1 Lake Michigan Air Directors Consortium Area

The study was performed by Ramboll under contract to the Lake Michigan Air Directors Consortium (LADCO). LADCO is a Multi-Jurisdictional Organization (MJO) and its area includes the states of Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin.

1.2 Background and Purpose

The United States Environmental Protection Agency (EPA) sets a NAAQS for ozone in order to protect public health and welfare. Under the Clean Air Act, the EPA is required to review the NAAQS periodically. EPA's most recent review of the ozone standard was finalized on October 1, 2015, and on that date the EPA lowered the ozone NAAQS from the 75 parts per billion (ppb) standard set in 2008 to a more stringent value of 70 ppb. In August 2018, EPA established attainment designations for the 2015 NAAQS and included several NAAs in the LADCO region as shown in Figure 1-1.

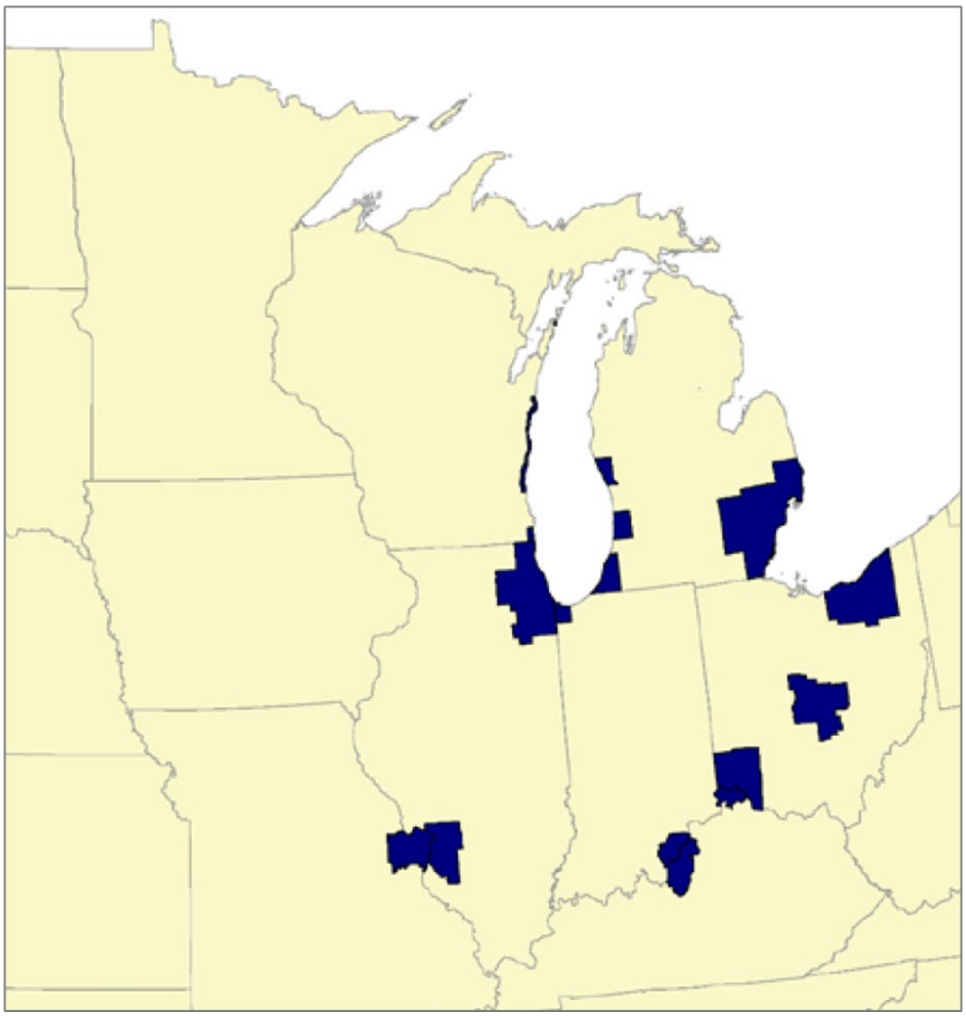

Figure 1-1. Nonattainment Area Designations for the 2015 Ozone Standards in the LADCO region[2].

[2] https://www.epa.gov/sites/production/files/2018-04/documents/placeholder_3.pdf, Accessed online January 2021.

Ozone is not emitted directly, but forms in the atmosphere from emissions of ozone precursors, namely NOx and VOCs. Evaluation of potential emission control strategies for the LADCO region is a critical step toward reducing regionally-formed ozone and also for the development of State Implementation Plans (SIPs).

1.3 Purpose of Report

The purpose of this study is to identify and evaluate NOx and VOC emissions reduction potential for anthropogenic sources in the LADCO region. The goal is to identify strategies for lowering ground-level ozone concentrations in counties that are designated nonattainment for the 2015 ozone NAAQS. This report provides sufficient information to modify emissions inventory input files and for proper documentation of the strategies in any SIP revision.

1.4 Structure of Report

This report includes the sections listed below.

- **Section 1** summarizes background and purpose for this study.
- **Section 2** summarizes existing regulations to control ozone precursor emissions in the LADCO region.
- **Section 3** describes the screening analysis which was performed to determine which emission control measures and source categories to evaluate in detail.
- **Section 4** presents detailed analyses of control measures for specific source categories and control measures identified during the screening analysis.
- **Section 5** presents potential updates to the LADCO region HDDT and VCP source categories emission inventories and identifies potential emission control options for these categories.

2.0 EXISTING REGULATIONS

In order to develop the LADCO ozone precursor emissions control strategies analysis, potential emission reductions must be informed by an understanding of on-the-books (OTB) and on-the-way (OTW) regulations. Ultimately, new emissions control strategies must be based on emissions and/or activity reductions beyond the requirements that exist under current or emerging federal, state, and/or local regulations.

Ramboll compiled, and LADCO member states reviewed and commented on, local and state regulations applicable to anthropogenic sources responsible for the majority of NOx and VOC emissions in the LADCO region (table included as Appendix A)[3]. State/local regulations which incorporated Federal regulations by reference, and that do not require emissions control beyond Federal requirements are not included in this chapter (e.g. Minnesota Rules Chapter 7011.0830 incorporates 40 CFR Subpart F: New Source Performance Standards for Portland Cement Plants). The regulation list is comprehensive for a majority of anthropogenic source category NOx and VOC emissions in the LADCO region. Ramboll engaged with states to ensure applicable regulations were included for all LADCO states.

State regulations listed in Appendix A are indicative of control requirements that are more stringent than Federal requirements. However, in many cases, it may be feasible to increase control stringency further. During control option screening, the presence of an existing state regulation did not preclude selection of a control option for more detailed analysis if additional control would result in substantial emission reductions. For example, Ohio adopted the 2006 OTC model rule for Consumer Products, but there are several more recent OTC model rules for Consumer Products that could result in greater emission reductions.

Control measures listed in resources such as EPA’s Menu of Control Measures and other state implementation planning references are based on existing Federal regulations. In addition, potential measures compiled for the screening analysis are based on more stringent regulatory and/or voluntary programs proposed by EPA or in other non-LADCO regions which go beyond established Federal regulations. Therefore, to perform a screening analysis of potential control measures, a listing of Federal regulations is not required.

[3] Emission category groupings that represent >0.5% of total NOx+VOC inventory are included in the state regulations compilation.

3.0 CONTROL MEASURE SCREENING

As part of the control measure screening we:

- Compiled and reviewed ozone precursor emissions contributions in the LADCO region;
- Identified a master list and screened potential candidate control measures;
- Developed a control measure short-list; and
- In collaboration with LADCO, selected source categories and control measures for further, detailed analysis.

3.1 Emission Inventory

Emissions inventories are used to assess which types of emissions sources are good candidates for emissions controls that would reduce the area's ozone levels. Ramboll used the 2016v1 Modeling Platform[4] 2028 future year emission inventory to develop screening level emission inventory reductions estimates for control measures by state and NAA.

Table 3-1 and Table 3-2 summarize NOx and VOC emissions, respectively by emission source. In the LADCO region, substantial NOx emissions contributions are made by several point sources (e.g., Power Plants and Industrial Processes), nonpoint fuel combustion, and several mobiles sources (e.g., non-road equipment, light and heavy-duty vehicles (HDVs), and rail). In the LADCO region, the largest VOC emission source (35%) is solvent utilization. Solvent utilization is comprised of emissions from several categories such as surface coating, decreasing, personal care products, household products, adhesives and sealants, pesticides, and asphalt. Smaller, but substantial VOC emissions contributions are also made by non-road equipment, light-duty vehicles, fires, residential wood combustion and oil and gas sources. Both NOx and VOC emission contributions vary by state (shown) and by county (not shown) depending on demographic, industrial, and other factors.

[4] https://www.epa.gov/air-emissions-modeling/2016v1-platform, Accessed online October 2020.

Table 3-1. 2028 NOx emission summary by LADCO state.

NOx Emission Source	NOx Emissions (tons per year)						
	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin	LADCO-wide
Power Plants	32,546	45,524	32,138	15,375	38,655	10,066	**174,303**
Fuel Combustion (Nonpt)	42,758	11,091	34,221	20,829	30,669	17,896	**157,463**
Non-road Equipment	25,563	18,381	16,667	23,854	22,417	13,902	**120,784**
Industrial Processes (Pt Src)	15,115	23,375	29,805	13,714	21,583	7,536	**111,128**
Light-Duty Vehicles	19,028	17,337	22,406	14,608	25,488	11,772	**110,640**
Heavy-Duty Vehicles	22,388	18,697	9,517	7,416	14,527	13,499	**86,046**
Rail (Locomotive)	25,443	12,047	3,905	10,493	18,008	7,731	**77,628**
Oil and Gas	22,525	10,524	20,268	2,685	15,488	617	**72,108**
External Combustion (Pt Src)	7,945	13,569	7,000	9,213	8,896	12,013	**58,637**
Airports	14,195	2,252	4,976	4,314	2,696	1,470	**29,903**
Internal Combustion Engines (Pt Src)	7,349	2,974	3,708	3,949	4,963	2,430	**25,373**
Miscellaneous Nonpoint Sources	3,649	2,436	4,334	4,209	4,234	2,638	**21,500**
Category 3 Commercial Marine	166	275	6,299	664	724	856	**8,985**
Category 1&2 Commercial Marine (Harbor Craft)	3,021	838	2,244	405	1,231	821	**8,560**
Fires	1,397	700	440	2,666	461	714	**6,378**
Miscellaneous Point Sources	1,174	347	658	488	835	646	**4,148**
Totals	**244,263**	**180,367**	**198,588**	**134,880**	**210,876**	**104,608**	**1,073,582**

Table 3-2. 2028 VOC emission summary by LADCO state.

VOC Emission Source	VOC Emissions (tons per year)						
	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin	LADCO-wide
Solvent Utilization (Nonpt)	114,317	82,912	105,670	54,451	137,352	52,476	**547,178**
Non-road Equipment	28,451	15,974	33,843	33,205	27,287	24,730	**163,490**
Light-Duty Vehicles	26,680	21,061	26,998	18,078	32,453	14,873	**140,144**
Fires	20,622	10,361	8,711	71,034	6,693	11,416	**128,836**
Residential Wood Combustion	10,543	12,990	18,827	48,654	16,876	11,651	**119,541**
Oil and gas (Pt+Nonpt)	58,316	13,968	22,964	182	20,662	325	**116,417**
Industrial Processes (Pt Src)	22,419	15,472	7,720	7,052	15,482	8,562	**76,707**
Miscellaneous Nonpoint Sources	14,614	10,365	10,813	15,883	15,011	8,903	**75,589**
Chemical Evaporation (Pt Src)	12,609	14,547	12,824	10,311	11,332	10,991	**72,614**
Petroleum Storage and Transport (Nonpt)	14,381	9,596	13,834	9,694	8,723	8,345	**64,572**
Miscellaneous Point Sources	3,388	2,602	3,289	1,719	2,801	2,648	**16,447**
Other Mobile Sources	5,230	1,469	2,124	1,861	1,959	1,063	**13,705**
Heavy-Duty Vehicles	2,591	2,745	1,270	1,013	1,645	1,665	**10,928**
Totals	**334,159**	**214,061**	**268,887**	**273,137**	**298,275**	**157,649**	**1,546,169**

3.2 Master List of Control Measures

Ramboll drew upon a wide range of references to identify potential control options for mobile, point and nonpoint (area) sources. EPA's Menu of Control Measures[5] was used as a starting point to identify a broad list of control options potentially applicable to the LADCO region. We complemented the list with additional control options identified from resources summarized in Table 3-3 below. Over 300 control measures were included on the master list of control measures.

Table 3-3. Sample supplemental control measure master list data sources.

Reference Source	Type	Sectors Affected			
		On-road	Non-road	Stationary/ Point	Area/ Nonpoint
EPA's Clean Air Technology Center[6]	Repository of control technologies			✓	
EPA's Transportation Initiatives Documents[7]	Collection of transportation related programs	✓	✓		
EPA's P2 source reduction program (waste management)[8]	Tools and resources for businesses				✓
EPA's Diesel Emissions from Construction and Agriculture Reduction Policy[9]	Federal guidelines and incentives	✓	✓		✓
EPA's Diesel Emissions from School Buses program[10]	Rebate program	✓			
RACT/BACT/LAER Clearinghouse (RBLC)[11]	Repository of control technologies for stationary sources			✓	
EPA's Smart Way Retrofit Technologies[12]	Repository for verified retrofit technologies	✓	✓		
South Coast AQMD 2016 air quality management plan[13] and South Coast AQMD rules[14]	Regional plan and Local Rules	✓	✓	✓	✓
California heavy-duty low-NOx standards[15]	Proposed state rule	✓			
California Truck and Bus Rule[16]	OTB state rule	✓			
California Harbor Craft Rule[17]	OTB state rule		✓		

[5] Menu of Control Measures for NAAQS Implementation. Accessed online in April 2020 at https://www.epa.gov/air-quality-implementation-plans/menu-control-measures-naaqs-implementation, Accessed October 2020.
[6] https://www.epa.gov/catc/about-clean-air-technology-center, Accessed October 2020.
[7] https://www.epa.gov/state-and-local-transportation/transportation-related-documents-state-and-local-transportation, Accessed October 2020.
[8] https://www.epa.gov/p2/learn-about-pollution-prevention#p2, Accessed October 2020.
[9] https://www.epa.gov/dera/reducing-diesel-emissions-construction-and-agriculture, Accessed October 2020.
[10] https://www.epa.gov/dera/reducing-diesel-emissions-school-buses, Accessed October 2020.
[11] https://cfpub.epa.gov/RBLC/index.cfm?action=Home.Home&lang=en, Accessed online October 2020.
[12] https://www.epa.gov/verified-diesel-tech, Accessed October 2020.
[13] http://www.aqmd.gov/home/air-quality/clean-air-plans/air-quality-mgt-plan/final-2016-aqmp, Accessed October 2020.
[14] https://www.aqmd.gov/home/rules-compliance/rules, Accessed October 2020.
[15] https://ww2.arb.ca.gov/our-work/programs/heavy-duty-low-nox, Accessed October 2020.
[16] https://ww2.arb.ca.gov/our-work/programs/truck-and-bus-regulation, Accessed October 2020.
[17] https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft/chc-regulatory-documents, Accessed October 2020.

Reference Source	Type	Sectors Affected			
		On-road	Non-road	Stationary/ Point	Area/ Nonpoint
In-Use Off-Road Diesel-Fueled Fleets Regulation	OTB state rule		✓		
Alternative fuel initiatives, such as Texas TxLED diesel program[18]	OTB state rule	✓	✓		
Plans to reduce freight industry related emissions, e.g. San Pedro Ports Climate Action Plan[19] and other Ports Initiatives[20]	Local industry initiative	✓	✓		
Enhanced locomotive emission standards[21]	Petition to EPA		✓		
Texas Emissions Reduction Plan (TERP)[22]	State financial incentives	✓	✓		
CARB[a] Carl Moyer Program	State financial incentives	✓	✓		
OTC VOC Controls	Regional plan and Local Rules				✓

[a] California Air Resources Board

The complete master list and associated reference(s) for each measure may be found in the companion screening analysis deliverables spreadsheet.

3.3 Qualitative Screening Analysis

For the screening analysis Ramboll compiled the control measure specific information listed below.

- Major emissions process or classification (i.e., affected source classification codes)
- Emissions benefit (for each state and for each NAA)
- Cost effectiveness
- Permanent, Quantifiable, Surplus, and Enforceable (Yes or No)
- Technical or implementation feasibility
- Likely public acceptance

Two shortlists were compiled based on 1) the control measures estimated to achieve the greatest emission reductions and 2) the most cost-effective control measures.

For the control measures on the shortlists, Ramboll determined whether the control methods meet the permanent (real), quantifiable, surplus, and enforceable criteria required for control measures to be credible and creditable in the SIP and estimated technical or implementation feasibility and likely public acceptance.

[18] https://www.tceq.texas.gov/airquality/mobilesource/txled/cleandiesel.html, Accessed October 2020.
[19] https://cleanairactionplan.org/, Accessed October 2020.
[20] https://www.epa.gov/ports-initiative, Accessed October 2020.
[21] https://ww2.arb.ca.gov/resources/documents/carb-petitions-us-epa-strengthen-locomotive-emission-standards, Accessed October 2020.
[22] https://www.tceq.texas.gov/airquality/terp, Accessed October 2020.

Detailed information compiled during the screening analysis may be found in the companion screening analysis deliverables spreadsheet.

3.4 Screening Results

In collaboration with LADCO and member states, source categories and control measures were selected for detailed analysis. Point source categories were not considered for further analysis as part of this study because these analyses will be performed as needed by state/region specific agency staff on an as needed basis. Several mobile and nonpoint source categories with substantial NOx and/or VOC emissions were selected for further evaluation in this study based on screening analysis results which showed substantial potential NOx reductions and potential cost-effective control measures. Table 3-4 shows source categories and control measures selected for further analysis. Detailed analysis of source categories and control measures "Prioritized for Analysis" may be found in Section 4.0. Source categories and control measures "Prioritized for Analysis in Subsequent Study" are not addressed herein; analysis of these source categories and control measures may be developed in the future.

Table 3-4. Measures selected by LADCO for evaluation.

Source Category	Control Measure
Prioritized for Analysis	
Locomotives	Anti-idling
	Engine Rebuilds
	Engine Replacements
Harbor Craft	Engine Repowers
	Engine Replacements
Gasoline Non-road Small Off-road Equipment	Opt-in to California SORE Regulation
HDTs	Anti-idling
	Anti-tampering for diesel-fueled HDTs
Diesel Non-road	Anti-idling
	Enhanced fleet turnover to Tier 4 engines
	Enhanced electrification
Prioritized for Analysis in Subsequent Study	
AIM Coatings	Opt-into more stringent rules (e.g., California, OTC)
	UV/EB-cured coatings
VCP	Opt-into more stringent rules (e.g., California, OTC)
Commercial Marine	Vessel speed reductions
	Shoreside power
	Retrofits
	Alternative fuels
Water Heaters	Natural gas heater replacement
	Low NOx water heaters

4.0 CONTROL MEASURES

In this section, we document the analysis of candidate control measures that may be considered by state and local agencies in the LADCO to reduce emission from ozone precursors. Emission reductions in addition to those resulting from on-the-books OTB regulations may be necessary to meet SIP requirements and to demonstrate attainment of ozone standards.

The candidate control measures identified in this section are for evaluation purposes only. The LADCO member states have not yet determined which control measures will be adopted. Therefore, inclusion of a candidate control measure herein does not represent a commitment or decision by any agency to adopt that measure.

Each source category analysis includes the following information: summary table, source category description, regulatory history summary, candidate control measure(s) description, estimated emission reductions, estimated cost effectiveness, geographic and seasonal applicability discussion, implementation timing and feasibility discussion, and public acceptance discussion.

4.1 Locomotives

This section focuses on emissions reductions for locomotives. Locomotives are defined as either 'line-haul' or 'switcher'. Line-haul locomotives are used to pull freight and passenger trains and 'switcher' locomotives are used to shunt rail cars to build or break up trains or pull smaller short-haul trains. For emission inventory development, the rail sector is classified as follows:

- **Class I Freight**: Rail operated by major railroad companies (BNSF, Canadian National, Canadian Pacific, CSX, Kansas City Southern, Norfolk Southern, Union Pacific railroads, and their subsidiaries)[23]
- **Class II and III Freight**: Rail operated by relatively smaller railroad companies which have limited geographic scope
- **Passenger** (AMTRAK and commuter) railroads
- Switching support[24]

Locomotives most often have diesel engines that power electric motors that power their wheels. Table 4-1 summarizes key information for the control measures presented in this section. Applicable emissions and emission reductions are presented in Table 4-1 on a LADCO region-wide basis; state- and NAA-level emissions and emission reductions are presented in Section 4.1.3.

[23] https://railroads.dot.gov/rail-network-development/freight-rail-overview, Accessed online October 2020.
[24] https://www.aslrra.org/web/About/Short_Line_Definitions.aspx, Accessed online October 2020.

Table 4-1. Control measure summary for locomotives.[25]

Current Regulations and 2026 Emissions Estimates		
OTB regulations:	EPA Tier 0, 1, 2, 3, and 4 emission standards	
2026 Emissions [a]	Total NOx:	111,864 TPY
2026 reductions from OTB regulations and/or measures not accounted for in 2026 emission inventory	NOx Reduction:	0 TPY
	Remaining NOx:	111,864 TPY
Control Measure Summary, Including 2026 Emission Reduction Estimates		
Rebuild existing older engines to more stringent Tier 2 or 3 emission levels	NOx Reduction:	433 TPY
	Cost Effectiveness:	*$1,000/ton - $2,000/ton*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs except Door Wisconsin and Berrien, Michigan*
Replace engines on locomotives with the most stringent Tier 4 emission level	NOx Reduction:	305 TPY
	Cost Effectiveness:	*$10,000/ton - $20,000/ton*
	Applicable States:	*all LADCO states*
	Applicable NAAs [c]:	*all NAAs except Door Wisconsin and Berrien, Michigan*
Idle limiting or shut-off devices	NOx Reduction:	3,242 TPY
	Cost Effectiveness:	*$0/ton [b]*
	Applicable States:	*all LADCO states*
	Applicable NAAs [c]:	*all NAAs except Door Wisconsin and Berrien, Michigan*

[a] interpolated from 2016v1 modeling platform 2023 and 2028

[b] Locomotive-idle-reduction technology has a reported capital cost of $40,000 per device and cost effectiveness of $1,500 to $5,000 per ton of NOx. Capital costs are offset by fuel cost savings up to $20,000 per year.

4.1.1 Source Category Description

Locomotives are used for long and short-haul freight movements, local or in rail yard shunting, and cross country and commuter passenger rail. Railroads are separated into Class I freight, Class II/III freight, and passenger rail. Class I rail operates across many states. There are many Class I and II/III railyards in the LADCO states. Smaller Class II/III railroads operate on rail networks that are limited, geographically. Passenger rail includes interstate AMTRAK and local commuter rail (e.g., Metra in Chicagoland and Northstar in Minnesota). A summary of rail emission source categories is listed below:

- Line-haul Class I railroads (interstate),
- Line-haul or switching Class II/III railroads,
- Commuter passenger railroads (Metra and Northstar),
- National passenger railroad (AMTRAK), and
- Railyard switching locomotive operations, primarily Class I.

In the LADCO area, all Class I freight railroads are active, including BNSF, Canadian National, Canadian Pacific, CSX, Kansas City Southern, Norfolk Southern, and Union Pacific. The primary activity of Class I railroads is interstate freight using high-powered locomotives, but they also operate line-

[25] The effect on VOC emissions resulting from this strategy is expected to be negligible.

haul and switching locomotives in many railyards within the state assembling and breaking up trains and performing maintenance and other support functions. Line-haul locomotives typically have engines that are 4,000 – 4,400 horsepower (hp). Switching engines typically have less power, as low as 1,500 hp, though some older line-haul engines are employed in switch duty near the end of their useful life.

Class II/III railroads are smaller railroads with geographically limited rail networks supporting individual customers, Class I railroads, and other activities. Some of the Class II/III railroads are mostly dedicated to switching functions for local customers, while other Class II/III railroads operate line-haul trains on short routes.

Passenger locomotives usually use locomotives of about 3,000 hp, but also have significant auxiliary engines to provide climate control and meet other power requirements. EPA (1998) estimated as much as 1070 hp. Both commuter (Chicago and Minneapolis regional) and AMTRAK fall into the "passenger" locomotive category.

NOx emissions from locomotives are a significant source of statewide emissions and can be significant on a regional basis near large railroad hubs. These large diesel engines may also emit substantial particulate matter (PM), depending on engine Tier-level.

EPA (1998; 2008) estimates line-haul and switching locomotives service life of 40 and 70 years, respectively. This means that, assuming natural fleet turnover, the lowest emissions Tier 4 engines (introduced into the fleet beginning in 2015) will make up only a small portion of the fleet by 2026.

4.1.1 Regulatory History

EPA[26] regulated locomotives in two rulemakings, a 1998 regulation that set emission standards for Tier 0, 1, and 2 locomotives, and a 2008 regulation that combined new engine standards for Tier 3 and 4 and rebuild requirements for Tiers 0, 1, and 2 engines. Both regulations have elements that describe reduced maximum emission levels when rebuilding existing engines that were built prior to the date of the regulation. In order to determine the potential emission reduction from a locomotive rebuild or replacement project, the Tier level to which the existing engine is certified needs to be determined based on both engine model year and the year of the most recent rebuild.

The emissions standards for locomotives shown in Table 4-2 include new engine and rebuilt engine standards. Rebuild requirements apply based on the year of rebuild.

[26] https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-emissions-locomotives, Accessed online October 2020.

Table 4-2. Locomotive final exhaust emission standards (g/bhp-hr).[27]

Duty Cycle	Tier	Rebuilt Engines Model Year	HC	NOx	PM	CO
Line-Haul	**Tier 0**	1973 – 1992[a]	1.00	9.5	0.22	5.0
	Tier 1	1993 – 2004[b]	0.55	7.4	0.22	2.2
	Tier 2	2005 – 2011[c]	0.30	5.5	0.10	1.5
	Tier 3	2012 – 2014	0.30	5.5	0.10	1.5
	Tier 4	2015+	0.14	1.3	0.03	1.5
Switch[d]	**Tier 0**	1973 – 2001	2.10	11.8	0.26	8.0
	Tier 1	2002 – 2004	1.20	11.0	0.26	2.5
	Tier 2	2005 – 2010	0.60	8.1	0.13	2.4
	Tier 3	2011 – 2014	0.60	5.0	0.10	2.4
	Tier 4	2015+	0.14	1.3	0.03	2.4

[a] Original 1998 Tier 0 standards applied to new 2001 locomotives with rebuild requirements for all 1994 – 2001 and, depending on engine configuration, back to 1973. Exemptions from this standard exist for some models.
[b] Original 1998 Tier 1 standards applied to new 2002 – 2004 locomotives and updated emissions levels when rebuilding earlier models.
[c] Original 1998 Tier 2 standards for PM were higher than Tier 3, so these emission levels reflect the rebuild requirements of 2008 regulations.
[d] It is more difficult to meet the same numerical emission level on the switcher duty cycle as on the line-haul cycle, so the emission factor is numerically larger.

Table 4-3 shows EPA (2009) emissions factor estimates by Tier level. Engines that have not yet been rebuilt (engine rebuilds are indicated by a +) will have the emissions level applicable at the time of the original manufacture. Rebuilds are expected to occur every seven to ten years of operations.[28]

Table 4-3. Locomotive exhaust emission factors[29] (rebuild emissions levels denoted by +).

Duty Cycle	Tier	Model Years	Emission Factors (g/bhp-hr)			
			HC[b]	CO[c]	NOx	PM
Line-haul	**Uncontrolled**	<1973 & Special designs up to 1992	0.48	1.28	13.00	0.32
	Tier 0	2001 and 1994 - 2000 and some models back to 1973 when rebuilt through CY2010	0.48	1.28	8.60	0.32
	Tier 0+	Tier 0 rebuilt after CY2010	0.30	1.28	7.20	0.20
	Tier 1	2002 – 2004	0.47	1.28	6.70	0.32
	Tier 1+	When Rebuilt after CY2010	0.29	1.28	6.70	0.20
	Tier 2	2005 – 2010	0.26	1.28	4.95	0.18
	Tier 2+	When rebuilt after CY2013	0.13	1.28	4.95	0.08
	Tier 3	2011 – 2014	0.13	1.28	4.95	0.08
	Tier 4	2015+	0.04	1.28	1.00	0.015
Switch[a]	**Uncontrolled**	<1973 & Special designs up to 1992	1.01	1.83	17.40	0.44

[27] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA09.pdf, Accessed online October 2020.
[28] https://ww2.arb.ca.gov/sites/default/files/classic//msprog/tech/techreport/final_rail_tech_assessment_11282016.pdf, Accessed online October 2020.
[29] EPA 2009. "Emission Factors for Locomotives," EPA-420-F-09-025, April 2009.

Duty Cycle	Tier	Model Years	Emission Factors (g/bhp-hr)			
			HC[b]	CO[c]	NOx	PM
Switch[a]	**Tier 0**	2001 and 1994 - 2000 and some models back to 1973 when rebuilt through CY2010	1.01	1.83	12.60	0.44
	Tier 0+	Tier 0 rebuilt after CY2010	0.57	1.83	10.60	0.23
	Tier 1	2002 – 2004	1.01	1.83	9.90	0.43
	Tier 1+	When Rebuilt after CY2010	0.57	1.83	9.90	0.23
	Tier 2	2005 – 2010	0.51	1.83	7.30	0.19
	Tier 2+	When rebuilt after CY2013	0.26	1.83	7.30	0.11
	Tier 3	2011 – 2014	0.26	1.83	4.50	0.08
	Tier 4	2015+	0.08	1.83	1.00	0.015

[a] Emission levels on the switcher duty cycle are higher than on the line-haul cycle.

[b] hydrocarbons

[c] carbon monoxide

California[30] has signed enforceable agreements with the two major railroads (Union Pacific and BNSF) that operate in the state to eliminate excessive locomotive idling and reduce fleet-average emissions levels among other testing and evaluation initiatives. In the 1998 agreement (Memorandum of Understanding, MOU), "*UP and BNSF agreed to operate locomotive fleets that "on average" meet a Tier 2 NOx emission standard, or 5.5 g/bhp-hr by 2010 (and through 2030).*" EPA (2009) forecasted that the national average Class I operations will have met the California MOU goal by 2020 or earlier. The 2005 Memorandum of Agreement (MOA) included provisions for technology development, railyard evaluations, and anti-idling requirements.

Many states have participated in voluntary programs to replace and rebuild locomotive engines using a variety of funding sources. For example, the Texas Emissions Reduction Plan (TERP) funding has been used to introduce clean and advanced (generator set) locomotive models.

4.1.2 Candidate Control Measures

Measures for reducing emissions include rebuilding or replacing engines, selective use of advanced technologies including alternative fuels (CNG/LNG) or hybrid designs, and application of idle limiting devices. Emission reductions could be obtained through voluntary grants to install and use technologies, or enforceable agreements between states and railroads. To date, no state has implemented regulations governing railroad operations.

4.1.2.1 Engine Rebuild or Replacement

The most straightforward approach to reducing locomotive emissions is to rebuild or replace older engines with engines meeting more stringent emission standards. Major locomotive manufacturers, Progress Rail (a Caterpillar Company [formerly EMD])[31] and Wabtec (formerly GE)[32], 1) provide services and parts to upgrade older engines to meet more stringent emission standard Tier levels and 2) sell new locomotive engines meeting emission standards applicable to new engines.

[30] https://ww2.arb.ca.gov/resources/documents/rail-emission-reduction-agreements, Accessed online October 2020.

[31] https://www.progressrail.com/en/rollingstock/locomotives.html ; https://www.cat.com/en_US/articles/customer-stories/marine/retrofit-kits.html, Accessed online October 2020.

[32] https://www.wabtec.com/business-units/motivepower/products ; https://www.assemblymag.com/articles/94429-ge-stays-on-track-by-rebuilding-locomotives, Accessed online October 2020.

Several locomotive projects to reduce locomotive engine emissions to Tier 4[33] or Tier 3 are in-progress (e.g., Chicago area Metra[34] commuter rail fleet).

4.1.2.2 Advanced Technology and Alternative Fuels

Hybrid technology uses batteries (or other energy storage) combined with an engine to recover braking energy, allow the engine to operate more efficiently, and provide power that can exceed the rated power of the engine(s) for short durations. Hybrid technology has been used in some types of locomotive operations (switching and passenger) and is in-development for line-haul. The use of a hybrid powertrain typically requires redesign of the locomotive; therefore, the latest Tier 4 engines are typically used. Wabtec (formerly GE Locomotives)[35] produces hybrid demonstration models which have substantially lower emissions than even diesel Tier 4 engines. The use of battery power in place of diesel engine power for a portion of the work reduces fuel consumption and emissions. Hybrid models typically include a lower power engine (675 hp with some short duration electric power boost when more power is required) and are reported to cost $233 million for 25 locomotives (or $9.32 million per locomotive compared with an estimated cost of $2.6 million for a new Tier 4 engine [see Table 1-8]). The hybrid models, while more costly that diesel-fueled models, allow locomotives to operate on battery power alone in confined spaces such as subways and other zones.

Natural gas engines may also be used in place of diesel engines in most types of locomotive operations. The fuel price advantage, in addition to lower emissions for natural gas-fueled locomotives, is creating interest in developing demonstration models[36] that can run on natural gas. Natural gas demonstration models generate NOx emissions at 0.04 g/bhp-hr, well below the Tier 4 1.3 g/bhp-hr NOx standard (see Table 4-2) and EPA estimated emission factor of 1.0 g/bhp-hr NOx (see Table 4-3). The use of natural gas engines has been demonstrated in the LADCO area through a Regional Transportation Authority study (LTK, 2019) that used dual-fuel CNG locomotives to reduce NOx by 55% when CNG replaced 50% of the energy of a diesel-only engine producing 6.8 g/bhp-hr NOx (likely originally a Tier 1 locomotive) on Metra commuter duty. The 2019 Regional Transportation Authority study documented a demonstration project; natural-gas fueled commercial models are not currently available. Cost estimates from LTK (2019) are therefore uncertain and possibly biased high because it was a demonstration project. Much of the higher capital cost for natural gas engines can be repaid in lower fuel costs, but new fueling infrastructure may also be needed which would increase capital costs.

Catenary or third-rail electric rail uses overhead wires or a third rail to transmit electricity to power locomotives. Catenary rail is not widely used in the US for locomotives operating on freight rail lines but is used on some commuter rail lines. Compatibility issues for catenary technology applied to freight cars, especially catenary height issues with limited space for bridges and overpasses of all sorts, have limited electric power application in line-haul operations.

Battery-powered electric locomotives could also become available if development projects[37] can lead to commercially available models. At this time, battery powered locomotives are not yet ready for implementation and may have operational limitations.

[33] https://www.railwayage.com/mechanical/locomotives/up-taps-progress-rail-for-switcher-repowers/, Accessed online October 2020.

[34] https://metrarail.com/about-metra/newsroom/metra-board-approves-locomotive-purchase, Accessed online October 2020.

[35] https://www.railwayage.com/passenger/mta-orders-25-hybrid-locomotives-from-wabtec-for-233mm/, Accessed online October 2020.

[36] https://highways.today/2020/07/23/optifuel-natural-gas-locomotive/, Accessed online October 2020.

[37] https://www.post-gazette.com/business/powersource/2020/08/09/Making-the-pitch-for-battery-powered-trains-Wabtec-prepares-for-a-major-demonstration/stories/202008090039, Accessed online October 2020.

4.1.2.3 Idle Reduction

Locomotive operation includes idle mode operation in which engines are not required to generate propulsion power. Unless an anti-idling program and/or technology is in place, a diesel locomotive engine will emit pollutants under low-load conditions during idle-mode operation. A simple solution is to have operators turn-off, rather than idle locomotives and/or use idle time limit devices. Idle time limit devices are either 1) purchased and installed on older locomotives or 2) factory-installed on newer models. Locomotives are designed and used without anti-freeze coolant. During cold temperatures, engines must not be turned-off or engine heaters must be used. Above freezing temperatures, there is little reason for excessive idling. Many if not all newer locomotives had Auto Engine Start Stop (AESS) installed (GE-manufactured locomotives began installing AESS in 2001[38]) as required by EPA (2008, § 1033.115 (g) "*All new locomotives must be equipped with automatic engine stop/start*"), and this technology (ZTR SmartStart[39] and AESS) can be retrofitted[40] onto older engines. Locomotives with ZTR SmartStart and AESS technology shut engines down when the locomotive is stopped and engine oil and coolant temperatures conditions are met. Kim HOTSTART[41] provides block heaters along with engine-off devices that allow the engine to be shutoff even under cold weather conditions.

4.1.3 Emissions Reductions

Emissions by LADCO states are presented in Table 4-4 by railroad type in accordance with source category codes (SCCs) available in the 2016v1 modeling platform. Nationally, Class I NOx emission consisted of 92% from line-haul and 8% from switcher locomotive in 2016. LADCO-region switcher operations are estimated to be responsible for a larger percentage of Class I NOx emissions (14%). Line-haul locomotive fleet turnover to newer, lower emitting locomotives is expected to result in a 23% reduction in NOx emissions from 2016 to 2026 despite forecasted activity growth. Class II/III emissions are estimated to increase as emission reductions from fleet turnover are not enough to offset increases in emissions resulting from activity growth. Some of the Class II/III railroads operate entirely as switching support and others also conduct line-haul duty. Commuter passenger lines consist of Metra in the Chicagoland region and the Northstar line in and around Minneapolis. The in-state Class I switching, Class II/III, and passenger emissions comprise about 24% of 2026 locomotive NOx emissions. Table 4-5 summarizes the emissions by category and NAA and by state in Table 4-4 using the selected projects outlined in the cost effectiveness Section 4.1.4 and summarized in Table 4-8.

[38] https://www.businesswire.com/news/home/20030421005337/en/GE-Transportation-Systems-Launches-New-Fuel-Saving-Technology-for-Locomotives-Auto-Engine-Start-Stop-System-for-Non-GE-Locomotives-Saves-Fuel-Lowers-Emissions-Noise, Accessed online October 2020.

[39] https://www.ztr.com/product-service/smartstart-iie, Accessed online October 2020.

[40] https://www.ztr.com/case-study/smartstart-aess-saving-money-cutting-emissions, Accessed online October 2020.

[41] ftp://ftp.ci.missoula.mt.us/DEV%20ftp%20files/Transportation/Clean%20Diesel/Appendix/C_Appendix_Hotstart_Letter.pdf, Accessed online October 2020.

Table 4-4. NOx Emissions from locomotives for 2026 by state and 2016 totals.

State	2026 NOx Emissions (TPY)							Engine Rebuild NOx Emission Reduction (TPY)	Engine Replacement NOx Emission Reduction (TPY)	Idle NOx Emission Reduction Maximum (TPY)
	Class I	Class II/III	Comm-uter	AMTRAK	Rail-yards	All	Local [b]			
2026										
IL	20,059	1,474	3,581	1,372	4,316	**30,803**	**9,371**	**185**	**130**	**1,177**
IN	10,802	1,453	0	267	1,253	**13,775**	**2,706**	**53**	**38**	**438**
MI	2,204	1,475	0	314	546	**4,539**	**2,021**	**40**	**28**	**162**
MN	9,882	726	79	241	1,492	**12,420**	**2,297**	**45**	**32**	**442**
OH	16,836	1,690	0	227	2,381	**21,134**	**4,071**	**80**	**57**	**732**
WI	7,290	570	52	145	862	**8,918**	**1,484**	**29**	**21**	**50**
LADCO-wide	67,073	7,389	3,712	2,565	10,850	**91,589**	**21,951**	**433**	**305**	**3,242**
2016										
LADCO-wide	86,666	7,103	4,713	2,311	11,072	**111,864**	**22,888**	**---**	**---**	**---**

[a] Nationally about 8.4% of the Class I NOx emissions were from yard switching in 2016. [42]

[b] Local is defined as the sum of Class I Rail Yard, Class II/III and Commuter

Table 4-5. Locomotive exhaust emissions 2026 by nonattainment area.

Nonattainment Area Name	2026 NOx Emissions (TPY)							Engine Rebuild NOx Emission Reduction (TPY)	Engine Replacement NOx Emission Reduction (TPY)	Idle NOx Emission Reduction Maximum (TPY)
	Class I	Class II/III	AMTRAK	Comm-uter	Rail-yards	All	Local [a]			
Allegan	20	19	16	0	0	**55**	**19**	**0.4**	**0.3**	**1**
Berrien	47	0	48	0	0	**95**	**0**	**0**	**0**	**2**
Chicago	5,591	654	469	3,360	2,492	**12,566**	**6,506**	**128.3**	**90.4**	**575**
Cincinnati	872	123	27	0	296	**1,319**	**419**	**8.3**	**5.8**	**65**
Cleveland	2,899	199	78	0	274	**3,450**	**473**	**9.3**	**6.6**	**105**
Columbus	813	106	0	0	179	**1,097**	**284**	**5.6**	**3.9**	**45**
Detroit	774	331	68	0	405	**1,578**	**737**	**14.5**	**10.2**	**84**
Door	0	0	0	0	0	**0**	**0**	**0**	**0**	**0**
Louisville	42	43	0	0	0	**85**	**43**	**0.8**	**0.6**	**2**
Manitowoc County	2	1	0	0	0	**3**	**1**	**0**	**0**	**0**
Muskegon	0	28	0	0	0	**28**	**28**	**0.6**	**0.4**	**1**
Northern Milwaukee/ Ozaukee	167	32	14	0	99	**312**	**131**	**2.6**	**1.8**	**19**
Sheboygan	5	17	0	0	13	**35**	**30**	**0.6**	**0.4**	**2**
St. Louis	510	46	49	0	598	**1,203**	**644**	**12.7**	**8.9**	**102**

[a] Local is the defined as the sum of Class I Rail Yard, Class II/III and Commuter

[42] Mark Janssen and Matthew Harrell 2020. "National Rail Emissions Inventory Training," EPA/LADCO Training, May 7, 2020. Slide 15.

EPA (2008) estimated the service life of line-haul locomotives to be 40 years; after the first 8 years, annual activity was estimated to gradually decline to less than half the new engine activity when the engine is retired. This means that locomotive fleet activity distribution by age will be skewed younger than fleet population distribution by age. Tier 4 locomotives will have been sold for about 10 years by 2026 and will comprise about 25% of the line-haul fleet at that time. Locomotive duty and owners will change as the engine ages, gradually moving from cross-country to more local service such as in smaller Class II/III railroad ownership. Switcher engines are expected to have a service life of 70 years with a small decrease in use near the end or service life. Without intervention, the turnover to new engine technologies will occur more slowly for switcher compared to line-haul engines.

EPA duty cycles by vocation are presented in Table 4-6. The duty for line-haul and switching are considerably different; there is substantially more idling for switching duty. Locomotives use notch settings to indicate power delivered to the electric generator drivetrain, so idle modes can occur while the locomotive is moving. Dynamic braking is a mode used to slow trains with electrical resistance where the engine is running at no load but often at higher revolutions per minute than during idling.

Table 4-6. Locomotive average duty cycle. (EPA 1998)

Mode	Test mode ID	Approximate Power Factor	Line-haul Time in Mode	Switch Time in Mode	Passenger Time in Mode
Low Idle	A	0.000	0.190	0.299	0.237
Normal Idle	B	0.000	0.190	0.299	0.237
Dynamic Brake	C	0.000	0.125	0	0.062
Notch 1	1	0.045	0.065	0.124	0.070
Notch 2	2	0.115	0.065	0.123	0.051
Notch 3	3	0.235	0.052	0.058	0.057
Notch 4	4	0.350	0.044	0.036	0.047
Notch 5	5	0.485	0.038	0.036	0.040
Notch 6	6	0.640	0.039	0.015	0.029
Notch 7	7	0.850	0.030	0.002	0.014
Notch 8	8	1.000	0.162	0.008	0.156

Switcher locomotive idle mode accounts for 59.8% of all operation time (Table 4-6). Based on time in idle mode and emission rates by mode for switcher locomotives (EPA 1998), the idle mode is responsible for about 20% of the cycle total NOx emissions. The comparable line-haul calculation indicates that the idle mode is responsible for about 3% of cycle total NOx emissions. Because some idling occurs while the engine is moving or is otherwise unavoidable, we estimated that the maximum reduction in idling time would be at most 75% of the total. We estimate a 15% reduction in switcher and 2% reduction in line-haul NOx emissions if all unnecessary idling was eliminated.

Table 4-7 shows overall expected reductions from each technology compared with the EPA (2009) fleet average forecast for 2026. For commuter rail, EPA expected that the fleet would turnover more quickly, but Tier 3 locomotives replacing older models may still provide reductions relative to the lowest Tier/highest emitting portion of the fleet in 2026.

Table 4-7. Locomotive NOx emission reduction measures.

Technology	NOx Emission Factor (g/bhp-hr)	Reduction from 2026 Average NOx Emissions			Cost Effectiveness ($/ton)
		Class II/III (11.8 g/bhp-hr)[a]	Switcher (9.5 g/bhp-hr)[a]	Commuter (3.1 g/bhp-hr)[a]	
Tier 3	4.95 LH / 4.50 SW	58%	53%	---	$1,000 – 2,000
Tier 4	1.0	92%	89%	68%	$10,000 – 20,000
Hybridization	<1.0	>95%	>95%	>80%	>$100,000
CNG/LNG	0.04 (new) – 3.1 (Tier 1 conversion)	70 – 99%	64 – 99%	0 – 99%	Situationally Dependent
Idle Shutoff	---	~15%	~15%	~2%	$0 [b]

[a] EPA (2009) fleet average forecast for 2026.

[b] Locomotive-idle-reduction technology has a reported capital cost of $40,000 per device and cost effectiveness of $1,500 to $5,000 per ton of NOx. Capital costs are offset by fuel cost savings up to $20,000 per year.

A locomotive emission reduction program should include a mix of all of the measures presented in Table 4-7 to enhance fleet modernization for all types of local rail (i.e., sum of Class I Rail Yard, Class II/III and Commuter) by 2026. For example, a $100 million funding allocation to Tier 3/Tier 4 engine upgrade projects listed in Table 4-7 would result in a 2026 NOx emission reduction of about 738 tons per year (3% reduction for combined local rail emissions and 1% reduction across all locomotive emissions). These reductions may be made preferentially by region to affect a larger percentage of that region's emissions.

4.1.4 Cost Effectiveness

Cost and cost effectiveness will depend upon the type of project, base engine activity and emission rates, and project life.

4.1.4.1 Engine Rebuild and Replacement

The most straightforward projects would rebuild or replace older engines with engines meeting more stringent emissions standards. In a project for the Environmental Defense Fund (EDF) and the Diesel Technology Forum (DTF), Ramboll used costs provided by the manufacturers participating with DTF and EPA to estimate annual emission reductions and calculate emission reductions and cost effectiveness as shown in Table 4-8.

The cost to rebuild an existing engine is considerably less than a complete engine replacement, but the cleanest emission standard possible with a rebuild is Tier 3. Metra[43] has commissioned engine upgrades from Tier 0 or 0+ to Tier 3, but the reported cost ($70.9 million for the first 15 locomotives) included a complete remanufacture of the locomotive, including 1) remanufacture of the traction motors, 2) refurbishing, upgrading, or replacing essentially all other components, and 3) engine upgrades including an increase in power to 4,300 hp, and 4) Tier 3 upgrade. The Tier 3 engine upgrades to lower emitting models represent only a fraction of the total reported cost.

[43] https://www.railjournal.com/regions/north-america/chicagos-metra-to-order-remanufactured-locomotives-from-progress-rail/; https://metrarail.com/about-metra/newsroom/metra-board-approves-locomotive-purchase, Accessed online October 2020.

The Table 4-8 total cost ($8,835,000) divided by the total annual emission reduction (65 tons) for the projects shown results in approximately $136,000 to reduce NOx by one ton per year, compared with the amortized cost effectiveness of $6,800 per ton NOx reduced over the life of the projects for this fleet. If grant funding in the amount of $100 million (a significant fraction of the VW Settlement money) were allocated to the project listed in Table 4-8, we estimate 2026 NOx emission reductions of 738 tons per year (or about 4% of the forecasted Class I switch, Class II/III, and commuter rail category emissions).

Table 4-8. Switch locomotive engine rebuild or replacement project benefit and cost.

Project Description			Engine Input Data				NOx Emission Factor (EF; g/bhp-hr)		NOx Emissions (TPY)			Cost Effectiveness
Original Engine Tier Level	New Engine Tier Level	Parts and Labor Cost	Average Power (hp)	Load Factor	Activity (hr/yr)	Remaining Service Life (years)	Original	New	Original Engine	New Engine	Reduction	Full Cost ($/ton)
Unregulated	Tier 0+[a]	$210,000	3,150	0.10	3,250	20	17.4	10.6	19.64	11.96	7.67	$1,368
Unregulated	Tier 3 [a]	$275,000	3,150	0.10	3,250	20	17.4	4.5	19.64	5.08	14.56	$945
Tier 0	Tier 3 [a]	$275,000	3,150	0.10	3,250	20	12.6	4.5	14.22	5.08	9.14	$1,504
Tier 0+	Tier 3 [a]	$275,000	3,150	0.10	3,250	20	10.6	4.5	11.96	5.08	6.88	$1,997
Unregulated	Tier 4	$2,600,000	2,000	0.10	3,250	20	17.4	1	12.47	0.72	11.75	$11,063
Tier 0	Tier 4	$2,600,000	2,000	0.10	3,250	20	12.6	1	9.03	0.72	8.31	$15,641
Tier 0+	Tier 4	$2,600,000	2,000	0.10	3,250	20	10.6	1	7.59	0.72	6.88	$18,900
Total		$8,835,000									65	$6,776

[a] Tier 3 or Tier 0+ Engine retrofit upgrades (all others are full engine replacements)

4.1.4.2 Advanced Technologies

The use of natural gas fuel replacement or new engines designed to use natural gas will result in substantial NOx reductions as well as PM emissions reductions. The newest design from OptiFuel[44] can nearly eliminate NOx emissions, and retrofitting engine to dual fuel usage can also substantially reduce NOx emissions. The cost of natural gas implementation is complicated by the need to develop fueling infrastructure in addition to engine retrofits. However, fueling infrastructure capital cost will be offset by using natural gas which has a lower cost than diesel. The project life and relative maintenance costs for the infrastructure and engines also is unknown, making it infeasible to estimate a cost for a natural gas retrofit or replacement program.

The reported cost of hybrid-electric models purchased in New York by the Metropolitan Transit Authority (MTA) is considerably more expensive (over $9 million per low powered locomotive; $233 million for 25 locomotives) compared with purchase of new non-hybrid locomotives (Metra extensive rebuilds of high-powered locomotives cost $4.7 million, $70.9 million for 15; or about $2.6 million for a new Tier 4 lower powered switching engine). Hybrid models will reduce emissions only to the extent that electric power is used. Compared to a Tier 4 replacement, a new hybrid locomotive will, at most, reduce emissions by 1 g/hp-hr (see Table 1-7) for an incremental cost of $4 to $6 million over an equivalent non-hybrid Tier 4 version. The incremental cost effectiveness for a hybrid compared to a Tier 4 replacement would be at least $100,000 per ton of NOx reduced, assuming a 70-year service life.

4.1.4.3 Engine Idle Reduction

For idle reduction projects, costs vary by the locomotive outfitted, project specific factors (e.g., operational characteristics for the engine being replaced), and AESS device cost. Kim Hotstart[45] (the primary supplier of AESS devices for locomotives) quoted a cost of $40,000 per locomotive in 2009. Kim Hotstart devices include both AESS and engine block heater. An alternative vendor of a verified idle reductions device[46] is Power Drives Inc.[47] AESS units not produced by Kim Hotstart will likely cost less, but can only be used in warmer months because they do not include an engine block heater.

According to the EPA[48], locomotive-idle-reduction technology cost effectiveness ranges from $1,500 to $5,000 per ton of NOx on average. Additional cost savings are expected from reduced fuel consumption. Additional benefits also include emission reductions of PM and small amounts of VOC (compared to NOx emission reductions). Fuel consumption at idle for switcher and line-haul engines is about 4 – 6 gallons per hour, and these engines could idle up to 2000 hours per year according to the EPA duty cycle. Based on a diesel fuel cost of $2 per gallon, fuel cost savings for idle reduction devices could be up to $20,000 per year. A reduction in fuel cost in the range of $20,000 is substantial considering a Kim Hotstart AESS cost of $40,000 per year.

4.1.5 Geographic Applicability

Emission reduction projects could be targeted to railroads (Class II/III or commuter) or rail yard equipment that operate at specific locations or perform short-haul within a discrete region. Northern Illinois is recognized as a major rail hub with several rail yards, Class II/III railroads, and a large

[44] http://biomassmagazine.com/articles/17241/optifuel-to-test-preproduction-rng-hybrid-line-haul-locomotive, Accessed online October 2020.
[45] ftp://ftp.ci.missoula.mt.us/DEV%20ftp%20files/Transportation/Clean%20Diesel/Appendix/C_Appendix_Hotstart_Letter.pdf, Accessed online October 2020.
[46] http://www.epa.gov/smartway/forpartners/technology.htm, Accessed online October 2020.
[47] http://www.dieselwarming.com/, Accessed online October 2020.
[48] "Talking Freight Seminar", Paul Bubbosh, EPA 2004, http://www.fhwa.dot.gov/planning/freight_planning/talking_freight/04talking.cfm, Accessed October 2020.

commuter line. Other states have significant Class II/III operations and rail yards that may be produce substantial emissions, locally.

4.1.6 Seasonal Applicability

Locomotives may not be able to stop idling during colder winters in the LADCO states because of the lack of antifreeze coolant. Otherwise, the control measures described herein are applicable year-round.

4.1.7 Implementation Schedule

The schedule for implementing grant funding for locomotive projects will likely occur over several years, and the replacement and retrofit projects, once funded, will take several months before the locomotive is put back into service. The Texas TERP program[49] spends about $80 million per year on all types of emission reduction projects, so $100 million could be expended relatively quickly. However, finding the most cost-effective projects could take several years because railroads need to feel comfortable with the grant program, schedule locomotives for emissions rebuild or replacement (usually when the engine would be rebuilt on a normal maintenance schedule), and take the locomotives out of service for the rebuild or replacement.

4.1.8 Implementation Feasibility

To implement emission reductions measures, voluntary and mandatory programs could be designed to reduce overall emissions. Voluntary reductions encouraged with grants would have less resistance, especially if Federal funds are made available in lieu of taxes. Mandatory measures without financial support would meet more resistance, but mandated measures could be developed with the participation of affected stakeholders to ease implementation.

In 2005, the California Air Resources Board (CARB) and the two major Class I railroads (Union Pacific and BNSF)[50] that operate in California entered an agreement to install and use idle reduction devices (15 minute maximum idling per event within incurring safety and component failures), evaluation of railyard emissions, opacity and repair requirements, and other initiatives. The 2005 CARB agreement was preceded by a 1998 memorandum of understanding on fleet averaging NOx standards. CARB agreements were limited to the two Class I railroads that operate in California. Seven Class I railroads and many more regionally important Class II/III railroads operate in the LADCO states. California also represents the start and end of BNSF and Union Pacific rail networks, which makes it is easier to define the fleets operating there. It could be possible to define activity requirements within LADCO state boundaries, such as within rail yards. California[51] continues investigate approaches to reducing locomotive emissions throughout the state and at railyards near sensitive communities.

4.1.9 Public Acceptance

Visible smoke and excessive locomotive idling were two complaints that CARB/Railroad agreement provisions allowed to be reported by employees and communities. If the NOx reductions could be coupled with particulate (smoke) emissions and idling noise reductions, such measures could gain more support with local communities.

Locomotive emission reduction projects are among the most cost effective and therefore can be shown to be a good regional emission reductions strategy. Railroads may object to any regulation of their

[49] https://lbb.state.tx.us/Documents/Publications/Presentation/5266_HAC_TERP.pdf, Accessed online October 2020.
[50] CARB, Union Pacific, and BNSF 2005. "ARB/Railroad Statewide Agreement, Particulate Emission Reduction Program at California Rail Yards" June 2005. https://ww2.arb.ca.gov/resources/documents/rail-emission-reduction-agreements, Accessed online October 2020.
[51] https://ww2.arb.ca.gov/our-work/programs/reducing-rail-emissions-california, Accessed online October 2020.

operations, and, especially for idle reductions, winter operations present unknown challenges. Grant funding can be used to facilitate the transition to lower emitting technologies.

4.1.10 Affected Source Category Codes

The affected SCCs are shown in Table 4-9, as implemented in the 2016v1 modeling platform.

Table 4-9. Locomotive source category codes (SCC).

SCC	SCC Description
2285002006	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Class I Operations
2285002007	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Class II / III Operations
2285002008	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Passenger Trains (Amtrak)
2285002009	Mobile Sources; Railroad Equipment; Diesel; Line Haul Locomotives: Commuter Lines
2285002010	Railroad Equipment; Diesel; Yard Locomotives

4.2 Harbor Craft

This section focuses on emissions reductions for harbor craft. Harbor craft are defined as commercial marine vessels, smaller than the large ocean-going or large laker vessels (OGV), comprised of tugs, excursion, ferry, dredges, commercial fishing, and other work boats. Table 4-1 summarizes key information for the control measures presented in this section. Applicable emissions and emission reductions are presented in Table 4-1 on a LADCO region-wide basis; more detailed emission reductions by state and NAA are presented in Section 4.2.4.

Table 4-10. Control measure summary for harbor craft.[52]

Current Regulations and 2026 Emissions Estimates		
OTB regulations:	International Maritime Organization Tier I, II, and III; EPA Tier 1, 2, 3, and 4 emission standards	
2026 Emissions [a]	Total NOx:	9,506 TPY
2026 reductions from OTB regulations and/or measures not accounted for in 2026 emission inventory	NOx Reduction:	0 TPY
	Remaining NOx:	9,506 TPY
Control Measure Summary, Including 2026 Emission Reduction Estimates		
Candidate Control Measure: Rebuild and/or replace harbor craft engines	NOx Reduction:	3,081 TPY
	Cost Effectiveness:	*\$500/ton - \$5,000/ton*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs except Columbus, Ohio* [b]

[a] interpolated from 2016v1 modeling platform 2023 and 2028
[b] emission reductions are concentrated on river systems and near ports

4.2.1 Source Category Description

Harbor craft is a source category that encompasses a range of vessels, including tugs, excursion, ferries, fishing vessels, dredges, and various work boats. Essentially, harbor craft is comprised of commercial vessels that use Category 1 and 2 engines. Harbor craft are smaller than the larger,

[52] The effect on VOC emissions resulting from this measure is expected to be negligible.

deeper-draft laker or ocean-going ships, which primarily use Category 3 engines for propulsion power. A complete list of harbor craft vessels and vocations is available in EPA (2020).

In the LADCO region, the most important harbor craft category and vocation are tow boats that push barges[53] along the river systems and near shore in the lakes. Tugs are also used for shunting barges and assisting larger ships. Tugs may be based locally, to support ports and larger barge terminals and provide general support for other waterfront activities. Harbor craft emissions, especially NOx, are emitted along the Illinois, Mississippi, and Ohio rivers and along the shore and at or near ports on the lakes.

Other locally-based vessel activity, besides harbor tugs, includes excursion vessels and ferries that could be emission sources of interest to local planners. Ferries that carry vehicles can be eligible for Federal Congestion Mitigation and Air Quality (CMAQ) funding because they are considered by the Federal agencies to be part of the highway network.

4.2.2 Regulatory History

Emissions regulations for marine vessels include international and U.S. Federal new engine emission standards and fuel sulfur regulations.

The International Maritime Organization (IMO)[54] promulgated regulations affecting operations world-wide and special regulations in US waters in 1997. New engine NOx emission standards started with vessels built after January 1, 2000 (Tier I), Tier II for 2011 ships, and Tier III for 2016 ships. World-wide fuel sulfur was limited to 0.5% in 2020, and Emission Control Areas (ECA) were defined where fuel sulfur was limited to 1% in 2010 and 0.1% in 2015. ECA also limits NOx emissions when operating in an ECA for Tier III engines, which when outside an ECA are limited to Tier II emissions rates. The ECA within the US and Canadian waters and near Puerto Rico and the US Virgin Islands was declared by the US in 2010 to begin in 2012. IMO issued other regulations affecting tanker vapor control, shipboard incineration, and ozone-depleting substances. Temporary fuel sulfur exemptions were granted to steamships (using boilers as the source of propulsion energy) that expired January 1, 2020.

EPA's more stringent engine emissions regulations superseded the IMO fuel sulfur and emission standards for marine engines used in harbor craft, engines with less than 30 liters/cylinder displacement. Engines with greater than 30 liters per cylinder are used on larger ocean-going and some laker ships which are not the focus of this section. EPA[55] formulated new emissions standards for engines with less than 30 liters/cylinder displacement in two main parts: 1) Tier 1, 2, and 3 standards (published in 1998) and 2) Tier 3 expansion, Tier 4 engines, and fuel sulfur limited to 15 ppm beginning 2012 (published in 2008).

Table 4-11 shows the phase-in schedule for NOx and PM emission standards (hydrocarbon and carbon monoxide emissions are typically low for these engines). Emission regulations distinguish engines by cylinder size, engine total power, and power density (kW/l displacement) to set applicable implementation dates and emission standards.[56] Engine manufacturers certify their engines below the

[53] Tow boats is another name for these tug types, but these tow boat tugs primarily push (rather than tow) barges on rivers for safety reasons.

[54] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Air-Pollution.aspx, Accessed online October 2020.

[55] https://www.epa.gov/regulations-emissions-vehicles-and-engines/domestic-regulations-emissions-marine-compression, Accessed online October 2020.

[56] EPA-420-B-20-021, July 2020, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZP4H.pdf, Accessed online October 2020.

emission standard (referred to as a compliance margin); therefore, actual in-use emissions factors are expected to be lower than the standards shown in Table 4-11. Smaller bore engines have lower emissions standards than larger bore engines. Engines less than 5 (Tier 1 and 2) or 7 (Tier 3 and 4) liters per cylinder are considered Category 1, and the larger engines up to 30 liters per cylinder are Category 2. Category 3 engines have larger than 30 l/cylinder displacement are used nearly exclusively in OGV and almost never in harbor craft.

Table 4-11. Smaller (<30 l/cylinder) commercial marine engines emissions standards.

Tier Level	Year Implemented[1]	HC + NOx (g/kW-hr)	PM (g/kW-hr)
Uncontrolled	Emission Factors -- >	10 – 13.36 (NOx only)	0.19 – 0.36
Tier 1	2004	~10 – 12 (NOx only)	None
Tier 2	2004 – 2007	7.2 – 11.0	0.20 – 0.50
Tier 3	2012 – 2018 2013 – 2014	5.4 – 5.8 smaller bore engines 6.2 – 11.0 larger bore engines	0.10 – 0.14 0.14 – 0.34
Tier 4	2014 – 2017	1.8 (NOx only)	0.04 – 0.12 small 0.04 – 0.25 large

4.2.3 Candidate Control Measures

The most cost-effective measures for reducing emissions from harbor craft are replacing existing engines with newer, cleaner engines or rebuilding engines to meet cleaner emission standards. Whether engine replacement and/or engine rebuild is applied, the basis for the emission reductions is the cleaner emission standard of the new and/or rebuilt engine.

The primary strategy is to use grant funding to reduce emissions by rebuilding or replacing existing engines with those meeting a more stringent emission standard. The decision to either rebuild or replace engines depends largely on whether installing new replacement engines will require the vessel to be reconfigured. If reconfiguration is required, a rebuild may be a more effective strategy to save the resources required for vessel reconfiguration.

The main candidate measures to reduce emissions are either (1) to rebuild and recertify existing engines to more stringent (higher Tiers) emission standards or (2) to replace the engines with new engines meeting the latest emission standards. Tugs (either used in local harbors or as long-haul push boats) are usually configured with two main propulsion and two smaller auxiliary (for on-board electric power) engines, but some have more propulsion engines.

The cost advantage of rebuilding the engine is predicated on the reuse of many engine parts (e.g. engine blocks, gearing, etc.), fewer or no vessel modifications, less time to return the vessel to service, and other reasons. Several engine manufacturers[57] offer rebuild strategies to improve the emission characteristics of existing marine vessel engines.

Some engine replacements even to Tier 4 can be accomplished with little difficulty or vessel modifications. One special instance that usually does not involve vessel modifications is auxiliary engine replacement[58].

[57] https://www.cat.com/en_US/articles/customer-stories/marine/retrofit-kits.html ; https://portal.ct.gov/-/media/DEEP/air/mobile/DERA/ct-recovery-summary.pdf?la=en ; https://www.assemblymag.com/articles/94429-ge-stays-on-track-by-rebuilding-locomotives ; https://www.maritime.dot.gov/sites/marad.dot.gov/files/docs/innovation/meta/9606/semo-rpc-final-report-5.pdf ; https://www.wabtec.com/products/5117/emissions-kits, Accessed online October 2020.
[58] https://www.ckpower.com/considerations-marine-engine-replacement/, Accessed online October 2020.

California[59] has instituted aggressive rules to force engine upgrades to at least Tier 2 engines for most harbor craft operating in its State's waters. California requirements begin in 2009 for older engines and are to be completed for model year 2007 engines by 2023. New vessels and engines must meet the new engine emission standards for the production model year. California is considering further upgrade requirements beyond the Tier 2 requirement.

Funding for such engine emissions upgrade projects is available from the Federal Diesel Emission Reduction Act (DERA) and the VW Settlement pools. California (Carl Moyer Memorial) and Texas (TERP) have state funding mechanisms similar and in addition to the Federal efforts. Car and truck ferries have been considered for upgrade using CMAQ funding as part of highway networks.

Advanced technologies could be employed for some applications. Some examples[60] for excursion vessels and some types of tugs, allow the use of hybrid-electric drives (using plug-in or solar panel electrical power) to eliminate emissions for some of each vessel's activity. Excursion vessels often operate at lower power demand, and the referenced examples were specially designed to use electric power for this special duty. Tugs that only assist larger ships spend a significant portion of their operation time at low loads or idling while waiting, and electric power can be used during that time.

Another option is to use a cleaner hydrotreated diesel fuel (renewable diesel or Fischer-Tropsch [FT] diesel). CARB[61] estimated NOx emission reductions of about 10% and PM of 30% for renewable diesel which has lifecycle CO_2 emissions 65% lower than fossil diesel fuel. EPA[62] showed NOx reductions of about 18% and PM of 36% for renewable diesel. Renewable diesel is produced by hydrotreating biomass, while FT diesel is usually produced from natural gas. Both alternative diesel fuels are characterized by high cetane and fewer high distillation components and can be used in place of fossil diesel fuel without engine modification. The cost and availability of these fuels has been limited. California offers emission credits to be generated from renewable diesel through their Low Carbon Fuel Standard (LCFS) program to enhance the market for renewable diesel by reducing the price differential between renewable and fossil diesel.

4.2.4 Emissions Reductions

Emissions reductions depend upon the emission standard to which the replaced and rebuilt/replacement engine is certified. More cost effective rebuild/replacement engines are those vessels that emit more pollutants by operating a higher number of hours and at greater average engine loads (e.g., long-haul push boats which operate primarily on river systems, but also in the lakes).

NOx emissions in 2026 for these smaller Category 1 and 2 engine types are shown in Table 4-12 for LADCO states, and LADCO NAAs in Table 4-13. In Table 4-12, LADCO-wide NOx emissions in 2016 are compared with 2026 NOx emissions to show that the emissions are expected to be reduced by almost 40% between 2016 and 2026, implying substantial fleet turnover over that time period. However, we raised questions in a recent study[63] about the expected useful life and fleet turnover for this source

[59] https://ww2.arb.ca.gov/our-work/programs/commercial-harbor-craft, Accessed online October 2020.
[60] https://redandwhite.com/enhydra/ ; https://www.alcatrazcruises.com/fleet/ ; https://www.foss.com/foss-innovation/the-hybrid-tug/#:~:text=With%20its%20efficient%20combination%20of,was%20built%20at%20Foss%20shipyard.&text=The%20hybrid%20is%20quieter%20than,be%20recharged%20using%20shore%20power, Accessed online October 2020.
[61] https://ww2.arb.ca.gov/sites/default/files/2018-08/Renewable_Diesel_Multimedia_Evaluation_5-21-15.pdf, Accessed online October 2020.
[62] https://www.epa.gov/sites/production/files/2015-03/documents/01172001mstrs_passavant.pdf, Accessed online October 2020.
[63] https://www.edf.org/media/new-research-doubles-service-life-estimate-marine-workboat-engines-reveals-big-opportunities, Accessed online October 2020.

category, and have shown that actual reductions may be only about 20% over that period (Ramboll, 2019).

Table 4-12. Smaller (<30 l/cylinder) commercial marine engines emissions.

Category	2026 NOx Emissions (TPY)			Estimated 2026 NOx Emission Reduction (TPY)
	Port	Underway	Total	
2026				
Illinois	85	3,270	**3,354**	1087
Indiana	79	852	**931**	302
Michigan	269	2,224	**2,492**	808
Minnesota	18	432	**450**	146
Ohio	66	1,301	**1,367**	443
Wisconsin	65	847	**912**	296
LADCO-wide	581	8,925	**9,506**	3,081
2016				
LADCO-wide	945	14,507	**15,452**	---

Table 4-13. Smaller (<30 l/cylinder) commercial marine engines emissions 2026 by nonattainment area (tons).

Nonattainment Area Name	2026 NOx Emissions (TPY)			Estimated 2026 NOx Emission Reduction (TPY)
	Port	Underway	Total	
Allegan	0	24	**24**	8
Berrien	0	21	**21**	7
Chicago	55	736	**791**	256
Cincinnati	0	145	**145**	47
Cleveland	4	162	**165**	53
Columbus	0	0	**0**	0
Detroit	5	209	**214**	69
Door	26	207	**233**	76
Louisville	0	194	**194**	63
Manitowoc County	0	33	**33**	11
Muskegon	1	99	**100**	32
Northern Milwaukee/Ozaukee	25	119	**144**	47
Sheboygan	0	20	**20**	6
St. Louis	36	236	**273**	88

Mandating replacing or upgrading engines is the approach that will assure substantial emission reductions from these sources. One issue in implementing a mandated program, like California's, is that vessels engaged in interstate commerce may not be affected by state regulations. Emissions from vessels engaged in interstate commerce likely comprise most NOx emissions from this category as is evidenced by the higher emissions from 'underway' compared to 'port' in Table 4-13.

The approach for replacing and retrofitting engines or employing advanced technologies could be encouraged voluntarily through grants evaluated on a case-by-case basis. Grant programs currently exist through DERA and VW Settlement money pools, but the marine sector can only tap into a portion of available funds. We estimate that $100 million (a fraction of the VW Settlement pool for the six LADCO states) spent judiciously (high-use engine replacements) could result in 3,081 tons NOx reduced/year for the project life, or about 32% of 2026 emissions for this category, using the cost and reduction estimates described in next section. Applying a 32% reduction, Tables 2-3 and 2-4 show the expected emissions reduction by state and by NAA.

4.2.5 Cost Effectiveness

Ramboll[64] estimated the cost effectiveness of engine rebuild and new engine installations for a project co-funded by the Environmental Defense Fund (EDF) and Diesel Technology Forum (DTF). Ramboll estimated the impact of the emission reduction from the lower cost rebuilds to Tier 2 emissions standards or higher cost full engine replacement projects. The cost effectiveness shown in Table 4-14 ranges from about $500/ton for higher activity push boats (used for long haul barge moves) to $2,000 to $3,000/ton for lower (but still high use) activity and loads used by general purpose tugs. EPA (2020) posted default annual operating hours of as low as 170 hours for smaller fishing vessels up to 3,329 hours for ferries. If the annual activity is less than the estimates shown in Table 4-14, the project would be less cost effective; for example, if activity were reduced by 50%, the cost effectiveness would be twice that shown or as high as $10,000/ton reduced.

Because vessel configuration (e.g. size of engine room) may not allow new Tier 4 engines to replace existing engines without a significant investment to reconfigure the vessel, engine rebuilds could be a lower cost option to reduce emissions from existing tugs that have substantial remaining operating life. The remaining life of the vessel and engine compared to the 50-year service life are a significant reason for the low $/ton cost effectiveness estimates shown in Table 4-14.

Each project is different, and smaller engines could have a much shorter expected life than shown in Table 4-14. The normal maintenance schedule for diesel engine rebuilds occurs at up to 30,000 hours of operation from the last rebuild (Miller et al. 2016) depending on the average engine loads and engine design; and most engines will be rebuilt numerous times throughout their life. Using the annual hours estimated in Table 4-14, the normal maintenance rebuild occurs every 5 – 12 years. In the Miller (2016) example project, the river push boat operated about 8,500 hours per year, so this vessel type and vocation was a high-activity example. For smaller engines, it could be lower cost to replace rather than rebuild the engine, but the replacement engine could be an older model (factory rebuilt) rather than one meeting lower emission standards. The time of rebuild could offer an opportunity to upgrade the engine to a lower emitting Tier level with a minimum of inconvenience to the owner\operator.

The emissions benefits and cost effectiveness figures shown in Table 4-14 depend upon the annual vessel activity and vessel characteristics (load, power, load factor, remaining life); cost effectiveness will vary depending for each vessel. The costs and benefits shown are per engine, and most often vessels have two or more engines for propulsion power. Auxiliary engine benefits are not shown because the emission reductions are much lower than for propulsion engines.

The estimates in Table 4-14 can also be used to estimate the effectiveness of a pool of money spent on the sector. For example, dividing the cost ($9,451,000) by the annual emission reductions (291)

[64] https://www.edf.org/media/new-research-doubles-service-life-estimate-marine-workboat-engines-reveals-big-opportunities, Accessed online October 2020.

results in $32,460 to reduce 1 ton-NOx/year. The most cost-effective emissions are gained from push boats, but tugs and other similar harbor craft types are more likely to have a greater fraction of their activity in NAA regions. The mix of projects shown in Table 2-5 was used to estimate emission reductions. Overall, $100 million in grant spending could result in 3,081 tons of NOx reduced per year.

Table 4-14. Commercial marine emission reduction and cost effectiveness.

Project Description							Engine Input Data				NOx Emission Factor (g/kw-hr)		NOx Emissions (TPY)			Cost Effectiveness
Vessel Type	Original Engine Tier and Model Year		Retrofit or Replacement New Engine Tier and Model Year		Engine Cylinder Displace. (l/cylinder)	Parts and Labor Cost	Engine Rated Power (kW)	Load Factor	Activity (hr/yr)	Remaining Service Life (years)	Original	New	Original Engine	New Engine	Reduction	Full Cost ($/ton)
Push Boats	Unreg.	1998	Tier 3	2013	11.6	$1,100,000	3,729	0.60	6000	30	13.36	8.33	197.7	123.3	74.43	$493
Push Boats	Unreg.	1998	Tier 2[a]	2012	10.4	$545,000	1,417	0.60	6000	30	13.36	8.33	75.1	46.8	28.28	$642
Push Boats	Unreg.	1998	Tier 2[a]	2010	4.9	$468,000	1,570	0.60	6000	30	11	6	68.5	37.4	31.15	$501
Push Boats	Tier 2	2010	Tier 4	2018	11.6	$1,400,000	2,983	0.60	6000	42	8.33	1.3	98.6	15.4	83.22	$401
Push Boats	Unreg.	1998	Tier 3	2017	2.7	$650,000	746	0.60	6000	30	10	4.69	29.6	13.9	15.72	$1,378
Tug	Unreg.	1998	Tier 3	2013	11.6	$1,100,000	3,729	0.30	2500	30	13.36	8.33	41.2	25.7	15.51	$2,365
Tug	Unreg.	1998	Tier 2[a]	2010	10.4	$620,000	2,289	0.30	2500	30	13.36	8.33	25.3	15.8	9.52	$2,171
Tug	Tier 2	2010	Tier 4	2018	11.6	$1,400,000	2,983	0.30	2500	42	8.33	1.3	20.5	3.2	17.34	$1,923
Tug	Unreg.	1998	Tier 3	2015	4.9	$1,700,000	2,350	0.30	2500	30	11	4.81	21.4	9.3	12.03	$4,712
Tug	Tier 1	2005	Tier 2[a]	2010	4.9	$468,000	1,870	0.30	2000	37	9.2	6	11.4	7.4	3.96	$3,196
All						$9,451,000									291	$981
Push Boat Only						$4,136,000									233	$539
Tug Only						$5,288,000									58	$2,742

[a] Tier 2 Engine retrofit upgrades (all others are full engine replacements)

4.2.6 Geographic Applicability

The benefits of lower emitting engines may accrue over many jurisdictions, even outside of the LADCO region, especially for harbor craft that operate on the Mississippi and Ohio rivers that border the LADCO States. Some tugs are based and operate near ports or barge terminals[65]; lower emitting engine rebuilds and/or replacements for these could be reasonably certain to deliver emission reductions within a defined region. Ferries are usually operated on regular routes, and excursion craft are operated near their base, so both vessel types could be targeted for emission reductions in regions of interest. The most air quality effective projects in or near NAAs would be to upgrade vessels based in NAA counties. However, some of the highest-use vessel activity occurs on river systems often between states.

4.2.7 Seasonal Applicability

Because of the colder winters in the northern LADCO states, harbor craft vessels usually operate to a greater extent in the warmer months. Ice can hinder vessel movements especially on the upper Mississippi and Great Lakes. Excursion and some ferries would preferentially or only operate in the summer months, so projects would result in more emissions reductions in warmer months in which ice does not hinder vessel movements.

4.2.8 Implementation Schedule

The schedule for implementing grant funding for harbor craft engine replacement projects will likely occur over several years, and the replacement or retrofit projects, once funded, will require several months to complete before the vessel can return to service. The Texas TERP program[66] spends about $80 million per year on all types of emission reduction projects, so $100 million could be expended relatively quickly. However, finding and implementing the most cost-effective projects could take several years because owner\operators need to feel comfortable with the grant program, schedule vessels for emissions rebuild or replacement (usually when the engine would be rebuilt on a normal maintenance schedule), and temporarily remove vessels from service for the rebuild or replacement. The search and implementation or cost-effective projects for $100 million in grant funding will take several years, perhaps five years, even if state officials are aggressive at identifying and funding emission reduction projects.

4.2.9 Implementation Feasibility

Several states have funded voluntary programs to turnover older, higher emitting engines and equipment to newer, cleaner models. EPA’s DERA Program also provides models programs, guidelines and assistance in implementing such spending programs. Texas TERP[67], California Carl Moyer[68], and EPA DERA[69] all have issued guidance, tools and resources for implementing voluntary emission reduction grants.

Because a large fraction of the emissions from this source category are likely from tugs used to move barges on rivers and lakes, the candidate tugs likely operate between and outside LADCO states. Therefore, for voluntary use of DERA or VW Settlement grants, multiple states benefitting from

[65] https://www.mvr.usace.army.mil/Portals/48/docs/Nav/NavigationCharts/ILW/AppendixA.pdf, Accessed online October 2020.

[66] https://lbb.state.tx.us/Documents/Publications/Presentation/5266_HAC_TERP.pdf, Accessed online October 2020.

[67] https://www.tceq.texas.gov/airquality/terp, Accessed online October 2020.

[68] https://ww2.arb.ca.gov/our-work/programs/carl-moyer-memorial-air-quality-standards-attainment-program, Accessed online October 2020.

[69] https://www.epa.gov/dera/national, Accessed online October 2020.

projects should share the projects' costs, or EPA or other Federal entity could coordinate the emission reduction projects.

4.2.10 Public Acceptance

Very little or no public opposition has been encountered with voluntary grant programs in general. For a fixed funding pool, there will be competing interests between marine, locomotive, other off-road, and on-road vehicle emission reduction projects.

4.2.11 Affected Source Category Codes

The affected SCCs are shown in Table 4-15 as implemented in the 2016v1 modeling platform. These reflect vessel activity locally, near ports and in-transit, underway on rivers and lakes.

Table 4-15. Smaller commercial marine source category codes.

SCC	Description
2280002101	Mobile Sources; Marine Vessels, Commercial; Diesel; Port emissions
2280002102	Mobile Sources; Marine Vessels, Commercial; Diesel; Port emissions
2280002201	Mobile Sources; Marine Vessels, Commercial; Diesel; Underway emissions
2280002202	Mobile Sources; Marine Vessels, Commercial; Diesel; Underway emissions

4.3 Gasoline Small Off-Road Engine Equipment

This section focuses on emissions reductions for gasoline-fueled small off-road engines (SORE) equipment, which is defined as *gasoline-fueled spark-ignition (SI) engines rated at or below 19 kilowatts (horsepower of 25 or less)*. Engines in this category are primarily used for lawn, garden, and light commercial applications (e.g., small generators). A principal control measure evaluated herein is LADCO's states opting-in to California's proposed emission standards regulation for SORE (currently under rulemaking process) which includes more stringent emission control requirements than current federal standards. Table 4-16 summarizes key information for the control measure evaluated herein. Applicable emissions and emission reductions are presented on a LADCO region-wide basis; state- and nonattainment-level emissions and emission reductions are presented in Section 4.3.4.

Table 4-16. Summary of gasoline SORE equipment control measure.

LADCO-wide Current Regulations and 2026 Emissions Estimates		
OTB regulations:	**Federal:** Phase 3 emission standards under 40 CFR Part 1054 (exhaust emission standards) and 40 CFR Part 1060 (evaporative emission standards) **State:** none	
2026 Emissions [a]	Total NOx: Total VOC:	14,387 TPY 74,717 TPY
2026 reductions from OTB regulations and/or measures not accounted for in 2026 emission inventory [b]	NOx Reduction: VOC Reduction:	0 TPY 0 TPY
	Baseline NOx: Baseline VOC:	14,387 TPY 74,717 TPY
Control Measure Summary, Including 2026 Emission Reduction Estimates		
Candidate Control Measure: Opt-in to California SORE Proposed Regulation	NOx Reduction: VOC Reduction:	8,895 TPY 54,918 TPY
	Cost Effectiveness:	*$39,600-62,400/ton of NOx* *$6,400-10,100/ton of VOC*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs*

[a] Interpolated emissions between 2023 and 2028 from 2016v1 modeling platform. Represents total gasoline non-road emissions from Lawn/Garden, Commercial, Logging, Agriculture, Construction, Railroad and Industrial sectors
[b] No state/local regulations affecting gasoline SORE currently available

4.3.1 Source Category Description

As noted in the introduction, gasoline SORE refers to small gasoline-fueled spark-ignition engines rated at 25 horsepower or less. As shown in Table 4-17, SORE is the largest source of non-road equipment VOC emissions, accounting for 93% of all VOC emissions. VOC emissions from SORE are largely generated in the lawn/garden sector and the commercial sector, which include equipment that is commonly used in residential and commercial applications such as lawnmowers, leaf blowers, and small generator sets. The lawn/garden and commercial sectors comprise about 93% of all SORE VOC emissions, and SORE accounts for 16% of all non-road NOx emissions.

Table 4-17 also shows that the majority of SORE VOC emissions are attributed to fairly new equipment of four years old and newer, suggesting a quick turnover and relatively short useful life of small engines in the lawn/garden and commercial sectors. For example, 96% of SORE VOC emissions in 2026 are generated from engines 0-5 years old (i.e., model years 2026-2022). This is consistent with the average population breakdown for SORE, in which 90% of the fleet is 0-6 years old, as shown in Table 4-18. Only agriculture and logging sectors fleets have substantial equipment populations that are 6 years old or older.

Table 4-17. Breakdown of SORE 2026 VOC emissions.

Breakdown of VOC emissions by Sector[1]								
	Lawn/Garden	**Commercial**	**Logging**	**Agriculture**	**Construction**	**Railroad**	**Industrial**	**Total**
Fleetwide	74%	19%	0%	0%	6%	0%	1%	**100%**
Breakdown of VOC emissions by Sector and Model Year[a]								
Model Year (Age)	**Lawn/Garden**	**Commercial**	**Logging**	**Agriculture**	**Construction**	**Railroad**	**Industrial**	**Total**
2026 (0)	33%	33%	70%	8%	72%	23%	67%	**36%**
2025 (1)	24%	25%	19%	8%	14%	25%	20%	**23%**
2024 (2)	18%	14%	1%	8%	9%	20%	6%	**17%**
2023 (3)	10%	8%	1%	5%	3%	18%	3%	**9%**
2022 (4)	7%	7%	1%	4%	1%	6%	2%	**7%**
2021 (5)	3%	4%	1%	3%	1%	4%	1%	**3%**
2020 and before (6+)	4%	8%	7%	65%	1%	4%	1%	**5%**
Fleetwide	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**
Percent of SORE (≤25HP) over Total Non-road[b]								
% VOC	99%	95%	99%	23%	72%	37%	39%	**93%**
% NOx	74%	34%	24%	1%	2%	3%	2%	**16%**

[a] Approximate breakdown of LADCO-wide 2026 emissions by horsepower bin based on MOVES2014b for largest LADCO counties

[b] National split of Gasoline SORE VOC emissions versus total NON-ROAD emissions from MOVES2014b for 2026

Table 4-18. Breakdown of SORE 2026 equipment population[70].

Breakdown of SORE 2026 Population by Sector and Model Year								
Model Year (Age)	**Lawn/Garden**	**Commercial**	**Logging**	**Agriculture**	**Construction**	**Railroad**	**Industrial**	**Total**
2026 (0)	20%	30%	19%	8%	37%	28%	75%	21%
2025 (1)	18%	24%	13%	7%	23%	27%	15%	19%
2024 (2)	17%	17%	10%	7%	16%	19%	5%	17%
2023 (3)	14%	10%	10%	6%	8%	16%	3%	14%
2022 (4)	13%	8%	8%	4%	5%	5%	2%	12%
2021 (5)	8%	5%	5%	4%	3%	3%	1%	8%
2020 (6)	4%	2%	4%	3%	3%	1%	0%	4%
2019 (7)	2%	1%	5%	4%	2%	0%	0%	2%
2018 and before (8+)	3%	3%	26%	57%	4%	0%	0%	3%
Fleetwide	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

MOtor Vehicle Emissions Simulator (MOVES) source type naming conventions are used throughout this section to describe equipment types, consistent with EPA SCCs and non-road equipment emissions model (MOVES) methods.

NOx emissions from SORE are generated from engine combustion processes. VOC emissions are generated from engine combustion and fuel evaporation processes (e.g., running losses, permeation

[70] Based on MOVES2014b national defaults

and hot soaking and diurnal). SORE is comprised of both 2-stroke and 4-stroke engines. 2-stroke engines have higher power density due to their light weight-to-power ratio, but tend to generate substantial exhaust hydrocarbons due to scavenging losses of fuel; NOx emissions, however, tend to be lower due to cooler combustion processes. Whereas, combustion processes in 4-stroke engines are more controlled and hydrocarbon emissions tend to be lower than 2-stroke engines, but NOx emissions tend to be higher.

4.3.2 Regulatory History

OTB federal regulations limit emissions from SORE. Potential emission reductions estimated in Section 4.3.4 are for reductions above and beyond OTB regulations. Table 4-19 shows OTB regulations for SORE. LADCO states do not currently have any state or local regulations limiting emissions from SORE.

In 2011-2012, EPA adopted the most recent emission standards applicable to SORE under 40 CFR Part 1054 (exhaust emission standards) and 40 CFR Part 1060 (evaporative emission standards). These are referred to as Phase 3 emission standards (EPA, 2008a; 2008b).

CARB is currently developing a rule to impose new, more stringent standards, which are evaluated as a potential control measure for LADCO (CARB, 2020a). Current California standards[71] are also summarized in Table 4-19.

Current EPA exhaust emission standards, promulgated in 2004, are equivalent to CARB's existing exhaust standards (CARB, 2020d). Unlike California, EPA's current controls for small spark-ignition fuel tanks are not subject to evaporative diurnal and hot soak emission standards, in addition to the evaporative permeation emission standards. U.S. manufacturers of non-handheld SORE outside of California may optionally meet CARB diurnal emission standards.

Emissions durability periods (i.e., engine useful life) are also specified by these emissions standards. Durability periods affect testing protocols and expected deterioration for non-road equipment. The "deterioration factor" is the calculated or assigned estimate of a certified engine's emissions change over the durability period. This durability period also determines manufacturer warranty duration requirements for non-road equipment emission control devices.

Table 4-19. Federal (EPA) and California (CARB) on-the-books SORE regulations.

Regulations->	EPA Existing	CARB Existing	Durability Periods/Useful Life
Exhaust Emissions			
Displacement Category	**NOx+VOC Exhaust Standard**	**NOx+VOC Exhaust Standard**	**Emissions Durability Period: Hours of Operation**
< 50 cc, handheld (Class III, IV)	Effective year: 2010 Standard: 50 g/kw-hr	Effective year: 2005 Standard: 50 g/kw-hr	CARB existing.: 50/125/300 EPA: 50/125/300 (light/medium/heavy use)
≥50 to ≤ 80 cc, handheld (Class V)	Effective year: 2010 Standard: 72 g/kw-hr	Effective year: 2005 Standard: 72 g/kw-hr	CARB existing.: 50/125/300 EPA: 50/125/300 (light/medium/heavy use)

[71] CARB existing regulation documents. https://ww2.arb.ca.gov/small-road-engine-or-equipment-regulatory-and-certification-documents, Accessed online October 2020

Regulations->	EPA Existing	CARB Existing	Durability Periods/Useful Life
>80 cc to < 225 cc, non-handheld (Class I)	Effective year: 2012 Standard: 10 g/kw-hr	Effective year: 2008 Standard: 10 g/kw-hr	CARB existing.: 125/250/500 EPA: 125/250/500 (residential/extended/commercial)
≥225 cc to < 825 cc, non-handheld (Class II)	Effective year: 2011 Standard: 8 g/kw-hr	Effective year: 2008 Standard: 8 g/kw-hr	CARB existing.: 125/250/500/1000 EPA: 250/500/1000 (residential/extended/commercial)
≥825 cc, non-handheld (Class I)	Effective year: 2011 Standard: 8 g/kw-hr	Effective year: 2008 Standard: 8 g/kw-hr	CARB existing.: 125/250/500/1000 EPA: 125/250/500 (residential/extended/commercial)
Evaporative Emissions			
Displacement Categories	**Hot Soak + Diurnal Standard**	**Hot Soak + Diurnal Standard**	**Notes**
≤80 cc	None[1]	None	Both EPA and CARB have equivalent permeation control standards for fuel tanks and fuel lines in Small SI engines.
> 80 cc to < 225 cc, walk-behind mowers	None[1]	Effective year: 2008 Standard: 8 g HC per day[72]	
> 80 cc to < 225 cc, other equipment	None[1]	Effective year: 2012 Standard (g of HC per day): 0.95 + 0.056*capacity in liters	
≥225 cc	None[1]	Effective year: 2013 Standard (g of HC per day): 1.2 + 0.056*capacity in liters	

[1] Small SI fuel tanks are not subject to diurnal emission standards. Manufacturers of non-handheld Small SI equipment may optionally meet the diurnal emission standards adopted by the CARB in the Final Regulation Order, Article 1, Chapter 15, Division 3, Title 13, California Code of Regulation.

[72] 'g of HC per day' (grams of hydrocarbon per day)

4.3.3 Candidate Control Measures

4.3.3.1 Evaluated Control Measures

In response to LADCO and member states' request, Ramboll evaluated LADCO opt-in to California's Proposed Emission Standards Regulation for SORE. The proposed California SORE regulation has more stringent emission standards than currently required under Federal regulations. Requirements under the proposed standards are summarized in Table 4-20.

CARB's proposed rule has two phases. The first phase begins in model year 2023 and requires reduced NOx+VOC exhaust emissions (40-90% lower than currently required, depending on the engine displacement). Currently, CARB and EPA have design standards for evaporative emissions related to fuel line permeation and fuel tank permeation. These are not changing with the proposed interim standards for model years 2023-2024. The second phase applies to model year 2025+ and requires zero emissions; in other words, SORE equipment would be electric.

The proposed CARB rule has not yet been promulgated, but formal regulatory language has been drafted[73,74] and preliminary impacts of the proposed rule on California emissions have been estimated[75]. CARB's evaluation of this proposed rule indicates a substantial decrease of VOC emissions from SORE equipment. In Section 4.3.4 the effect on LADCO-wide emissions based on opt-in to the California proposed regulation is evaluated.

The strategy evaluated herein assumes that the proposed California standards will apply to model year 2023+ SORE equipment in the LADCO region. Given that the lawn and garden and commercial sector SORE equipment generate substantial VOC emissions (see Table 4-17), and that the population of SORE equipment for model years 2023-2026 in calendar year 2026 is projected to be around 70% of the entire SORE equipment fleet (see Table 4-18), this measure is expected to achieve substantial VOC emission reductions for LADCO states were it adopted. And over time, this measure would continue to accrue larger reductions as older equipment gets scrapped and turned over to newer equipment meeting these more stringent standards.

[73] https://ww2.arb.ca.gov/sore-potential-exhaust-emission-regulation-amendments, Accessed online October 2020

[74] https://ww2.arb.ca.gov/sore-potential-evaporative-emission-regulation-amendments, Accessed online October 2020

[75] https://ww2.arb.ca.gov/sites/default/files/2020-06/6.8.20%20SORE%20Workshop%20Slides%20ADA.pdf, Accessed online October 2020

Table 4-20. Federal (EPA) OTB emission standards and California (CARB) proposed standards for SORE equipment.

Regulations->	EPA Existing	CARB Proposed Rule	Proposed Rule Reductions	Durability Periods/Useful Life
Exhaust Emissions				
Displacement Category	**NOx+VOC Exhaust Standard (g/kw-hr)**	**NOx+VOC Exhaust Standard (g/kw-hr)**	**% Reduction by Model Year**	**Hours of Operation**
< 50 cc, handheld (Class III, IV)	2010 / 50	2023 / 20 2025 / 0 (electric)	60% reduction by 2023-2024 100% reduction by 2025+	CARB proposed: 1000 EPA: 50/125/300 (light/medium/heavy use)
≥50 to ≤ 80 cc, handheld (Class V)	2010 / 72	2023 / 13 2025 / 0 (electric)	82% reduction by 2023-2024 100% reduction by 2025+	CARB proposed: 1000 EPA: 50/125/300 (light/medium/heavy use)
>80 cc to < 2275 cc, non-handheld (Class I)	2012 / 10	2023 / 6 2025 / 0 (electric)	40% reduction by 2023-2024 100% reduction by 2025+	CARB proposed: 2000 EPA: 125/250/500 (residential/extended/commercial)
≥225 cc to < 825 cc, non-handheld (Class II)	2011 / 8	2023 / 3 2025 / 0 (electric)	63% reduction by 2023-2024 100% reduction by 2025+	CARB proposed: 5000 EPA: 250/500/1000 (residential/extended/commercial)
≥825 cc, non-handheld (Class I)	2011 / 8	2023 / 0.8 2025 / 0 (electric)	90% reduction by 2023-2024 100% reduction by 2025+	CARB proposed: 5000 EPA: 125/250/500 (residential/extended/commercial)
VOC Evaporative Emissions				
Displacement Categories	**Hot Soak + Diurnal Standard (g HC per day)**	**Hot Soak + Diurnal Standard (g HC per day)**	**% Reduction by Model Year**	**Notes**
≤80 cc	None[1]	2023 / 0.5 2025 / 0 (electric)	100% reduction by 2025+	No changes to permeation standards in CARB's proposed rule
> 80 cc to < 225 cc, walk-behind mowers	None[1]	2023 / 0.6 2025 / 0 (electric)	100% reduction by 2025+	
> 80 cc to < 225 cc, other equipment	None[1]	2023 / 0.6 2025 / 0 (electric)	100% reduction by 2025+	
≥225 cc	None[1]	2023 / 0.7 2025 / 0 (electric)	100% reduction by 2025+	

4.3.3.2 Other Typical Control Measures

There are several other measures that may be used to reduce emissions from SORE. The measures summarized below were not evaluated herein.

In-Use Fleet Modernization and/or Electrification

Fleet modernization is a common strategy to lower fleet-wide non-road emissions by replacing older engines with 1) newer models meeting cleaner emission standards or 2) alternative fuels such as electricity or propane. In general, SORE equipment have a relatively short useful life, as indicated in Table 4-18. Approximately 90% of the SORE fleet is 6 years or younger. Some sectors, like the agricultural sector, have a larger proportion (~60%) of older SORE (as old as 25 years). In the absence of a fleet modernization program, the fraction of the SORE population that is comprised of older, higher-emitting engines may continue to linger and increase fleet-wide emissions. Fleet modernization programs typically accelerate turnover of a fleet by using monetary incentives or grants.

Example programs which aim to decrease SORE emissions through fleet modernization are listed below.

- California has a series of Zero-Emission Landscaping Equipment Incentive Programs focused on providing rebates for residential and commercial usage of lawn and garden equipment[76].
- Colorado has an exchange program known as "Mow Down Pollution"[77] which provides funding every year through grants to fund the purchase of low emission, commercial-grade, lawn and garden equipment to improve air quality in the Denver Metro/North Front Range ozone NAA. They also have a parallel program for residential lawn and garden equipment grants.
- Utah has a yearly electric lawn mower discount program[78] partnering with Home Depot that offers a discount code to the first 600 homeowners that live within the NAA of the state.

The cost effectiveness for a gasoline SORE electrification program has been estimated at $16,000 per ton of NOx+VOC (Grant et al., 2015).

Government Contract Requirements

Through climate action plans, sustainability plans or simply air quality initiatives, municipal and state funded operations can lower SORE emissions by:

- Setting contract requirements for landscaping contractors to adhere to a percentage of their equipment fleet to be electric or meet the latest standard.
- Ensuring that the municipal-owned, county-owned or state-owned SORE fleet meets the latest standards and/or is electric.

Fossil-fueled SORE Bans

Several areas have banned certain types of fossil-fueled SORE equipment to reduce pollution:

[76] https://ww2.arb.ca.gov/our-work/programs/zero-emission-landscaping-equipment/zero-emission-landscaping-equipment-incentive, Accessed online October 2020
[77] https://www.mowdownpollution.org/, Accessed online October 2020
[78] https://deq.utah.gov/communication/news/switch-to-electric-deqs-electric-lawn-mower-discount-program, Accessed online October 2020

- Washington DC banned the sale and use of leaf blowers with an average sound level exceeding 70 decibels within city limits under Section 20-2808 of DC municipal code, effectively banning fossil-fueled leaf blowers.
- According to hdsupplysolutions.com[79], several cities in California have banned the use of gasoline-powered leaf blowers and several cities in Illinois have banned the use of gasoline leaf blowers except during certain seasons (typically allowed during the fall).

4.3.4 Emission Reductions

2026 emission reductions from LADCO region-wide adoption of California's Proposed Emission Standards Regulation for SORE are described below. SORE emissions estimates are based on both EPA's 2016v1 modeling platform future year emission inventories (2026 estimates are interpolated from 2023 and 2028 inventories) and emissions estimated by EPA's MOVES2014b model. MOVES2014b estimates were used to add gap-fill instances where emissions granularity in the 2016v1 modeling platform was not sufficient for this analysis. For example, modeling platform emissions do not include model year and horsepower bin information necessary to separate non-road equipment between SORE (≤25 HP) and larger SI engines. Model year detail was necessary to assign percent reductions to the gasoline SORE fleet by model year and horsepower bin according to Table 4-21.

Table 4-21. CARB proposed SORE regulation emission reductions by model year and by horsepower bin.

Displacement Category	MOVES Horsepower Bin (Max Rated)	Model Years Affected	% NOx + VOC Reduction
< 50 cc, handheld (Class III, IV)	1	2023	60%
	1	2024	60%
	1	2025	100%
	1	2026	100%
≥50 to ≤ 80 cc, handheld (Class V)	3	2023	60%
	3	2024	60%
	3	2025	100%
	3	2026	100%
>80 cc to < 225 cc, non-handheld (Class I)	6	2023	82%
	6	2024	82%
	6	2025	100%
	6	2026	100%
>80 cc to < 225 cc, non-handheld (Class I)	11	2023	40%
	11	2024	40%
	11	2025	100%
	11	2026	100%
≥225 cc to < 825 cc, non-handheld (Class II)	16	2023	63%
	16	2024	63%
	16	2025	100%
	16	2026	100%
≥825 cc, non-handheld (Class II)	25	2023	90%
	25	2024	90%
	25	2025	100%
	25	2026	100%

[79] https://hdsupplysolutions.com/s/leaf_blower_noise_regulation, Accessed online October 2020

Emissions fractions by horsepower bin and model year for six representative LADCO counties (one per state) with the largest gasoline non-road emissions (generated with MOVES2014b) were used as the basis to calculate fleet-wide emission reductions. Reductions by model year and horsepower bin were applied to MOVES2014b emissions by sector, SCC horsepower bin, and model year. Baseline and reduced-scenario emissions were aggregated to the SCC and sector level to estimate fleet-wide percent reductions from the application of this rule. The estimated fleet-wide reductions by sector are presented in Table 4-22. Notice that the agricultural sectors has the lowest reductions because its fleet is much older and thus would not benefit as much from this regulation.

Table 4-22. LADCO region SORE emission reductions by sector from adoption of the proposed California SORE regulation.

SORE Sector	% Emissions Reduction	
	NOx	VOC
Commercial	-67%	-72%
Lawn/Garden	-73%	-77%
Logging	-41%	-90%
Agriculture	-18%	-24%
Construction	-85%	-94%
Railroad	-66%	-65%
Industrial	-95%	-96%

Fleet-wide percent reductions by SCC were applied to the 2026 gasoline SORE inventory derived from the 2026v1 modeling platform at the state and county level. Baseline LADCO emissions and emission reductions from this control measure are summarized in Table 4-23 by state and in Table 4-24 by NAA.

Table 4-23. VOC and NOx baseline emissions and reductions by state resulting from opt-in to the proposed California SORE regulation.

State	2026 Baseline NOx Emissions (tons)[a]	Reduction %	NOx Reductions in TPY[b]	2026 Baseline VOC Emissions (tons)[a]	Reduction %	VOC Reductions in TPY
Illinois	3,625	-63%	2,293	18,894	-74%	13,922
Indiana	2,056	-60%	1,240	10,727	-74%	7,967
Michigan	2,222	-62%	1,369	11,380	-72%	8,194
Minnesota	1,855	-60%	1,114	9,002	-73%	6,578
Ohio	3,043	-63%	1,924	16,850	-74%	12,480
Wisconsin	1,587	-60%	954	7,863	-73%	5,777
LADCO-wide	**14,387**	**-62%**	**8,895**	**74,717**	**-74%**	**54,918**

[a] Baseline emissions are for gasoline-fueled non-road equipment with rated horsepower of 25 or less

[b] Tons per year

Table 4-24. VOC and NOx baseline emissions and reductions by NAA resulting from opt-in to the proposed California SORE regulation.

Nonattainment Area County	2026 Baseline NOx Emissions (tons)[a]	Reduction %	NOx Reductions in TPY	2026 Baseline VOC Emissions (tons)[a]	Reduction %	VOC Reductions in TPY
Chicago, IL	2,481	-66%	1,643	13,108	-75%	9,877
St. Louis, IL	98	-62%	61	556	-71%	396
Chicago, IN	115	-62%	72	596	-74%	439
Louisville, IN	48	-63%	30	265	-74%	197
Allegan, MI	27	-57%	15	127	-72%	92
Berrien, MI	32	-58%	19	160	-70%	111
Detroit, MI	1,080	-63%	681	5,540	-73%	4,026
Muskegon, MI	28	-57%	16	131	-69%	90
Cincinnati, OH	397	-65%	257	2,224	-74%	1,651
Cleveland, OH	874	-66%	575	4,867	-75%	3,670
Columbus, OH	391	-66%	258	2,295	-75%	1,713
Chicago, WI	30	-61%	18	154	-72%	111
Door, WI	10	-60%	6	47	-72%	34
Manitowoc County, WI	21	-53%	11	89	-70%	62
Northern Milwaukee/ Ozaukee, WI	258	-63%	163	1,300	-74%	957
Sheboygan, WI	30	-54%	16	126	-71%	90

[a] Baseline represents emissions from gasoline-fueled non-road equipment with rated horsepower of 25 or less

Results of the analysis suggest potential emission reductions for VOC of 70-75% for the SORE fleet throughout LADCO. NOx emission reduction estimates are slightly smaller (53-66%). Emission reductions would become larger as the fleet turns over to newer equipment meeting the proposed California rule requirements.

4.3.5 Cost Effectiveness and Basis

CARB has not published a complete rulemaking package including regulatory impact analysis (RIA) for this proposed rule. Therefore, potential implementation costs were estimated based on cost-analysis performed by EPA during the promulgation of Phase 3 emission standards for small SI engines (EPA, 2008c). In other words, the cost analysis here assumes the cost switching from Phase 3 standards to CARB's newly proposed standards will be comparable to the cost to switching from less stringent, Phase 2 standards to more stringent, Phase 3 standards, especially on the fixed cost portion of the cost analysis, which included research and development, tooling, certification and compliance costs. This approach, however, would under-estimate the program cost for the handheld SORE equipment as the Phase 3 standards for handheld SORE equipment added only evaporative emission controls, and the cost to comply with the standards are primarily related to fuel tank volume and fuel hose length. Therefore, we propose to use the cost for Class I non-handheld equipment to meet the exhaust standards as the cost basis for handheld equipment as well, noting that it would overestimate the program cost, especially the variable cost portion of the cost analysis due to simpler design and smaller size of handheld equipment. CARB's full rulemaking package (not yet available) should include cost information that can be used to update cost-effectiveness estimates for this measure, once it becomes available.

As indicated above, EPA estimated fixed costs for manufacturers that consider engine research and development, engine tooling, engine certification, and equipment redesign. The manufacturing costs per equipment from that regulation were assumed to be similar in magnitude to the costs for this scenario, and the dollar amounts (in $2005) were adjusted for inflation to 2020. Table 4-25 summarizes these average costs from the EPA RIA.

Based on the estimated manufacturing costs, cost effectiveness of this measure was estimated (see Table 4-26). Using the estimated affected SORE population (i.e., model years 2023-2026) projected for LADCO states in 2026, cost-effectiveness for VOC was estimated to be around $10,100 (near-term) and $6,400 (long-term) per ton of VOC reduced.

Table 4-25. Average manufacturing costs by piece of equipment ($2020) for small SI engines[80].

Equipment Class	Exhaust		Evaporative		Total (without fuel savings)	
	Near-term	Long-term	Near-term	Long-term	Near-term	Long-term
Class I	$24	$15	$4	$3	$27	$19
Class II	$52	$29	$9	$7	$94	$54
Handheld* (Class III-V)	$24	$15	$1	$1	$26	$16

*Manufacturing costs are assumed to be similar to Class I's.

Table 4-26. Estimated cost effectiveness ($2020) for adoption of more stringent standards for SORE engines.

Equipment Class	LADCO-wide SORE population[1]	Total manufacturing costs ($ millions)		2026 Annual Cost-Effectiveness ($/ton VOC reduced)		2026 Annual Cost-Effectiveness ($/ton NOx reduced)	
		Near-term	Long-term	Near-term	Long-term	Near-term	Long-term
Class I	7,996,723	$218	$152	$10,100	$6,400	$62,400	$39,600
Class II	2,108,257	$198	$113				
Handheld (Class III-V)	5,458,810	$140	$87				
Total	15,563,791	$555	$352				

[1] Represents LADCO-wide equipment population estimated in 2026 from MOVES2014b defaults for gasoline SORE equipment of model years 2023-2026

4.3.6 Geographic Applicability

Given that this measure is for adoption of California mobile source emission standards, it would likely be adopted at the state level and apply statewide, for states that adopt the measure. SORE emissions are broadly distributed; therefore, emission reductions are expected in any jurisdiction that adopts the rule.

[80] Table 5 in EPA document. https://nepis.epa.gov/Exe/ZyPDF.cgi/P10017GP.PDF?Dockey=P10017GP.PDF, Accessed online October 2020

4.3.7 Seasonal Applicability

Seasonal variation in activity levels is common among SORE equipment (e.g., leaf blowers, lawn mowers, snow blowers). However, there would be no seasonal variation in applicability for this control measure.

4.3.8 Implementation Schedule

The implementation schedule for this measure must include the rule promulgation process, which may require months or longer for program adoption as part of state legislative processes. Air quality regulatory agencies must guide this process to expedite approval and implementation.

4.3.8.1 Implementation Feasibility

Implementation of the opt-in to the Proposed California SORE Rule would require states to adopt this measure through legislative processes. EPA notes the following with respect to adoption of California mobile source standards:

> *The Clean Air Act allows California to seek authorization to enforce its own standards for new non-road engines and vehicles, despite the preemption which prohibits states from enacting emission standards for new non-road engines and vehicles.*[81]
>
> *The Clean Air Act also allows other states to adopt California's non-road vehicle or engine emission standards under section 209(e)(2)(B). Section 209(e)(2)(B) requires, among other things, that such standards be identical to the California standards for which an authorization has been granted. States are not required to seek EPA approval under the terms of section 209(e)(2)(B).*[81]

State adoption of this strategy is contingent upon 1) California promulgating the regulation and seeking a waiver from EPA, 2) EPA granting the waiver, and 3) adoption of the standard 2 years prior to implementation.

4.3.9 Public Acceptance

It is possible that these programs will face resistance, particularly from SORE manufacturers. Acceptance from the general public may be mixed. The new standards, if adopted, would result in reduced emissions, particularly at residences and commercial establishments. However, the new standard, if adopted, would also limit new equipment choice to electric models after 2025.

4.3.10 Affected Source Category Codes

The affected SCCs are shown in Table 4-27, as implemented in the 2016v1 modeling platform.

[81] https://www.epa.gov/state-and-local-transportation/vehicle-emissions-california-waivers-and-authorizations, Accessed online October 2020

Table 4-27. Affected non-road SCCs (aggregated SMOKE format).

SCCs	Description
2260002022	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Construction and Mining Equipment; Total
2260003022	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Industrial Equipment; Total Except AC Refrigeration
2260004020	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; Chain Saws < 6 HP (Residential)
2260004021	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; Chain Saws < 6 HP (Commercial)
2260004022	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; Mowers, Tractors, Turf Equipment (Commercial)
2260004033	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; All Residential Except Chain Saws and Snowblowers
2260004035	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; Snowblowers (Residential)
2260004036	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; Snowblowers (Commercial)
2260004044	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Lawn and Garden Equipment; Other Commercial
2260005022	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Agricultural Equipment; Total
2260006022	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Commercial Equipment; Total
2260007022	Mobile Sources; Off-highway Vehicle Gasoline, 2-Stroke; Logging Equipment; Total
2265002022	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Construction and Mining Equipment; Total
2265003022	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Industrial Equipment; Total Except AC Refrigeration
2265003060	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Industrial Equipment; AC\\Refrigeration
2265004022	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Lawn and Garden Equipment; Mowers, Tractors, Turf Equipment (Commercial)
2265004033	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Lawn and Garden Equipment; All Residential Except Chain Saws and Snowblowers
2265004035	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Lawn and Garden Equipment; Snowblowers (Residential)
2265004036	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Lawn and Garden Equipment; Snowblowers (Commercial)
2265004044	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Lawn and Garden Equipment; Other Commercial
2265005022	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Agricultural Equipment; Total
2265006022	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Commercial Equipment; Total
2265007022	Mobile Sources; Off-highway Vehicle Gasoline, 4-Stroke; Logging Equipment; Total
2285004015	Mobile Sources; Railroad Equipment; Gasoline, 4-Stroke; Railway Maintenance

4.4 Heavy-duty Trucks

Table 4-16 summarizes key information for the Tampering Detection and Enforcement program presented in this section. Applicable emissions and emission reductions are presented on a LADCO-wide basis; state- and nonattainment-level emissions and emission reductions are presented in Section 4.3.4.

Table 4-28. Summary of diesel heavy-duty trucks control measure: tampering detection and enforcement.

LADCO-wide Current Regulations and 2026 Emissions Estimates		
OTB regulations:	**Federal:** Clean Air Act Title II Prohibitions for Defeat Devices and Tampering **State:** Chapter NR 485 (Wisconsin), Revised Code Section 3704.16 (Ohio)	
2026 Emissions [a]	Total NOx:	87,496 TPY
2026 reductions from OTB regulations and/or measures not accounted for in 2026 emission inventory	Rules NOx Reduction [b]:	0 TPY
	Baseline NOx:	87,496 TPY
Control Measure Summary, Including 2026 Emission Reduction Estimates		
Candidate Control Measure: Tampering Detection and Enforcement	Measure NOx Reduction [c]:	19,416 TPY
	Cost Effectiveness:	*$10,360/ton - $15,700/ton*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs*

[a] Interpolated emissions between 2023 and 2028 from 2016v1 modeling platform. Represents Diesel HDT running exhaust emissions.
[b] Wisconsin I/M program could have some co-benefits but not feasible to estimate reduction at this time
[c] Based on 50% detection and participation in the program.

Table 4-29 summarizes key information for the Short-Term Idling program. Applicable emissions and emission reductions are presented on a LADCO-wide basis; state- and nonattainment-level emissions and emission reductions are presented in Section 4.3.4.

Table 4-29. Summary of diesel heavy-duty trucks control measure: state-wide short-term idling restrictions.

LADCO-wide Current Regulations and 2026 Emissions Estimates		
OTB regulations:	**Federal:** none **State:** Municipal codes limiting idling throughout LADCO	
2026 Emissions [a]	Total NOx: Total VOC:	15,179 TPY 2,351 TPY
2026 reductions from OTB regulations and/or measures not accounted for in 2026 emission inventory [b]	NOx Reduction: VOC Reduction:	641 TPY 89 TPY
	Baseline NOx: Baseline VOC:	14,538 TPY 2,262 TPY
Control Measure Summary, Including 2026 Emission Reduction Estimates		
Candidate Control Measure: Short-term Idling Restrictions	NOx Reduction: VOC Reduction:	9,214 TPY 1,441 TPY
	Cost Effectiveness:	*$270/ton of NOx* *$1,730/ton of VOC*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs*

[a] interpolated from 2016v1 modeling platform 2023 and 2028
[b] Represents estimated LADCO-wide short-term idling emissions from Diesel HDTs. Does not include other emission processes like extended idling, starting and driving emissions. Reductions calculated from anti-idling municipal codes from counties and cities throughout LADCO.

4.4.1 Source Category Description

In this section we describe the vehicle types and the typical vocations or activities that may be affected by the control measures under review. Broadly speaking, the measures in this section affect HDTs. HDTs account for a substantial fraction of NOx emissions from on-road vehicles in the LADCO states (see Table 4-17).

Table 4-30. LADCO-wide contribution of HDTs to total 2026 on-road emissions.

MOVES Source Types	Percent of on-road total NOx	Percent of on-road total VOC
Diesel Combination Long-haul Trucks	22.9%	2.1%
Diesel Combination Short-haul Trucks	6.6%	0.4%
Diesel Single Unit Short-haul Trucks	6.3%	1.1%
Diesel Single Unit Long-haul Trucks	1.8%	0.3%
Diesel Refuse Trucks	0.4%	0%
Gasoline Combination Short-haul Trucks	0%	0%
Gasoline Single Unit Short-haul Trucks	1.0%	1.0%
Gasoline Single Unit Long-haul Trucks	0.6%	0.4%
Gasoline Refuse Trucks	0%	0%
TOTAL contribution from HDTs	**40%**	**5%**

MOVES source type classifications are used throughout this section to describe vehicle types, consistent with EPA's SCCs and on-road vehicle emissions model (MOVES) method. MOVES source type classifications include a mixture of regulatory classes which are based on gross vehicle weight rating, as shown in Table 4-31.

Table 4-31. National average vehicle population distribution by regulatory class for HDT MOVES source types.

MOVES Source Type	Percent of Population by Regulatory Class			
	Class 2b Trucks with 2 Axles and at least 6 Tires or Class 3 Trucks (8,500 lbs < GVWR <= 14,000 lbs)	Class 4 and 5 Trucks (14,000 lbs < GVWR <= 19,500 lbs)	Class 6 and 7 Trucks (19,500 lbs < GVWR <= 33,000 lbs)	Class 8a and 8b Trucks (GVWR > 33,000 lbs)
Combination Long-haul Truck	0%	0%	4%	96%
Combination Short-haul Truck	0%	0%	22%	78%
Single Unit Long-haul Truck	26%	19%	28%	27%
Single Unit Short-haul Truck	29%	29%	23%	19%
Refuse Truck	0%	0%	3%	97%

NOx emissions from HDTs are mostly characterized by running exhaust, except for combination long-haul trucks category for which a significant portion of their emissions come from extended idling (26% of diesel combination long haul truck NOx emissions). As shown in Table 4-3, the contribution of HDTs to total on-road VOC is small, as expected.

Two emission reduction measures for HDTs are being evaluated in this work:

- Short-term idling restrictions
- Tampering detection (remote sensing) and enforcement

Short-term idling restrictions are expected to reduce emissions from activities such as those listed below:

- Delivery to commercial establishments, such as grocery store long haul trucks, loading/unloading at warehouses
- Door-to-door package delivery (short haul single unit trucks)
- Good movement operations at ports and railyards, including gate queueing, loading and unloading operations

Tampering detection (remote sensing) and enforcement are expected to reduce emissions from activities such as those listed below:

- Short and long-distance traveling freight/goods haul trucks (combination trucks)
- Local delivery haul trucks (single unit trucks)
- Refuse trucks

In addition to the programs analyzed herein, additional measures may be used to reduce emission from HDTs, such as those listed below.

- Fleet modernization incentive programs to accelerate fleet turnover of older vehicles and engines to vehicles and engines meeting lower emission standards (e.g., DERA, TERP, California Carl Moyer Program).

- Acceleration of deployment of zero emission vehicles. Several states recently signed a memorandum of understanding (MOU) to ensure that 100% of medium- and heavy-duty vehicle sales be comprised of zero emission vehicles by 2050, with an interim goal of 30% by 2030[82].
- Alternative fuels such as renewable diesel have been shown to reduce NOx emissions.
- Freight and/or traffic optimization measures.

4.4.1.1 Key concepts

In this section we define several key concepts related to HDT control measures presented herein.

Short-term idling

In this section, we refer to short-term idling as any idle activity of HDTs with an engine on-time less than 1 hour per event. This is distinct from "extended idling" mode which EPA and the MOVES model defines as any idling activity longer than an hour. Extended idling activity represents multiple-hour hoteling activity for combination long-haul trucks, also referred to as sleeper trucks.

Typical short-term idling for HDTs include stopping at traffic signals and railroad crossings and idling during truck loading and unloading. Short-term idling emissions are implicitly included in MOVES "running" mode emissions estimates; short-term idling emissions are not estimated explicitly, nor available to be exported discretely from the MOVES model. In this analysis, we focus on short-term idling emissions and emission reductions that occur during unloading, loading, or other activities that occur during deliveries when an engine may be turned-off. Emissions from idle during normal en route operations (e.g., stops at traffic lights) are not the focus of this analysis.

Tampering and mal-maintenance

Tampering refers to the deliberate modification of a vehicle, engine, or emission control device in order to improve its performance, improve fuel economy, and/or save costs. Tampering may lead to increased emissions. Examples of tampering are reprogramming a vehicle's electronic control unit ("reflashing") and removing a vehicle's catalytic converter or exhaust gas recirculation (EGR) system (ICCT, 2015).

Mal-maintenance refers to negligent or incorrect vehicle maintenance or operation which can cause increased emissions. This includes actions such as neglecting to replace air and fuel filters, mis-calibrated spark timing, not changing the lubricating oil at regular intervals, unresolved fueling rate issues, injector leaks, diesel exhaust fluid (DEF) improper dosing or use, and refilling the tank with improper fuel.

Another example of negligence is ignoring the malfunction indication light (MIL) that is a feature of the On-Board Diagnostics (OBD) system designed to alert the driver in case of malfunctions that can lead to increased emissions. Operating a vehicle while disregarding the MIL activation can lead to emission increases (ICCT, 2015).

Remote sensing

Remote sensing is an emission rate identification tool that may be used to complement inspection and maintenance programs or anti-tampering programs to gather real-world emissions data and identify high-emitting vehicles in a fleet. Remote sensing refers to methods of identifying vehicle emissions using remote sensing technology. Remote sensing devices typically consist of a light beam (or other

[82] NESCAUM, 2020, nescaum.org/documents/multistate-truck-zev-mou-media-release-20200714.pdf, Accessed online October 2020.

emission characterization technique) that is directed at the exhaust plume of vehicles that pass by the device. The remote sensing device measures the exhaust gas stream and is able to estimate emission levels for certain pollutants or pollutant indicators. In addition to measuring the exhaust gas stream, remote sensing devices, also are typically designed to collect information on speed and acceleration in order to put emission rates in context of the drive cycle. Typically, vehicle license plate information is also collected to allow for cross-reference of vehicle characteristics (e.g., fuel type, model year, owner) with observed emissions.

4.4.1.2 Idling sources and example programs not included in this analysis:

This analysis focuses on reducing short-term idling for HDTs. Other sources of vehicle idling which are not analyzed herein include:

- **Light-duty Vehicles**: Passenger and light commercial vehicle operation includes short-term idling during travel (at traffic lights or during traffic queue) or while operating the vehicle with engine-on while parked (e.g. waiting for passengers or door-to-car delivery, at drive-through locations, during extreme temperatures to keep AC/heater on, etc.).
- **Buses**: Buses may include substantial idling during stops to pick up passengers.
- **Extended Idling**: MOVES defines extended idling as heavy-duty long-haul trucks with a duration over 1-hour per event. Extended idling is typically observed at locations where sleeper cargo trucks hotel during long-distance travel (e.g., rest stops along the interstate highway system).

4.4.2 Regulatory History

There are several existing rules applicable to HDTs that must be understood in order to estimate potential emission reductions for HDT emission control measures presented herein.

CARB is currently developing a rule to impose new, more stringent standards, which are evaluated as a potential control measure for LADCO (CARB, 2020a). Current California standards are also summarized in Table 4-19.

Current EPA exhaust emission standards, promulgated in 2004, are equivalent to CARB's existing exhaust standards (CARB, 2020d). Unlike California, EPA's current controls for small spark-ignition fuel tanks are not subject to evaporative diurnal and hot soak emission standards, in addition to the evaporative permeation emission standards. U.S. manufacturers of non-handheld SORE outside of California may optionally meet CARB diurnal emission standards.

Emissions durability periods (i.e., engine useful life) are also specified by these emissions standards. Durability periods affect testing protocols and expected deterioration for non-road equipment. The "deterioration factor" is the calculated or assigned estimate of a certified engine's emissions change over the durability period. This durability period also determines manufacturer warranty duration requirements for non-road equipment emission control devices.

Table 4-19 shows on-the-books regulations related to tampering detection and enforcement and Table 4-33 shows potential future regulation related to tampering detection and enforcement.

Cases of tampering with control devices have been identified within the past few years[83,84], and EPA has taken actions to address these tampering activities. Under the Clean Air Act, tampering is illegal; however, often tampering is difficult to detect and it is possible that many cases of tampering (and mal-maintenance) go unnoticed because there is not a systematic method in place to detect and rectify vehicles that have been tampered or mal-maintained. Statewide inspection and maintenance programs are typically limited to light-duty vehicles. The State of Wisconsin requires inspections for motor vehicle tampering as part of their motor vehicle inspection and maintenance program (NR 485.07); however, a majority of HDTs are not required to be inspected based on an inspection exemption for vehicles with greater than 14,000 pounds.

Table 4-32. State and Federal on-the-books regulations and codes related to HDT tampering.

Federal	
Regulation name/reference	Clean Air Act Title II Prohibitions for Defeat Devices and Tampering[85,86]
Promulgation date	Last amendment – 1990
Affected sources	Motor vehicles including HDTs
Requirement description	The following acts and the causing thereof are prohibited: • For any person to manufacture or sell, or offer to sell, or install, a part or component for a motor vehicle, where a principle effect of the part or component is to bypass, defeat, or render inoperative any emission control device, and the person knows or should know that such part or component is being offered for sale or installed for such use or put to such use. • For anyone to remove or render inoperative an emission control component on a certified motor vehicle or engine prior to sale or delivery to ultimate purchaser, or • For anyone to knowingly remove or render inoperative any emission control component on a certified motor vehicle or engine after sale and delivery to the ultimate purchaser.
Geographic applicability	Entire US
Implementation schedule	Since 1990
Ohio	
Regulation name/ reference	Ohio Revised Code Section 3704.16[87] and Ohio Administrative Code Chapter 3745-80[88]
Promulgation date	1993
Affected sources	All motor vehicles, light, medium and heavy
Requirement description	The regulation states that it is illegal to: • Knowingly sell, lease, rent or offer to sell, lease or rent or offer to transfer title or a right to possession of a motor vehicle that has been tampered with. • Tamper with any emission control system installed on or in a motor vehicle prior to its sale and delivery to the ultimate purchaser. • Knowingly operate a motor vehicle that has been tampered with. • Sell, offer for sale, possess for sale, advertise, manufacture, install, or use any part intended for use with or as part of any motor vehicle with the primary effect is to bypass, defeat or render inoperative, in whole or part, the emission control system.

[83] https://www.epa.gov/newsreleases/epa-highlights-enforcement-actions-against-those-who-violate-defeat-device-and, Accessed online October 2020.
[84] https://www.epa.gov/vw/learn-about-volkswagen-violations#affected, Accessed online October 2020.
[85] https://www.govinfo.gov/content/pkg/USCODE-2013-title42/html/USCODE-2013-title42-chap85-subchapII-partA-sec7522.htm
[86] https://www.epa.gov/sites/production/files/2019-05/documents/tampering-aftermarket-defeat-devices-2019-mcdi-mtg-33pp.pdf, Accessed online October 2020.
[87] https://epa.ohio.gov/dapc/echeck/other_programs/tampering#:~:text=Under%20state%20law%2C%20it%20is,pollution%20control%20system%20is%20prohibited, Accessed online October 2020.
[88] https://www.epa.ohio.gov/dapc/regs/3745_80, Accessed October 2020.

Geographic applicability	State of Ohio
Implementation schedule	Applicable since 1993
Wisconsin	
Regulation name/ reference	Chapter NR 485 Control of Emissions from Motor Vehicles, Internal Combustion Engines and Mobile Sources; Tampering Prohibition [89]
Promulgation date	November 2010
Affected sources	All motor vehicles, light and heavy
Requirement description	485.06 Tampering with air pollution control equipment: No person may tamper with or fail to maintain in good working order any air pollution control equipment which has been installed on a motor vehicle by the manufacturer prior to sale unless the person repairs or restores the equipment or replaces the equipment with new identical or comparable tested replacement equipment. NR 485.07 Requires inspections for motor vehicle tampering as part of 110.2 motor vehicle inspection and maintenance program
Geographic applicability	State of Wisconsin
Implementation schedule	Already in place since 2010

Table 4-33. Potential future Federal regulation related to HDDT tampering.

Federal	
Regulation name/reference	Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine Standards. Also known as Cleaner Trucks Initiative (CTI)[90]
Promulgation date	Not yet promulgated. Advanced notice of proposed rulemaking was published Jan 20 2020.
Affected sources	On-road Heavy-duty Engines
Requirement description	(Among other goals), this regulation would reduce in-use deterioration of emission controls through potential actions such as: • Warranties that cover an appropriate fraction of engine operational life • Improved, more tamper-resistant electronic controls • Serviceability improvements for vehicles and engines • Education and potential incentives • Improve engine rebuilding practices
Geographic applicability	Entire US
Implementation schedule	To be determined

In the LADCO region, there are anti-idling ordinances of varying stringency per municipal codes for specific cities and villages. Table 4-34 summarizes local anti-idling ordinances affecting HDTs throughout the LADCO region. The largest region which has established anti-idling rules are the counties within the Chicago Metropolitan Area (Cook County and DuPage County, Illinois). As of 2020, there are no statewide statutes or rules limiting short-term idling emissions from HDTs in the LADCO region. Some municipal or local ordinances affect all HDTs, while others are limited to city-owned or

[89] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/485.pdf, Accessed online October 2020.
[90] https://www.federalregister.gov/documents/2020/01/21/2020-00542/control-of-air-pollution-from-new-motor-vehicles-heavy-duty-engine-standards, Accessed online October 2020.

municipal fleets. The latter tend to be more stringent (zero idling except for emergencies), but apply to a small fraction of the vehicle population. The most stringent of the local anti-idling regulation limits public fleets idling to 3 minutes in a 60-minute period and the least stringent limits idling to 15 minutes within a 60-minute period. To ensure compliance, most local ordinances rely on fines ranging from $100 to $700 per violation, with increasing fines for repeated violations.

Outside of the LADCO region, stringent anti-idling rules and ordinances can be found. For example, in California, it is required that drivers of diesel-fueled commercial motor vehicles with gross vehicle weight ratings greater than 10,000 pounds, including buses and sleeper trucks, not idle the vehicle's primary diesel engine longer than five minutes at any location, or otherwise face a violation penalty[91]. New Jersey also has a stringent program that limits diesel vehicles to a maximum idle period of three minutes per hour. The violation penalty may be issued to both the fleet owner/operator and to the business that neglects to enforce anti-idling rules in its premises (e.g. warehouses, any establishment receiving a delivery)[92].

[91] https://ww2.arb.ca.gov/sites/default/files/classic//msprog/truck-idling/13ccr2485_09022016.pdf, Accessed online October 2020.
[92] https://www.stopthesoot.org/sts-idle.htm, Accessed online October 2020.

Table 4-34. Local Anti-Idling Regulations for HDTs in the LADCO region.

State	Geographical Scope	In NAA?	Type of Vehicle Affected	Idling Restriction	Regulation	Resources [b]
Illinois	Counties in the Chicago Area	Y	Diesel vehicles ≥8,000 lbs	10 minutes in 60 min period	625 Illinois Compiled Statutes (ILCS) 5/11-1429	http://www.ilga.gov/legislation/ilcs/fulltext.asp?DocName=062500050K11-1429
Illinois	City of Chicago	Y	Diesel-powered vehicles	3 minutes in a 60-minute period	Chicago Municipal Code, Section 9-80-095	http://www.cityofchicago.org/dam/city/depts/doe/general/ESB_PDFs/StandingLimitOrdinanceAsPassed.pdf
Illinois	City of Chicago	Y	City fleet vehicles	3 minutes in a 60-minute period	City of Chicago Vehicle Idling Management Policy	http://www.cityofchicago.org/content/dam/city/depts/doe/general/ESB_PDFs/CitysVehicleIdlingManagementPolicy05202010.pdf
Illinois	City of Evanston	N	Motor vehicles GVWR ≥8,000 lb	5 minutes in a 60-minute period	City of Evanston Ordinance 75-O-06, Amending Title 10, Chapter 4, “Stopping, Standing Or Parking” of the Evanston City Code (10-4-18-1)	https://www.cityofevanston.org/Home/ShowDocument?id=10025
Illinois	Village of Westmont	N	Commercial vehicle or vehicle designed to transport 16 or more persons along 61st St. from Cass Ave. to Williams St.	10 minutes	Westmont Municipal Code, Ordinance 13-01	http://www.westmont.illinois.gov/DocumentCenter/View/532
Illinois	Village of Villa Park	N	Motor vehicles that operate on diesel fuel	10 minutes within any 60-minute period	Ord. No. 3788, § 1, 4-28-14	https://www.municode.com/library/il/villa_park/codes/code_of_ordinances?nodeId=MUCO_CH14MOVETR
Indiana	City of Fort Wayne	N	City-owned vehicles	5 minutes per 60-minute period	City Energy Policy enacted by mayor	http://cityoffortwayne.org/latest-news/1078-mayor-enacts-city-energy-policy.html
Michigan	City of Ann Arbor	N	Commercial motor vehicles. All motor vehicles are prohibited from idling in no-idling zones.	5 minutes in any 60-minute period (effective July 1, 2017)	Ordinance No. Ord-16-18, Idling Reduction Ordinance	http://www.a2gov.org/departments/city-clerk/Documents/16-18%20Idling%20Ordinance%20Approval%20Notice.pdf
Michigan	City of Detroit	Y	On-road, commercial vehicles (diesel-fueled and nondiesel-fueled) that exceed a gross vehicle weight rating of 8,500 lbs.	5 consecutive minutes per 60-minute period	Detroit City Code, Article VI, Division 5, Section 55-6-91§94	https://www.municode.com/library/mi/detroit/codes/code_of_ordinances

State	Geographical Scope	In NAA?	Type of Vehicle Affected	Idling Restriction	Regulation	Resources [b]
Minnesota	City of Minneapolis	N	Commercial diesel-powered vehicles designed to operate on highways and travel to locations where such vehicles load or unload.	5 minutes in any 60-minute period. No load/unload location owner or operator shall cause vehicles to idle for a period greater than 30 minutes in any 60-minute period	Code of Ordinances, City of Minneapolis, Minnesota, Title 3, Chapter 58, Article I	http://library.municode.com/index.aspx?clientId=11490&stateId=23&stateName=minnesota
Minnesota	City of Minneapolis	N	Gas or diesel-powered motor vehicles (for commercial diesel powered vehicles, see previous entry	3 consecutive minutes in any 1-hour period.	Code of Ordinances, City of Minneapolis, Minnesota, Title 3, Chapter 58, article II	http://library.municode.com/index.aspx?clientId=11490&stateId=23&stateName=minnesota
Ohio	City of Cincinnati	Y	Municipal vehicles	Gasoline powered, 1 minute; diesel powered, 3 minutes	City of Cincinnati, Department of Public Services/Fleet Services, Vehicle/Equipment Idle Free Policy	http://www.government-fleet.com/fc_resources/documents/vehicle_equip_idle_free_policy.pdf
Ohio	City of Cleveland	Y	All vehicles	5 minutes in any 60-minute period. During loading or unloading at a loading dock area, vehicles shall not idle in that area for more than 10 minutes in any 60-minute period.	Codified Ordinances of Cleveland, Ohio, Title V, Section 431.44	https://codelibrary.amlegal.com/codes/cleveland/latest/cleveland_oh/0-0-0-22912#JD_431.44
Ohio	City of Cleveland	Y	City vehicles or equipment	No City vehicle or piece of equipment is to be idled in a nonemergency situation	City of Cleveland, Anti-Idling Policy	http://www.earthdaycoalition.org/cleantransport/files/City%20of%20Cleveland%20Idle%20Reduction.pdf
Ohio	City of Columbus	Y	City vehicles and equipment	No idling	Executive Order 2005-02	http://columbus.gov/uploadedFiles/Columbus/Programs/Get_Green/Documents_and_Principles/Non-IdlingExecutiveOrderFinal12-5-05.pdf
Ohio	City of Maple Heights	N	Vehicles	5 minutes in any 60-minute period (10 minutes for loading or unloading)	Codified Ordinances of Maple Heights Ohio, Section 432.42	http://www.amlegal.com/nxt/gateway.dll/Ohio/mapleheights_oh/codifiedordinancesofmapleheightsohio?f=templates$fn=default.htm$3.0$vid=amlegal:mapleheights_oh

State	Geographical Scope	In NAA?	Type of Vehicle Affected	Idling Restriction	Regulation	Resources [b]
Ohio	City of South Euclid	N	Motor vehicles	No idling except for extreme temperatures and other situations (see list of exceptions)	Codified Ordinances of the City of South Euclid, Ohio, Section 339.19, Excessive Idling	https://partnersforcleanair.files.wordpress.com/2010/11/south-euclid-idling-ordinance.pdf
Ohio	City of North Olmsted	N	Any Motor Vehicle	5 minutes in any 60-minute period (10 minutes for loading and unloading).	City of North Olmstead Ordinance 331.43	https://partnersforcleanair.files.wordpress.com/2010/11/north-olmsted-idle-ordinace.pdf
Ohio	Village of Highland Hills	N	Any Motor Vehicle	5 minutes in any 60-minute period (10 minutes for loading and unloading).	City of Highland Hills, Ordinance 521.13	https://codelibrary.amlegal.com/codes/highlandhills/latest/highlandhills_oh/0-0-0-1
Ohio	City of Lakewood	N	Any Motor Vehicle	5 minutes	Lakewood Code 331.49	https://codelibrary.amlegal.com/codes/lakewood/latest/overview
Wisconsin	City of Madison	N	Motor bus weighing over 8,000 lbs	15 minutes when such motor bus is on a highway abutting a residential building	City of Madison, Code of Ordinances 12.129(2)	http://library.municode.com/index.aspx?clientId=50000&stateId=49&stateName=Wisconsin

Source: U.S. Department of Energy. Clean Cities Idling Database. Available at: https://cleancities.energy.gov/technical-assistance/idlebox/

[a] Accessed online October 2020.

4.4.3 Candidate Control Measures

4.4.3.1 Evaluated Control Measures

In collaboration with LADCO and member states, two control measures were selected for detailed analysis herein: short-term idling restrictions and tampering detection and enforcement.

Short-term Idling Restrictions

As described in Section 4.3.2, anti-idling ordinances are not uncommon within the LADCO region but are currently limited to specific geographical regions. In order to achieve maximum reductions of short-term idling emissions, the entire HDT fleet within the LADCO region would be covered by anti-idling rules. Exemptions would need to be clearly delineated in the programs to provide adequate flexibility. Some examples of exemptions under existing regulations are:

- No limit on short-term idle duration:
  - During ambient temperatures less than 32ºF
  - When powering auxiliary equipment
  - During service or repair or government inspection
  - During mechanical difficulties
  - For emergency vehicles
  - For occupied armored vehicles
- Higher limit (e.g., 30 minutes) on short-term idle duration during ambient temperatures greater than 80ºF

State agencies should consider the industries and fleet characteristics in their states to develop a list of exemptions to ensure that the anti-idling program is comprehensive and practical. Some programs (e.g., New Jersey[93]) enhance motivation to comply with anti-idling programs by making businesses that neglect to enforce anti-idling rules on their premises (e.g. businesses receiving a delivery) subject to violations (in addition to HDT owners/operators).

The anti-idling program considered in this analysis is assumed to apply to all HDT operations in the LADCO region, including short-term idling activities at trip origins or destinations, rest stops, or work sites. En route idling (e.g., at traffic lights) and extended idling (during hoteling by sleeper trucks) is not considered in this analysis. The program assumes a 3 minute idling limit per hour, consistent with the most stringent anti-idling programs in the US.

Tampering Detection and Enforcement

New vehicles are penetrating the fleet every year and are typically subject to cleaner, more stringent emission standards than vehicles scrapped due to attrition. However, HDTs typically have a relatively long service life and accumulate substantial mileage and hours of operation. Limiting emissions from existing, older vehicles is important to reducing emissions from HDTs. Tampering with control devices is a common issue that has been observed for HDTs. Tampering may save fuel costs or improve performance. Mal-maintenance (or negligence) of HDTs operating for prolonged periods with the check-engine light on or malfunction indicator lights (MIL) on is also a common issue, which can result in increased operational emissions until vehicles are repaired. Vehicles operating with failed control

[93] https://www.stopthesoot.org/sts-idle.htm

system devices may emit much higher emissions compared to vehicles operating with working control system devices and may be referred to as "high-emitters".

A comprehensive anti-tampering program should include the following components to effectively reduce fleet-wide HDT emissions:

a) **Detection Program to Identify High Emitters**: A network of remote sensing devices (RSD) measures exhaust emissions from vehicles' exhaust plumes as the vehicles are driven by the operator under real-word conditions. RSD networks eliminate the need for trucks to report to a centralized facility since they can be setup at state operated truck weighing stations, border crossings, cargo terminals or other strategic locations of high HDT traffic. These systems have low operational costs and require limited manned operations.

   In addition to plume measurement license plate information is typically captured with an automated license plate reader and a time and date stamp is recorded. License plate can be used to cross-reference to important ancillary information such as truck make/model, model year, and owner. This information can be used to put RSD emission measurements in context with emissions standards applicable to the HDT make/model and model year and also can be used to contact the owner regarding required repairs.

b) **Follow-up Repair Program**: After high-emitting vehicles have been identified, it is essential that these vehicles be repaired as quickly as possible to avoid further excess emissions. If after an RSD test, vehicle emissions are found to exceed emission limits, or if any component of the emissions control system is found to be malfunctioning (through complementary OBD program, discussed below), owners or operators of high-emitting vehicles are required to take steps to repair the vehicle or face penalties. Operators may be encouraged to make repairs through incentive programs. Deliberate tampering is unlawful under the Clean Air Act and under state administrative codes, so this type of program would curb continued violation of these rules by providing a way to identify high-emitters by placing stations in strategic places of high HDT traffic, such as weight stations and near port or warehousing industrial areas.

c) **Complementary OBD-based Program**: A shortcoming of RSD systems is that they only evaluate emission rates over the limited operating conditions that occur while the HDT is passing through the system. Under certain conditions, some high emitters could be overlooked, or, conversely, artifact high emitters could be identified with no tampering or mal-maintenance problem.

   Since 2010, OBD has been required for HDTs. OBD's advantage is that it will monitor and report on specific emissions control systems that need repair. OBD scan tests are relatively quick, but without a program to evaluate OBD scans, tampering and mal-maintenance issues may remain unaddressed. OBD can also be remotely monitored using telematics, which enables the scan test to be administered with little intrusion for the owner/operator. Upgrading the OBD to remote OBD is relatively inexpensive (less than $100 per unit). With a remote OBD system, the OBD scan can be performed by a kiosk or other roadside antenna through a wireless network (Wi-Fi). Studies by ICCT and University of California Riverside (Durbin, 2019; Posada, 2015) suggest that the combination of RSD systems and OBD testing (preferably remotely), has the advantages of being both cost effective and scalable to capture substantial fractions of an HDT fleet.

The Tampering Detection and Enforcement measure evaluated in this analysis is assumed to apply to diesel HDT (HDDTs) operations in the LADCO region. The program focuses on detection and repair of control device failures for HDDTs of model years 2010 and newer (2010+ HDDTs) because these are equipped with selective catalytic reduction (SCR) devices, the technology largely responsible for controlling NOx in HDDTs. Gasoline HDTs and diesel HDTs of model years 2009 and older are not the focus of the program evaluated here, given that programs are available to incentivize or fund replacement of older vehicles (which by 2026 would be at least 16 years old). Fleet modernization is a more effective way to reduce emissions from older vehicles.

4.4.3.2 Other Typical Control Measures that were not Evaluated

We have summarized below, several other measures that may be used to reduce emissions from HDTs. The measures summarized below were not evaluated herein.

Fleet Modernization

Fleet modernization is a common measure to lower fleet-wide HDT emissions by replacing older engines with 1) newer models meeting cleaner emission standards or 2) alternative fuel models such as electric or natural gas. Diesel engines may operate for 30 years or more, therefore, in the absence of a fleet modernization program, there may be a substantial fraction of the population that is comprised of older, higher-emitting engines. Fleet modernization programs typically accelerate turnover of a fleet using economic incentives or grants. Fleet modernization may also be mandated through regulatory requirements (e.g., California Truck and Bus Rule[94]).

Examples of programs focused on this are:

- California’s Truck and Bus Rule: requiring most diesel vehicles with a Gross Vehicle Weight Rating (GVWR) greater than 14,000 lbs. that are of model years 2009 or older that operate in California to be replaced with engines of model year 2010 or newer by calendar year 2023.[95]
- TERP help reduce emissions from older vehicles by providing grants through programs like Emissions Reduction Incentive Grants (ERIG) Program that help fund early retirement of HDTs (and pieces of equipment), particularly those with large diesel engines.[96]
- DERA is a federal grants program to aid in older diesel vehicle replacement.[97]
- Volkswagen Clean Air Act Civil Settlement (Consent Decree)
- California’s Carl Moyer Program provides grant funding for cleaner-than-required on-road engines, equipment, and other sources of air pollution through voucher incentive programs to fund small fleet vehicle replacement and engine repowering.[98]

Intermodal Rail/ Port-wide / Fleet-wide Requirements:

Through climate action plans, sustainability plans or simply air quality initiatives, marine ports, airports and railyards can encourage HDT fleet owners and operators to reduce their operational emissions by taking actions such as those listed below.

[94] https://ww2.arb.ca.gov/our-work/programs/truck-and-bus-regulation, Accessed online October 2020.
[95] https://ww3.arb.ca.gov/msprog/onrdiesel/documents/fsregsum.pdf?_ga=2.21289595.1790587916.1603215907-436809490.1599751744, Accessed online October 2020.
[96] https://www.tceq.texas.gov/airquality/terp/erig.html, Accessed online October 2020.
[97] https://www.epa.gov/dera/learn-about-impacts-diesel-exhaust-and-diesel-emissions-reduction-act-dera, Accessed online October 2020.
[98] https://ww2.arb.ca.gov/carl-moyer-program-eligible-equipment, Accessed online October 2020.

- Terminal operators reduce truck congestion and idling emissions at terminals by installing electric gates, redesigning gates, and extending gate hours (NY/NJ Port Authority, Port of Houston).
- Reduce idling emissions by developing near-Port truck parking areas with plug-in electrification technology and rest stop amenities (NY/NJ Port Authority).
- Reduce short-term idling of cargo trucks by increasing the efficiency of cranes and other good movement operations (Port of Houston).
- Reduce fleet-wide emissions through fleet requirements (e.g., vehicle model year, alternative fuels, or electrification) at specific terminals or port-wide (NY/NJ Port Authority, Port of Houston). For example, the Port of Los Angeles/Port of Long Beach Clean Truck Program banned pre-1989 trucks in 2008 followed by a progressive ban on all trucks that did not meet 2007 emission standards by 2012. In 2018, only model year 2014 or newer are allowed to sign up in the Port Drayage Truck Registry (PDTR).

4.4.4 Emission Reductions

Emission reductions from HDT anti-tampering and anti-idling control measures are described below. HDT emissions estimates are based on both EPA's 2016v1 modeling platform future year emission inventories (2026 estimates interpolated from 2023 and 2028 inventories) and emissions estimated by EPA's MOVES2014b model emissions for 2026 to gap fill instances where information available from the 2016v1 modeling platform was not sufficient (e.g., emission rates by model year and short-term idle emission rates and activity).

4.4.4.1 Tampering Detection and Enforcement Program

The program evaluated under this analysis focuses on detection and repair of control device failures for diesel HDT (HDDTs) model years 2010 and newer (2010+ HDDTs) because 2010+ HDDTs are equipped with SCR. For 2010+ HDDTs, SCR technology is largely responsible for NOx emission reductions. Failures on diesel HDTs of model year 2009 and older tend to be on control devices focused on PM (e.g. diesel particulate filters [DPFs]) and therefore are not the focus of this study.

2010 and newer diesel HDT emissions factors by model year for LADCO states for calendar year 2026 were developed by running MOVES2014b for LADCO states at the national scale. The rate and effect for NOx-focused failures in 2010+ HDDTs is available from MOVES2014b documentation[99]. The compounded effect of failure rates and failure effects is shown in Table 4-21, representing excess emissions that could be reduced through timely identification and repair of these failures. It is important to note that MOVES2014b assumptions for tampering and mal-maintenance (TM&M) effects tend to be lower than those estimated by the CARB 2017 EMission FACtors model (EMFAC2017). EMFAC2017 incorporates results of more recent experimental data. Therefore, potential real-word emission reductions from repairs could be even higher than indicated in Table 4-21.

[99] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NO46.pdf, Accessed online October 2020.

Table 4-35. Effects on NOx emission rates from tampering and mal-maintenance for model year 2010+ Diesel HDTs in MOVES2014b.

Failure types	Failure Frequency (FF)	Failure NOx Increase (FI)	TM&M NOx effect (FFxFI)
EGR Stuck Open	0.2%	-20%	0%
EGR Disabled/Low Flow - EPA	10%	5%	1%
NOx Aftertreatment Sensor	10%	200%	20%
NOx Aftertreatment Malfunction - EPA	13%	500%	65%
Total	**33%**		**85%**

For this analysis, we have assumed that an anti-tampering program could rectify 50% of 2010+ HDDT failures. Running exhaust emissions from 2010+ HDDTs were multiplied by the TM&M NOx effect and a 50% program detection/participation rate to estimate NOx emission reductions. Extended idling (i.e., for idle periods of greater than one hour for sleeper trucks) and start exhaust emissions are assumed to be unchanged by this program because SCRs typically do not function very well at low loads and low exhaust temperatures that occur during engine start and hoteling.

Table 4-23 shows state-wide baseline emissions and potential reductions from the anti-tampering program. Baseline emissions represent fleet-wide running exhaust emissions from diesel heavy-duty source types (Combination/Single, Long/Short Haul trucks and Refuse Trucks); therefore, the percent reduction represents the decrease in emissions over the entire fleet whereas repairs only apply to the 2010+ HDDTs. Estimates show that a program achieving a 50% reduction in failures could accrue LADCO region-wide HDDT NOx emission reductions of about 22%. Table 4-24 shows estimated reductions for NAA counties.

Table 4-36. NOx estimated emissions and reductions from tampering detection and enforcement program by state.

State	2026 Baseline NOX Emissions (tons)[a]	Reduction %	NOx Reductions in TPY
Illinois	21,502	21%	4,523
Indiana	28,164	23%	6,466
Michigan	7,719	23%	1,782
Minnesota	7,840	23%	1,837
Ohio	7,974	20%	1,578
Wisconsin	14,297	23%	3,230
LADCO-wide	**87,496**	**22%**	**19,416**

[a] Baseline represents running exhaust emissions from diesel HDTs

Table 4-37. NOx Estimated Emissions and Reductions from Tampering Detection and Enforcement Program by NAA.

Nonattainment Area County	2026 Baseline NOX Emissions (tons)[a]	% Reduction	NOx Reductions in TPY
Chicago, IL	8,155	20%	1,626
St. Louis, IL	760	21%	160
Chicago, IN	674	23%	157
Louisville, IN	990	26%	262
Allegan, MI	58	24%	14
Berrien, MI	452	20%	93
Detroit, MI	1,970	22%	435
Muskegon, MI	194	27%	53
Cincinnati, OH	1,106	20%	219
Cleveland, OH	1,630	20%	322
Columbus, OH	1,097	20%	217
Chicago, WI	227	24%	54
Door, WI	83	24%	20
Manitowoc County, WI	219	23%	51
Northern Milwaukee/Ozaukee, WI	1,106	23%	260
Sheboygan, WI	247	23%	57

[a] Baseline represents running exhaust emissions from diesel HDTs

NOx emission reduction estimates could be even larger as the fleet ages and more vehicles with SCRs and NOx-sensitive devices are added to the fleet. Ohio has anti-tampering regulations, but with no defined regulatory enforcement mechanism, we have not estimated any emission reductions from Ohio's on-the-books regulations. Wisconsin's anti-tampering exempts inspections of HDDTs with a gross vehicle weight rating greater than 14,000 pounds. Because of the lack of lack of dedicated and refined inspection and enforcement mechanisms for HDDTs emission reductions were not estimated for the Ohio and Wisconsin programs.

4.4.4.2 Short-term Idling Restrictions

Short-term idling emissions are not explicitly available from MOVES output[100]. MOVES calculates short-term idling emissions implicitly within (as a portion of) running mode emission calculations. Running mode emissions are based on emission testing over various driving cycles, that are specific to vehicle source types, road types and driving speeds. In order to estimate short-term idle hours in a regional inventory, the fraction of that vehicles spend in short-term idling mode versus running mode, and other modes like braking, must be estimated. This short-term idling fraction is applied to the driving operational hours (referred to in MOVES as source hours of operation or "SHO") to estimate short-term idle hours.

A study by the University of California at Riverside (Boriboonsomsin et al., 2017) included analysis of the time spent in brake, idle, coast and cruise modes for HDTs of different vocations. Ramboll cross-referenced vehicle vocations in Boriboonsomsin et al. (2017) to MOVES source types to estimate an

[100] https://www.epa.gov/moves/what-difference-between-extended-idling-and-normal-idling-it-possible-get-distinct-idling, Accessed online October 2020.

average fraction of time spent in short-term idle mode (see Table 4-38). The type of idling reviewed in Boriboonsomsin et al. (2017) excluded idling at stop signs and traffic lights, as well as extended idling, consistent with the definition of short-term idling in this analysis. A 3 minute maximum idle time per 60 min period was assumed as the basis for the program. HDTs, both gasoline and diesel, are estimated to reduce idle time and idle emissions by 77 to 89%.

Table 4-38. Short-term Idle Time Estimates per Vehicle Type and Measure Reduction.

MOVES Vehicle	% Time in Short-Term Idle	Operational time per day (all modes; min)	Idle Time per Day (min)	3-min Reduced Program (min/day)	Percent Reduction of Idle Time
Combination Long-haul Truck	22%	338.05	74.88	17	-77%
Combination Short-haul Truck	43%	162.21	70.48	8	-88%
Refuse Truck	45%	90.61	40.50	5	-89%
Single Unit Long-haul Truck	26%	90.63	23.32	5	-81%
Single Unit Short-haul Truck	35%	64.16	22.58	3	-86%

Fleet-wide baseline emissions and emission reductions for short term idling were calculated based on MOVES project-level grams-per-hour idling emission factors[101], combined with interpolated hours of operations for 2026 derived from EPA's 2016v1 modeling platform future on-road activity projections. Exemptions for extreme weather conditions are assumed to waive compliance requirements and decrease participation. A 78% annual compliance level was estimated for the HDT fleet based on exemptions for extreme temperatures (100% compliance for 9 months and 10% compliance for three months). Emission reductions estimates are shown in Table 4-39 and Table 4-40. These emissions would represent a maximum reduction case from this program; real-world compliance levels could result in lower emission reductions based on non-compliance and other program exemptions.

Emission reductions from existing state/local anti-idling regulations in LADCO member states and NAA regions were estimated (see Table 4-39 and Table 4-40). Short-term idling restriction control measure emission reductions are exclusive of emission reductions accrued under existing state/local regulations.

The anti-idling measure is estimated to reduce LADCO-wide short-term idle emissions by up to 60%. Short-term idle emission reductions represent about 8-25%[102] of NOx running exhaust emissions from HDT in the LADCO states. Obtaining a high rate of compliance is a key factor required to maximize success of the program. Incentives for compliance and penalties for non-compliance will need to be carefully considered if this program is implemented. Section 4.5.2 notes several programs in other states and provides examples of enforcement measures.

[101] Short-term idle emission rates were estimated based on EPA's methodology https://www.epa.gov/moves/what-difference-between-extended-idling-and-normal-idling-it-possible-get-distinct-idling, Accessed online October 2020.

[102] This is a rough estimate based on a 2026 HDT emissions inventory (only running exhaust), derived from linear interpolation of EPA's 2016v1 future year projection on-road inventories.

Table 4-39. Estimated emissions and reductions from state-wide short-term idling restrictions by state.

State	2026 Emissions [a]		2026 Emission Reductions from Existing State/Local Regulations		2026 Emission Reductions from Short-term Idling Restrictions Control Measure		
	NOx (TPY)	VOC (TPY)	NOx (TPY)	VOC (TPY)	Percent Reduction	NOx (TPY)	VOC (TPY)
Illinois	2,668	414	510	70	58%	1,553	245
Indiana	4,150	661	0	0	65%	2,694	429
Michigan	2,875	458	47	7	65%	1,867	298
Minnesota	1,632	259	56	8	64%	1,052	167
Ohio	1,738	245	19	3	63%	1,103	157
Wisconsin	1,475	225	9	2	64%	945	145
LADCO-wide	**14,538**	**2,262**	**641**	**89**	**63%**	**9,214**	**1,441**

[a] Baseline represents estimated short-term idling emissions from diesel HDTs

Table 4-40. Estimated emissions and reductions from short-term idling restrictions by NAA.

Nonattainment Area County	2026 Emissions [a]		2026 Emission Reductions from Existing State/Local Regulations		2026 Emission Reductions from Short-term Idling Restrictions Control Measure (TPY)		
	NOx (TPY)	VOC (TPY)	NOx (TPY)	VOC (TPY)	Percent Reduction	NOx (TPY)	VOC (TPY)
Chicago, IL	617	85	454	62	38%	235	33
St. Louis, IL	104	15	0	0	65%	68	10
Chicago, IN	108	17	0	0	66%	71	11
Louisville, IN	102	19	0	0	65%	67	13
Allegan, MI	27	5	0	0	66%	18	3
Berrien, MI	193	25	0	0	65%	126	17
Detroit, MI	650	96	28	4	63%	412	61
Muskegon, MI	39	8	0	0	65%	25	5
Cincinnati, OH	244	34	0	0	64%	156	22
Cleveland, OH	353	50	7	1	63%	223	32
Columbus, OH	242	34	0	0	64%	154	22
Chicago, WI	23	4	0	0	65%	15	2
Door, WI	8	1	0	0	64%	5	1
Manitowoc County, WI	22	3	0	0	64%	14	2
Northern Milwaukee/Ozaukee, WI	112	18	0	0	65%	73	12
Sheboygan, WI	25	4	0	0	64%	16	3

[a] Baseline represents estimated short-term idling emissions from diesel HDTs

4.4.5 Cost Effectiveness and Basis

The potential cost of these programs could vary widely by level of engagement and enforcement in each state. Annual administrative costs are hard to determine. Capital cost and operational costs were estimated based on available literature.

For the Tampering Detection and Enforcement program, cost effectiveness was estimated based on reference capital and operational costs from Durbin, et al. (2019). Durbin, et al. (2019) studied various detection technologies and program components (summarized in Table 4-41). A key component of this program will be determining how to effectively deploy RSD stations based on local and regional HDT traffic patterns. Assuming a testing capacity per station of 200 test per day, 73,000 vehicle tests would be conducted annually. The LADCO-wide diesel HDT population is 590,000 vehicles. Locating 41 stations throughout LADCO would allow for 5 tests per year per vehicle, on average. Assuming a conservative 5-year life of these stations, the amortized annual cost-effectiveness for the RSD stations is only small fraction of the total program cost. A vast majority of program cost is for repairs, which were estimated assuming failure rates per MOVES estimates (33% total), 50% of all emission system failures are detected by the program over all vehicles in the LADCO region. The total cost-effectiveness for the program is estimated to be around $10,000/ton NOx reduced. A potential feature that was mentioned in section 4.5.2 is combining the RSD/enforcement program with a remote OBD monitoring program. Considering the price of the remote OBD transmitter and the annual operational cost, and assuming an 80% participation of the registered diesel HDT fleet, the cost-effectiveness is estimated to be as high as $15,000/ton of NOx reduced.

The cost for the short-term idling restriction program would mainly be administrative, and is therefore, difficult to estimate. The effectiveness of the program and its cost will depend on the balance of education programs for the drivers/fleet owners, signage to encourage compliance, and potentially, a penalty system to encourage accountability. The cost for signage could vary widely, but signage should focus on ensuring that high-traffic areas for HDTs are covered. Assuming an investment in 100,000 signs per year, the program is estimated to be extremely cost-effective (see Table 4-42); real costs are likely to be more substantial as a result of administrative costs. Penalty fees may partially cover program administrative and capital costs.

Table 4-41. Estimated cost-effectiveness of anti-tampering program.

Elements	Reference Capital Cost	Reference Operational Cost ($)	LADCO-wide number of RSD stations, repairs, OBD dongle units	Annual Operational Cost ($)	Annual Amortized Capital Cost ($)	2026 Annual Cost-Effectiveness ($/ton NOx reduced)
Detection						
Remote Sensing Device station [1]	$20k - $200k per station	unknown	41	unknown	892,132	46
Repairs/Enforcement						
Average repair cost [2]	n/a	$2,037 per repair	98,280	200,197,304	n/a	10,311
Complementary OBD program						
OBD remote continuous monitoring [3]	$50-100 per vehicle	$204 per vehicle	473,641	96,622,721	7,104,612	5,342
Program RSD + Repairs [4]						**10,357**
Program RSD + Repairs + Continuous OBD[4]						**15,700**

[1] assumes 41 RSD stations

[2] assumes number of repairs = LADCO-wide vehicle population [590,000 vehicles] x failure frequency [33%] x program penetration [50%]

[3] assumes 80% of the fleet participates

[4] does not include administrative costs

Table 4-42. Estimated cost-effectiveness of short-term idling restrictions program.

Element	Cost per unit	Units (LADCO-wide)	Total Cost ($)	Annual NOx Cost Effectiveness ($/ton)	Annual VOC Cost Effectiveness ($/ton)
Signage cost	$25	100,000	$2,500,000	$271	$1,734
Total Cost [1]			$2,500,000	$271	$1,734

[1] does not include administrative costs

4.4.6 Geographic Applicability

The tampering detection and enforcement program could be implemented on local fleets or at a regional- or state-level. Statewide implementation would avoid competitive advantages within a state based on whether the fleet was located within an area that required compliance (avoids potential loss of business from affected areas or transfer of business from affected to unaffected areas).

Anti-idling rules could be implemented statewide or target specific regional NAAs. There are currently no statewide anti-idling regulations for HDTs in the LADCO region, but there are several municipal and county anti-idling programs.

4.4.7 Seasonal Applicability

The anti-tampering program should be little affected by seasonal variation. The anti-idling program should consider exemptions during extreme summer and winter temperatures.

4.4.8 Implementation Schedule

The implementation schedule for tampering detection and enforcement and anti-idling measures must include a key few milestones that will determine when emissions reductions from both programs may be expected:

- Rule/program promulgation process: it will take time (months to possibly years) for such programs to be approved by the legislature. Air quality regulatory agencies must guide this process to expedite approval of these programs.
- The anti-idling program must identify locations, build stations and develop a network of remote sensing/testing locations in order to identify and collect data on high-emitting vehicles.

4.4.9 Implementation Feasibility

Anti-idling programs have been implemented in several states and at the municipal- and county-levels in LADCO states. Program exemptions such as for cold weather and emergency vehicles should be carefully considered for inclusion in the rule. Otherwise, technological, infrastructure, and logistical barriers are not expected for this measure.

Comprehensive anti-tampering programs to reduce emission of NOx from diesel HDTs have been researched for several years. As described above, such programs include RSDs, OBD monitoring, and repair verification and enforcement mechanisms. California is currently considering adopting such a program[103].

4.4.10 Public Acceptance

It is likely that a substantial portion of the general public as well as environmental groups will welcome this type of program because emission reductions have the potential to result in better local and regional air quality and health benefits in communities impacted by HDT idling. It is also possible that these programs will face industry push back, particularly the anti-tampering program. A funding program could be established to provide funds for truck repairs that are not related to deliberate tampering. The anti-idling program will result in fuel savings for truck fleets (estimated in Table 4-43), which could enhance its public acceptance.

[103] https://ww2.arb.ca.gov/our-work/programs/heavy-duty-inspection-and-maintenance-program, Accessed online October 2020.

Table 4-43. Estimated fuel savings from short-term idling restrictions program.

Vehicle type	Fuel Usage During Idling (gal/hr)[a]		Fraction unloaded	LADCO-wide	Annual Fuel Savings per Vehicle ($/vehicle)[b]
	Loaded	Unloaded		Program idle time reductions (hrs)	
Combination Long-haul Truck	1.15	0.64	0.3	79,667,211	5,126
Combination Short-haul Truck	1.15	0.64	0.3	91,670,332	2,460
Refuse Truck	1.15	0.64	0	52,927,099	1,585
Single Unit Long-haul Truck	1.15	0.64	0.3	40,878,173	1,374
Single Unit Short-haul Truck	1.15	0.64	0.3	109,518,064	973

[a] Fuel usage during idling obtained from US. Department of Energy IdleBox fuel savings calculator. Based on average fuel price of $2.5/gallon

[a] Fuel savings represent combined savings from gasoline- and diesel-fueled HDTs

4.4.11 Affected Source Category Codes

The affected SCCs are shown in Table 4-27, as implemented in the 2016v1 modeling platform.

Table 4-44. Affected On-road SCCs (SMOKE format).

SCCs	Description	Fuel	Emissions	Applicable measure
2201510272	Refuse Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201510372	Refuse Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201510472	Refuse Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201510572	Refuse Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201520272	Single Unit Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201520372	Single Unit Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201520472	Single Unit Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201520572	Single Unit Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201530272	Single Unit Long-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201530372	Single Unit Long-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201530472	Single Unit Long-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201530572	Single Unit Long-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201610272	Combination Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201610372	Combination Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201610472	Combination Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2201610572	Combination Short-haul Truck	Gasoline	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202510272	Refuse Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202510372	Refuse Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202510472	Refuse Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202510572	Refuse Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202520272	Single Unit Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202520372	Single Unit Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202520472	Single Unit Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202520572	Single Unit Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202530272	Single Unit Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202530372	Single Unit Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202530472	Single Unit Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202530572	Single Unit Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202610272	Combination Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling

SCCs	Description	Fuel	Emissions	Applicable measure
2202610372	Combination Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202610472	Combination Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202610572	Combination Short-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202620272	Combination Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202620372	Combination Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202620472	Combination Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202620572	Combination Long-haul Truck	Diesel	All Processes except refueling and extended idling	Anti-Tampering, Short Term Idling
2202620291	Combination Long-haul Truck	Diesel	Extended Idle	Anti-Tampering
2202620391	Combination Long-haul Truck	Diesel	Extended Idle	Anti-Tampering
2202620491	Combination Long-haul Truck	Diesel	Extended Idle	Anti-Tampering
2202620591	Combination Long-haul Truck	Diesel	Extended Idle	Anti-Tampering

4.5 Non-Road Diesel Construction and Industrial Equipment

This section focuses on emissions reductions for non-road diesel construction and industrial equipment. Table 4-1 summarizes key information for control measures presented in this section. Applicable emissions and emission reductions are presented in Table 4-1 on a LADCO region-wide basis; more detailed state- and nonattainment-level emissions and emission reductions are presented in Appendix B.

Table 4-45. Control measure summary for non-road diesel construction and industrial equipment.[104]

Current Regulations and 2026 Emissions Estimates		
OTB regulations:	EPA[b] Tier 1, 2, 3, and 4 emission standards	
2026 Emissions [a]	Total NOx[c]:	33,829 TPY
	Total VOC[d]:	2,260 TPY
2026 reductions from OTB regulations and/or measures not accounted for in 2026 emission inventory	NOx Reduction:	0 TPY
	Remaining NOx:	33,829 TPY
	VOC Reduction:	0 TPY
	Remaining VOC:	2,260 TPY
Control Measure Summary, Including 2026 Emission Reduction Estimates		
Candidate Control Measure: Fleet Modernization	NOx Reduction	
	Fleet Turnover to Tier 4:	2,061 TPY
	Electrification:	2,705 TPY
	Alternative Fuel Engines	648 TPY
	Cost Effectiveness	
	Fleet Turnover to Tier 4:	*$19,394/ton*
	Electrification:	*$45,573/ton*
	Alternative Fuel Engines	*$13,264/ton*
	Applicability	
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs*
Candidate Control Measure: Anti-idle Rule	NOx Reduction:	1,926 TPY
	Cost Effectiveness:	*$0/ton*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs*
Candidate Control Measure: Emission Specifications in Government Contracts	*NOx Reduction:*	*880 TPY*
	Cost Effectiveness:	*$15,141/ton*
	Applicable States:	*all LADCO states*
	Applicable NAAs:	*all NAAs*

[a] interpolated from 2016v1 modeling platform 2023 and 2028
[b] Environmental Protection Agency (EPA)

4.5.1 Source Category Description

Non-road equipment is defined as any equipment that changes locations at least once every season or year which are not generally licensed or certified for highway use. In the LADCO region, the largest

[104] The effect on VOC emissions resulting from this measure is expected to be minimal.

emissions from non-road diesel equipment are from agricultural, construction, and industrial sectors which contribute 49%, 30%, and 11% of 2026 NOx emissions from diesel engines, respectively. Per direction from LADCO, agricultural emissions and emission reductions are not evaluated herein because emissions from agricultural equipment are mostly located in rural areas which are not as impacted by ozone pollution as urban areas. Figure 4-1 shows contributions by equipment type to LADCO region diesel construction and industrial equipment NOx emissions.

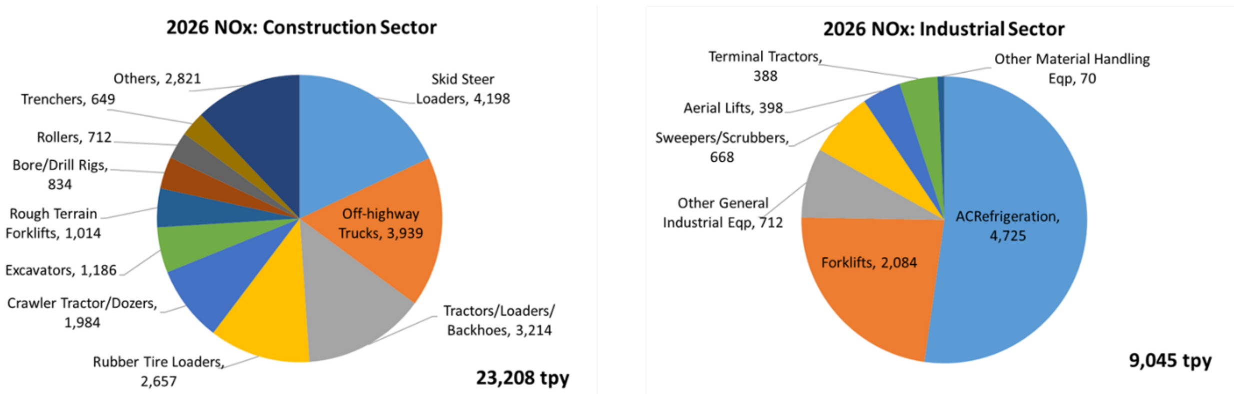

Figure 4-1. 2026 NOx emission contributions from diesel construction and industrial equipment in the LADCO region[105].

Year 2026 NOx and VOC emissions by sector and LADCO state are presented in Table 4-4. Table 4-5 summarizes the emissions by sector and NAA.

Table 4-46. NOx and VOC Emissions from construction and industrial sector non-road diesel engines for 2026 by state and totals.

State	2026 NOx Emissions [a] (TPY)		2026 VOC Emissions [a] (TPY)	
	Construction	Industrial	Construction	Industrial
Illinois	4,720	2,186	416	80
Indiana	5,116	1,621	360	59
Michigan	2,392	1,470	191	54
Minnesota	3,686	1,012	292	36
Ohio	5,305	1,923	389	70
Wisconsin	3,276	1,120	232	41
LADCO-wide	**24,496**	**9,333**	**1,881**	**378**

[a] interpolated from 2016v1 modeling platform 2023 and 2028

[105] 2016v1 emissions are not readily available by detailed equipment type; therefore, this figure shows an emission inventory based on MOVES2014b default estimates for the LADCO region which differs slightly from 2016v1 estimates presented in Table 5-2.

Table 4-47. NOx and VOC emissions from construction and industrial sector non-road diesel engines for 2026 by NAA.

Nonattainment Area	2026 NOx Emissions [a] (TPY)		2026 VOC Emissions [a] (TPY)	
	Construction	Industrial	Construction	Industrial
Allegan, MI	38	24	3	1
Berrien, MI	22	27	2	1
Chicago, IL	2,966	1,380	255	50
Chicago, IN	375	102	26	4
Chicago, WI	77	27	5	1
Cincinnati, OH	905	244	65	9
Cleveland, OH	1,180	479	85	17
Columbus, OH	889	200	64	7
Detroit, MI	1,142	687	91	25
Door, WI	12	6	1	0
Louisville, IN	136	42	10	2
Manitowoc County, WI	25	22	2	1
Muskegon, MI	30	28	2	1
Northern Milwaukee/Ozaukee, WI	217	189	15	7
Sheboygan, WI	38	36	3	1
St. Louis, IL	179	79	15	3
Total	**8,231**	**3,572**	**645**	**130**

[a] interpolated from 2016v1 modeling platform 2023 and 2028

4.5.2 Regulatory History

Diesel engines are significant contributors to the nationwide NOx and PM emissions, while their emissions of CO and VOC are low in comparison to those from spark-ignited engines. Thus, emissions regulations for diesel engines are generally focusing on reducing NOx and PM emissions. EPA adopted the first Tier 1 emission standards for non-road compression-ignition (CI) or diesel engines at or above 50 horsepower (hp) (37 kilowatts [kW]) in June 1994. Subsequently, in October 1998, EPA adopted Tier 1 emission standards for non-road CI engines below 50 hp, as well as Tier 2 and Tier 3 emission standards for all engine sizes of these non-road CI engines. CI engines were required to meet Tier 1 standards beginning in 1996. Tier 2 standards were phased in from 2001 to 2006, depending on horsepower range, while Tier 3 standards were phased in from 2006 to 2008 depending on horsepower range. In June 2004, EPA adopted Tier 4 emission standards that further reduce NOx emissions, as well as PM emissions, from non-road diesel engines. Ozone precursor (i.e., NOx, non-methane hydrocarbon [NMHC], and the summation of NMHC+NOx) emission standards for diesel-fueled non-road equipment are summarized in Table 4-48.

Table 4-48. Emission standards and uncontrolled levels for non-road diesel engines[106].

Rated Power (HP)	Tier	Model Year	NMHC (g/hp-hr)	NMHC + NOx (g/hp-hr)	NOx (g/hp-hr)
HP < 11	1	2000-2004	-	7.84	-
	2	2005-2007	-	5.60	-
	4	2008+	-	5.60	-
11 ≤ HP < 25	1	2000-2004	-	7.09	-
	2	2005-2007	-	5.60	-
	4	2008+	-	5.60	-
25 ≤ HP < 50	1	1999-2003	-	7.09	-
	2	2004-2007	-	5.60	-
	4	2008-2012	-	5.60	-
		2013+	-	3.51	-
50 ≤ HP < 7,5	1	1998-2003	-	-	6.87
	2	2004-2007	-	5.60	-
	3[a]	2008-2011	-	3.51	-
	4 (Option 1)[b]	2008-2012	-	3.51	-
	4 (Option 2)[b]	2012	-	3.51	-
	4	2013+	-	3.51	-
75 ≤ HP < 100	1	1998-2003	-	-	6.87
	2	2004-2007	-	5.60	-
	3	2008-2011	-	3.51	-
	4	2012-2013[c]	-	3.51	-
		2014+[i]	0.14	-	0.30
100 ≤ HP < 175	1	1997-2002	-	-	6.87
	2	2003-2006	-	4.93	-
	3	2007-2011	-	2.99	-
	4	2012-2013[c]	-	2.99	-
		2014+	0.14	-	0.30
175 ≤ HP < 300	1	1996-2002	0.97	-	6.87
	2	2003-2005	-	4.93	-
	3	2006-2010	-	2.99	-
	4	2011-2013[c]	-	2.99	-
		2014+[d]	0.14	-	0.30
300 ≤ HP < 600	1	1996-2000	0.97	-	6.87
	2	2001-2005	-	4.78	-
	3	2006-2010	-	2.99	-
	4	2011-2013[c]	-	2.99	-
		2014+[d]	0.14	-	0.30
600 ≤ HP < 750	1	1996-2001	0.97	-	6.87
	2	2002-2005	-	4.78	-

[106] "Non-road Compression-Ignition Engines: Exhaust Emission Standards", EPA ,2016, https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100OA05.pdf, accessed October 2020

Rated Power (HP)	Tier	Model Year	NMHC (g/hp-hr)	NMHC + NOx (g/hp-hr)	NOx (g/hp-hr)
	3	2006-2010	-	2.99	-
	4	2011-2013[c]	-	2.99	-
		2014+[d]	0.14	-	0.30
750 ≤ HP < 1200	1	2000-2005	0.97	-	6.87
	2	2006-2010	-	4.78	-
	4	2011-2014	0.30	-	2.61
		2015+[d]	0.14	-	2.61
HP > 1200	1	2000-2005	0.97	-	6.87
	2	2006-2010	-	4.78	-
	4	2011-2014	0.30	-	2.61
		2015+[d]	0.14	-	2.61

[a] These Tier 3 standards apply only to manufacturers selecting Tier 4 Option 2. Manufacturers selecting Tier 4 Option 1 will be meeting those standards in lieu of Tier 3 standards.
[b] A manufacturer may certify all their engines to either Option 1 or Option 2 sets of standards starting in the indicated model year. Manufacturers selecting Option 2 must meet Tier 3 standards in the 2008-2011 model years.
[c] These standards are phase-out standards. Not more than 50 percent of a manufacturer's engine production is allowed to meet these standards in each model year of the phase out period. Engines not meeting these standards must meet the final Tier 4 standards.
[d] These standards are phased in during the indicated years. At least 50 percent of a manufacturer's engine production must meet these standards during each year of the phase in. Engines not meeting these standards must meet the applicable phase-out standards.

4.5.3 Candidate Control Measures

There are several control strategies available to reduce emissions from non-road diesel equipment. Fleet modernization refers to replacing older, high emitting engines with cleaner and/or newer engines to reduce NOx and PM emissions. There are several fleet modernization options available such as replacement with Tier 4 engines, replacement with alternative fuel engines (CNG/LPG)[107], and electrification.

Additional control methods include limiting idle emissions through mandates and/or idle limiting devices, and emission specifications in government contracts requiring the use of low emissions equipment fleets. Measure descriptions and emission reductions and cost effectiveness analyses are presented below for each applicable control measure.

Engine and/or aftertreatment device retrofits is another available measure in which emission control devices (e.g., EGR, lean NOx catalyst, SCR) are integrated into an existing engine. Per direction from LADCO, engine and aftertreatment retrofits were not evaluated herein. Based on past analyses (Grant et al., 2014), emission reductions through addition of SCR from engine retrofits are expected to be similar to, albeit slightly less than emission reductions obtained through Tier 4 engine replacements. Cost effectiveness for SCR engine retrofits is expected to be similar to, albeit slightly more cost effective than Tier 4 engine replacements.

Another option is to use a cleaner hydrotreated diesel fuel (renewable diesel or Fischer-Tropsch [FT] diesel). CARB[108] estimated NOx emission reductions of about 10% and PM of 30% for renewable diesel

[107] Compressed Natural Gas (CNG); Liquified Petroleum Gas (LPG)
[108] https://ww2.arb.ca.gov/sites/default/files/2018-08/Renewable_Diesel_Multimedia_Evaluation_5-21-15.pdf, Accessed October 2020

which has lifecycle CO_2 emissions 65% lower than fossil diesel fuel. EPA[109] showed NOx reductions of about 18% and PM of 36% for renewable diesel. Renewable diesel is produced by hydrotreating biomass, while FT diesel is usually produced from natural gas. Both alternative diesel fuels are characterized by high cetane and fewer high distillation components and can be used in place of fossil diesel fuel without engine modification. While the availability of FT diesel fuel is limited, the availability of renewable diesel fuel is expanding. However, nearly all domestically produced and imported renewable diesel is used in California due to economic benefits under the LCFS program. California offers emission credits to be generated from renewable diesel through their LCFS program to enhance the market for renewable diesel by reducing the price differential between renewable and fossil diesel.

4.5.3.1 Fleet Modernization

Under a fleet modernization program, higher-emitting off-road mobile equipment is replaced with a similar piece of equipment with lower emissions. This is achieved by 1) replacing existing engines with newer, cleaner engines or rebuilding engines to meet cleaner emission standards; 2) replacing fossil-fueled engines with all electric models; and/or 3) replacing conventional fuel engines with alternative fuel (CNG/LPG) models.

There are several existing programs that provide grant funding for fleet modernization such as the DERA[110] (administered by EPA), Carl Moyer Off-Road Voucher Incentive Program[111] (administered by CARB), and the Texas Emissions Reduction Plan[112] (TERP; administered by the Texas Commission on Environmental Quality [TCEQ]). Each program has provided grants to turnover equipment and provide emission reductions.

<u>Fleet turnover to Tier 4</u>
This control measure consists of replacing an engine or an entire piece of equipment with a new engine meeting the final Tier 4 emission standard, or a remanufactured engine that meets the final Tier 4 emission standard.

The most widely employed method for reducing emissions from non-road diesel engines is replacing older engines with newer lower-emitting engines or replacing the entire piece of equipment with equipment that has a lower-emitting diesel engine, including replacement with both new and remanufactured engines.

The actual emission reduction will depend upon the actual engine replaced. Like any scrappage program, the scrapped engine should be in good working order and would otherwise be used for many years to come if not replaced under this program. The life of the emission credit generated will be equivalent to the remaining life of the engine to be replaced.

Ramboll analyzed NOx emissions contributions from construction and industrial equipment by tier level. In 2026, 33% of NOx emissions from diesel-fueled construction equipment are from engines with relatively high emissions rates (e.g., Tier 0, Tier 1, and Tier 2) per MOVES2014b estimates. There are substantial emission reductions available for Tier 4 replacements of diesel-fueled construction equipment. For diesel-fueled industrial equipment in the LADCO region, in 2026, 93% of NOx emissions are estimated by MOVES2014b to be from Tier 4 engines. Only 7% of industrial sector non-

[109] https://www.epa.gov/sites/production/files/2015-03/documents/01172001mstrs_passavant.pdf, Accessed online October 2020.
[110] https://www.epa.gov/dera, accessed October 2020
[111] https://ww2.arb.ca.gov/our-work/programs/carl-moyer-program-road-vip/about, accessed October 2020
[112] The TERP program, established by the Texas legislature in 2001, is a program aimed at improving air quality in Texas by reducing emissions of oxides of nitrogen (NOx) from both on-road and non-road high-emitting internal combustion engines. https://www.tceq.texas.gov/airquality/terp/erig.html, accessed October 2020

road diesel fleet NOx emissions are from engines not certified to Tier 4 standards. Therefore, fleet turnover to Tier 4 certified engines focused on construction equipment.

Electrification

This measure is similar to the accelerated equipment replacement strategy, except that it would replace diesel engines with electric equipment with zero direct emissions[113]. Currently, all-electric construction equipment is not available for widespread use. Therefore, the electrification analysis focuses on industrial equipment. We estimated emission reductions for replacement of diesel engines with all-electric A/C refrigeration units, forklifts and terminal tractors because electric models are readily available for these equipment types.

Alternative Fuel

Ramboll reviewed EPA[114] and CARB[115] engine certification databases to determine construction and industrial equipment applications for which CNG/LPG models are available. CNG/LPG engines available for use in construction equipment were limited to low horsepower tractors. For industrial equipment, alternative fuel models were found for forklifts, sweeper/scrubbers, and terminal tractors. Table 4-49 shows alternative fuel and diesel fuel certification standards for the applicable equipment. We estimated emission reductions resulting from engines for which emission standards indicated substantially lower CNG/LPG emission rates compared to diesel emission rates. As shown in Table 4-49, engines in the 50-75 hp range have substantially lower CNG/LPG emission rates compared to Tier 4 emission rates.

Table 4-49. Emission rates for alternative fuel and comparable Tier 4 diesel industrial equipment.

Diesel Equipment Type	HP Bin	2026 NOx Emissions (tpy)	Alternative Fuel		HC+NOx Diesel Tier 4 Standard (g/bhp-hr)	Ratio of Alternative Fuel to Tier 4 Emission Factor
			Fuel Type	HC+NOx Standard (g/bhp-hr)		
Forklift	50-75 HP	1,324	CNG	0.60	3.51	17%
	75-100 HP	621	CNG	0.60	0.44	136%
Sweepers/ Scrubbers	100-175 HP	107	LPG	0.60	0.44	136%
	50-75 HP	111	LPG	0.60	3.51	17%
	75-100 HP	203	LPG	0.60	0.44	136%
Aerial Lifts	50-75 HP	199	LPG	0.60	3.51	17%
	75-100 HP	71	LPG	0.60	0.44	136%
Terminal Tractors	100-175 HP	56	LPG	0.60	0.44	136%
	175-300 HP	96	LPG	0.60	0.44	136%
	50-75 HP	126	LPG	0.60	3.51	17%
	75-100 HP	100	LPG	0.60	0.44	136%

[113] "Direct" refers to emissions emitted by a piece of equipment (e.g., tailpipe) whereas "indirect" refers to emissions from electricity generation required to power a piece of electric equipment. Indirect emissions are not analyzed herein.

[114] https://www.epa.gov/compliance-and-fuel-economy-data/annual-certification-data-vehicles-engines-and-equipment, accessed October 2020

[115] https://ww3.arb.ca.gov/msprog/offroad/cert/cert.php, accessed October 2020

<u>Emission Reductions</u>

Fleet Turnover to Tier 4

Emission reductions depend on several factors such as the standard to which the engine to be replaced is certified (i.e., Tier 0, Tier 1, Tier 2), number of equipment available for replacement (i.e., equipment population), annual hours or use, load factor, and horsepower range of the engine replaced. Ramboll ran MOVES2014b[116] to generate LADCO-specific emission inventories with sufficient detail (i.e., by diesel engine Tier level) for this analysis. Emission standards[106,117] by horsepower bin (see Table 4-48[118]) were used to estimate emission rate reductions associated with Tier 4 engine replacement.

We lumped construction equipment into three groups (Table 4-50) by load factor and estimated emission reductions for each group based on turnover of Tier 0, Tier 1, and Tier 2 equipment to Tier 4 emission standards. Emission reductions were estimated for horsepower bins within each equipment group that comprise a vast majority of NOx emissions. We assumed that 30% of Tier 0, Tier 1, and Tier 2 equipment is turned over by 2026. Given a different Tier 0, Tier 1, and Tier 2 turnover percentage, emission reductions would change proportional to the change in turnover percentage. For example, if 10% of Tier 0, Tier 1, and Tier 2 equipment is turned over by 2026, then emissions reductions would change by the ratio of 10% to 30%, or a multiplicative scalar of one-third. Cost effectiveness is not sensitive to turnover percentage.

Table 4-50. List of construction equipment by group.

Equipment Group	Load Factor	Equipment
Group A	0.21	Diesel Tractors, Loaders, Backhoes, Skid Steer Loaders, Dumpers, Tenders, and Other Underground Mining Equipment
Group B	0.43	Diesel Tampers, Rammers, Plate Compactors, Signal Boards, Light Plants, Bore/Drill Rigs, Cement & Mortar Mixers, Cranes, Crushing/Proc. Equipment
Group C	0.59	Diesel Pavers, Paving Equipment, Surfacing Equipment, Trenchers, Excavators, Concrete/Industrial Saws, Graders, Off-highway Trucks, Rough Terrain Forklifts, Rubber Tire Loaders, Crawler Tractor/Dozers, Off-highway Tractors, and Other Construction Equipment

LADCO-wide equipment population and NOx emission reduction estimates are summarized in Table 4-51 and Table 4-52 respectively. Equipment population and emission reductions by state and NAA are presented in Appendix B (Table B 1 - Table B 2).

[116] https://www.epa.gov/moves/latest-version-motor-vehicle-emission-simulator-moves, accessed October 2020
[117] Tier 0 emission factors from "Exhaust and Crankcase Emission Factors for Non-road Engine Modeling Compression-Ignition", EPA, 2010. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081UI.pdf, accessed October 2020
[118] In instances where emission factors are only available for NOx+NMHC, 95% of emissions are apportioned to NOx for diesel-fueled equipment

Table 4-51. LADCO region 2026 engine population for Tier 0, Tier 1, and Tier 2 construction equipment.

Equipment Group	Horsepower Range	Tier 0	Tier 1	Tier 2	Total (Tier 0+ Tier 1+ Tier 2)
Group A	50-75 HP	3,140	10,719	6,915	20,774
	75-100 HP	2,786	9,722	6,110	18,618
	100-175 HP	515	1,717	2,433	4,665
Group B	100-175 HP	90	234	402	726
	175-300 HP	64	203	311	578
	300-600 HP	52	130	384	566
	750-1000 HP	11	41	10	61
Group C	300-600 HP	27	217	679	923
	600-750 HP	4	37	103	144
	750-1000 HP	2	29	74	105

Table 4-52. LADCO region NOx emission reduction estimates for construction equipment modernized with Tier 4 engines.

Equipment Group	Horsepower Range	2026 Baseline NOx Emissions (tpy)	Average NOx Emission Reduction per Unit (tpy[a]/unit)	Total NOx Emission Reduction (tpy)	NOx Emissions Reduction (%)
Group A	50-75 HP	2,478	< 0.1	257	10%
	75-100 HP	3,142	0.1	709	23%
	100-175 HP	1,125	0.2	282	25%
Group B	100-175 HP	193	0.3	60	31%
	175-300 HP	244	0.5	85	35%
	300-600 HP	471	0.9	149	32%
	750-1000 HP	118	0.9	17	15%
Group C	300-600 HP	1,906	1.3	356	19%
	600-750 HP	632	2.2	94	15%
	750-1000 HP	1,532	1.7	53	3%

[a] short tons per year (tpy)

Electrification

For select equipment and horsepower ranges for which electric equipment models were identified, we estimated emission reductions resulting from turnover of diesel-fueled equipment to electric models. Emission reductions were estimated based on MOVES2014b. LADCO region estimates for diesel-fueled equipment emission inventory inputs such as population, load factor and annual activity by equipment type and hp range. We assumed turnover of 30% of equipment population by 2026 for applicable equipment types and hp ranges. Given a different Tier 0, Tier 1, and Tier 2 turnover percentage, emission reductions would change proportional to the change in turnover percentage. For example, if 10% of Tier 0, Tier 1, and Tier 2 equipment is turned over by 2026, then emissions reductions would change by the ratio of 10% to 30%, or a multiplicative scalar of one-third. Cost effectiveness is not sensitive to turnover percentage.

LADCO-wide equipment population and NOx emission reductions are summarized in Table 4-53 and Table 4-54 respectively. Equipment population and emission reductions by state and NAA counties are presented in Appendix B (Table B 3 – Table B 4).

Table 4-53. Engine population available for industrial equipment electrification.

Equipment	Horsepower Range	Diesel Equipment Population
A/C Refrigeration	6-11 HP	1,829
	11-16 HP	5,621
	16-25 HP	5,270
	25-40 HP	1,352
	40-50 HP	9,906
	50-75 HP	37,730
Forklifts	50-75 HP	7,738
	75-100 HP	7,796
Terminal Tractors	50-75 HP	978
	75-100 HP	1,693
	100-175 HP	2,719
	175-300 HP	4,531

Table 4-54. LADCO region NOx emission reduction estimates for industrial equipment electrification.

Equipment	Horsepower Range	2026 Baseline NOx Emissions (tpy)	Average NOx Emission Reduction Per Unit (tpy/unit)	Total NOx Emission Reduction (tpy)	NOx Emissions Reduction (%)
A/C Refrigeration	6-11 HP	46	<0.1	10	21%
	11-16 HP	175	<0.1	48	27%
	16-25 HP	242	<0.1	69	28%
	25-40 HP	68	0.1	28	41%
	40-50 HP	704	0.1	283	40%
	50-75 HP	3489	0.1	1,498	43%
Forklifts	50-75 HP	1324	0.2	534	40%
	75-100 HP	621	<0.1	68	11%
Terminal Tractors	50-75 HP	126	0.2	50	40%
	75-100 HP	100	<0.1	11	11%
	100-175 HP	56	<0.1	27	49%
	175-300 HP	96	0.1	79	82%

<u>Alternative Fuel</u>

For select equipment and horsepower ranges for which CNG/LPG equipment models were identified, we estimated emission reductions resulting from turnover of diesel-fueled equipment to electric models. Table 4-55 summarizes the list of equipment and hp ranges considered in the analysis. Emission reductions were estimated based on MOVES2014b LADCO region estimates for emission inventory inputs such as population, load factor and annual activity by equipment type and hp range. We assumed turnover of 30% of equipment population by 2026 for applicable equipment types and hp ranges. Given a different Tier 0, Tier 1, and Tier 2 turnover percentage, emission reductions would change proportional to the change in turnover percentage. For example, if 10% of Tier 0, Tier 1, and Tier 2 equipment is turned over by 2026, then emissions reductions would change by the ratio of 10% to 30%, or a multiplicative scalar of one-third. Cost effectiveness is not sensitive to turnover percentage.

Table 4-55. Industrial equipment population by horsepower ranged included in alternative fuel analysis.

Equipment	Horsepower Range	Approximate Engine Population
Forklifts	50-75 HP	7,738
Sweepers/Scrubbers	50-75 HP	1,231
Terminal Tractors	50-75 HP	978
Aerial Lifts	50-75 HP	7,297

LADCO-wide NOx emission reductions are summarized in Table 4-56. Equipment population and emission reduction broken down by State and NAA are presented in Appendix B (Table B 5 - Table B 6).

Table 4-56. LADCO region NOx emission reduction estimates for industrial equipment modernized with alternative fuel engines.

Equipment	Horsepower Range	2026 Baseline NOx Emissions (tpy)	NOx Emission Reduction Per Unit (tpy/unit)	Total NOx Emission Reduction (tpy)	NOx Emissions Reduction (%)
Forklifts	50-75 HP	1,324	0.2	534	40%
Sweepers/Scrubbers	50-75 HP	111	0.1	38	34%
Terminal Tractors	50-75 HP	126	0.1	42	33%
Aerial Lifts	50-75 HP	199	<0.1	34	17%

<u>Cost Effectiveness</u>

Fleet Turnover to Tier 4

Ramboll estimated that Tier 4 engines cost about $285 per hp (for engines <300 hp) and $140 per hp (for engines >300 hp) yielding a range of Tier 4 engine costs of about $18K to $123K for construction equipment (this is the cost for engine replacement, not equipment replacement). The average cost of certain pieces of equipment could be more or less depending on the complexity of the replacement.

The cost-effectiveness of engine or equipment replacement depends on emissions reductions from the replaced engines and the cost associated with the engine replacement. Cost effectiveness estimates for construction fleet modernization are summarized in Table 4-57. Cost effectiveness estimates by state and NAA counties are presented in Appendix B (Table B 1 - Table B 2).

Table 4-57. Average cost effectiveness for fleet modernization to Tier 4 equipment.

Equipment Group	Horsepower Range	Cost Effectiveness ($/ton NOx)			Average Cost Effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton NOx)
		Tier 0	Tier 1	Tier 2	
Group A	50-75 HP	$28,126	$42,048	$78,102	$45,648
	75-100 HP	$16,258	$20,758	$27,983	$21,698
	100-175 HP	$14,774	$18,863	$28,434	$22,062
Group B	100-175 HP	$10,714	$13,679	$20,620	$16,129
	175-300 HP	$10,429	$12,097	$20,070	$15,050
	300-600 HP	$4,996	$5,795	$9,947	$7,922
	750-1000 HP	$10,064	$12,399	$31,407	$13,145
Group C	300-600 HP	$3,255	$3,776	$6,481	$5,412
	600-750 HP	$2,906	$3,370	$5,785	$4,765
	750-1000 HP	$3,561	$4,387	$11,113	$7,602
Total		**$16,224**	**$19,302**	**$20,825**	**$19,394**

Electrification

CARB (2015) estimated the cost of full-electric transportation refrigeration units (TRU) to be $23K for all horsepower ranges. A/C refrigeration equipment horsepower in MOVES is skewed slightly higher than CARB TRU horsepower. CARB does not show any TRUs greater than 50 horsepower whereas MOVES includes A/C refrigeration in the 50-75 hp bin (but with a relatively low average rated power of 57 hp). We have assumed the CARB capital cost applied to all A/C refrigeration units, though the cost could be biased slightly low for A/C refrigeration if engine horsepower is biased slightly low.

California's Clean Off Road Equipment Voucher Incentive Project (CORE) program (CARB, 2020) estimates a cost of $15K-$20K for electric forklifts and $68K-$259K for terminal tractors (CORE voucher costs vary by equipment horsepower bin).

The cost effectiveness estimates for all-electric industrial equipment analyzed are summarized in Table 4-58 (detailed cost effectiveness calculation data are presented in the electronic spreadsheet). The cost effectiveness estimates by State and NAA counties are presented in Appendix B (Table B 3 – Table B 4). These cost effectiveness estimates are based on estimated capital cost for electric equipment purchases. Maintenance and electricity costs are not included. Compared to diesel-fueled models, regular maintenance of electric equipment tends to be less costly because certain maintenance (e.g., oil changes) is unnecessary. Similarly, electricity costs are typically lower than diesel costs. However, the cost of electrification is complicated by the need for recharge infrastructure. Recharge stations range in cost from approximately $500 (portable) to $3000 (stationary) per charger.

Table 4-58. Average cost effectiveness for fleet electrification.

Equipment	Horsepower Range	Average Cost Effectiveness ($/ton)
A/C Refrigeration	6-11 HP	$258,356
	11-16 HP	$162,669
	16-25 HP	$107,123
	25-40 HP	$49,669
	40-50 HP	$35,872
	50-75 HP	$18,864
Forklifts	50-75 HP	$7,230
	75-100 HP	$53,829
Terminal Tractors	50-75 HP	$44,446
	75-100 HP	$347,458
	100-175 HP	$347,456
	175-300 HP	$347,456
Total		**$45,573**

Alternative Fuel

Alternative fuel equipment capital cost was estimated based on readily available information obtained through literature search (Table 4-59). The cost of alternative fuel implementation is complicated by the need to develop fueling infrastructure. To some extent, fueling infrastructure capital cost will be offset by using alternative fuel which has a lower cost than diesel.

Table 4-59. Sample cost of alternative fuel powered industrial equipment.

Industrial Equipment	Fuel Type	Purchase Cost
Forklifts	CNG	$14K
Sweepers/Scrubbers	LPG	$13K
Terminal Tractors	LPG	$45K
Aerial Lifts	LPG	$13K

The cost effectiveness estimates for alternative fuel industrial equipment are summarized in Table 4-60. The cost effectiveness estimates by State and NAA are presented in Appendix B (Table B 5 – Table B 6).

Table 4-60. Average cost effectiveness for alternative fuel fleet modernization.

Equipment	Horsepower Range	Average Cost Effectiveness for CNG/LPG ($/ton)
Forklifts	50-75 HP	$6,520
Sweepers/Scrubbers	50-75 HP	$14,205
Terminal Tractors	50-75 HP	$34,957
Aerial Lifts	50-75 HP	$92,410
Total		**$13,264**

4.5.3.2 Anti-Idle Rule

Non-road equipment operation includes idle mode operation in which engines are not required to generate propulsion power. Unless an anti-idling program and/or technology is in place, a diesel engine will emit pollutants under low-load conditions during idle-mode operation. Idling cannot be avoided in all cases, such as during normal work when medium or high load operations are performed intermittently and the time to restart the engine would be considered a significant delay. This measure would limit excessive idling. Suggested maximum idle duration could be as low as 3 consecutive minutes of idling. Newer equipment includes telematics systems that allow operators to set auto shutdown systems to power engines down after they idle for a set period. Idle limiting devices may also be installed on older equipment. Operator training could also provide significant idle reduction for small or little used equipment where additional hardware is not cost effective.

Examples of existing off-road diesel idle reduction programs are provided below:

- **California In-use Off-road Diesel-fueled Fleets Rule**[119] allows no more than 5 consecutive minutes of idling for non-road engines subject to the regulation. The regulation is applicable to non-road construction equipment greater than 25 hp.
- **State of New Jersey Idling Law**[120] allows no more than 3 consecutive minutes of idling for the engines subject to this regulation. New Jersey's anti-idling rule includes the following cold temperature provision: "A motor vehicle that has been stopped for three or more hours when the ambient temperature is below 25 degrees Fahrenheit may idle for up to 15 consecutive minutes."

Emission Reductions

Emission reductions for an anti-idling mandate are based on estimated time in idle and relative emissions rates while at idle. This analysis focuses on emission reductions from construction equipment. Based on test data for construction diesel engines (Cao et. al, 2016), it is estimated that non-road engines are at idle 20%-29% of the time that they are in operation. Using emission results for twenty-seven diesel engines (Cao et. al, 2016), idle emissions are responsible for about 14% to 36% of all emissions (see Table 4-61). Engines tested in the study ranged from 2003-2012 model year and 92-540 hp.

[119] "Regulation for in-use off-road diesel-fueled", California Air Resource Board (CABR), 2011, https://ww2.arb.ca.gov/sites/default/files/classic/msprog/ordiesel/documents/finalregorder-dec2011.pdf, accessed October 2020
[120] "Non-road diesel equipment idling fact sheet", State of New Jersey Department of Environmental Protection, 2012, https://www.state.nj.us/dep/stopthesoot/Non-road%20Idling%20Fact%20Sheet%202012.pdf, accessed October 2020

It is not possible to eliminate all engine idling as some of the idle time occurs in short duration intervals between non-idle modes that occur during normal operations.

For new engines, especially those meeting the Tier 4 NOx emission standards, SCR is likely to be used to control NOx emissions. SCR does not work well at idle because the exhaust temperature can be too cool to keep catalysts within its operating range. For engines equipped with SCR, the fraction of idle emissions may be considerably higher if the idle emission rate is not substantially controlled by the SCR.

Table 4-61. Average engine idle and non-idle emissions by horsepower.

Parameter	Horsepower Range			
	50-100 HP	100-175 HP	175-300 HP	300-600 HP
Average fraction of NOx emissions from idling	36%	38%	26%	14%
Average Idle Time (%)	21%	20%	26%	29%
Average Non-Idle Time (%)	79%	80%	74%	71%
NOx Idling emissions (g/hr)	94	119	92	85
NOx Non-Idling emissions (g/hr)	164	194	268	511
VOC Idling emissions (g/hr)	7	8	4	5
VOC Non-Idling emissions (g/hr)	20	15	16	23

Common types of construction equipment such as excavators, loaders, and dozers average on the order of 1,000 annual hours of operation per unit, and may accrue hundreds of hours of idle time per unit. If idling hours were reduced by 67%, on average, NOx and VOC emissions would be reduced by 4-9% per year based on Cao et al. (2016) estimates in Table 4-61. For a 67% reduction in idle time, we estimate that 1,926 tons of NOx would be reduced. Corresponding emissions reductions by State and NAA are summarized in Appendix B (Table B 7- Table B 8).

Cost Effectiveness

Idle reductions requirements are typically extremely cost effective based on fuel savings accrued from idle reductions. Only in cases in which an engine is not often used would the capital cost required to add an idle limiting device to a piece of equipment result in a net cost. For little-used equipment, operator training would be a better option.

A sample idle limiting device cost is $155[121]. Assuming idle fuel consumption of about 1 gallon per hour[120], approximately $2,000 would be saved in fuel costs, annually, by reducing idle hours by 100 hours per year.

4.5.3.3 Emission Specifications in Government Contracts

This measure aims to reduce emissions associated with construction equipment that is operated as part of projects to fulfill state, county or municipal contracts. The goal of this measure is to adopt an ordinance that includes provisions to control emissions from non-road equipment which includes the

[121] https://www.flightsystems.com/engine-idling-management-controls/model-277/, accessed October 2020

use of best available technology for limiting NOx emissions and idle-reduction policies. Example contract language can be found in Northeast Diesel Collaborative (NEDC)[122] guidance.

Example agencies that have mandates to reduce non-road diesel equipment emissions through measures such as clean construction fleets and/or idle reductions are listed below.

- Portland Metro Area Clean Air Construction Collaborative (City of Portland, Port of Portland, Multnomah County, Washington County and Metro)[123]
- The Connecticut Department of Transportation[124]
- The Massachusetts Highway Department[125]
- New York State Department of Transportation[126]

Agencies rules may stipulate contract valuation thresholds for clean diesel measures; for example, in the Portland Metro Area, the contract valuation threshold for clean diesel provisions to apply varies from $0.5 million to $1 million.

Emission Reductions

This measure affects emissions from non-road sector diesel construction equipment. Information is not readily available to determine the fraction of emissions from construction equipment that is used to fulfill government contracts in LADCO states. In the Dallas-Fort Worth area, 20% to 25% (Grant, et al. 2015) of NOx emissions were estimated to be from equipment owned by, operated by or on behalf of, or leased by a state or local government/public agency. Grant et al. estimated that 5%-10% of construction equipment is used in the fulfillment of municipal contracts to which contract stipulations could reduce emissions. In addition to municipal contracts considered in Grant et al. (2015), equipment operated under state and county contracts may also be reduced by this measure. Therefore, we have assumed that 10% of NOx emissions from non-road construction equipment in LADCO states are from equipment owned by, operated by or on behalf of, or leased by a local government/public agency.

MOVES2014b estimates that less than one-third (32%) of diesel construction equipment in LADCO states in 2026 is certified to Tier 2 or less stringent emission standards. There is potential for significant reductions in emissions by adopting contract language that for example, limits using old engines on site, restricts long term idling, requires best operation practices, requires regular equipment maintenance, and/or specifies use of clean fuels.

Emission reductions will vary depending on specific actions and contract agreements. We have assumed that (a) emission reductions are consistent with percentage reduction available due to fleet modernization with Tier 4 certified engines, assuming 100% of the government fleet is powered by Tier 4 engines, and (b) anti-idling is assumed to affect the entire fleet of construction equipment which could be subject to the government contracts mandate.

We estimate LADCO region emission reductions of 193 tons from anti-idle rule and 687 tons from fleet modernization to Tier 4 for a total estimated NOx emissions reduction of 880 tons for the LADCO

[122] "Model Contract Language & Best Practices", NEDC, https://www.northeastdiesel.org/construction.html#ModelContractLanguage, accessed October 2020
[123] https://www.portland.gov/omf/brfs/procurement/clean-air-construction/clean-air-construction-overview-and-requirements , accessed October 2020
[124] https://www.northeastdiesel.org/pdf/construction/CT-DOT-bid-spec.pdf , accessed October 2020
[125] https://www.northeastdiesel.org/pdf/construction/MHD-contract-spec.pdf , accessed October 2020
[126] https://www.northeastdiesel.org/pdf/construction/RTE9A-NY.pdf , accessed October 2020

region from the emission specifications in government contracts measure. Emissions reductions by State and NAA are summarized in Appendix B (Table B 9- Table B 10).

Cost Effectiveness

The implementation of this measure may result in additional costs if contractor bids are higher due to the requirement to meet more stringent Tier 4 standards or if government agencies opt to share with contractors the cost of equipment upgrades that would be required. Detailed estimates of costs and cost effectiveness associated with upgrades to Tier 4 engines and anti-idle rule are provided above. A weighted average cost effectiveness for this measure assuming negligible cost for anti-idling is $15,141/ton. Part of the cost may be leveraged through opportunities to improve: (a) occupational exposure, (b) community health, (c) company image, and (d) community concerns including environmental justice issues.

4.5.4 Geographic Applicability

All control measures considered for non-road diesel equipment herein (fleet modernization, anti-idling, and emission specifications in government contracts) could be applied to local fleets, regional areas (e.g., NAAs), and/or on a statewide basis. As discussed above, a federal grant program (DERA) is available to facilitate fleet turnover of non-road diesel equipment. Grant programs have also been implemented at the state-level (e.g., TERP in Texas and Carl Moyer in California), but at this time there is no local/state/multi-state program to facilitate non-road diesel fleet turnover in the LADCO region nor are there currently anti-idling regulations for construction equipment in the LADCO region.

4.5.5 Seasonal Applicability

The fleet modernization program should be little affected by seasonal variation. The anti-idling program should consider exemptions during extreme winter temperatures; for example, New Jersey allows for idling up to 15 consecutive minutes after a cold start when the temperature is less than 25F.

4.5.6 Implementation Schedule

The schedule for implementing grant funding for the diesel engine emissions projects will likely occur over several years, and replacement or retrofit projects, require careful tracking to ensure that the project is completed according to grant program requirements. State and/or local agency tracking of grant programs and encouraging participation among potential applicants could potentially increase participation in federal programs.

4.5.7 Implementation Feasibility

Several states have funded voluntary programs to turnover older, higher emitting engines and equipment to newer, cleaner models. Texas TERP[112], California Carl Moyer[127], and the federal EPA DERA[110] program have issued guidance, tools and resources for implementing voluntary emission reduction grants. Guidelines for such a modernization program, especially eligibility criteria, and emission credit life, should be clearly defined to avoid potential issues related to surplus emissions versus normal turnover rates.

Anti-idle reduction measures have been successfully implemented in other areas in the U.S., such as in California[119] and New Jersey[120].

[127] https://ww2.arb.ca.gov/our-work/programs/carl-moyer-memorial-air-quality-standards-attainment-program , accessed October 2020

The emission specifications in government contracts for construction fleets enforcing emission reduction measure is feasible and widely accepted. It is commonly used to improve air quality around local construction sites. Many government agencies (e.g. Texas Department of Transportation [TxDOT][128]), local organizations, businesses and institutions have attempted to use contract specifications in sensitive areas to require the use of cleaner technology.

Recently, EPA has announced $73 million in grants to support various clean diesel programs and project across the county at the state and local level. The Fixing America's Surface Transportation Act (FAST)[129] provides flexible funding of $2.3 to $2.5 billion from 2016 through 2020 to State and local governments for eligible projects, including projects with emphasis on diesel engine retrofits including installation of diesel emission control technology on non-road diesel equipment that is operated on a highway construction projects, port-related landside non-road or on-road equipment, and electric and natural gas fuel infrastructure.

4.5.8 Public Acceptance

Very little or no public opposition has been encountered with voluntary grant programs. For a fixed funding pool, there will be competing interests between marine, locomotive, other off-road, and on-road vehicle emission reduction projects. The anti-idling program will result in fuel savings for construction fleets, which could enhance its public acceptance. The emission specifications in government contracts program to stipulate use of clean fleets could result in opposition from contractors without compliant fleets; participation in grant programs to replace or retrofit older equipment could help bring such fleets into compliance.

4.5.9 Affected Source Category Codes

The affected SCCs are shown in Table 4-15 as implemented in the 2016v1 modeling platform. These reflect aggregate SCCs over several individual equipment types that were used to characterize non-road diesel construction and industrial equipment emissions.

Table 4-62. Construction & mining and industrial equipment source category codes.

SCC	Description
2270002022	Mobile Sources; Off-highway Vehicle Diesel; Construction Equipment; Total
2270003022	Mobile Sources; Off-highway Vehicle Diesel; Industrial Equipment; Total Except AC Refrigeration
2270003060	Mobile Sources; Off-highway Vehicle Diesel; Industrial Equipment; AC\\Refrigeration
2270009010	Mobile Sources; Off-highway Vehicle Diesel; Underground Mining Equipment; Other Underground Mining Equipment

[128] "Standard Specification for Construction and Maintenance of Highways, Streets, and Bridges", TxDOT, 2014, https://ftp.txdot.gov/pub/txdot-info/cmd/cserve/specs/2014/standard/specbook-2014.pdf, accessed October 2020
[129] https://www.fhwa.dot.gov/fastact/factsheets/cmaqfs.cfm , accessed October 2020

5.0 EMISSIONS FROM NON-NATIONAL EMISSION INVNETORY SOURCES

5.1 Existing Conditions and Background

Ramboll reviewed the national emission inventories included in the 2016v1 Modeling Platform to determine whether there are sources for which emissions may be underrepresented and, for which, control strategies have not yet been identified. Under consultation with LADCO, we revised LADCO's emission inventory for HDDT and VCP source categories and identified potential emission control options for these categories. This section describes the steps taken:

1) Reviewed available documentation for the 2016v1 Modeling Platform and MOVES to identify emission processes that may not be accurately represented such as low-load/speed and tampering and mal-maintenance effects on HDDT exhaust emissions. Similarly, available literature and 2016v1 Modeling Platform documentation on VCPs was reviewed to evaluate potentially underestimated emissions for this sector in LADCO states.
2) Developed emission inventory adjustments that can be applied to LADCO emission inventories or future bottom-up inventories developed by LADCO (e.g. on-road inventories).
3) Investigated and quantified reductions from control strategies that address the estimated excess emissions for HDTs and nonpoint VCP sources.

The emission estimates developed in this chapter are for LADCO and member states' consideration. Use of these inventories for air quality planning is at the discretion of LADCO and member states.

5.1.1 Heavy Duty Trucks

HDTs are certified under emission standards which necessitate application of aftertreatment devices such as DPF and SCR for PM and NOx emission control, respectively. The latest PM standard has been required for 2007 model year and later engines. The latest NOx standard was phased-in from 2007 to 2010 model year engines. EPA[130] is considering further emission controls for new engines with as yet unspecified controls, levels, and implementation schedules.

EPA[131] is currently evaluating 2010+ model year HDT emissions rates and expects to update the MOVES model to better characterize emission profiles.

> "*We're updating MOVES to incorporate new data on HDVs. We're aiming to release the model later this year* [2020]*. The updates will include op-mode* [operating modes defined by speed/power bins] *specific changes to better account for real-world performance of SCR and other aftertreatment, updates to better account for idling (extended idle and "off-network"*[132] *idling) and updates to account for gliders, etc. Most of this work has been discussed at the MOVES Review Workgroup* https://www.epa.gov/moves/moves-model-review-work-group *and summarized in the EPA presentation* [at the 2019 International Emissions Inventory Conference, July 31, 2019, Dallas, TX.]" **EPA Group Mobile, June 16, 2020**

[130] Cleaner Truck Initiative, https://www.epa.gov/regulations-emissions-vehicles-and-engines/cleaner-trucks-initiative, Accessed online October 2020.

[131] Personal communication with EPA Group Mobile, June 16, 2020.

[132] Off-network idling, also known as short-term idling, refers to any idling activity of less than 1-hour per event at off-network locations (parking lots, driveways, warehouses, etc.). Extended idling refers to idling activity of more than 1-hour per event, typically observed in sleeper/long haul combination trucks hoteling by the road or at rest stops.

Many of the emission inventory updates have already been considered and implemented in EMFAC2017 model[133], which is used to estimate on-road emissions in California. The EMFAC2017 model has different activity and emissions binning but, compared to MOVES, incorporates more recent information on low load emissions characteristics and emission control device deterioration to estimate emissions from modern HDDTs. The MOVES2014[134] model relied on the numerical emission standards limits and engineering judgement instead of actual emissions data such as was used by CARB in the development of EMFAC2017.[135] EPA is quoted in the MOVES documentation to have not used emissions data for modern (2010+) diesel on-road engine and vehicle emissions:

> *"In this section we discuss the "hole-filling" methodology used to fill missing operating mode bins, and missing vehicle-type and model year combinations. To do so, we rely on the heavy-duty diesel emission standards, as well as engineering knowledge and test data of emission control technologies that were forecasted to be implemented to meet more stringent standards in 2007 and 2010." EPA 2015.*[5]

5.1.2 Volatile Chemical Products

A recent study[136] by McDonald et al. estimated that VOC emissions from VCPs (i.e., pesticides, coatings, printing inks, adhesives, cleaning agents, and personal care products) are potentially substantially underestimated in current emission inventories by a factor of about three, nationwide. We used this reference and developed a methodology to make emission adjustments for applicable categories. In collaboration with LADCO staff and members, we revised the LADCO VOC emissions for these source categories. McDonald et al. (2018) did not indicate how the underreported emissions occur, such as whether current sources are underestimated or whether additional sources and categories have been ignored. The conditions when or how the additional emissions are occurring is important to understand when crafting control programs to address these sources.

5.1.3 Regulatory Setting

In order to develop the LADCO ozone precursor emissions control strategies analysis, potential emission reductions must be informed by an understanding of OTB and OTW regulations. Ultimately, control strategies must result in emission reductions based on control of emissions and/or activity reductions on top of requirements under federal, state, and/or local regulations.

Ramboll compiled, and LADCO member states reviewed and commented on, local and state regulations applicable to anthropogenic sources responsible for a vast majority of NOx and VOC emissions in the LADCO region (table included as Appendix C for the HDDT and VCP emissions)[137]. State/local regulations which incorporated Federal regulations by reference, and that do not require emissions control beyond Federal requirements were not included (e.g. Minnesota Rules Chapter 7011.0830 incorporates 40 CFR Subpart F: New Source Performance Standards for Portland Cement Plants). While it is not comprehensive, the regulation list includes a vast majority of anthropogenic source category NOx and VOC emissions in the LADCO region.

[133] EMFAC2017 is the model referenced in this report

[134] EPA 2015. "Exhaust Emission Rates for Heavy-Duty On-road Vehicles in MOVES2014," EPA-420-R-15-015a, November 2015. https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NO46.pdf, Accessed online October 2020.

[135] https://ww3.arb.ca.gov/msei/downloads/emfac2017_workshop_11_09_2017_final.pdf, Accessed online October 2020. HDDT emission rates begin on slide 45.

[136] McDonald, B. C. et al. Volatile chemical products emerging as largest petrochemical source of urban organic emissions. Science 359, 760–764 (2018). https://science.sciencemag.org/content/359/6377/760, Accessed online October 2020.

[137] Emission category groupings that represent >0.5% of total NOx+VOC inventory are included in the state regulations compilation.

State regulations listed in Appendix C are indicative of control requirements that are more stringent than Federal requirements. However, in many cases, it may be feasible to increase control stringency further. During control option screening, the presence of an existing state regulation will not preclude selection of a control option for more detailed analysis if additional control would result in substantial emission reductions. For example, Ohio adopted the 2006 OTC model rule for Consumer Products, but there are several more recent 2014/2019 OTC model rules for Consumer Products that could result in greater emission reductions.

Control measures listed in resources such as EPA's Menu of Control Measures and other state implementation planning references take as the minimum starting point existing Federal regulations. In addition, potential measures compiled for the screening analysis are based on more stringent regulatory and/or voluntary programs proposed by EPA or in other non-LADCO regions which go beyond the established Federal regulations. Therefore, to perform a screening analysis of potential control measures, a listing of Federal regulations is not required.

Ramboll summarized OTB regulations and screened potential emission reduction strategies that could apply to a range of emission sources (Section 3.0). In this section we focus on the emission reduction strategies that specifically address emission increases described herein for HDDTs and VCPs.

5.2 Heavy-Duty Vehicle Emissions

5.2.1 Emissions Inventory Adjustments Methodology

Excess emissions were estimated by applying the California EMFAC2017 model assumptions to a LADCO emissions inventory. The EMFAC2017 model estimates additional tampering, mal-maintenance, and malfunction (TM&M) emissions. EMFAC2017 also addresses low speed and low load operations efficiency of new (2010 model year and later) technology vehicles with more updated data than was incorporated in the MOVES2014 emission estimates.

EMFAC2017 emission factors were applied to the LADCO emissions inventory to estimation emissions from TM&M using the age and model year associations shown in Table 5-1. EMFAC2017 assumes that engine model year lags truck model year by one year owing to the estimate that trucks take time to build, sell, and be introduced into the market. EMFAC22017 emissions rates were only used to adjust emissions for 2010+ model year trucks that use SCR devices. Adjustments were made to account for low load and low speed conditions and the deterioration rate effects built into EMFAC2017 that are possibly less well characterized by MOVES2014b.

Table 5-1. Age and model year vehicle model comparisons.

Calendar Year	EMFAC2017 Output		EMFAC2017* (Emissions Factors basis)	MOVES2014b Output	
	Truck Chassis		Engine**	Truck Chassis/ Engine**	
	Age	Model Year	Model Year	Age	Model Year
2026	-1	2027	2026	0	2026
2026	0	2026	2025	1	2025
2026	1	2025	2024	2	2024
2026	2	2024	2023	3	2023
2026	3	2023	2022	4	2022
2026	4	2022	2021	5	2021
2026	5	2021	2020	6	2020
2026	6	2020	2019	7	2019
	…	…	…	…	…

* EMFAC2017 assumes that the engine model year lags the truck model year by one year.

** Engine model year determines emission standard applicability

MOVES only exports speed-specific emissions rates (g/mile) under its Rate-Per-Distance (RPD) export when run in Rate Mode. These lookup tables are typically used to develop regional on-road emission inventories using SMOKE-MOVES. Ramboll developed adjustment factors that may be applied to SMOKE-MOVES by-speed emission rates tables during inventory development as described below. The resulting adjustment factors are included in Appendix D.

The approach uses EMFAC2017-based NOx emission factors for 2010+ model years, which include EMFAC2017 assumptions on failure rates and speed correction factors. The model-output EMFAC2017 rates were adjusted to account for MOVES-based relative mileage accumulation of HDDTs. These EMFAC2017-adjusted emissions factors by model year were aggregated to a fleet-wide average based on the MOVES national age distribution for HDDTs. The HDDTs categories covered for these adjustments were combination unit trucks (short and long haul) and refuse trucks because these vehicle types account for a vast majority of emissions from Class 8 trucks (33,000 GVWR+).

5.2.1.1 Developing Adjustments for MOVES Rate Tables

Emission factors by model year (MY) and by speed for HDDTs can be extracted from EMFAC2017 which include effects of speed corrections at low loads and EMFAC2017 deterioration and failure rates. However, these emission factors are based on California vehicles typical mileage accumulation rates and odometer readings. Ramboll adjusted the EMFAC2017 emission factors by updating the deterioration using EMFAC2017 methodology and MOVES mileage accumulation rates as indicated in Equations 1-3 shown below.

$$Default\ Emission\ Rate_{MY} = [\ ZMR_{MY} + DR * Odometer|_{EMFAC}/10{,}000] \quad \text{(eq. 1)}$$

$$MOVESadj\ Emission\ Rate_{MY} = [ZMR_{MY} + DR * Odometer|_{MOVES}/10{,}000] \quad \text{(eq. 2)}$$

$$\%\ Base\ Rate\ Change_{MY} = \frac{MOVESadj\ Emission\ Rate_{MY}}{Default\ Base\ Rate_{MY}} \quad \text{(eq. 3)}$$

where:

ZMR_{MY} is the zero-mile base rate for a specific MY (g/mile)

DR is the deterioration rate for a specific MY (g/mile/10k miles)

Odometer is the average accumulated mileage by vehicle age and type

% Base Rate Change is the percent change in emissions based on MOVES default mileage accumulation rate for HDDTs

The *% Base Rate Change* ratios were applied to by model year and by speed California-wide emission rate outputs from EMFAC2017 for model year 2010+. MOVES emission rates by model year and by speed for HDDTs of model 2009 and older were obtained from a MOVES National default run under rate mode. Both the EMFAC2017 adjusted emission factors (MY2010 and newer) and MOVES "raw" emission factors (MY2009 and older) were then combined into an aggregated fleet-wide rate using vehicle miles traveled (VMT) fractions that are based on MOVES default 2026 national age distribution and relative mileage accumulation rates for HDDTs, as shown in Equation 4. These rates were combined into a fleet-wide composite given that, typical SMOKE-MOVES RPD tables do not include model-year detail.

$$Composite.EMFAC.Adj.EF_{\substack{|by \\ speed}} = \sum_{1996}^{2009} EF_{MOVESraw} \times \frac{VMT_{|byMY}}{VMT_{fleet}} + \sum_{2010}^{2026} EF_{EMFACadjusted} \times \frac{VMT_{|byMY}}{VMT_{fleet}} \quad \text{(eq. 4)}$$

where:

$EF_{MOVESraw}$ is an MOVES emission factor from default rate run by MY, by speed (g/mile)

$EF_{EMFACadjusted}$ is an EMFAC2017 emission factor by MY by speed, multiplied by

$\%\ Base\ Rate\ Change_{MY}$

$\frac{VMT_{|byMY}}{VMT_{fleet}}$ is the VMT fraction, resulting from the ratio of VMT by MY over fleet-wide VMT

$Composite.EMFAC.Adj.EF_{\substack{|by \\ speed}}$ is the EMFAC2017 adjusted emission factor by speed

These rates ($Composite.EMFAC.Adj.EF$) have the following level of detail:

- Calendar Year: 2026
- Fuel type: Diesel
- Source types: Combination Long-haul Truck, Combination Short-haul Truck, Refuse Truck
- Average Speed: 5 mph increments
- Road type: all four MOVES road types. Emission factors do not vary by road type as they are speed dependent

The adjustment factors are based on the ratio of Composite EMFAC2017 adjusted emission rates (from eq. 4) and MOVES "raw" RDP rates, based on national defaults.

$$AdjustmentFactor_{|speed} = \frac{Composite.EMFAC.Adj.EF_{|speed}}{MOVES_{default}.RPD.EF_{|speed}} \quad \text{(eq. 5)}$$

The adjustment factor table can be used by LADCO to adjust lookup rate RPD tables developed through SMOKE-MOVES process, to capture increased TM&M and speed effects in the EMFAC2017 model. Below we note caveats for applying these adjustment factors to estimate revised MOVES inventories for the LADCO region for 2026.

- Effects that are considered and factored in the methodology
  - Age distribution: Based on MOVES2014b National 2026 default for each source type. SMOKE-MOVES "lookup rate tables" includes speed detail but not model year detail
  - Speed distribution: Based on MOVES2014b National default
  - Difference in Relative MAR between EMFAC2017 and MOVES: Captures MOVES national default assumptions
- Effects that are not considered
  - Fuel adjustments: Based on MOVES2014b National 2026 defaults. Fuel adjustment variations by state not captured. Likely not an issue for diesel-based NOx.
  - Meteorology: Methodology does not consider geographical variations in temperature and humidity (the basis of the estimates is a summer meteorology sample for Cook County, IL). Because these are modern diesel engine emissions and not gasoline, meteorological effects are not expected to be significant.

5.2.1.2 Estimating Adjustment Effect on Emissions Inventory Sample

For the LADCO geographic region, we exported 2026 VMT by SCC for a summer month (July) from MOVES2014 default database and allocated VMT to speed bins using the MOVES average speed distribution table.

With the VMT by speed bin and SCC, the running exhaust (RPD) SCC emissions by speed were calculated using two sets of emission factors:

1) MOVES Base = sum of (MOVES default output RPD table * VMT) by speed bin, SCC
2) EMFAC2017 Adjusted = sum of ($Composite.EMFAC.Adj.EF_{\substack{by \\ speed}}$ * VMT) by speed bin, SCC

The emissions by speed are aggregated to calculate MOVES Base Case and EMFAC2017 Adjusted Case Inventories.

5.2.2 Adjustment Emissions Results

As explained in the previous section, Ramboll used the MOVES default activity rates by speed bin to estimate the overall emissions inventory using the comparable EMFAC2017 emission rates (Eq. 4). Figure 5-1 shows NOx emission factors (EFs) by speed bin for the 2026 national average fleet. Overall, EMFAC2017 adjusted emission factors are generally higher, especially at lower speeds. The average speed emission rates from MOVES or EMFAC2017 models are based on driving cycles that reflect stops and idling which raise emission rates at slower speeds. At high speeds, the aerodynamic drag raises emissions rates.

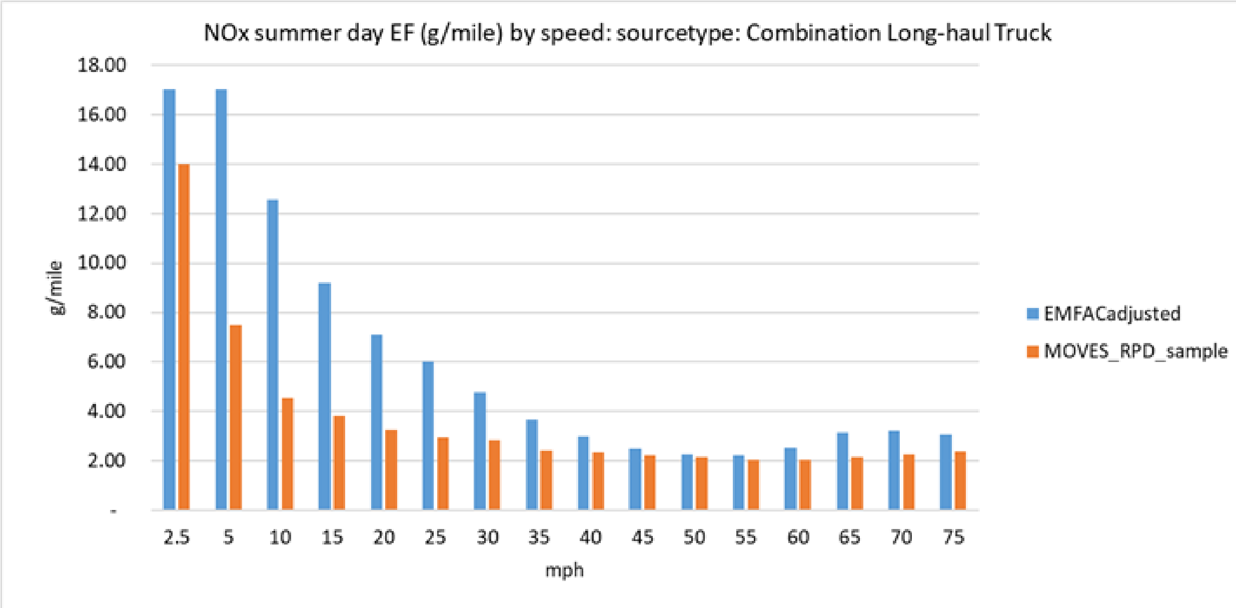

Figure 5-1. HDDT emission rate estimates by speed bin.

The overall adjusted LADCO emission inventory reflects the impact of added deterioration (including deliberate or unintentional failures) and the by-speed-bin adjustments. In Table 5-2, the emission inventory using EMFAC2017 adjusted emission rates is compared with an emissions inventory developed using the MOVES rate per distance estimates.

Table 5-2. HDDT emissions for the base case and adjusted inventory by source type and state (lbs/day).

Source Type	State	EMFAC2017 Adjusted	MOVES2014b Base Case	EMFAC2017 Adjustment Increase
Combination Long-haul Truck	IL	198,417	134,193	48%
	IN	175,747	122,731	43%
	MI	228,545	161,030	42%
	MN	129,845	92,420	40%
	OH	274,351	191,297	43%
	WI	140,509	100,617	40%
Combination Long-haul Truck Subtotal		**1,147,413**	**802,288**	**43%**
Combination Short-haul Truck	IL	47,225	34,601	36%
	IN	40,907	31,364	30%
	MI	52,874	41,049	29%
	MN	30,030	23,612	27%
	OH	64,077	48,985	31%
	WI	32,243	25,602	26%
Combination Short-haul Truck Subtotal		**267,355**	**205,212**	**30%**
Refuse Truck	IL	3,971	3,432	16%
	IN	3,419	3,104	10%
	MI	4,441	4,076	9%
	MN	2,513	2,333	8%
	OH	5,365	4,848	11%
	WI	2,701	2,536	7%
Refuse Truck Subtotal		**22,410**	**20,328**	**10%**
All States and Sources Total		**1,437,178**	**1,027,827**	**40%**
LADCO Average Emission Factors				
Combination Long-haul Truck (g/mile)		**3.45**	**2.40**	**43%**
Combination Short-haul Truck (g/mile)		**2.22**	**1.69**	**31%**
Refuse Truck (g/mile)		**1.81**	**1.64**	**11%**

5.2.3 EMFAC2017 Tampering, Mal-maintenance, and Malfunction (TM&M) Impact

CARB estimated the failure rates at full useful life (1,000,000 miles) and NOx emissions impact of those failures (see Table 5-3). EMFAC2017 uses these effects and apportions the failures to linearly increase with vehicle age. In SCR Systems, NOx sensors are used to improve the metering of diesel exhaust fluid (usually a urea/water mixture) prior to the SCR catalysts that reduces NOx emissions. EGR is used often with a cooler to reduce engine-out NOx emissions prior to the SCR systems. DPFs are used to reduce PM and have little effect on NOx emissions.

Table 5-3. EMFAC2017 NOx emission failure increases at useful life[138] (except as noted).

Failure Category	MY2010-2012		MY2013+	
	Fail Rate	Fail Effect	Fail Rate	Fail Effect
NOx Sensor	36%	200%	24%	200%
Replacement NOx Sensor	1.8%	200%	1.2%	200%
SCR System	40%	300%	27%	300%
EGR	16%	150%	11%	150%
DPF[1]	10%	5200%	6.7%	5200%

[1] PM Effect only.

To evaluate the effect of TM&M emissions adjustments separate from the low-load effects, Ramboll used the EMFAC2017 base emission factors combined with the 2010+ national average fleet to estimate the relative emissions with deterioration (reflecting mal-maintenance and defeat device identification and repairs) and without deterioration. The emissions results and comparisons are shown in Table 5-4. The fleet of long-haul combination trucks tend to be younger than short-haul truck fleets, and therefore, short-haul accrues a larger repair benefit. The older vehicles are more likely to have malfunctioning vehicles and benefit more from repairs. Table 5-4 also reflects 100% control, i.e., all vehicles are perfectly maintained with no deterioration implying that failures are identified, and repairs are made, immediately.

Table 5-4. Estimated effect of TM&M (Maximum Repair Benefit) on NOx emissions.

Source Type	TM&M Effect on NOx Emissions (Maximum Repair Benefit)
Combination Long-haul Truck	27%
Combination Short-haul Truck	33%
Refuse Truck	34%
Total	**29%**

5.2.4 Heavy-Duty Control Program Options

For HDTs, emission control programs need to address the two main updates (TM&M and low speed conditions). Programs or projects to address these issues will affect the fleet in different ways and could be implemented as intrusive mandatory or smaller scale voluntary programs.

5.2.4.1 Heavy-Duty Failure Identification and Repair

Programs to address TM&M emission failures seek to encourage owner/operators to promptly repair their vehicles by identifying faults or malfunctions quickly. The identification program could be designed as a responsibility of larger fleet managers or all vehicle owners with few small business exemptions. Centralized inspection stations are not typically considered to be a viable strategy for

[138] Source: CARB, 2018. EMFAC2017 Volume III – Technical Documentation. Available at https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf, Accessed October 2020.

HDTs, but remote sensing and other in-use verification methods (such as remote diagnostics[139]) could be considered.

CARB[140] estimated the cost of the emission control system warranty at $2,289 for 316,000 miles for HDDT averaging $0.0072/mile across the fleet. After the end of the warranty, there may be more failures through the useful life compared with newer vehicles. In addition to the raw repair costs, the indirect opportunity costs due to the lost revenue from downtime per vehicle would be incurred. CARB[141] estimated that lost revenue cost could be equivalent or higher than the cost of the repair. Lastly, in order to reduce the expected failure rates, the State needs to develop and administer an effective enforcement strategy. The elements of the enforcement strategy may be enhanced regulations for fleet owners to manage their fleets or more intensive inspection and remote sensing identification. The cost of these enhanced enforcement should be included in the cost of any approach. The overall cost then would be higher than the repair cost itself probably ranging from $0.01 to $0.02 per mile. For comparison, one estimate[142] of the operating cost of HDDTs is about $1.38 per mile including about $0.50 per mile from fuel alone.

The benefit of repair will not be realized to the full extent estimated in Table 5-4 because all failing vehicles are typically not quickly identified and repaired. Likewise, all vehicles may not be covered by an identification program with much of the long-haul truck fleet engaged in interstate commerce. Thus, benefit estimates presented in Table 5-4 would overestimate the benefit and underestimate the cost effectiveness. Assuming perfectly complete repair control, the cost effectiveness of repair at $0.02 per mile would range from $19,500/ton for long-haul combination trucks to $29,500/ton for refuse vehicles with an average of $20,250/ton for all source types considered. If the repair effectiveness is only 50%, these cost effectiveness estimates would double.

5.2.4.2 Heavy-Duty Freight Route Planning

To reduce low speed and low load activity, there are a few options to streamline operations. For example, limits on long- and short-term idling have been implemented in various metropolitan areas[143]. Short-term idling emission control measures are evaluated in Chapter 2. Secondly, traffic streamlining could take the form of infrastructure (e.g. dedicated freight movement lanes or routing), non-peak travel (afterhours deliveries), or improved signal timing. Probably the least expensive approach is improved signal timing for large trucking facilities.

Signalization improvements have historical costs (purchase cost for 10-year life, retiming, and maintenance) for timed traffic signals to improve traffic flows at about $3,600 per signal[144] per year in 2005 dollars or about $4,800 in 2020 dollars. As examples, three large urban rail intermodal facilities (BNSF Corwith, Norfolk Southern 47th St., and Union Pacific Global I) in the Chicago metropolitan area use surface streets as access to these facilities from nearby freeways. These facilities transfer containers (each container moved in or out of the facility is called a lift) to and from trains and trucks creating between one or two truck trips per lift each way to the local interstate. Table 5-5 shows the

[139] https://www.geotab.com/blog/remote-diagnostics/, Accessed online October 2020.
[140] CARB 2018. "Public Hearing To Consider Proposed Amendments To California Emission Control System Warranty Regulations And Maintenance Provisions For 2022 And Subsequent Model Year On-Road Heavy-Duty Diesel Vehicles And Heavy-Duty Engines With Gross Vehicle Weight Ratings Greater Than 14,000 Pounds And Heavy-Duty Diesel Engines In Such Vehicles Staff Report: Initial Statement Of Reasons, Date Of Release: May 8, 2018, Scheduled For Consideration: June 28, 2018.
[141] Ibid.
[142] https://www.thetruckersreport.com/infographics/cost-of-trucking/, Accessed online October 2020.
[143] https://cdllife.com/2014/idling-laws-state/, Accessed online October 2020.
[144] https://www.itscosts.its.dot.gov/its/benecost.nsf/0/215F723DB93D293C8525725F00786FD8, Accessed online October 2020.

intermodal activity and surface street route characteristics to each facility and the associated cost to install and maintain an improved traffic signal corridor.

Table 5-5. Rail intermodal example traffic routes.

Railroad	Yard	Annual Lifts[145]	Route from Interstate Each Way			Annualized Cost ($)
		2018	Number of Traffic Lights [a]	Road Miles	Lights per mile	
BNSF	Corwith	850,686	3.5	0.60	5.8	17,000
NS	47th St.	630,513	2.5	0.25	10	12,100
UP	Global I	336,729	9	1.75	5.1	43,600

[a] Depending on which entrance/exit of interstate is used. The assumption is the IN and OUT are different routes, so if the same route is used IN and OUT, then the project can effectuate 2x the emissions reductions and cost effectiveness is halved.

Depending on the local traffic conditions, the traffic lights could result in trucks braking, idling, and accelerating from the traffic lights. Traffic light timing could be maintained to result in a smooth flow of truck traffic and higher average trip speeds along the surface streets to and from the intermodal facility.

To analyze what benefit traffic signal improvements could realize, Ramboll assumed that untimed lights result in a delay (idling plus braking, acceleration, and added congestion) of about 20 seconds per light compared with timed lights. Assuming 25 mph with timed lights, for 5 lights per mile, the untimed average speed is about 15 mph, and 10 lights per mile results in 10 mph average speeds. The average speed incorporates the braking, idling, and accelerating inherent in stop and go driving that is reflected in the emission rates by speed bin shown in Figure 5-1. Using these average emission rates with the intermodal truck activity, we estimated the annual emissions for each case, determined the benefit of the project, and divided it into the annual costs to estimate project cost effectiveness shown in Table 5-6.

Table 5-6. Rail intermodal example project benefits and cost effectiveness.

Railroad	Yard	Annual Lifts[146]	Route to Interstate Each Way			Annual NOx Tons Reduced	Cost Effectiveness ($/ton)
		CY 2018	Road Miles	Timed lights NOx EF [25 mph] (g/mi)	Untimed lights NOx EF [Speed] (g/mi)		
BNSF	Corwith	850,686	0.60	6	9 [15 mph]	1.69	$10,000
NS	47th St.	630,513	0.25	6	12.5 [10 mph]	1.13	$11,000
UP	Global I	336,729	1.75	6	9 [15 mph]	1.95	$22,000

Assumptions in the above analysis may be refined with site-specific data to generate more accurate estimates, or this methodology could be applied to other areas for which benefits are available from such a project. These sample projects are likely to be among the most cost-effective examples

[145] Each lift is a container arriving or departing and moved through the facility. https://www.cmap.illinois.gov/mobility/freight/freight-data-resources, Accessed online October 2020.
[146] https://www.cmap.illinois.gov/mobility/freight/freight-data-resources, Accessed online October 2020.

because these facilities demand many truck trips and use relatively easy to define surface street routes that could benefit from traffic signalization improvements. Each program or project to address local truck traffic should be evaluated on its own merits based on local conditions and activity. Other similar programs (e.g. afterhours deliveries) or projects near these facilities could have a similar or better impact on emissions and program costs.

A more aggressive program to address local facilities is the California Drayage Truck regulation[147] that mandated that all trucks to major ports and rail intermodal yards use DPFs or be compliant with at least the 2007 and later engine emissions rule by 2014. CARB estimated a cost effectiveness of $12,000-$16,000 per ton of NOx reduced for the drayage truck rule.[148] California[149] extended this program to fleets across the state such that by 2023, all vehicles must use 2010 and later engines.

5.3 Volatile Chemical Products

5.3.1 Emission Inventory Adjustments

The primary evidence for an underestimate of emissions from VCPs comes from a study by McDonald et al. (2018)[150] which used chemical analysis of ambient samples, product use, and modeling to estimate a revised emission inventory. McDonald et al. investigated the production and use of various products releasing VOCs to identify chemical signatures related to each product type. McDonald et al. estimated the emission inventory that would result in the chemical species concentrations measured by air monitoring stations through modeling. The study then compared the revised and published emission inventories, which Ramboll used to develop emission inventory adjustment factors. Table 5-7 shows the McDonald et al. (2018) emission inventory comparison and the adjustment ratios that Ramboll used to adjust the emission inventory.

Table 5-7. VCP emission inventory adjustments.

VCP Category	McDonald et al. (2018)		Adjustment Ratio
	Total VOC [a] Study Estimate (Tg)	EPA NEI 2011 (Tg)	
Pesticides	1.1	0.65	1.69
Coatings	2.4	0.89	2.70
Printing Inks [b]	0.24	0.05	4.80
Adhesives	1.8	0.1	18.00
Cleaning Agents	0.66	0.59	1.12
Personal Care	1.4	0.27	5.19
All	**7.6**	**2.6**	**2.92**

[a] McDonald includes semi-, intermediate, and normal volatile organic compounds into total VOC

[b] includes graphic arts

[147] https://ww2.arb.ca.gov/our-work/programs/drayage-trucks-seaports-railyards, Accessed online October 2020.

[148] CARB, 2007. Staff Report: Initial Statement of Reasons: Proposed Regulation for Drayage Trucks. https://ww3.arb.ca.gov/regact/2007/drayage07/drayisor.pdf, Accessed online October 2020.

[149] https://ww2.arb.ca.gov/our-work/programs/truck-bus-regulation/truck-and-bus-regulation-regulation-advisories, Accessed online October 2020.

[150] "Volatile Chemical Products Emerging As Largest Petrochemical Source Of Urban Organic Emissions," Brian C. McDonald,* Joost A. de Gouw, Jessica B. Gilman, Shantanu H. Jathar, Ali Akherati, Christopher D. Cappa, Jose L. Jimenez, Julia Lee-Taylor, Patrick L. Hayes, Stuart A. McKeen, Yu Yan Cui, Si Wan Kim, Drew R. Gentner, Gabriel Isaacman-VanWertz, Allen H. Goldstein, Robert A. Harley, Gregory J. Frost, James M. Roberts, Thomas B. Ryerson, Michael Trainer, Published 16 February 2018, Science 359, 760 (2018).

It is important to understand that the emission increase adjustments are due to unidentified or under reported sources. This unknown nature of the emissions leads to uncertainty how or which programs would most effectively address the emissions increases estimated.

5.3.2 Emission Inventory Results

Each VCP category was associated with the 2016v1 modeling platform emissions for point and nonpoint source category using the category description. To obtain a 2026 base inventory for LADCO states, the 2028 (2028fh) and 2023 (2023fh) inventories from the modeling platform were interpolated. For point sources, the industrial categories include Organic Solvent Evaporation with subcategories of Cleaning/Stripping, Printing/Publishing, and Surface Coating. The nonpoint source categories are listed under the main Solvent Utilization categorization. Ramboll cross referenced the categories with the adjustment factors in Table 5-7 and summarized the unadjusted and adjustment emissions in Table 5-8 and Table 5-9. The overall estimated emission inventory for these categories is 3.2x the 2016v1 Modeling Platform emission inventory and the adjusted inventory is shown by State in Figure 5-2 and Table 5-10.

Table 5-8. Baseline 2016v1 modeling platform emission inventory for 2026.

VCP Category	Inventoried Emissions (short TPY)						LADCO-wide
	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin	
Pesticides	34,389	10,845	12,438	10,551	13,963	8,303	**90,489**
Coatings	44,277	40,843	57,802	27,367	60,828	30,383	**261,501**
Printing Inks [a]	4,975	20,594	13,766	5,888	33,719	3,034	**81,976**
Adhesives	3,995	2,328	3,601	1,977	3,640	2,171	**17,713**
Cleaning Agents	21,886	12,873	18,935	11,117	22,083	11,904	**98,799**
Personal Care	12,734	6,977	10,207	5,970	12,066	6,133	**54,087**
Others	246	87	85	54	74	462	**1,008**
LADCO Total	**122,503**	**94,547**	**116,836**	**62,924**	**146,373**	**62,392**	**605,573**

[a] includes graphic arts

Table 5-9. Adjusted emission inventory for 2026.

VCP Category	Adjusted Emissions (short TPY)						LADCO-wide
	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin	
Pesticides	58,197	18,353	21,049	17,855	23,629	14,051	**153,135**
Coatings	119,399	110,137	155,871	73,800	164,030	81,933	**705,171**
Printing Inks [a]	23,880	98,851	66,079	28,263	161,850	14,564	**393,487**
Adhesives	71,918	41,911	64,824	35,578	65,525	39,084	**318,839**
Cleaning Agents	24,483	14,401	21,182	12,436	24,703	13,317	**110,521**
Personal Care	66,027	36,175	52,923	30,957	62,565	31,803	**280,451**
Others	246	87	85	54	74	462	**1,008**
LADCO Total	**364,150**	**319,915**	**382,014**	**198,942**	**502,376**	**195,213**	**1,962,611**

[a] includes graphic arts

Table 5-10. Percent increase in VCP 2026 inventory due to adjustments.

VCP Category	Emissions Increase Difference (short TPY)						LADCO-wide
	Illinois	Indiana	Michigan	Minnesota	Ohio	Wisconsin	
Pesticides	69%	69%	69%	69%	69%	69%	**69%**
Coatings	170%	170%	170%	170%	170%	170%	**170%**
Printing Inks [a]	380%	380%	380%	380%	380%	380%	**380%**
Adhesives	1700%	1700%	1700%	1700%	1700%	1700%	**1700%**
Cleaning Agents	12%	12%	12%	12%	12%	12%	**12%**
Personal Care	419%	419%	419%	419%	419%	419%	**419%**
Others	0%	0%	0%	0%	0%	0%	**0%**
Total	**197%**	**238%**	**227%**	**216%**	**243%**	**213%**	**224%**

[a] includes graphic arts

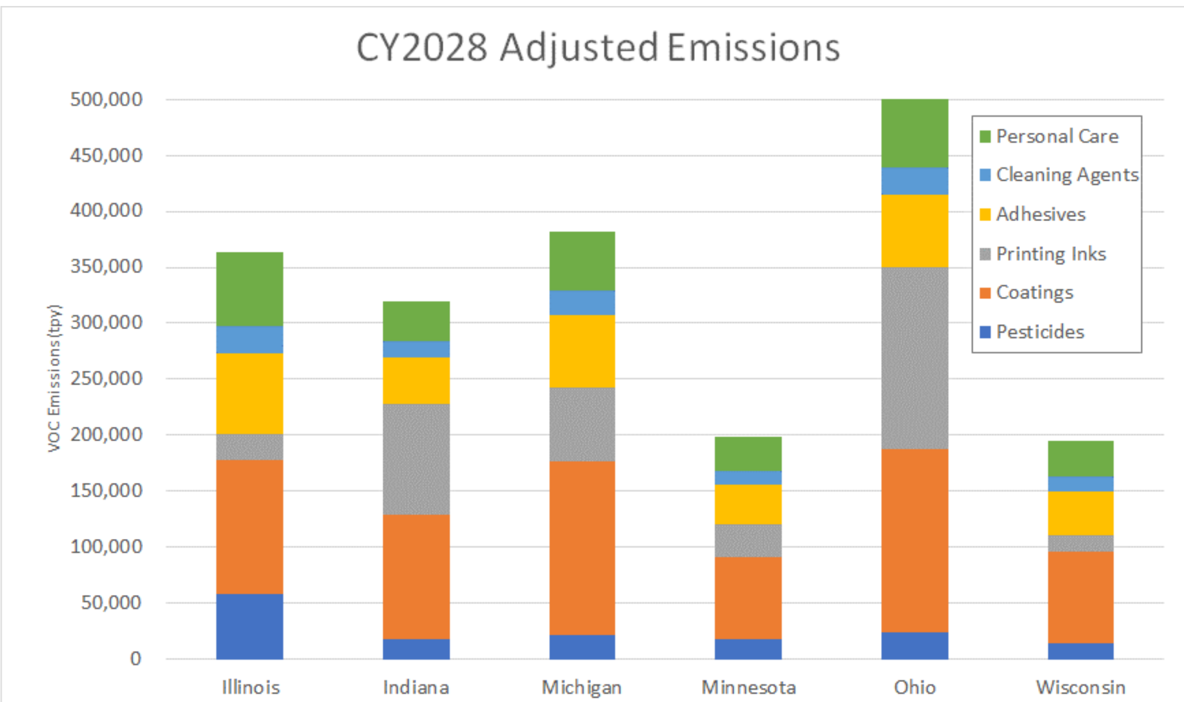

Figure 5-2. Adjustment VCP emissions inventory.

Use of VCPs encompasses a wide range of industrial, commercial, and consumer products and applications. The industrial uses could be incorporated and controlled within facilities through facility-based activities such as product coating, degreasing, and other operations. Commercial uses of products could be wide and varied with application usually outside of a controlled manufacturing setting. Consumer products are general use products that can only be controlled through product reformulation.

5.3.3 Volatile Chemical Products Control Programs

The control programs for VCPs include facility and product specific VOC limits. Facility VOC limits could apply to VCP sources such as printing and graphic arts, coatings, and cleaning sources, and would not generally limit the VOC in the products used, and instead would rely on VOC control systems. The VOC control systems include aftertreatment devices to capture and control the VOC emissions within the facility. Product VOC limits are used for products for which fugitive VOC emissions capture is infeasible.

Facility-based control programs seek to limit VOC emissions, usually by capture and control. There are usually small volume exemptions for facilities that have a lower 'potential to emit'[151], which do not need to comply with the rules. For those that exceed de minimis criteria, the VOC limits are set according to the local permitting rules. The facility-based rules are most likely to affect the printing/graphic arts, coatings, and adhesives VCP source categories. EPA[152] had reviewed reasonable available control technology (RACT) emissions controls for flexible package printing specifically and noted capture efficiency of 67 – 95%, and included backstop VOC content limits for inks for facilities not using capture and control. The San Joaquin Valley Air Pollution Control District (similar to other California districts) Rule 4607[153] outlined the rules for printing inks, coatings, and adhesives that include product specification if capture and control are not employed at capture efficiencies of 75 – 90% (increased from as low as 67% in previous rules). Rule 4607 also lowered the facility VOC control exemption limits to 200 pounds per year (less than 1 pound per day on average) from 400 pounds per month to increase the rule effectiveness. For example, Indiana Title 326, Article 8-16, exempts facilities below 15 pounds VOC per day.

For the major source categories of adhesives, coatings, and personal care products representing 66% of the post-adjusted VCP inventory in Table 5-9, the OTC[154] has developed model rules for various products within these source categories and compared these with earlier versions of the model rules. Our review of the existing LADCO states regulations (Section 2.0) revealed that the on-the-books regulations largely represents the OTC 2005/2009 model rules. The updated OTC rules for 2014/2019 represents emission reduction that could be realized with regulation updates. Table 5-11 outlines the change in rules for these three main categories; additional controls programs for cleaning and other products are available. Each product represents an unknown portion of the emissions under each VCP subcategory listed in Table 5-9 and only some products are forecasted to be reduced under the updated OTC model rules. California's[155] approach is to apply specific VOC limits that may exceed the OTC model rules each product category; some of the most recent proposed changes are shown in Table 5-11.

[151] For example, https://www.epa.gov/sites/production/files/2015-08/documents/lowmarch.pdf, Accessed online October 2020.
[152] EPA 2006. "Control Techniques Guidelines for Flexible Package Printing," EPA 453/R-06-003, September 2006
[153] SJVUAPCD 2008. "RULE 4607 Graphic Arts and Paper, Film, Foil and Fabric Coatings," https://www.valleyair.org/rules/currntrules/r4607.pdf, Accessed online October 2020.
[154] OTC Model Rule for Consumer Products - Phase V, Developed by the OTC Consumer Products Workgroup within the Stationary and Area Sources Committee' DRAFT, 4/17/2018
[155] https://ww2.arb.ca.gov/our-work/programs/consumer-products-program/consumer-products-regulatory-activity-workshops, Accessed online October 2020.

Table 5-11. OTC model rule summary of selected products.

Category	VOC % by Weight		Proposed California [a]
	OTC Earlier	OTC Phase V	
	2005/2009	2014/2019	2020
Adhesives and Sealants			
Adhesive Remover	various	same as earlier	
Aerosol Mist Spray	65	30	
Aerosol Web Spray	55	40	
Special Purpose: (Automotive, other polymers)	60 - 70	same as earlier	
Screen Printed	no standard	55	
Chemically Curing, Non-aerosol	4	3	
Nonchemically Curing, Non-Aerosol	4	1.5	
Construction, Panel, and Floor Covering	15	7	
Contact Adhesive: General and Special	55/80	same as earlier	
General Purpose	10	same as earlier	
Structural Waterproofing	15	same as earlier	
Personal Care			
Air Freshener:			
Single-Phase Aerosol	30	same as earlier	5
Double-Phase	25	20	5
Dual Purpose Air Freshener/Disinfectant	no standard	60	
Liquids/Pump Sprays	18	same as earlier	
Solids/semisolids	3	same as earlier	
Antiperspirants:			
Aerosol	40 HVOC; 10 HVOC		
Non-Aerosol	0		
Anti-Static Product:			
Aerosol	no standard	80	
Non-Aerosol	11	same as earlier	
Astringent/Toner	no standard	35	
Deodorants	various	same as earlier	
Disinfectants	no standard	70 aerosols, 1 non-aerosol	
Fabric Protectants:			
Aerosol	60	60	
Non-Aerosol	60	1	
Fabric Refresher	6-15 Aerosol	same as earlier	
Fragrance (<20%) [>20%]	no standard	(75) [65]	(50)
Hair Products	all types	same as earlier	
Hair Finishing Spray\Shine		55	50
Heavy-duty hand cleaner or soap	8	1	
Nail polish	75	1	

Category	VOC % by Weight		Proposed California [a]
	OTC Earlier	OTC Phase V	
	2005/2009	2014/2019	2020
Shaving cream	5	same as earlier	
Shaving gel	7	4	
Coatings			
Automotive Wax, Polish, Sealant or Glaze:			
Hard Paste Waxes	45	same as earlier	
Instant Detailers	3	same as earlier	
All Other Forms	15	same as earlier	
Floor Polishes or Waxes:			
Resilient Flooring Materials	7	1	
Nonresilient Flooring Materials	10	1	
Wood Floor Wax	90	70	
Floor Wax Strippers, Non-Aerosol	no standard	3 - 12 as used	
Metal polishes and cleaners	30	15 (3 non-aerosol)	
Paint removers or strippers	50	same as earlier	
Paint Thinner aerosol		10	
Paint Thinner nonaerosol		3	

[a] California measures that exceeded the stringency of the most recent OTC proposals are listed. Blank cells indicate that California VOC limits are consistent with OTC Phase V.

6.0 REFERENCES

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APPENDIX A
On-the-Books and On-the-Way Regulations State and Local Regulations

APPENDIX A. ON-THE-BOOKS AND ON-THE-WAY REGULATIONS STATE AND LOCAL REGULATIONS

State and Local Regulations by LADCO-wide emissions inventory groupings, organized from largest to smallest NOx+VOC contribution[156]

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Mobile Sources									
Passenger Cars and Light-duty Trucks	19.1%	21.2%	17.0%		Title 35, Part 241: Clean Fuel Fleet Program[159] Title 35, Part 275: Alternate Fuels Program[160] Title 35, Part 276: Vehicle emissions inspection program[161]	Title 326, Article 13 (Northwest Indiana Vehicle Emissions Testing Program)[162, 163] Title 326, Article 19 Mobile Source Rules (Northwest Clean Fuel Fleet Vehicles)[164]	Clean Cars Minnesota[165] (not yet adopted)	Chapter 3745-26, Motor Vehicle Inspection and Maintenance (I/M) Program[166] (Cuyahoga, Geauga, Lake, Lorain, Medina, Portage, and Summit counties) Chapter 3745-80, Statewide Motor Vehicle Anti-Tampering Program[167]	Chapter NR 485 Control of Emissions From Motor Vehicles, Internal Combustion Engines And Mobile Sources; Tampering Prohibition[168] Chapter NR 486 Employee Commute Options Program[169] Chapter NR 487 Clean Fuel Fleet Program[170]

156 2016v1 modeling platform for calendar year 2016 (v2016fh)
157 NOx+VOC values represent the ratio of NOx and VOC emissions by category to total NOx and VOC emissions in the 2016 LADCO inventory. The sum of individual NOx and VOC percentages does not equal the NOx+VOC value.
158 Ohio EPA has provided information on the geographical scope of Ohio regulations.
159 http://www.ilga.gov/commission/jcar/admincode/035/035002410B01130R.html
160 https://pcb.illinois.gov/documents/dsweb/Get/Document-11964/
161 https://www2.illinois.gov/epa/topics/air-quality/mobile-sources/Pages/vehicle-emissions-testing.aspx
162 https://www.in.gov/idem/airquality/2333.htm
163 http://www.in.gov/legislative/iac/T03260/A00130.PDF
164 http://www.in.gov/legislative/iac/T03260/A00190.PDF
165 https://www.pca.state.mn.us/air/clean-cars-mn-rulemaking
166 https://www.epa.ohio.gov/dapc/regs/3745_26
167 https://www.epa.ohio.gov/dapc/regs/3745_80
168 http://docs.legis.wisconsin.gov/code/admin_code/nr/400/485.pdf
169 http://docs.legis.wisconsin.gov/code/admin_code/nr/400/486.pdf
170 http://docs.legis.wisconsin.gov/code/admin_code/nr/400/487.pdf

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Heavy-duty Haul Trucks	6.4%	12.1%	1.0%					Chapter 3745-80, Statewide Motor Vehicle Anti-Tampering Program [171]	Chapter NR 485 Control of Emissions from Motor Vehicles, Internal Combustion Engines and Mobile Sources; Tampering Prohibition[172]
Off-highway equipment - Diesel	5.4%	10.2%	0.9%						
Off-highway equipment - Gasoline/LPG/CNG	3.6%	1.6%	5.5%						
Diesel Line/Yard Locomotives	3.4%	6.7%	0.3%						
Snowmobiles	2.4%	0.2%	4.4%						
Pleasure Craft	2.1%	1.2%	3.0%						
Aircraft	0.8%	1.2%	0.4%						
Marine Vessels	0.7%	1.4%	0.1%						
Other Mobile Sources (<0.5% contribution per SCC)	1.4%	1.7%	1.1%						
Mobile Sources Subtotal	**45.3%**	**57.5%**	**33.7%**						

[171] https://www.epa.ohio.gov/dapc/regs/3745_80
[172] http://docs.legis.wisconsin.gov/code/admin_code/nr/400/485.pdf

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Stationary Sources (Point and Non-Point Sources)									
Solvents: Consumer, Commercial, Household, Personal Care Products	7.4%		14.5%	Part 6. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1660, 336.1661)[173]	Title 35, Part 223: Subpart B: Consumer and Commercial Products[174]	Title 326, Article 8-15 (Standards for Consumer and Commercial Products)[175]		Chapter 3745-112, Consumer Products[176] based on 2006 OTC model rule Phase II (statewide)	
Electric Generation Coal Boiler	7.0%	14.1%	0.3%	Part 8. Emission Limitations and Prohibitions—Oxides of Nitrogen[177]	Title 35, Part 225, Subpart B, Multi-pollutant Standard and Combined Pollutant Standard[178] Title 35, Part 217, Subpart M: Electrical Generating Units, Subpart U: NOx Control and Trading Program for specified NOx Generating Units, Subpart V: Electric Power Generation,	Title 326, Article 10, Nitrogen Oxides Rules[180]		Chapter 3745-110, Nitrogen Oxides - Reasonably Available Control Technology[181] (Existing sources: Ashtabula, Cuyahoga, Geauga, Lake, Lorain, Medina, Portage, or Summit County; new or modified sources: statewide)	Chapter NR 428 Control of Nitrogen Compound Emissions[182] Chapter NR 433 Protection of Visibility by Application of Best Available Retrofit Technology[183]

173 https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
174 http://www.ilga.gov/commission/jcar/admincode/035/03500223sections.html
175 http://www.in.gov/legislative/iac/T03260/A00080.PDF
176 https://www.epa.ohio.gov/dapc/regs/3745_112
177 https://www.michigan.gov/documents/deq/deq-aqd-air-rules-apc-part8_314769_7.pdf
178 http://www.ilga.gov/commission/jcar/admincode/035/03500225sections.html
180 http://www.in.gov/legislative/iac/T03260/A00100.PDF
181 https://www.epa.ohio.gov/dapc/regs/3745_110
182 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/428/_2?up=1
183 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/433

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
					Subpart W: NOx Trading Program for Electrical Generating Units[179]				
Oil and Gas Exploration and Production	4.1%	1.9%	6.2%	Part 6 and 7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1629)[184]					
Residential Wood Combustion	3.9%	0.6%	7.1%	5514 of PA 451 of 1994 prohibits state regulation of “wood heaters”					
Open Burning/ Prescribed Burning	3.2%	0.6%	5.8%	Michigan Air Pollution Control Rules (336.1310) and Part 115 (Solid Waste) Rules[185]	Title 35, Part 237: Open Burning	Title 13, Article 17, Chapter 9, and Title 326, Article 4-1, Burning Regulations (Open Burning)[186]		Chapter 3745-19, Open Burning Standards[187] (statewide)	Chapter NR 429 Malodorous Emissions and Open Burning[188]
Residential Natural Gas Combustion	3.2%	6.1%	0.3%						
Surface Coating	2.9%		5.7%	Part 6 and7. Emission Limitation and Prohibitions – Existing and New	Title 35, Parts 218 and 219: Subpart F: Coating Operations[190, 191]	Title 326, Article 8-14 Volatile Organic Compound Rules (Standards for AIM Coatings) [192]		Chapter 3745-21, Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and	Chapter NR 421 Control of Organic Compound Emissions from Chemical, Coatings

[179] https://pcb.illinois.gov/documents/dsweb/Get/Document-11928/
[184] https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
[185] https://www.michigan.gov/egle/0,9429,7-135-3310_4106_70665_70668-234568--,00.html
[186] https://www.in.gov/idem/openburning/2399.htm
[187] https://www.epa.ohio.gov/dapc/regs/3745_19
[188] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/429
[190] https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
[191] https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
[192] http://www.in.gov/legislative/iac/T03260/A00080.PDF

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
				Sources of Volatile Organic Compounds Emissions (336.1610, 336.1620, 336.1621, 336.1632)[189]				Related Materials Standards[193] (geographic applicability varies by control technique guideline [CTG])	And Rubber Products Manufacturing[194] Chapter NR 422 Control of Organic Compound Emissions from Surface Coating, Printing And Asphalt Surfacing Operations[195]
Agriculture - Pesticides Application & Livestock	2.2%		4.2%						
Graphic Arts	2.1%		4.1%	Part 6 and 7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1624)[196]	Title 35, Parts 218 and 219, Subpart H: Printing and Publishing: Printing and Publishing[197, 198]	Title 326, Article 8-16 (Offset Lithographic Printing and Letterpress Printing)[199]		Chapter 3745-21, Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[200] (geographic applicability varies by CTG)	Chapter NR 422.14(422.145) Control of Organic Compound Emissions From Surface Coating, Printing And Asphalt Surfacing Operations[201]

[189] https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
[193] https://www.epa.ohio.gov/dapc/regs/3745_21
[194] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/421
[195] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/422
[196] https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
[197] https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
[198] https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
[199] http://www.in.gov/legislative/iac/T03260/A00080.PDF
[200] https://www.epa.ohio.gov/dapc/regs/3745_21
[201] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/422

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Architectural Coatings	1.8%		3.5%		Title 35, Part 223, Subpart C, Architectural and Industrial Maintenance Coatings[202] Title 35, Parts 218 and 219, Subpart X: Construction[203, 204]	Title 326, Article 8-14 Volatile Organic Compound Rules (Standards for AIM Coatings)[205]		Chapter 3745-113, AIM Coatings[206] based on 2001 OTC model rule (statewide)	Chapter 422.15 Control of Organic Compound Emissions From Surface Coating, Printing And Asphalt Surfacing Operations[207]
Commercial/Industrial Boilers and IC Engines - Natural gas (nonpoint)	1.8%	3.4%	0.2%	Part 8. Emission Limitations and Prohibitions—Oxides of Nitrogen[208]	Title 35, Part 217, Subpart C: Existing Fuel Combustion Emission Units, Subpart E: Industrial Boilers, Subpart F: Process Heaters, Subpart Q: Stationary Reciprocating Internal Combustion Engines and Turbines[209]	Title 326, Article 10, Nitrogen Oxides Rules[210]	Chapter 7011, Standards for Stationary Sources, Indirect and Direct Heating (7011.0600-7011-.0625, 7011.0500-7011.0550)[211]		
Commercial/Industrial Boilers and IC	1.6%	3.1%	0.2%	Part 8. Emission Limitations and Prohibitions—	Title 35, Part 217, Subpart C: Existing Fuel Combustion Emission Units,	Title 326, Article 10, Nitrogen Oxides Rules[214]	Chapter 7011, Standards for Stationary Sources, Indirect and Direct	Chapter 3745-14, NOx Budget Program[216]	Chapter NR 428 Control of Nitrogen Compound Emissions[218]

[202] https://casetext.com/regulation/illinois-administrative-code/title-35-environmental-protection/part-223-standards-and-limitations-for-organic-material-emissions-for-area-sources/subpart-c-architectural-and-industrial-maintenance-coatings
[203] https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
[204] https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
[205] http://www.in.gov/legislative/iac/T03260/A00080.PDF
[206] https://www.epa.ohio.gov/dapc/regs/3745_113
[207] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/422
[208] https://www.michigan.gov/documents/deq/deq-aqd-air-rules-apc-part8_314769_7.pdf
[209] https://pcb.illinois.gov/documents/dsweb/Get/Document-11928/
[210] http://www.in.gov/legislative/iac/T03260/A00100.PDF
[211] https://www.revisor.mn.gov/rules/7011/
[214] http://www.in.gov/legislative/iac/T03260/A00100.PDF
[216] https://www.epa.ohio.gov/dapc/regs/3745_14
[218] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/428

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Engines - Natural gas (Point)				Oxides of Nitrogen[212]	Subpart E: Industrial Boilers, Subpart F: Process Heaters, Subpart Q: Stationary Reciprocating Internal Combustion Engines and Turbines[213]		Heating (7011.0600-7011-.0625, 7011.0500-7011.0550)[215]	Chapter 3745-110, Nitrogen Oxides - Reasonably Available Control Technology[217] (Existing sources: Ashtabula, Cuyahoga, Geauga, Lake, Lorain, Medina, Portage, or Summit County; new or modified sources: statewide)	
Petroleum Product Storage, Transport, Processing	1.3%		2.6%	Part 6 and 7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1608, 336.1609, 336.1615-336.1617, 336.1622, 336.1705, 336.1706)[219, 220]	Title 35, Parts 218 and 219, Subpart B: Organic Emissions from Storage and Loading Operations and Subpart R: Petroleum Refining and Related Industries; Asphalt Materials[221, 222]	Title 326, Article 8-4 (Petroleum Sources)[223]		Chapter 3745-21, Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[224] (geographic applicability varies by CTG)	Chapter NR 420 Control of Organic Compound Emissions from Petroleum And Gasoline Sources[225]

[212] https://www.michigan.gov/documents/deq/deq-aqd-air-rules-apc-part8_314769_7.pdf
[213] https://pcb.illinois.gov/documents/dsweb/Get/Document-11928/
[215] https://www.revisor.mn.gov/rules/7011/
[217] https://www.epa.ohio.gov/dapc/regs/3745_14
[219] https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
[220] https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=477_10451_AdminCode.pdf
[221] https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
[222] https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
[223] http://www.in.gov/legislative/iac/T03260/A00080.PDF
[224] https://www.epa.ohio.gov/dapc/regs/3745_21
[225] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/420

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Solvents: Degreasing	1.1%		2.2%	Part 6 and 7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1611-336.1614, 336.1707-336.1710)[226, 227]	Title 35, Parts 218 and 219, Subpart E: Solvent Cleaning[228, 229]	Title 326, Article 8-3 (Organic Solvent Degreasing Operations)[230]		Chapter 3745-21, Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[231] (geographic applicability varies by CTG)	Chapter NR 423 Control of Organic Compound Emissions from Solvent Cleaning Operations[232]
Gasoline Service Stations	1.1%		2.2%	Part 6 and 7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1606, 336.1607, 336.1703, 336.1704)[233]	Title 35, Parts 218 and 219, Subpart Y: Gasoline Distribution[234, 235]	Title 326, Article 8-14 Volatile Organic Compound Rules (Gasoline Dispensing Facilities)[236, 237]	Chapter 7011, Standards for Stationary Sources, Stage-One Vapor Recovery 7011.0870[238]	Chapter 3745-21 Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[239] (geographic applicability varies by CTG)	Chapter NR 420 Control of Organic Compound Emissions From Petroleum and Gasoline Sources[240]

226 https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
227 https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=477_10451_AdminCode.pdf
228 https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
229 https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
230 http://www.in.gov/legislative/iac/T03260/A00080.PDF
231 https://www.epa.ohio.gov/dapc/regs/3745_21
232 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/423
233 https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
234 https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
235 https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
236 http://www.in.gov/legislative/iac/T03260/A00080.PDF
237 https://www.in.gov/idem/airquality/2373.htm
238 https://www.revisor.mn.gov/rules/7011.0870/
239 https://www.epa.ohio.gov/dapc/regs/3745_21
240 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/420

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
Metal Production: Taconite Iron Ore Processing	0.9%	1.9%	0.0%						
Other combustion (industrial wood; residential/industrial propane boilers; gas/oil/LPG-fired heaters; etc.)	0.9%	1.7%	0.1%	Part 8. Emission Limitations and Prohibitions—Oxides of Nitrogen[241]	Title 35, Part 217, Subpart C: Existing Fuel Combustion Emission Units, Subpart E: Industrial Boilers, Subpart F: Process Heaters, Subpart Q: Stationary Reciprocating Internal Combustion Engines and Turbines[242]	Title 326, Article 10, Nitrogen Oxides Rules[243] Title 326, Article 4-3 (Outdoor Hydronic Heaters)[244]	Chapter 7011, Standards for Stationary Sources[245]	Chapter 3745-110, Nitrogen Oxides - Reasonably Available Control Technology[246] (Existing sources: Ashtabula, Cuyahoga, Geauga, Lake, Lorain, Medina, Portage, or Summit County; new or modified sources: statewide)	Chapter NR 428 Control of Nitrogen Compound Emissions[247]
Electric Generation Natural Gas Turbine	0.4%	0.8%	0.1%	Part 8. Emission Limitations and Prohibitions—Oxides of Nitrogen[248]	Title 35, Part 217, Subpart M: Electrical Generating Units, Subpart U: NOx Control and Trading Program for specified NOx Generating Units, Subpart V: Electric Power Generation, Subpart W: NOx Trading Program for	Title 326, Article 10, Nitrogen Oxides Rules[250]		Chapter 3745-110, Nitrogen Oxides - Reasonably Available Control Technology[251] (Existing sources: Ashtabula, Cuyahoga, Geauga, Lake, Lorain, Medina, Portage, or Summit County; new or modified sources: statewide)	Chapter NR 428 Control of Nitrogen Compound Emissions[252]

241 https://www.michigan.gov/documents/deq/deq-aqd-air-rules-apc-part8_314769_7.pdf
242 https://pcb.illinois.gov/documents/dsweb/Get/Document-11928/
243 http://www.in.gov/legislative/iac/T03260/A00100.PDF
244 http://www.in.gov/legislative/iac/T03260/A00040.PDF
245 https://www.revisor.mn.gov/rules/7011/
246 https://www.epa.ohio.gov/dapc/regs/3745_110
247 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/428
248 https://www.michigan.gov/documents/deq/deq-aqd-air-rules-apc-part8_314769_7.pdf
250 http://www.in.gov/legislative/iac/T03260/A00100.PDF
251 https://www.epa.ohio.gov/dapc/regs/3745_110
252 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/428

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
					Electrical Generating Units[249]				
Cement Manufacturing (Dry Process)	0.4%	0.8%	0.0%	Part 8. Emission Limitations and Prohibitions—Oxides of Nitrogen (336.1817)[253]	Title 35, Part 217, Subparts H and T: Cement Kilns[254]	Title 326, Article 10, Nitrogen Oxides Rules[255]		Rule 3745-14-11, Portland Cement Kilns[256] (statewide)	Chapter NR 428 - Control of Nitrogen Compound Emissions[257]
Other Stationary Sources (<0.5% contribution per SCC)	7.2%	7.4%	7.0%	Emission of volatile organic compound from existing equipment utilized in manufacturing synthesized pharmaceutical products. (336.1625)[258]				Chapter 3745-31, Permits-to-Install New Sources and Permit-to-Install and Operate Program (statewide) Chapter 3745-77, Title V Permit Rules[259] (statewide) Chapter 3745-21 Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[260] (geographic applicability varies by CTG)	Chapter NR 419 – Control of Organic Compounds Emissions[261] Chapter NR 421 - Control of Organic Compound Emissions from Chemical, Coatings and Rubber Products Manufacturing[262] Chapter NR 423 Control of Organic Compound Emissions from Solvent Cleaning Operations[263]

249 https://pcb.illinois.gov/documents/dsweb/Get/Document-11928/
253 https://www.michigan.gov/documents/deq/deq-aqd-air-rules-apc-part8_314769_7.pdf
254 https://pcb.illinois.gov/documents/dsweb/Get/Document-11928/
255 http://www.in.gov/legislative/iac/T03260/A00100.PDF
256 https://www.epa.ohio.gov/dapc/regs/3745_14
257 http://docs.legis.wisconsin.gov/code/admin_code/nr/400/428.pdf
258 https://ars.apps.lara.state.mi.us/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
259 https://www.epa.ohio.gov/dapc/regs/3745_77
260 https://www.epa.ohio.gov/dapc/regs/3745_21
261 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/419
262 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/421
263 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/423

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[157]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[158]	Wisconsin
									Chapter NR 424 – Control of Organic Compounds Emissions from Process Lines[264] Chapter NR 428 - Control of Nitrogen Compound Emissions[265]
Stationary Sources (Point & Non-Point Sources) Subtotal	**54.7%**	**42.5%**	**66.3%**						
TOTAL	**100.0%**	**100.0%**	**100.0%**						

[264] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/424
[265] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/428

APPENDIX B
Emission Reduction and Cost Effectiveness by State and Nonattainment Area

APPENDIX B. EMISSIONS REDUCTION AND COST-EFFECTIVENESS FOR NON-ROAD DIESEL CONSTRUCTION AND INDUSTRIAL EQUIPMENT

Table B 1. Engine emission reduction estimates and average cost-effectiveness for construction equipment modernized with Tier 4 engines by State.

Equipment Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
Illinois									
Group A	0.21	50-75 HP	694	2,592	2,067	5,354	30%	64	$47,461
		75-100 HP	616	2,346	1,952	4,914	30%	183	$22,270
		100-175 HP	114	447	729	1,289	30%	76	$22,613
Group B	0.43	100-175 HP	20	62	110	191	30%	16	$16,371
		175-300 HP	14	53	82	149	30%	22	$15,188
		300-600 HP	12	35	100	146	30%	38	$7,959
		750-1000 HP	2	11	1	14	30%	4	$12,210
Group C	0.59	300-600 HP	6	59	174	239	30%	92	$5,397
		600-750 HP	1	9	27	37	30%	24	$4,801
		750-1000 HP	<1	8	10	18	30%	10	$6,587
								529	**$19,829**
Indiana									
Group A	0.21	50-75 HP	408	1,812	838	3,058	30%	39	$44,752
		75-100 HP	362	1,672	673	2,706	30%	105	$21,337
		100-175 HP	68	301	292	662	30%	41	$21,435
Group B	0.43	100-175 HP	12	39	48	99	30%	8	$15,711
		175-300 HP	8	34	40	82	30%	12	$14,680
		300-600 HP	7	21	53	81	30%	21	$7,839
		750-1000 HP	1	6	5	13	30%	3	$16,046

Equipment Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
Group C	0.59	300-600 HP	4	34	92	130	30%	51	$5,329
		600-750 HP	1	6	14	20	30%	13	$4,667
		750-1000 HP	<1	4	20	24	30%	11	$8,560
Total								**305**	**$19,125**
Michigan									
Group A	0.21	50-75 HP	573	736	647	1,955	30%	26	$42,380
		75-100 HP	507	703	586	1,797	30%	70	$20,886
		100-175 HP	93	134	221	448	30%	28	$21,173
Group B	0.43	100-175 HP	16	18	40	74	30%	6	$15,545
		175-300 HP	12	17	33	62	30%	9	$14,825
		300-600 HP	10	14	34	57	30%	16	$7,430
		750-1000 HP	2	3	<1	5	30%	2	$11,720
Group C	0.59	300-600 HP	5	24	70	99	30%	39	$5,300
		600-750 HP	1	4	11	16	30%	10	$4,776
		750-1000 HP	<1	3	7	10	30%	5	$7,395
Total								**212**	**$18,198**
Minnesota									
Group A	0.21	50-75 HP	398	1,856	1,453	3,708	30%	44	$48,209
		75-100 HP	353	1,661	1,330	3,344	30%	124	$22,406
		100-175 HP	64	265	466	795	30%	46	$22,855
Group B	0.43	100-175 HP	11	38	87	136	30%	11	$16,931
		175-300 HP	8	32	61	101	30%	14	$15,611
		300-600 HP	7	19	72	97	30%	25	$8,237
		750-1000 HP	1	8	1	10	30%	3	$12,828
Group C	0.59	300-600 HP	3	33	123	159	30%	60	$5,548
		600-750 HP	1	6	19	25	30%	16	$4,848

Equipment Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
		750-1000 HP	<1	5	10	16	30%	8	$7,141
Total								**351**	**$20,205**
Ohio									
Group A	0.21	50-75 HP	721	2,250	1,129	4,100	30%	53	$43,801
		75-100 HP	643	2,016	935	3,594	30%	140	$21,131
		100-175 HP	119	334	479	932	30%	57	$21,872
Group B	0.43	100-175 HP	20	46	71	137	30%	12	$15,770
		175-300 HP	14	40	58	113	30%	17	$14,847
		300-600 HP	12	25	76	112	30%	29	$7,893
		750-1000 HP	2	8	2	12	30%	3	$12,836
Group C	0.59	300-600 HP	6	39	133	179	30%	69	$5,436
		600-750 HP	1	7	20	28	30%	18	$4,746
		750-1000 HP	<1	5	17	23	30%	11	$7,907
Total								**409**	**$19,114**
Wisconsin									
Group A	0.21	50-75 HP	345	1,473	781	2,599	30%	32	$45,360
		75-100 HP	305	1,325	634	2,264	30%	87	$21,510
		100-175 HP	56	237	246	539	30%	33	$21,552
Group B	0.43	100-175 HP	10	32	46	88	30%	7	$15,994
		175-300 HP	7	27	38	72	30%	11	$14,959
		300-600 HP	6	17	50	72	30%	19	$7,993
		750-1000 HP	1	5	1	8	30%	2	$13,012
Group C	0.59	300-600 HP	3	28	86	117	30%	45	$5,418
		600-750 HP	<1	5	12	18	30%	12	$4,706
		750-1000 HP	<1	4	11	14	30%	7	$7,868
Total								**256**	**$19,150**

Table B 2. Engine emission reduction estimates and average cost-effectiveness for construction equipment modernized with Tier 4 engines by nonattainment area.

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
Allegan, MI									
Group A	0.21	50-75 HP	6	8	7	21	30%	0.3	$42,380
		75-100 HP	5	7	6	19	30%	0.8	$20,886
		100-175 HP	1	1	2	5	30%	0.3	$21,173
Group B	0.43	100-175 HP	<1	<1	<1	1	30%	0.1	$15,545
		175-300 HP	<1	<1	<1	1	30%	0.1	$14,825
		300-600 HP	<1	<1	<1	1	30%	0.2	$7,430
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$11,720
Group C	0.59	300-600 HP	<1	<1	1	1	30%	0.4	$5,300
		600-750 HP	<1	<1	<1	<1	30%	0.1	$4,776
		750-1000 HP	<1	<1	<1	<1	30%	0.1	$7,395
Total								**2.3**	**$18,198**
Berrien, MI									
Group A	0.21	50-75 HP	7	9	8	24	30%	0.3	$42,379
		75-100 HP	6	9	7	22	30%	0.9	$20,886
		100-175 HP	1	2	3	5	30%	0.3	$21,173
Group B	0.43	100-175 HP	<1	<1	<1	1	30%	0.1	$15,545
		175-300 HP	<1	<1	<1	1	30%	0.1	$14,825
		300-600 HP	<1	<1	<1	1	30%	0.2	$7,430
		750-1000 HP	<1	<1	<1	<1	30%	< 0.1	$11,720
Group C	0.59	300-600 HP	<1	<1	1	1	30%	0.5	$5,300
		600-750 HP	<1	<1	<1	<1	30%	0.1	$4,776
		750-1000 HP	<1	<1	<1	<1	30%	0.1	$7,395
Total								**2.6**	**$18,198**

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
Chicago, IL									
Group A	0.21	50-75 HP	472	1,766	1,357	3,596	30%	43.2	$47,204
		75-100 HP	418	1,598	1,240	3,256	30%	121.7	$22,148
		100-175 HP	76	304	400	781	30%	47.1	$22,072
Group B	0.43	100-175 HP	14	42	75	130	30%	10.6	$16,371
		175-300 HP	10	36	56	102	30%	14.8	$15,188
		300-600 HP	8	24	68	99	30%	26.0	$7,959
		750-1000 HP	2	7	<1	9	30%	2.8	$12,210
Group C	0.59	300-600 HP	4	40	119	163	30%	62.9	$5,397
		600-750 HP	1	6	18	25	30%	16.5	$4,801
		750-1000 HP	<1	5	7	12	30%	7.0	$6,587
Total								**352.7**	**$19,599**
Chicago, IN									
Group A	0.21	50-75 HP	26	117	53	196	30%	2.5	$44,623
		75-100 HP	23	108	41	172	30%	6.7	$21,267
		100-175 HP	4	19	16	40	30%	2.5	$21,115
Group B	0.43	100-175 HP	1	3	3	6	30%	0.5	$15,711
		175-300 HP	1	2	3	5	30%	0.8	$14,680
		300-600 HP	<1	1	3	5	30%	1.4	$7,839
		750-1000 HP	<1	<1	<1	1	30%	0.2	$16,046
Group C	0.59	300-600 HP	<1	2	6	8	30%	3.3	$5,329
		600-750 HP	<1	<1	1	1	30%	0.9	$4,667
		750-1000 HP	<1	<1	1	2	30%	0.7	$8,560
Total								**19.4**	$19,003
Chicago, WI									
Group A	0.21	50-75 HP	8	36	19	63	30%	0.8	$45,360

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
		75-100 HP	7	32	15	55	30%	2.1	$21,510
		100-175 HP	1	6	6	13	30%	0.8	$21,552
Group B	0.43	100-175 HP	<1	1	1	2	30%	0.2	$15,994
		175-300 HP	<1	1	1	2	30%	0.3	$14,959
		300-600 HP	<1	<1	1	2	30%	0.5	$7,993
		750-1000 HP	<1	<1	<1	<1	30%	0.1	$13,012
Group C	0.59	300-600 HP	<1	1	2	3	30%	1.1	$5,418
		600-750 HP	<1	<1	<1	<1	30%	0.3	$4,706
		750-1000 HP	<1	<1	<1	<1	30%	0.2	$7,868
Total								**6.2**	**$19,150**
Cincinnati, OH									
Group A	0.21	50-75 HP	124	386	184	694	30%	9.0	$44,023
		75-100 HP	110	346	143	600	30%	23.5	$21,078
		100-175 HP	20	57	64	141	30%	8.8	$21,323
Group B	0.43	100-175 HP	4	8	12	24	30%	2.0	$15,821
		175-300 HP	2	7	10	19	30%	2.9	$15,004
		300-600 HP	2	4	13	19	30%	5.1	$7,978
		750-1000 HP	<1	1	<1	2	30%	0.6	$12,911
Group C	0.59	300-600 HP	1	7	23	31	30%	11.8	$5,495
		600-750 HP	<1	1	3	5	30%	3.2	$4,802
		750-1000 HP	<1	1	3	4	30%	1.9	$8,118
Total								**68.7**	**$19,013**
Cleveland, OH									
Group A	0.21	50-75 HP	166	520	248	935	30%	12.1	$43,543
		75-100 HP	148	466	193	807	30%	31.6	$20,989
		100-175 HP	27	77	86	190	30%	11.9	$21,261

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
Group B	0.43	100-175 HP	5	11	16	32	30%	2.7	$15,770
		175-300 HP	3	9	13	26	30%	3.9	$14,847
		300-600 HP	3	6	17	26	30%	6.8	$7,893
		750-1000 HP	1	2	<1	3	30%	0.8	$12,836
Group C	0.59	300-600 HP	1	9	31	41	30%	15.9	$5,436
		600-750 HP	<1	2	5	6	30%	4.2	$4,746
		750-1000 HP	<1	1	4	5	30%	2.6	$7,907
Total								**92.5**	**$18,875**
Columbus, OH									
Group A	0.21	50-75 HP	162	507	242	911	30%	11.8	$43,543
		75-100 HP	144	454	188	786	30%	30.8	$20,989
		100-175 HP	26	75	84	185	30%	11.6	$21,261
Group B	0.43	100-175 HP	5	10	16	31	30%	2.6	$15,770
		175-300 HP	3	9	13	25	30%	3.8	$14,847
		300-600 HP	3	6	17	25	30%	6.6	$7,893
		750-1000 HP	1	2	<1	3	30%	0.8	$12,836
Group C	0.59	300-600 HP	1	9	30	40	30%	15.5	$5,436
		600-750 HP	<1	2	4	6	30%	4.1	$4,746
		750-1000 HP	<1	1	4	5	30%	2.5	$7,907
Total								**90.1**	**$18,875**
Detroit, MI									
Group A	0.21	50-75 HP	281	362	318	961	30%	12.6	$42,380
		75-100 HP	249	346	288	883	30%	34.6	$20,886
		100-175 HP	46	66	109	220	30%	13.8	$21,173
Group B	0.43	100-175 HP	8	9	20	37	30%	3.1	$15,545
		175-300 HP	6	8	16	30	30%	4.5	$14,825

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
		300-600 HP	5	7	17	28	30%	7.8	$7,430
		750-1000 HP	1	2	<1	3	30%	0.8	$11,720
Group C	0.59	300-600 HP	2	12	34	48	30%	19.1	$5,300
		600-750 HP	<1	2	6	8	30%	5.0	$4,776
		750-1000 HP	<1	1	3	5	30%	2.6	$7,395
Total								**104.0**	**$18,198**
Door, WI									
Group A	0.21	50-75 HP	2	8	4	14	30%	0.2	$45,360
		75-100 HP	2	7	3	12	30%	0.5	$21,510
		100-175 HP	<1	1	1	3	30%	0.2	$21,552
Group B	0.43	100-175 HP	<1	<1	<1	<1	30%	<0.1	$15,994
		175-300 HP	<1	<1	<1	<1	30%	0.1	$14,959
		300-600 HP	<1	<1	<1	<1	30%	0.1	$7,993
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$13,012
Group C	0.59	300-600 HP	<1	<1	<1	1	30%	0.2	$5,418
		600-750 HP	<1	<1	<1	<1	30%	0.1	$4,706
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$7,868
Total								**1.4**	**$19,150**
Louisville, IN									
Group A	0.21	50-75 HP	14	60	27	101	30%	1.3	$44,623
		75-100 HP	12	56	21	89	30%	3.5	$21,267
		100-175 HP	2	10	8	21	30%	1.3	$21,115
Group B	0.43	100-175 HP	<1	1	2	3	30%	0.3	$15,711
		175-300 HP	<1	1	1	3	30%	0.4	$14,680
		300-600 HP	<1	1	2	3	30%	0.7	$7,839
		750-1000 HP	<1	<1	<1	<1	30%	0.1	$16,046

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
Group C	0.59	300-600 HP	<1	1	3	4	30%	1.7	$5,329
		600-750 HP	<1	<1	<1	1	30%	0.4	$4,667
		750-1000 HP	<1	<1	1	1	30%	0.4	$8,560
Total								**10.1**	**$19,003**
Manitowoc County, WI									
Group A	0.21	50-75 HP	2	9	5	16	30%	0.2	$45,360
		75-100 HP	2	8	4	14	30%	0.5	$21,510
		100-175 HP	<1	1	2	3	30%	0.2	$21,552
Group B	0.43	100-175 HP	<1	<1	<1	1	30%	<0.1	$15,994
		175-300 HP	<1	<1	<1	<1	30%	0.1	$14,959
		300-600 HP	<1	<1	<1	<1	30%	0.1	$7,993
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$13,012
Group C	0.59	300-600 HP	<1	<1	1	1	30%	0.3	$5,418
		600-750 HP	<1	<1	<1	<1	30%	0.1	$4,706
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$7,868
Total								**1.6**	**$19,150**
Muskegon, MI									
Group A	0.21	50-75 HP	9	12	10	32	30%	0.4	$42,379
		75-100 HP	8	11	9	29	30%	1.1	$20,886
		100-175 HP	1	2	4	7	30%	0.5	$21,173
Group B	0.43	100-175 HP	<1	<1	1	1	30%	0.1	$15,545
		175-300 HP	<1	<1	1	1	30%	0.1	$14,825
		300-600 HP	<1	<1	1	1	30%	0.3	$7,430
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$11,720
Group C	0.59	300-600 HP	<1	<1	1	2	30%	0.6	$5,300
		600-750 HP	<1	<1	<1	<1	30%	0.2	$4,776

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
		750-1000 HP	<1	<1	<1	<1	30%	0.1	$7,395
Total								**3.4**	**$18,198**
Northern Milwaukee/Ozaukee, WI									
Group A	0.21	50-75 HP	57	245	130	432	30%	5.4	$45,360
		75-100 HP	51	220	105	376	30%	14.4	$21,510
		100-175 HP	9	39	41	90	30%	5.5	$21,552
Group B	0.43	100-175 HP	2	5	8	15	30%	1.2	$15,994
		175-300 HP	1	5	6	12	30%	1.8	$14,959
		300-600 HP	1	3	8	12	30%	3.1	$7,993
		750-1000 HP	<1	1	0	1	30%	0.4	$13,012
Group C	0.59	300-600 HP	<1	5	14	19	30%	7.5	$5,418
		600-750 HP	<1	1	2	3	30%	2.0	$4,706
		750-1000 HP	<1	1	2	2	30%	1.2	$7,868
Total								**42.5**	**$19,150**
Sheboygan, WI									
Group A	0.21	50-75 HP	7	29	16	52	30%	0.6	$45,360
		75-100 HP	6	27	13	45	30%	1.7	$21,510
		100-175 HP	1	5	5	11	30%	0.7	$21,552
Group B	0.43	100-175 HP	<1	1	1	2	30%	0.1	$15,994
		175-300 HP	<1	1	1	1	30%	0.2	$14,959
		300-600 HP	<1	<1	1	1	30%	0.4	$7,993
		750-1000 HP	<1	<1	<1	<1	30%	<0.1	$13,012
Group C	0.59	300-600 HP	<1	1	2	2	30%	0.9	$5,418
		600-750 HP	<1	<1	<1	<1	30%	0.2	$4,706
		750-1000 HP	<1	<1	<1	<1	30%	0.1	$7,868
Total								**5.1**	**$19,150**

Group	Load Factor	Horsepower	Available Equipment Population					Total NOx Emission Reduction (tpy)	Average Cost-effectiveness for Tier 0, Tier 1, & Tier 2 ($/ton)
			Tier 0	Tier 1	Tier 2	Total Tier 0, Tier 1 and Tier 2	Population Available for Modernization		
St. Louis, IL									
Group A	0.21	50-75 HP	33	124	95	252	30%	3.0	$47,204
		75-100 HP	29	112	87	228	30%	8.5	$22,148
		100-175 HP	5	21	28	55	30%	3.3	$22,072
Group B	0.43	100-175 HP	1	3	5	9	30%	0.7	$16,371
		175-300 HP	1	3	4	7	30%	1.0	$15,188
		300-600 HP	1	2	5	7	30%	1.8	$7,959
		750-1000 HP	<1	1	<1	1	30%	0.2	$12,210
Group C	0.59	300-600 HP	<1	3	8	11	30%	4.4	$5,397
		600-750 HP	<1	<1	1	2	30%	1.2	$4,801
		750-1000 HP	<1	<1	<1	1	30%	0.5	$6,587
Total								**24.7**	**$19,599**

Table B 3. Engine emission reduction estimates and average cost-effectiveness for industrial equipment electrification by state.

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
Illinois					
A/C Refrigeration	6-11 HP	475	30%	3	$258,356
	11-16 HP	1,459	30%	13	$162,669
	16-25 HP	1,368	30%	18	$107,123
	25-40 HP	351	30%	7	$49,669
	40-50 HP	2,571	30%	74	$35,872
	50-75 HP	9,786	30%	389	$18,864
Forklifts	50-75 HP	1,593	30%	110	$7,230
	75-100 HP	1,605	30%	14	$53,829
Terminal Tractors	50-75 HP	201	30%	10	$44,446
	75-100 HP	349	30%	2	$347,458
	100-175 HP	560	30%	6	$347,456
	175-300 HP	933	30%	16	$347,456
Total				**661**	**$43,150**
Indiana					
A/C Refrigeration	6-11 HP	285	30%	2	$258,356
	11-16 HP	876	30%	8	$162,669
	16-25 HP	821	30%	11	$107,123
	25-40 HP	211	30%	4	$49,669
	40-50 HP	1,543	30%	44	$35,872
	50-75 HP	5,883	30%	234	$18,864
Forklifts	50-75 HP	1,507	30%	104	$7,230
	75-100 HP	1,518	30%	13	$53,829
Terminal Tractors	50-75 HP	190	30%	10	$44,446
	75-100 HP	330	30%	2	$347,458
	100-175 HP	530	30%	5	$347,456
	175-300 HP	883	30%	15	$347,456
Total				**452**	**$48,125**
Michigan					
A/C Refrigeration	6-11 HP	290	30%	2	$258,356
	11-16 HP	892	30%	8	$162,669
	16-25 HP	837	30%	11	$107,123
	25-40 HP	215	30%	4	$49,669

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
	40-50 HP	1,573	30%	45	$35,872
	50-75 HP	5,987	30%	238	$18,864
Forklifts	50-75 HP	1,190	30%	82	$7,230
	75-100 HP	1,199	30%	10	$53,829
Terminal Tractors	50-75 HP	150	30%	8	$44,446
	75-100 HP	261	30%	2	$347,458
	100-175 HP	418	30%	4	$347,456
	175-300 HP	697	30%	12	$347,456
Total				**426**	**$45,234**
Minnesota					
A/C Refrigeration	6-11 HP	208	30%	1	$258,356
	11-16 HP	639	30%	5	$162,669
	16-25 HP	599	30%	8	$107,123
	25-40 HP	154	30%	3	$49,669
	40-50 HP	1,126	30%	32	$35,872
	50-75 HP	4,290	30%	170	$18,864
Forklifts	50-75 HP	805	30%	56	$7,230
	75-100 HP	811	30%	7	$53,829
Terminal Tractors	50-75 HP	102	30%	5	$44,446
	75-100 HP	176	30%	1	$347,458
	100-175 HP	283	30%	3	$347,456
	175-300 HP	471	30%	8	$347,456
Total				**300**	**$44,602**
Ohio					
A/C Refrigeration	6-11 HP	373	30%	2	$258,356
	11-16 HP	1,147	30%	10	$162,669
	16-25 HP	1,076	30%	14	$107,123
	25-40 HP	276	30%	6	$49,669
	40-50 HP	2,022	30%	58	$35,872
	50-75 HP	7,698	30%	306	$18,864
Forklifts	50-75 HP	1,608	30%	111	$7,230
	75-100 HP	1,620	30%	14	$53,829
Terminal Tractors	50-75 HP	203	30%	10	$44,446
	75-100 HP	352	30%	2	$347,458
	100-175 HP	565	30%	6	$347,456

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
	175-300 HP	941	30%	16	$347,456
Total				**555**	**$45,775**
Wisconsin					
A/C Refrigeration	6-11 HP	198	30%	1	$258,356
	11-16 HP	608	30%	5	$162,669
	16-25 HP	570	30%	7	$107,123
	25-40 HP	146	30%	3	$49,669
	40-50 HP	1,072	30%	31	$35,872
	50-75 HP	4,086	30%	162	$18,864
Forklifts	50-75 HP	1,035	30%	72	$7,230
	75-100 HP	1,043	30%	9	$53,829
Terminal Tractors	50-75 HP	131	30%	7	$44,446
	75-100 HP	226	30%	1	$347,458
	100-175 HP	364	30%	4	$347,456
	175-300 HP	606	30%	11	$347,456
Total				**313**	**$47,989**

Table B 4. Engine emission reduction estimates and average cost-effectiveness for industrial equipment electrification by nonattainment area.

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
Allegan, MI					
A/C Refrigeration	6-11 HP	3	30%	<0.1	$258,356
	11-16 HP	10	30%	0.1	$162,669
	16-25 HP	9	30%	0.1	$107,123
	25-40 HP	2	30%	<0.1	$49,669
	40-50 HP	17	30%	0.5	$35,872
	50-75 HP	65	30%	2.6	$18,864
Forklifts	50-75 HP	26	30%	1.8	$7,230
	75-100 HP	26	30%	0.2	$53,829
Terminal Tractors	50-75 HP	3	30%	0.2	$44,446
	75-100 HP	6	30%	<0.1	$347,458
	100-175 HP	9	30%	0.1	$347,456
	175-300 HP	15	30%	0.3	$347,456
Total				**5.9**	**$53,656**
Berrien, MI					
A/C Refrigeration	6-11 HP	5	30%	<0.1	$258,356
	11-16 HP	14	30%	0.1	$162,669
	16-25 HP	14	30%	0.2	$107,123
	25-40 HP	3	30%	0.1	$49,669
	40-50 HP	25	30%	0.7	$35,872
	50-75 HP	97	30%	3.8	$18,864
Forklifts	50-75 HP	25	30%	1.7	$7,230
	75-100 HP	25	30%	0.2	$53,829
Terminal Tractors	50-75 HP	3	30%	0.2	$44,446
	75-100 HP	6	30%	<0.1	$347,458
	100-175 HP	9	30%	0.1	$347,456
	175-300 HP	15	30%	0.3	$347,456
Total				**7.5**	**$48,298**
Chicago, IL					
A/C Refrigeration	6-11 HP	304	30%	1.6	$258,356
	11-16 HP	934	30%	8.0	$162,669
	16-25 HP	876	30%	11.4	$107,123
	25-40 HP	225	30%	4.6	$49,669

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
	40-50 HP	1,647	30%	47.1	$35,872
	50-75 HP	6,268	30%	248.9	$18,864
Forklifts	50-75 HP	986	30%	68.1	$7,230
	75-100 HP	993	30%	8.6	$53,829
Terminal Tractors	50-75 HP	125	30%	6.4	$44,446
	75-100 HP	216	30%	1.4	$347,458
	100-175 HP	346	30%	3.5	$347,456
	175-300 HP	577	30%	10.0	$347,456
Total				**419.7**	**$42,810**
Chicago, IN					
A/C Refrigeration	6-11 HP	22	30%	0.1	$258,356
	11-16 HP	69	30%	0.6	$162,669
	16-25 HP	65	30%	0.8	$107,123
	25-40 HP	17	30%	0.3	$49,669
	40-50 HP	122	30%	3.5	$35,872
	50-75 HP	464	30%	18.4	$18,864
Forklifts	50-75 HP	74	30%	5.1	$7,230
	75-100 HP	75	30%	0.6	$53,829
Terminal Tractors	50-75 HP	9	30%	0.5	$44,446
	75-100 HP	16	30%	0.1	$347,458
	100-175 HP	26	30%	0.3	$347,456
	175-300 HP	44	30%	0.8	$347,456
Total				**31.2**	**$42,985**
Chicago, WI					
A/C Refrigeration	6-11 HP	6	30%	<0.1	$258,356
	11-16 HP	17	30%	0.1	$162,669
	16-25 HP	16	30%	0.2	$107,123
	25-40 HP	4	30%	0.1	$49,669
	40-50 HP	30	30%	0.9	$35,872
	50-75 HP	116	30%	4.6	$18,864
Forklifts	50-75 HP	22	30%	1.5	$7,230
	75-100 HP	22	30%	0.2	$53,829
Terminal Tractors	50-75 HP	3	30%	0.1	$44,446
	75-100 HP	5	30%	<0.1	$347,458
	100-175 HP	8	30%	0.1	$347,456

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
	175-300 HP	13	30%	0.2	$347,456
Total				**8.1**	**$44,597**
Cincinnati, OH					
A/C Refrigeration	6-11 HP	50	30%	0.3	$258,356
	11-16 HP	154	30%	1.3	$162,669
	16-25 HP	144	30%	1.9	$107,123
	25-40 HP	37	30%	0.8	$49,669
	40-50 HP	271	30%	7.7	$35,872
	50-75 HP	1,031	30%	40.9	$18,864
Forklifts	50-75 HP	192	30%	13.2	$7,230
	75-100 HP	193	30%	1.7	$53,829
Terminal Tractors	50-75 HP	24	30%	1.2	$44,446
	75-100 HP	42	30%	0.3	$347,458
	100-175 HP	67	30%	0.7	$347,456
	175-300 HP	112	30%	2.0	$347,456
Total				**72.0**	**$44,516**
Cleveland, OH					
A/C Refrigeration	6-11 HP	93	30%	0.5	$258,356
	11-16 HP	286	30%	2.5	$162,669
	16-25 HP	268	30%	3.5	$107,123
	25-40 HP	69	30%	1.4	$49,669
	40-50 HP	503	30%	14.4	$35,872
	50-75 HP	1,917	30%	76.1	$18,864
Forklifts	50-75 HP	400	30%	27.6	$7,230
	75-100 HP	403	30%	3.5	$53,829
Terminal Tractors	50-75 HP	51	30%	2.6	$44,446
	75-100 HP	88	30%	0.6	$347,458
	100-175 HP	141	30%	1.4	$347,456
	175-300 HP	234	30%	4.1	$347,456
Total				**138.2**	**$45,769**
Columbus, OH					
A/C Refrigeration	6-11 HP	49	30%	0.3	$258,356
	11-16 HP	150	30%	1.3	$162,669
	16-25 HP	140	30%	1.8	$107,123
	25-40 HP	36	30%	0.7	$49,669

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
	40-50 HP	264	30%	7.5	$35,872
	50-75 HP	1,004	30%	39.9	$18,864
Forklifts	50-75 HP	122	30%	8.5	$7,230
	75-100 HP	123	30%	1.1	$53,829
Terminal Tractors	50-75 HP	15	30%	0.8	$44,446
	75-100 HP	27	30%	0.2	$347,458
	100-175 HP	43	30%	0.4	$347,456
	175-300 HP	72	30%	1.2	$347,456
Total				**63.7**	**$40,481**
Detroit, MI					
A/C Refrigeration	6-11 HP	141	30%	0.8	$258,356
	11-16 HP	433	30%	3.7	$162,669
	16-25 HP	406	30%	5.3	$107,123
	25-40 HP	104	30%	2.1	$49,669
	40-50 HP	763	30%	21.8	$35,872
	50-75 HP	2,903	30%	115.3	$18,864
Forklifts	50-75 HP	534	30%	36.9	$7,230
	75-100 HP	538	30%	4.7	$53,829
Terminal Tractors	50-75 HP	68	30%	3.4	$44,446
	75-100 HP	117	30%	0.7	$347,458
	100-175 HP	188	30%	1.9	$347,456
	175-300 HP	313	30%	5.4	$347,456
Total				**202.1**	**$44,403**
Door, WI					
A/C Refrigeration	6-11 HP	1	30%	<0.1	$258,356
	11-16 HP	3	30%	<0.1	$162,669
	16-25 HP	3	30%	<0.1	$107,123
	25-40 HP	1	30%	<0.1	$49,669
	40-50 HP	6	30%	0.2	$35,872
	50-75 HP	21	30%	0.8	$18,864
Forklifts	50-75 HP	5	30%	0.3	$7,230
	75-100 HP	5	30%	<0.1	$53,829
Terminal Tractors	50-75 HP	1	30%	<0.1	$44,446
	75-100 HP	1	30%	<0.1	$347,458
	100-175 HP	2	30%	<0.1	$347,456

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
	175-300 HP	3	30%	0.1	$347,456
Total				**1.6**	**$47,097**
Louisville, IN					
A/C Refrigeration	6-11 HP	8	30%	<0.1	$258,356
	11-16 HP	24	30%	0.2	$162,669
	16-25 HP	23	30%	0.3	$107,123
	25-40 HP	6	30%	0.1	$49,669
	40-50 HP	42	30%	1.2	$35,872
	50-75 HP	162	30%	6.4	$18,864
Forklifts	50-75 HP	36	30%	2.5	$7,230
	75-100 HP	36	30%	0.3	$53,829
Terminal Tractors	50-75 HP	5	30%	0.2	$44,446
	75-100 HP	8	30%	0.1	$347,458
	100-175 HP	13	30%	0.1	$347,456
	175-300 HP	21	30%	0.4	$347,456
Total				**11.9**	**$46,550**
Manitowoc County, WI					
A/C Refrigeration	6-11 HP	3	30%	<0.1	$258,356
	11-16 HP	9	30%	0.1	$162,669
	16-25 HP	9	30%	0.1	$107,123
	25-40 HP	2	30%	<0.1	$49,669
	40-50 HP	16	30%	0.5	$35,872
	50-75 HP	62	30%	2.5	$18,864
Forklifts	50-75 HP	25	30%	1.7	$7,230
	75-100 HP	25	30%	0.2	$53,829
Terminal Tractors	50-75 HP	3	30%	0.2	$44,446
	75-100 HP	5	30%	<0.1	$347,458
	100-175 HP	9	30%	0.1	$347,456
	175-300 HP	15	30%	0.3	$347,456
Total				**5.7**	**$53,776**
Muskegon, MI					
A/C Refrigeration	6-11 HP	5	30%	<0.1	$258,356
	11-16 HP	15	30%	0.1	$162,669
	16-25 HP	14	30%	0.2	$107,123
	25-40 HP	4	30%	0.1	$49,669

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
	40-50 HP	27	30%	0.8	$35,872
	50-75 HP	103	30%	4.1	$18,864
Forklifts	50-75 HP	25	30%	1.7	$7,230
	75-100 HP	25	30%	0.2	$53,829
Terminal Tractors	50-75 HP	3	30%	0.2	$44,446
	75-100 HP	5	30%	<0.1	$347,458
	100-175 HP	9	30%	0.1	$347,456
	175-300 HP	15	30%	0.3	$347,456
Total				**7.7**	**$47,501**
Northern Milwaukee/Ozaukee, WI					
A/C Refrigeration	6-11 HP	37	30%	0.2	$258,356
	11-16 HP	114	30%	1.0	$162,669
	16-25 HP	107	30%	1.4	$107,123
	25-40 HP	27	30%	0.6	$49,669
	40-50 HP	201	30%	5.7	$35,872
	50-75 HP	765	30%	30.4	$18,864
Forklifts	50-75 HP	158	30%	10.9	$7,230
	75-100 HP	159	30%	1.4	$53,829
Terminal Tractors	50-75 HP	20	30%	1.0	$44,446
	75-100 HP	35	30%	0.2	$347,458
	100-175 HP	55	30%	0.6	$347,456
	175-300 HP	92	30%	1.6	$347,456
Total				**54.9**	**$45,633**
Sheboygan, WI					
A/C Refrigeration	6-11 HP	4	30%	<0.1	$258,356
	11-16 HP	13	30%	0.1	$162,669
	16-25 HP	12	30%	0.2	$107,123
	25-40 HP	3	30%	0.1	$49,669
	40-50 HP	22	30%	0.6	$35,872
	50-75 HP	85	30%	3.4	$18,864
Forklifts	50-75 HP	44	30%	3.0	$7,230
	75-100 HP	44	30%	0.4	$53,829
Terminal Tractors	50-75 HP	6	30%	0.3	$44,446
	75-100 HP	10	30%	0.1	$347,458
	100-175 HP	15	30%	0.2	$347,456

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness Tier ($/ton)
		Tier 4	Population Available for Modernization		
	175-300 HP	26	30%	0.4	$347,456
Total				**8.7**	**$56,914**
St. Louis, IL					
A/C Refrigeration	6-11 HP	20	30%	0.1	$258,356
	11-16 HP	60	30%	0.5	$162,669
	16-25 HP	56	30%	0.7	$107,123
	25-40 HP	14	30%	0.3	$49,669
	40-50 HP	106	30%	3.0	$35,872
	50-75 HP	404	30%	16.0	$18,864
Forklifts	50-75 HP	47	30%	3.3	$7,230
	75-100 HP	48	30%	0.4	$53,829
Terminal Tractors	50-75 HP	6	30%	0.3	$44,446
	75-100 HP	10	30%	0.1	$347,458
	100-175 HP	17	30%	0.2	$347,456
	175-300 HP	28	30%	0.5	$347,456
Total				**25.4**	**$40,140**

Table B 5. Engine emission reduction estimates and average cost-effectiveness for industrial equipment alternative fuel by state.

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Alternative Fuel		
Illinois					
Forklifts	50-75 HP	1,593	30%	110	$6,520
Sweepers/Scrubbers	50-75 HP	253	30%	8	$14,205
Terminal Tractors	50-75 HP	201	30%	9	$34,957
Aerial Lifts	50-75 HP	1,424	30%	7	$92,410
Total				**133**	**$13,048**
Indiana					
Forklifts	50-75 HP	1,507	30%	104	$6,520
Sweepers/Scrubbers	50-75 HP	240	30%	7	$14,205
Terminal Tractors	50-75 HP	190	30%	8	$34,957
Aerial Lifts	50-75 HP	1,461	30%	7	$92,410
Total				**126**	**$13,378**
Michigan					
Forklifts	50-75 HP	1,190	30%	82	$6,520
Sweepers/Scrubbers	50-75 HP	189	30%	6	$14,205
Terminal Tractors	50-75 HP	150	30%	6	$34,957
Aerial Lifts	50-75 HP	1,089	30%	5	$92,410
Total				**99**	**$13,140**
Minnesota					
Forklifts	50-75 HP	805	30%	55	$6,520
Sweepers/Scrubbers	50-75 HP	128	30%	4	$14,205
Terminal Tractors	50-75 HP	102	30%	4	$34,957
Aerial Lifts	50-75 HP	784	30%	4	$92,410
Total				**67**	**$13,403**
Ohio					
Forklifts	50-75 HP	1,608	30%	111	$6,520
Sweepers/Scrubbers	50-75 HP	256	30%	8	$14,205
Terminal Tractors	50-75 HP	203	30%	9	$34,957
Aerial Lifts	50-75 HP	1,508	30%	7	$92,410
Total				**135**	**$13,244**
Wisconsin					
Forklifts	50-75 HP	1,035	30%	71	$6,520

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Alternative Fuel		
Sweepers/Scrubbers	50-75 HP	165	30%	5	$14,205
Terminal Tractors	50-75 HP	131	30%	6	$34,957
Aerial Lifts	50-75 HP	1,032	30%	5	$92,410
Total				**87**	**$13,498**

Table B 6. Engine emission reduction estimates and average cost-effectiveness for industrial equipment alternative fuel by nonattainment area.

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
Allegan, MI					
Forklifts	50-75 HP	26	30%	1.8	$6,520
Sweepers/Scrubbers	50-75 HP	4	30%	0.1	$14,205
Terminal Tractors	50-75 HP	3	30%	0.1	$34,957
Aerial Lifts	50-75 HP	24	30%	0.1	$92,410
Total				**2.2**	**$13,140**
Berrien, MI					
Forklifts	50-75 HP	25	30%	1.7	$6,520
Sweepers/Scrubbers	50-75 HP	4	30%	0.1	$14,205
Terminal Tractors	50-75 HP	3	30%	0.1	$34,957
Aerial Lifts	50-75 HP	23	30%	0.1	$92,410
Total				**2.1**	**$13,140**
Chicago, IL					
Forklifts	50-75 HP	986	30%	68.0	$6,520
Sweepers/Scrubbers	50-75 HP	157	30%	4.8	$14,205
Terminal Tractors	50-75 HP	125	30%	5.4	$34,957
Aerial Lifts	50-75 HP	881	30%	4.1	$92,410
Total				**82.3**	**$13,048**
Chicago, IN					
Forklifts	50-75 HP	74	30%	5.1	$6,520

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
Sweepers/Scrubbers	50-75 HP	12	30%	0.4	$14,205
Terminal Tractors	50-75 HP	9	30%	0.4	$34,957
Aerial Lifts	50-75 HP	72	30%	0.3	$92,410
Total				**6.2**	**$13,378**
Chicago, WI					
Forklifts	50-75 HP	22	30%	1.5	$6,520
Sweepers/Scrubbers	50-75 HP	3	30%	0.1	$14,205
Terminal Tractors	50-75 HP	3	30%	0.1	$34,957
Aerial Lifts	50-75 HP	22	30%	0.1	$92,410
Total				**1.8**	**$13,498**
Cincinnati, OH					
Forklifts	50-75 HP	192	30%	13.2	$6,520
Sweepers/Scrubbers	50-75 HP	31	30%	0.9	$14,205
Terminal Tractors	50-75 HP	24	30%	1.0	$34,957
Aerial Lifts	50-75 HP	180	30%	0.8	$92,410
Total				**16.0**	**$13,244**
Cleveland, OH					
Forklifts	50-75 HP	400	30%	27.6	$6,520
Sweepers/Scrubbers	50-75 HP	64	30%	1.9	$14,205
Terminal Tractors	50-75 HP	51	30%	2.2	$34,957
Aerial Lifts	50-75 HP	375	30%	1.8	$92,410
Total				**33.5**	**$13,244**
Columbus, OH					
Forklifts	50-75 HP	122	30%	8.4	$6,520
Sweepers/Scrubbers	50-75 HP	19	30%	0.6	$14,205
Terminal Tractors	50-75 HP	15	30%	0.7	$34,957
Aerial Lifts	50-75 HP	115	30%	0.5	$92,410
Total				**10.2**	**$13,244**
Detroit, MI					
Forklifts	50-75 HP	534	30%	36.8	$6,520
Sweepers/Scrubbers	50-75 HP	85	30%	2.6	$14,205
Terminal Tractors	50-75 HP	68	30%	2.9	$34,957
Aerial Lifts	50-75 HP	488	30%	2.3	$92,410
Total				**44.6**	**$13,140**
Door, WI					
Forklifts	50-75 HP	5	30%	0.3	$6,520

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
Sweepers/Scrubbers	50-75 HP	1	30%	<0.1	$14,205
Terminal Tractors	50-75 HP	1	30%	<0.1	$34,957
Aerial Lifts	50-75 HP	5	30%	<0.1	$92,410
Total				**0.4**	**$13,498**
Louisville, IN					
Forklifts	50-75 HP	36	30%	2.5	$6,520
Sweepers/Scrubbers	50-75 HP	6	30%	0.2	$14,205
Terminal Tractors	50-75 HP	5	30%	0.2	$34,957
Aerial Lifts	50-75 HP	35	30%	0.2	$92,410
Total				**3.0**	**$13,378**
Manitowoc County, WI					
Forklifts	50-75 HP	25	30%	1.7	$6,520
Sweepers/Scrubbers	50-75 HP	4	30%	0.1	$14,205
Terminal Tractors	50-75 HP	3	30%	0.1	$34,957
Aerial Lifts	50-75 HP	25	30%	0.1	$92,410
Total				**2.1**	**$13,498**
Muskegon, MI					
Forklifts	50-75 HP	25	30%	1.7	$6,520
Sweepers/Scrubbers	50-75 HP	4	30%	0.1	$14,205
Terminal Tractors	50-75 HP	3	30%	0.1	$34,957
Aerial Lifts	50-75 HP	23	30%	0.1	$92,410
Total				**2.1**	**$13,140**
Northern Milwaukee/Ozaukee, WI					
Forklifts	50-75 HP	158	30%	10.9	$6,520
Sweepers/Scrubbers	50-75 HP	25	30%	0.8	$14,205
Terminal Tractors	50-75 HP	20	30%	0.9	$34,957
Aerial Lifts	50-75 HP	157	30%	0.7	$92,410
Total				**13.2**	**$13,498**
Sheboygan, WI					
Forklifts	50-75 HP	44	30%	3.0	$6,520
Sweepers/Scrubbers	50-75 HP	7	30%	0.2	$14,205
Terminal Tractors	50-75 HP	6	30%	0.2	$34,957
Aerial Lifts	50-75 HP	43	30%	0.2	$92,410
Total				**3.7**	**$13,498**
St. Louis, IL					
Forklifts	50-75 HP	47	30%	3.3	$6,520

Equipment	Horsepower	Available Equipment Population		Total NOx Emission Reduction (tpy)	Average Cost-effectiveness ($/ton)
		Tier 4	Population Available for Modernization		
Sweepers/Scrubbers	50-75 HP	8	30%	0.2	$14,205
Terminal Tractors	50-75 HP	6	30%	0.3	$34,957
Aerial Lifts	50-75 HP	42	30%	0.2	$92,410
Total				**3.9**	**$13,048**

Table B 7. Engine emission reduction estimates by State for construction equipment with anti-idle rule.

State	NOx Emissions Reductions (tpy)
Illinois	371
Indiana	403
Michigan	188
Minnesota	289
Ohio	419
Wisconsin	256
Total	**1,926**

Table B 8. Engine emission reduction estimates by NAA area for construction equipment with anti-idle rule.

Area	NOx Emissions Reductions (tpy)
Allegan, MI	2
Berrien, MI	2
Chicago, IL	247
Chicago, IN	26
Chicago, WI	6
Cincinnati, OH	71
Cleveland, OH	95
Columbus, OH	93
Detroit, MI	92
Door, WI	1
Louisville, IN	13
Manitowoc County, WI	2
Muskegon, MI	3
Northern Milwaukee/Ozaukee, WI	43
Sheboygan, WI	5
St. Louis, IL	17
Total	**720**

Table B 9. Engine emission reduction estimates by State area for construction equipment subject to emission specifications in government contracts.

State	NOx Emissions Reductions from Fleet Modernization to Tier 4 (tpy)	NOx Emissions Reductions from Anti-Idle Rule (tpy)	Total NOx Emissions Reductions (tpy)
Illinois	177	37	213
Indiana	102	40	142
Michigan	70	19	89
Minnesota	117	29	146
Ohio	136	42	178
Wisconsin	85	26	111
Total	**687**	**193**	**880**

Table B 10. Engine emission reduction estimates by NAA area for construction equipment subject to emission specifications in government contracts.

Area	NOx Emissions Reductions from Fleet Modernization to Tier 4 (tpy)	NOx Emissions reductions from Anti-Idle Rule (tpy)	Total NOx Emissions Reductions (tpy)
Allegan, MI	1	<1	1
Berrien, MI	1	<1	1
Chicago, IL	117	25	142
Chicago, IN	7	3	9
Chicago, WI	2	<1	3
Cincinnati, OH	23	7	30
Cleveland, OH	31	10	40
Columbus, OH	30	9	39
Detroit, MI	35	9	44
Door, WI	<1	<1	<1
Louisville, IN	3	1	5
Manitowoc County, WI	<1	<1	<1
Muskegon, MI	1	<1	2
Northern Milwaukee/Ozaukee, WI	14	4	19
Sheboygan, WI	2	<1	2
St. Louis, IL	8	2	10
Total	**276**	**72**	**348**

APPENDIX C
Existing State Regulations for Heavy-Duty Trucks and Volatile Chemical Products

APPENDIX C. EXISTING STATE REGULATIONS FOR HEAVY-DUTY TRUCKS AND VOLATILE CHEMICAL PRODUCTS

Table C-1. State and Local Regulations by LADCO-wide emissions inventory groupings, organized from largest to smallest NOx+VOC contribution[266]

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC[267]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[268]	Wisconsin
Mobile Sources									
Heavy-duty Haul Trucks	6.4%	12.1%	1.0%					Chapter 3745-80, Statewide Motor Vehicle Anti-Tampering Program [269]	Chapter NR 485 Control of Emissions from Motor Vehicles, Internal Combustion Engines and Mobile Sources; Tampering Prohibition[270]
Stationary Sources (Point and Non-Point Sources)									
Solvents: Consumer, Commercial, Household, Personal Care Products	7.4%		14.5%	Part 6. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1660, 336.1661)[271]	Title 35, Part 223: Subpart B: Consumer and Commercial Products[272]	Title 326, Article 8-15 (Standards for Consumer and Commercial Products)[273]		Chapter 3745-112, Consumer Products[274] based on 2006 OTC model rule Phase II (statewide)	

[266] 2016v1 modeling platform for calendar year 2016 (v2016fh)
[267] NOx+VOC values represent the ratio of NOx and VOC emissions by category to total NOx and VOC emissions in the 2016 LADCO inventory. The sum of individual NOx and VOC percentages does not equal the NOx+VOC value.
[268] Ohio EPA has provided information on the geographical scope of Ohio regulations.
[269] https://www.epa.ohio.gov/dapc/regs/3745_80
[270] http://docs.legis.wisconsin.gov/code/admin_code/nr/400/485.pdf
[271] https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
[272] http://www.ilga.gov/commission/jcar/admincode/035/03500223sections.html
[273] http://www.in.gov/legislative/iac/T03260/A00080.PDF
[274] https://www.epa.ohio.gov/dapc/regs/3745_112

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC [267]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio[268]	Wisconsin
Surface Coating	2.9%		5.7%	Part 6 and7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1610, 336.1620, 336.1621, 336.1632)[275]	Title 35, Parts 218 and 219: Subpart F: Coating Operations[276, 277]	Title 326, Article 8-14 Volatile Organic Compound Rules (Standards for AIM Coatings) [278]		Chapter 3745-21, Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[279] (geographic applicability varies by control technique guideline "CTG")	Chapter NR 421 Control of Organic Compound Emissions from Chemical, Coatings And Rubber Products Manufacturing[280] Chapter NR 422 Control of Organic Compound Emissions from Surface Coating, Printing And Asphalt Surfacing Operations[281]
Agriculture - Pesticides Application & Livestock	2.2%		4.2%						
Graphic Arts	2.1%		4.1%	Part 6 and 7. Emission Limitation and Prohibitions – Existing and New Sources of Volatile Organic Compounds Emissions (336.1624)[282]	Title 35, Parts 218 and 219, Subpart H: Printing and Publishing: Printing and Publishing [283, 284]	Title 326, Article 8-16 (Offset Lithographic Printing and Letterpress Printing)[285]		Chapter 3745-21, Carbon Monoxide, Photochemically Reactive Materials, Hydrocarbons, and Related Materials Standards[286] (geographic applicability varies by CTG)	Chapter NR 422.14(422.145) Control of Organic Compound Emissions From Surface Coating, Printing And Asphalt Surfacing Operations[287]

275 https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
276 https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
277 https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
278 http://www.in.gov/legislative/iac/T03260/A00080.PDF
279 https://www.epa.ohio.gov/dapc/regs/3745_21
280 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/421
281 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/422
282 https://dtmb.state.mi.us/ARS_Public/AdminCode/DownloadAdminCodeFile?FileName=1608_2016-003EQ_AdminCode.pdf
283 https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
284 https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
285 http://www.in.gov/legislative/iac/T03260/A00080.PDF
286 https://www.epa.ohio.gov/dapc/regs/3745_21
287 https://docs.legis.wisconsin.gov/code/admin_code/nr/400/422

Category	Percent of 2016 Emissions LADCO-wide			On-the-Books /On-the-Way Regulations					
	NOx+VOC [267]	NOx	VOC	Michigan	Illinois	Indiana	Minnesota	Ohio [268]	Wisconsin
Architectural Coatings	1.8%		3.5%		Title 35, Part 223, Subpart C, Architectural and Industrial Maintenance Coatings [288] Title 35, Parts 218 and 219, Subpart X: Construction [289, 290]	Title 326, Article 8-14 Volatile Organic Compound Rules (Standards for AIM Coatings) [291]		Chapter 3745-113, AIM Coatings [292] based on 2001 OTC model rule (statewide)	Chapter 422.15 Control of Organic Compound Emissions From Surface Coating, Printing And Asphalt Surfacing Operations [293]

[288] https://casetext.com/regulation/illinois-administrative-code/title-35-environmental-protection/part-223-standards-and-limitations-for-organic-material-emissions-for-area-sources/subpart-c-architectural-and-industrial-maintenance-coatings
[289] https://pcb.illinois.gov/documents/dsweb/Get/Document-11930/
[290] https://pcb.illinois.gov/documents/dsweb/Get/Document-11932/
[291] http://www.in.gov/legislative/iac/T03260/A00080.PDF
[292] https://www.epa.ohio.gov/dapc/regs/3745_113
[293] https://docs.legis.wisconsin.gov/code/admin_code/nr/400/422

APPENDIX D
HDDT Rates EMFAC2017 Adjustment Factors

APPENDIX D. HDDT EMFAC2017 ADJUSTMENT FACTORS

SCC	avgSpeedBinID	AvgSpeed (mph)	Pollutant	EMFAC_toMOVES_adjFactor
2202510272	1	2.5	NOX	0.963606782
2202510272	2	5	NOX	1.792782273
2202510272	3	10	NOX	2.23428226
2202510272	4	15	NOX	1.953205493
2202510272	5	20	NOX	1.746376774
2202510272	6	25	NOX	1.616856167
2202510272	7	30	NOX	1.317279656
2202510272	8	35	NOX	1.156854887
2202510272	9	40	NOX	0.945959007
2202510272	10	45	NOX	0.799024998
2202510272	11	50	NOX	0.736938263
2202510272	12	55	NOX	0.765324146
2202510272	13	60	NOX	0.866887398
2202510272	14	65	NOX	1.06102694
2202510272	15	70	NOX	1.042471636
2202510272	16	75	NOX	0.946747639
2202510372	1	2.5	NOX	1.299050161
2202510372	2	5	NOX	2.086737539
2202510372	3	10	NOX	2.266359085
2202510372	4	15	NOX	1.934661885
2202510372	5	20	NOX	1.737099537
2202510372	6	25	NOX	1.616372294
2202510372	7	30	NOX	1.323962222
2202510372	8	35	NOX	1.176748886
2202510372	9	40	NOX	0.966972274
2202510372	10	45	NOX	0.81914334
2202510372	11	50	NOX	0.757651003
2202510372	12	55	NOX	0.79053071
2202510372	13	60	NOX	0.894694163
2202510372	14	65	NOX	1.0915587
2202510372	15	70	NOX	1.06626818
2202510372	16	75	NOX	0.962474113
2202510472	1	2.5	NOX	0.963606782
2202510472	2	5	NOX	1.792782273
2202510472	3	10	NOX	2.234282261
2202510472	4	15	NOX	1.953205493
2202510472	5	20	NOX	1.746376775
2202510472	6	25	NOX	1.616856167
2202510472	7	30	NOX	1.317279657
2202510472	8	35	NOX	1.156854888
2202510472	9	40	NOX	0.945959007
2202510472	10	45	NOX	0.799024998
2202510472	11	50	NOX	0.736938263
2202510472	12	55	NOX	0.765324146
2202510472	13	60	NOX	0.866887398
2202510472	14	65	NOX	1.06102694
2202510472	15	70	NOX	1.042471637
2202510472	16	75	NOX	0.946747639
2202510572	1	2.5	NOX	1.299050161
2202510572	2	5	NOX	2.086737539
2202510572	3	10	NOX	2.266359084
2202510572	4	15	NOX	1.934661885
2202510572	5	20	NOX	1.737099536
2202510572	6	25	NOX	1.616372294
2202510572	7	30	NOX	1.323962222
2202510572	8	35	NOX	1.176748886
2202510572	9	40	NOX	0.966972274
2202510572	10	45	NOX	0.81914334
2202510572	11	50	NOX	0.757651003
2202510572	12	55	NOX	0.79053071
2202510572	13	60	NOX	0.894694163
2202510572	14	65	NOX	1.0915587
2202510572	15	70	NOX	1.06626818
2202510572	16	75	NOX	0.962474113
2202610272	1	2.5	NOX	1.218126431
2202610272	2	5	NOX	2.249430345
2202610272	3	10	NOX	2.819766262
2202610272	4	15	NOX	2.457787812

SCC	avgSpeedBinID	AvgSpeed (mph)	Pollutant	EMFAC_toMOVES_adjFactor
2202610272	5	20	NOX	2.188628062
2202610272	6	25	NOX	2.018815016
2202610272	7	30	NOX	1.631670643
2202610272	8	35	NOX	1.419598104
2202610272	9	40	NOX	1.146989656
2202610272	10	45	NOX	0.957744927
2202610272	11	50	NOX	0.874337393
2202610272	12	55	NOX	0.90600933
2202610272	13	60	NOX	1.035273918
2202610272	14	65	NOX	1.267776376
2202610272	15	70	NOX	1.236649333
2202610272	16	75	NOX	1.116495113
2202610372	1	2.5	NOX	1.210965843
2202610372	2	5	NOX	2.266959677
2202610372	3	10	NOX	2.808119628
2202610372	4	15	NOX	2.427179791
2202610372	5	20	NOX	2.166119203
2202610372	6	25	NOX	2.005061313
2202610372	7	30	NOX	1.623807385
2202610372	8	35	NOX	1.427139373
2202610372	9	40	NOX	1.157311773
2202610372	10	45	NOX	0.969233629
2202610372	11	50	NOX	0.887966391
2202610372	12	55	NOX	0.922980645
2202610372	13	60	NOX	1.053436766
2202610372	14	65	NOX	1.285039565
2202610372	15	70	NOX	1.248819759
2202610372	16	75	NOX	1.122475125
2202610472	1	2.5	NOX	1.218126432
2202610472	2	5	NOX	2.249430345
2202610472	3	10	NOX	2.819766262
2202610472	4	15	NOX	2.457787812
2202610472	5	20	NOX	2.188628063
2202610472	6	25	NOX	2.018815017
2202610472	7	30	NOX	1.631670643
2202610472	8	35	NOX	1.419598104
2202610472	9	40	NOX	1.146989656
2202610472	10	45	NOX	0.957744928
2202610472	11	50	NOX	0.874337393
2202610472	12	55	NOX	0.906009331
2202610472	13	60	NOX	1.035273918
2202610472	14	65	NOX	1.267776376
2202610472	15	70	NOX	1.236649333
2202610472	16	75	NOX	1.116495113
2202610572	1	2.5	NOX	1.210965843
2202610572	2	5	NOX	2.266959677
2202610572	3	10	NOX	2.808119628
2202610572	4	15	NOX	2.427179791
2202610572	5	20	NOX	2.166119203
2202610572	6	25	NOX	2.005061312
2202610572	7	30	NOX	1.623807385
2202610572	8	35	NOX	1.427139373
2202610572	9	40	NOX	1.157311773
2202610572	10	45	NOX	0.969233629
2202610572	11	50	NOX	0.887966391
2202610572	12	55	NOX	0.922980645
2202610572	13	60	NOX	1.053436766
2202610572	14	65	NOX	1.285039565
2202610572	15	70	NOX	1.248819759
2202610572	16	75	NOX	1.122475124
2202620272	1	2.5	NOX	1.226161167
2202620272	2	5	NOX	2.266228868
2202620272	3	10	NOX	2.772673461
2202620272	4	15	NOX	2.45059298
2202620272	5	20	NOX	2.198478106
2202620272	6	25	NOX	2.056004798
2202620272	7	30	NOX	1.704298074
2202620272	8	35	NOX	1.514841127
2202620272	9	40	NOX	1.272320173
2202620272	10	45	NOX	1.106075827

SCC	avgSpeedBinID	AvgSpeed (mph)	Pollutant	EMFAC_toMOVES_adjFactor
2202620272	11	50	NOX	1.037806604
2202620272	12	55	NOX	1.077757027
2202620272	13	60	NOX	1.211991107
2202620272	14	65	NOX	1.438424361
2202620272	15	70	NOX	1.412568667
2202620272	16	75	NOX	1.292493923
2202620372	1	2.5	NOX	1.218182958
2202620372	2	5	NOX	2.28031921
2202620372	3	10	NOX	2.758472358
2202620372	4	15	NOX	2.419412695
2202620372	5	20	NOX	2.174471233
2202620372	6	25	NOX	2.039888941
2202620372	7	30	NOX	1.694148763
2202620372	8	35	NOX	1.518643747
2202620372	9	40	NOX	1.27914731
2202620372	10	45	NOX	1.114716516
2202620372	11	50	NOX	1.048762901
2202620372	12	55	NOX	1.091972319
2202620372	13	60	NOX	1.227724179
2202620372	14	65	NOX	1.452602492
2202620372	15	70	NOX	1.42208161
2202620372	16	75	NOX	1.296543554
2202620472	1	2.5	NOX	1.226161167
2202620472	2	5	NOX	2.266228868
2202620472	3	10	NOX	2.772673461
2202620472	4	15	NOX	2.45059298
2202620472	5	20	NOX	2.198478106
2202620472	6	25	NOX	2.056004798
2202620472	7	30	NOX	1.704298074
2202620472	8	35	NOX	1.514841128
2202620472	9	40	NOX	1.272320174
2202620472	10	45	NOX	1.106075827
2202620472	11	50	NOX	1.037806604
2202620472	12	55	NOX	1.077757027
2202620472	13	60	NOX	1.211991107
2202620472	14	65	NOX	1.438424361
2202620472	15	70	NOX	1.412568674
2202620472	16	75	NOX	1.292493923
2202620572	1	2.5	NOX	1.22
2202620572	2	5	NOX	2.28
2202620572	3	10	NOX	2.76
2202620572	4	15	NOX	2.42
2202620572	5	20	NOX	2.17
2202620572	6	25	NOX	2.04
2202620572	7	30	NOX	1.69
2202620572	8	35	NOX	1.52
2202620572	9	40	NOX	1.28
2202620572	10	45	NOX	1.11
2202620572	11	50	NOX	1.05
2202620572	12	55	NOX	1.09
2202620572	13	60	NOX	1.23
2202620572	14	65	NOX	1.45
2202620572	15	70	NOX	1.42
2202620572	16	75	NOX	1.30