WHITE PAPER

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# CALIFORNIA'S CLEAN DIESEL PROGRAM

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# 1. INTRODUCTION AND GENERAL OVERVIEW

The California Air Resources Board (CARB) has been engaged since the 1960s in improving the health of citizens by reducing air pollution. Motor vehicles were recognized as a major source of air pollution, and first-step emission standards were imposed on new passenger vehicles sold in the state. The main pollutants of concern at that time were hydrocarbons (HC), and oxides of nitrogen ($NO_x$), which combine to create ambient ozone in the presence of warm temperatures and sunlight. Other air pollutants of concern were carbon monoxide (CO) and lead. Over succeeding decades, emission standards were developed for other mobile sources as well as for stationary sources of air pollutants.

Diesel truck emissions came under regulation in 1974 with the imposition of a $NO_x$ standard for new vehicles. The regulation was made increasingly stringent in five steps, reaching the current level effective with 2010 models. Specifications for cleaner diesel fuel were also adopted.

The toxicity of air pollution became better understood with scientific advances—importantly the adverse effects on health and premature death of fine particulate matter, or particles that are 2.5 microns or less in diameter ($PM_{2.5}$). Diesel engines are an important source of fine particles because the emissions occur at ground level, often in areas where large numbers of people live. Their $NO_x$ emissions also create atmospheric nitrates, another kind of fine particle. Beginning with 1987 models, CARB imposed the first particulate matter (PM) exhaust standard for new heavy-duty diesel trucks. The standard has been revised downward three times to its current level, effective with the 2007 models.

In 2000 CARB set a goal of reducing diesel $PM_{2.5}$ emissions 75% by 2010 and 85% by 2020 under its Diesel Risk Reduction Plan (California Air Resources Board, 2000). Beginning in 2006, sulfur was reduced in diesel fuel to 15 parts per million (ppm) to allow exhaust aftertreatment devices to function properly. In 2012 along with the U.S. Environmental Protection Agency (EPA), CARB adopted $NO_x$ and $PM_{2.5}$ emission standards for new off-road diesel engines typically used in construction and agriculture.

By the turn of the century, CO air pollution was reduced to safe levels throughout California because of increasingly stringent standards on automobiles. The requirement to sell only lead-free gasoline essentially eliminated lead as an air pollutant. Although ambient levels of ozone improved, ozone remains a persistent and harmful pollutant. Expanded air monitoring of fine particles and an increasing concern with their harmful health effects resulted in greater focus on reducing PM emissions from both new and legacy diesel trucks as quickly as possible. This included the retrofit of in-use diesels with particulate filters and acceleration of the replacement of older diesel trucks with cleaner ones.

The threat of climate change also emerged as a major concern in the new century. In California, transportation is the largest source of greenhouse gas (GHG) emissions, as passenger vehicles accounted for 28% of GHGs and medium and heavy trucks 8% in 2018. CARB adopted GHG standards for new passenger vehicles that were the most stringent in the world, including a requirement to sell specific volumes of zero-emission vehicles (ZEVs). GHG standards for new heavy-duty engines and trucks were later adopted nationwide effective with 2014 models. To accelerate the reduction of GHG emissions and the conversion of diesel vehicles to cleaner alternative fuels, California

invested billions of dollars in clean vehicle purchase incentives and pilot programs to demonstrate the feasibility of zero-emission freight movement.

The currently priorities for CARB include reducing ambient ozone, $PM_{2.5}$, and toxic air pollution to levels protective of public health by the mid-2030s in all urban areas, and transforming all vehicles on- and off-road to zero emissions by 2045 to address climate change and further reduce ambient air pollution. The zero-emission transformation includes a 100% zero-emission sales requirement for new passenger cars by 2035, new transit buses by 2029, new drayage trucks by 2023, and new government vehicles by 2027. Further reducing $NO_x$, PM and GHG emissions of medium- and heavy-duty diesel trucks and off-road equipment to zero is a necessary part of this challenge.

Figure 1 shows a historical timeline highlighting the actions taken to reduce diesel emissions.

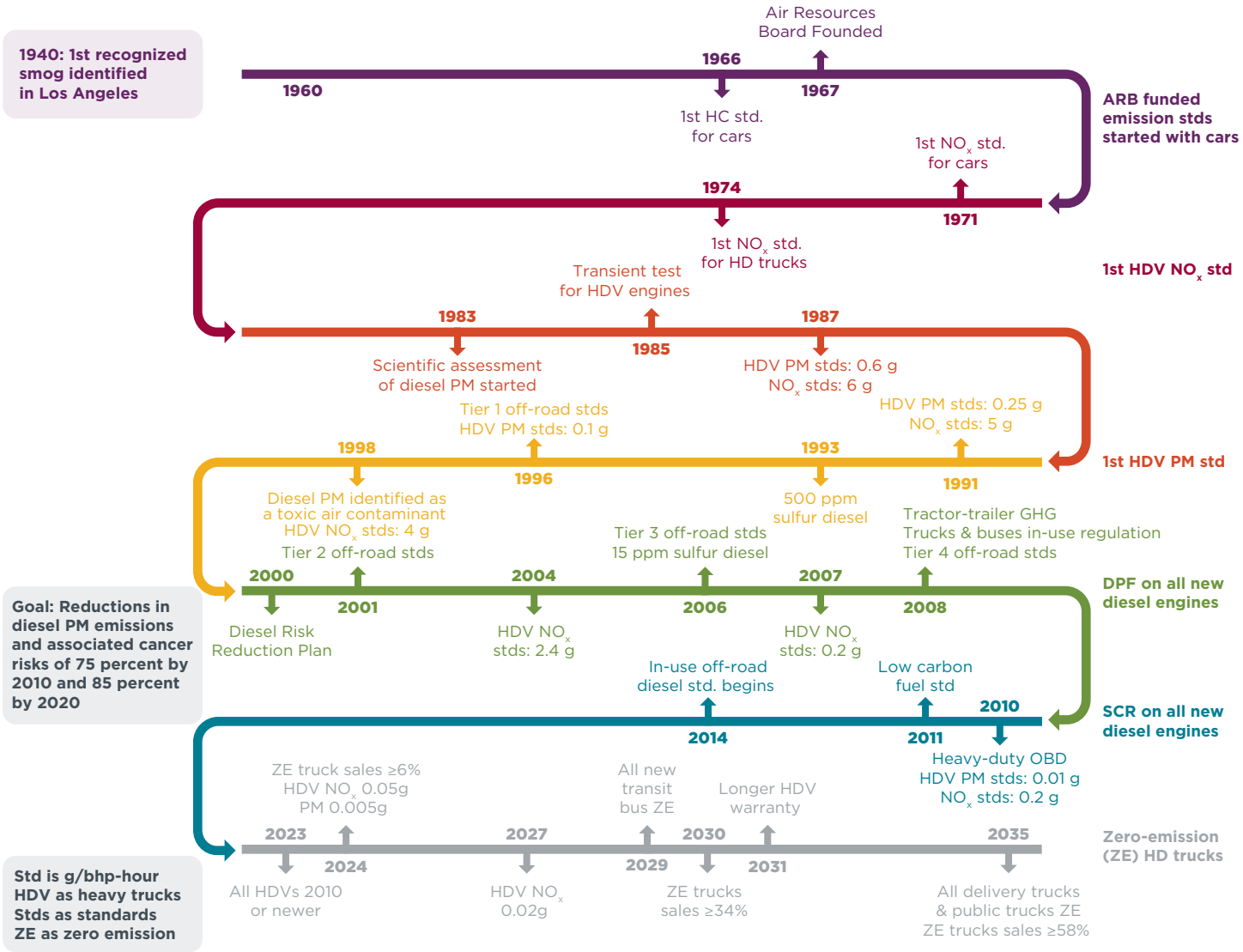


**Figure 1.** Timeline of significant CARB actions to reduce diesel emissions

Today in California and the rest of the U.S., diesel engines remain the predominant power source for all heavy-duty trucks over 14,000 pounds gross vehicle weight

rating (GVWR) because of their low fuel consumption. The exception is most transit buses, and some garbage trucks and last-mile delivery trucks are fueled with natural gas because of its lower price, perception of lower emissions, and the availability of renewable methane, which reduces GHG emissions. About half of the medium-duty pickup trucks and vans weighing more than 8,500 pounds GVWR have diesel engines. Diesels are used in all large off-road equipment, locomotives, oceangoing vessels, many harbor craft, and larger forklifts. Unlike Europe, very few diesel passenger cars are sold in the U.S., largely a result of the 2016 Volkswagen emissions cheating scandal.

This white paper focuses on the efforts California has made and plans to make to reduce emissions from diesel vehicles of all types. Section 2 is a discussion of the importance of California's clean air law and how it has supported CARB's successful efforts to reduce air pollution. Section 3 provides examples of how CARB develops plans and strategies to help guide its efforts to reduce pollution.

The remainder of the report describes programs CARB has developed to reduce diesel emissions. Section 4 explores how CARB developed $NO_x$ and PM emission standards for new diesel engines and equipment. Section 5 identifies the programs used to assess in-use vehicle emissions and the enforcement actions it takes in cases of noncompliance. Section 6 describes programs to accelerate the replacement of older, high-emitting vehicles and equipment. Section 7 discusses standards for cleaner diesel fuel, alternative fuels and the low carbon fuel standard. Section 8 shifts to programs that reduce GHG emissions from traditionally diesel fueled vehicles and equipment. Section 9 addresses CARB's efforts to initiate the inevitable need to transform to zero-emission propulsion, and Section 10 identifies the financial incentives to accelerate the transition. Section 11 provides a high-level summary of lessons learned and how they be applied to shape the future.

# 2. CALIFORNIA LEGISLATION AND GENERAL AUTHORITIES TO REDUCE AIR POLLUTION

In the mid-1960s California established the first U.S. standards limiting emissions of HC and CO from new passenger cars. In 1970 the federal Clean Air Act established nationwide emission standards for new passenger vehicles, preempting other states from doing so. Because California previously set its own standards, the state was allowed to continue doing so. CARB has since adopted many regulations for all types of mobile sources and fuels, establishing its leadership in vehicle emissions control and becoming the testing ground for emerging technologies. The EPA often adopts CARB standards nationwide, and the two agencies work together closely.

Through the annual budget process, the legislature provides resources to CARB to implement and manage the programs that form the basic framework of CARB's effective motor vehicle pollution reduction program. About 85% of the proposed $1.1 billion CARB budget for fiscal year 2021–2022 is derived from motor vehicle fees, fines, and the state's cap and trade fund (California Department of Finance, 2021). California's spending on the agency amounts to about a sixth of the EPA's 2021 budget of $6.66 billion (U.S. Environmental Protection Agency, 2020).

## 2.1. CALIFORNIA STATE AIR POLLUTION LAW

Authority for actions to reduce air pollution and climate emissions originates with the legislature and the governor. The legislature passes bills that the governor signs into law. The legislature also authorizes fiscal support for the laws' implementation. Such legislation may provide general authority, such as the mandate for CARB to reduce air pollution, or establish specific goals, such as requiring the state's public utilities to produce 100% renewable electricity by 2045. Clean air laws may also require development of plans, such as a strategic plan for enforcing current and future diesel emission controls. Occasionally laws may be highly prescriptive, containing sufficient details that the implementing authority may need to adopt few or no regulations. One example is the state's periodic emission inspection program (Smog Check) for passenger vehicles, which is run by the state's Department of Consumer Affairs.

Sometimes the governor may issue executive orders directing agencies to take actions not specifically established by the legislature, such as setting a goal of net carbon neutrality for the state's economy by 2045 (State of California, Office of the Governor, 2018). CARB conducts post-implementation assessments of regulations and plans that provide feedback for improvements. Complicated regulations such as reducing emissions from diesel trucks and equipment are rarely 100% effective at first, and feedback from the field is important for enhancing a regulation's effectiveness.

Figure 2 shows in general how authorities at the state level progress to specific actions by agencies to reduce air pollution and climate emissions.

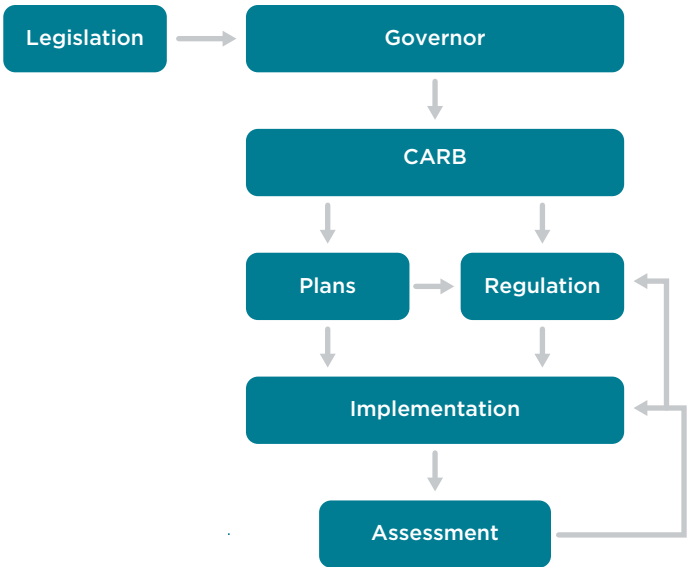


**Figure 2.** California legal authorities leading to action to reduce emissions

The CARB emissions reduction program is based on the authorizing state law, contained in the Health and Safety Code. The clean air law clearly establishes the goals of the program. The law provides general authority to CARB to take the steps necessary to achieve clean air. (See California Health and Safety Code section 39003 and 39602.5).[1] The law also directs CARB to adopt regulations to achieve the maximum possible reduction in public exposure to toxic air contaminants (HSC 39667). The authority to regulate diesel PM derives from these sections.

The state law specifically authorizes CARB to adopt emission standards for motor vehicles of all types, including in-use performance standards, and their fuels (HSC 43013). In 2002, the law directed CARB to adopt regulations reducing GHG emissions from motor vehicles (HSC 43108.5). The emission standards for new vehicles and engines must be feasible and cost-effective under the legislation. However, the standards do not need to be based on available off-the-shelf technologies. Rather, CARB adopts emission standards based on technologies that are not yet fully developed but show great promise (HSC 39602.5(b)). This technology-forcing approach to setting standards challenges vehicle manufacturers and parts suppliers to innovate while providing lead time to develop and prove advanced technologies. Competition among vehicle manufacturers—or fear of failing where others succeed—provides an incentive for compliance with more-stringent standards. Technology-forcing accelerates the introduction of new technologies, enabling more-stringent standards. If the standards are proven to be too optimistic, compliance dates can be revised, though that has rarely happened.

Diesel engine emissions are specifically addressed in the law. The measure directs CARB to expeditiously reduce $NO_x$ emissions from diesel vehicles (HSC 43013 (h)). It also directs CARB to review existing enforcement of diesel emission control regulations every three years and develop a strategic plan for enforcement of existing and future regulations to promote a maximum level of compliance (HSC 43011.5).

1 California Health and Safety Code (HSC) including subsequent section references can be found at: Calfornia Legislative Information, Health and Safety Code, https://leginfo.legislature.ca.gov/faces/codes_displayexpandedbranch.xhtml?tocCode=HSC&division=26.&title=&part=&chapter=&article=&nodetreepath=31

Moreover, the legislation requires that emission controls and their performance be warranted for specified periods and that vehicle manufacturers pay to repair individual vehicles within the warranty period if they have defective emission control parts or fail to pass in-use emission tests (HSC 43204). Federal law requires that states with serious air pollution implement and operate periodic in-use emission inspection tests for all registered passenger vehicles. State law prohibits vehicle operators or repair facilities from removing or tampering with a vehicle's emission control devices or systems (California Vehicle Code § 12-5-27156). The law authorizes CARB to enter a property that uses motor vehicles for commercial purposes to determine whether vehicles have been tampered with or mis-fueled (subject to penalties of $1,500 per vehicle, HSC 43008.6).

The sections of law discussed above authorize CARB to take specific actions to reduce emissions from diesel engines and vehicles, some of which are summarized in Table 1.

**Table 1.** Authorities allowing CARB to reduce diesel emissions

| Pre-production | Production | Post-production | Other |
|---|---|---|---|
| Adopt emission standards | Assembly line tests | Manufacturer portable emissions measurement system (PEMS) test | Diesel fuel specifications |
| Establish test protocols | Audit assembly line | Warranty reporting | Alternative fuel specifications |
| Require application | | Store $NO_x$ data in electronic-control-unit (ECU) | Low carbon fuel standard |
| Test results ≤ standards | | CARB field inspections | Administer purchase incentives |
| Durability demonstration | | CARB in-use testing | |
| On-board diagnostics (OBD) approval | | Recall if noncompliant | |
| Pay certification fee | | Fines for noncompliance | |
| CARB approval required | | Tampering illegal | |
| | | Periodic inspection tests | |

## 2.2. THE CARB BOARD AND STAFF

CARB's regulations are adopted by a board with 14 voting members. Of those, 12 are appointed by the governor and one by each house of the legislature. Members serve staggered six-year terms. The chair is the only full-time board member. Other members serve part-time and represent local air pollution agencies or have expertise in subjects such as public health, automotive engineering, or law. The regulatory adoption process occurs at monthly public meetings. Public testimony and input are encouraged. A majority vote is required to adopt a regulation.

There are approximately 1,500 CARB staff managed by an Executive Officer, who works closely with the Board Chair. Staff and the Executive Officer are career civil servants. In addition to motor vehicles, staff is involved with research, emission inventory development, stationary source regulation, enforcement, cooperation with and oversight of local air pollution agencies, plan development, management of the cap-and-trade and incentive programs, operation of laboratories and air pollution monitoring, and many other activities. Most staff are degreed engineers and scientists, and many have advanced degrees. CARB has multiple research laboratories around the state.

Developing proposed regulations, interacting with stakeholders, and proposing regulations to the board are the responsibilities of the CARB staff. Responsibility for administration, implementation, and enforcement has been delegated by the board to the staff. This increases the efficiency of implementing emission control programs and reduces political interference on issues such as enforcement.

## 2.3. ENFORCEMENT OF AIR POLLUTION LAWS

State law also gives CARB broad enforcement authority. For example, no new motor vehicle may be sold in California if the manufacturer has violated emission standards and has failed to take corrective action including a recall (HSC 43105). CARB must certify that a new vehicle or engine complies with emission standards and requirements before it can be put on the market (HSC 43100, 43102(a)). The holder of a certificate of compliance is also responsible for in-use compliance. For heavy-duty diesel vehicles, the holder is the engine manufacturer, whereas for passenger vehicles it is the vehicle maker.[2] The law gives CARB the power to adopt in-use performance standards (HSC 43013), and it establishes a period of operation during which vehicles must comply with emission standards. CARB may test vehicles for compliance and can recall any group of vehicles whose emission control device(s) or performance do not result in meeting the applicable emission standards (HSC 43105). The burden and cost of repair or upgrade falls on the manufacturer. Any motor vehicle that is in violation of the air pollution regulations of the Health and Safety Code may be denied registration (Vehicle Code 4750 and 4755).

State law authorizes maximum fines per new vehicle sold that fails to comply with any provision of CARB regulations ($37,500, HSC 43106), for anyone selling a new vehicle that has not been certified ($37,500, HSC 43211), or for transporting or selling a fuel that does not meet specifications (fines vary by offense, HSC 43025-43031.5).

CARB's 2017 Annual Enforcement Report, Appendix J, provides a comprehensive list of the potential penalties for each CARB program, not just for diesels, and the number of annual inspections performed (California Air Resources Board, 2018a). Also provided are examples of specific enforcement actions and the fines imposed.

It is important to note that enforcement actions are decided by the CARB enforcement and legal staff, who are civil servants. CARB board members, who are political appointees, do not involve themselves in enforcement. The staff investigates and determines whether a violation has occurred. A notice of violation is issued, and the accused party is invited to meet to discuss the facts and amount of penalty. The staff may decide on a fine that is less than the maximum set by law. This depends on whether the violation was purposeful, was due to lax controls in assuring compliance, or was simply a mistake. The fine may also be reduced if the offending company reports the violation to CARB before the agency discovers it through testing or inspections. This encourages self-reporting of violations.

Major violations may be resolved through a different, mutual settlement process and agreement with the violating party, often as an alternative to threatened litigation. The 1998 heavy-duty diesel truck settlement and the Volkswagen diesel passenger

2 For passenger vehicles through 10,000 pounds GVWR, the compliance test is conducted on a chassis dynamometer, so the vehicle manufacturer applies for and receives the certificate of compliance. For heavy-duty diesel engines, compliance is based on an engine dynamometer, so the engine manufacturer applies for and receives the certificate. For GHGs, the engine manufacturer obtains the certificate of compliance, while the truck manufacturer also applies for and receives a certificate of compliance based on modeling that reflects both the engine and truck features, such as aerodynamics.

car defeat device settlement of 2016 are examples.[3] Almost all settlement agreements include a monetary fine paid to the state. A settlement may also have several other elements that are not specified in the clean air laws. For example, a settlement may include a Supplement Environmental Project (SEP) directly funded by the offending party to offset emissions caused by the violation. The violator can't benefit from the SEP, and such projects are limited to 50% of the total settlement value (California Air Resources Board, 2016a).

## 2.4. WORKING WITH OTHER CALIFORNIA STATE AND LOCAL GOVERNMENT AGENCIES

In 1991, the legislature created the California Environmental Protection Agency (CalEPA) to bring together agencies and departments responsible for other environmental pollution and to ensure coordination. For example, CARB regulates vapor emissions from dispensing of gasoline, while the underground gasoline storage tanks which can affect the amount of vapor emissions are regulated by the Water Resources Control Board, requiring coordination.

Agencies within CalEPA include the State Water Resources Control Board, the Department of Toxic Substance Control (waste disposal and cleanup), the Department of Pesticide Regulation, CalRecycle (bottle recycling), and an Office of Environmental Health Hazard Assessment (which determines the health risks of pollution). CARB's regulatory authority is largely independent of CalEPA, but for issues such as climate change CalEPA provides guidance and oversight of all agencies with responsibility for reducing statewide GHG emissions and climate impacts. CalEPA issues an annual report card of state actions to reduce GHG emissions and how they comply with state goals and targets, providing the public and lawmakers with a clear assessment of progress. CalEPA also works with the Governor's Office of Business and Economic Development on a state market plan for zero-emission vehicles.

CARB works closely with the California Energy Commission on technology and energy efficiency. The commission takes the lead on providing refueling infrastructure for battery and hydrogen ZEVs. The Public Utilities Commission regulates investor-owned utilities and their efforts to reduce emissions from electricity generation toward carbon neutrality. It has authorized utilities to financially support installation of zero-emission heavy-duty truck recharging facilities. California's Smog Check vehicle inspection program (Smog Check) is operated separately by the Bureau of Automotive Affairs, over which CARB has little authority or control.

State law also created more than 30 local Air Pollution Control Districts (APCDs). The districts are managed by boards of local elected officials, such as county supervisors. CARB is responsible for coordinating the APCDs' efforts to meet ambient air quality standards. The districts regulate emissions from stationary sources and indirect

3 In 1998, a court settlement was reached between the EPA, Department of Justice, California ARB and engine manufacturers (Caterpillar, Cummins, Detroit Diesel, Volvo, Mack Trucks/Renault and Navistar) over the issue of high $NO_x$ emissions from heavy-duty diesel engines during certain driving modes, with civil penalty of $83.4 million against the companies. In addition, the EPA required the companies to introduce new cleaner engines, rebuild or retrofit older engines to cleaner emission levels, recall all vehicles and engines with existing defeat device technology installed, and conduct new in-use emissions testing. The companies collectively spent over $1 billion on the largest settlement in environmental enforcement history. In 2016, VW paid $2.8 billion in criminal fine and a $1.45 billion civil penalty for the alleged civil violations of the Clean Air Act. For California, VW paid a $154 million penalty, established a $422 million trust fund to offset the excess $NO_x$ emissions its vehicles emitted, established an $800 million fund to expand electric vehicle charging infrastructure, bought back approximately 80,000 vehicles that could not be modified to meet emission standards, and paid the owners several thousand dollars each for misleading them that the cars were clean diesels.

sources such as shopping centers. The districts are required periodically to produce plans for meeting national ambient air quality standards established by the EPA. CARB works with the APCDs to develop the mobile source portion of the plans and to establish plans of action to lower GHGs through reduced vehicle travel and urban planning. Some APCDs assist CARB in enforcing in-use motor vehicle regulations, and some help implement the state's financial incentive programs to reduce emissions by modernizing the vehicle fleet.

Figure 3 illustrates the interaction and main responsibilities of major state and local governments involved in reducing diesel air pollution

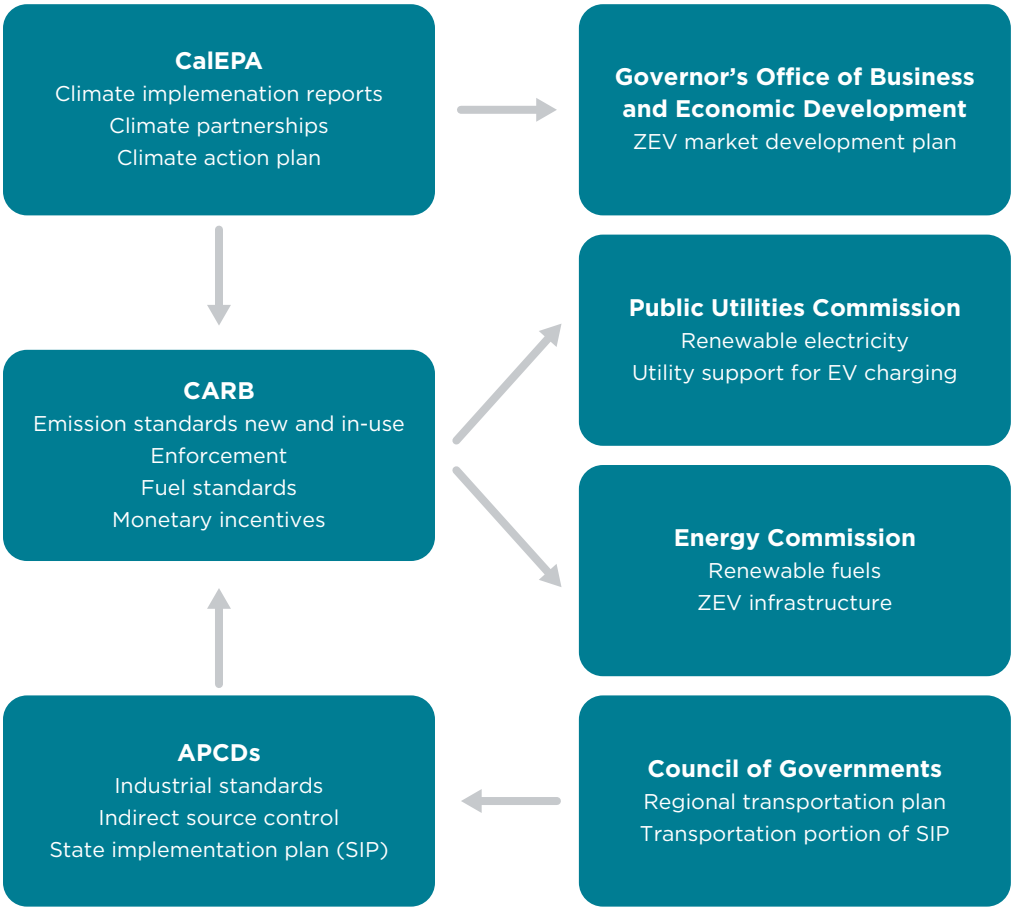


**Figure 3.** Typical interactions between state and local agencies to reduce emissions

## 2.5. WORKING WITH OTHER STATES

The federal Clean Air Act allows states with persistent air pollution problems to choose whether they require vehicles sold in their state to meet EPA or CARB standards. Fourteen states representing almost 40% of national passenger vehicle sales have adopted CARB standards.[4] California has had stable political and citizen support for clean-vehicle standards, while at the federal level there have been times when efforts

4 The 14 states are Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New York, Oregon, Pennsylvania, Rhode Island, Vermont, Washington, and Virginia, plus the District of Columbia. Minnesota, Nevada and New Mexico have begun the process of adopting California standards. Delaware and Pennsylvania did not adopt CARB's ZEV requirements.

to reduce emissions have stalled for political reasons. CARB provides technical and compliance information to states that apply CARB standards, which reduces the state resources needed to implement California standards. The main obligation of the states adopting CARB standards is to ensure that new car dealers do not sell cars that don't comply. Three additional states are considering adoption of CARB's passenger vehicle standards, and several are beginning to consider adoption of CARB's recent heavy-duty truck standards, which are more stringent than the EPA requirements.

## 2.6. WORKING WITH THE FEDERAL GOVERNMENT

The Clean Air Act establishes many of the responsibilities and obligations of states to control air pollution, and the EPA may impose sanctions if a state fails to meet its obligations. For example, states are required to submit plans demonstrating attainment of national ambient air quality standards by specified dates. Failure to do so may result in the withholding of federal transportation funds.

CARB must also request an EPA waiver of federal preemption for each regulation affecting new motor vehicle emission standards. Federal law specifies that the EPA can deny such a waiver only if CARB was arbitrary or capricious in adopting the standards, or if the standards are not needed to reduce air pollution, or if the standards and enforcement procedures are not consistent with the Clean Air Act.[5] CARB has been granted nearly every waiver it has requested over 50 years, and the administrative record is clear that the EPA will defer to CARB's judgment on issues such as technical feasibility and cost.

CARB has often taken the lead in adopting more-stringent emission standards for new passenger vehicles and for many smaller off-road engines and watercraft. The EPA has often taken the lead in adopting standards for heavy diesel trucks and large diesel off-road equipment. If CARB is satisfied that a regulation first adopted by the EPA adequately meets California's air quality needs, it will also adopt it so that CARB can independently enforce the rule in California. The technical staffs share testing results from their laboratories and cooperate on enforcement actions such as the 1998 heavy-duty truck and the VW diesel car defeat device settlements. The two agencies also coordinate recall enforcement testing to avoid duplication.

CARB often pushes the EPA to adopt national standards that will benefit Californians. For example, California and other states have established more contemporaneous and stringent goals for climate change and for the introduction of zero-emission vehicles. About half of the $NO_x$ emissions from heavy-duty trucks in California are from trucks in interstate commerce not registered in California, so CARB has to depend on the EPA to reduce such emissions. CARB can't regulate pollution from certain sources because of federal preemption, such as new locomotives. The EPA staff has often responded to California's needs especially when higher emissions from federally regulated vehicles or equipment prevent California from attaining the federal imposed ambient air quality standards. Pressure from California can help accelerate national efforts to reduce air pollution and GHG emissions.

5 The third criterion means CARB certification test procedures must be sufficiently consistent with those of the EPA so that testing of different vehicles is not required to demonstrate compliance with both EPA and CARB standards. The federal statutory language regarding the California waiver may be found at: 42 U.S. Code § 7543 - State standards, https://www.law.cornell.edu/uscode/text/42/7543.

# 3. GOALS AND PLANS AFFECTING DIESEL EMISSIONS

California's governor and legislature over the years have adopted a number of high-level goals for ambient air quality standards and climate change. The legislature directed CARB in 2007 to take necessary actions to comply with federal ambient air quality standards, which define "clean healthful air" and establish a specific deadline for attainment (HSC 39602.5). In 2018, an executive order was issued directing CARB and other state agencies to achieve carbon neutrality for the state no later than 2045 (EO B-55-18).

Examples of more vehicle-specific goals set by the governor include a target of transitioning 100% of the medium- and heavy-duty fleet to zero emissions by 2045 and achieving 100% zero emissions from off-road vehicles and equipment by 2035, under a 2020 executive order (EO-79-20).

To achieved these goals, the CARB staff often develops a strategic plan to present to the board for approval at a public hearing. Some plans and strategies affecting diesel emissions are:

**State Implementation Plan**. Required by federal law, it includes steps the board will take to reduce urban emissions to achieve federal clean air standards throughout California. Reducing $NO_x$ and PM emissions from on- and off-road diesel engines is a current focus because these engines are the largest sources of $NO_x$ emissions and a significant contributor of ground level exposure to toxic diesel $PM_{2.5}$ (South Coast Air Quality Management District, 2017).[6]

**Scoping Plan**. A roadmap of actions needed to meet climate goals including all sources of GHG emissions is updated every five years (California Air Resources Board, 2017b).[7]

**Mobile Source Strategy**. The plan identifies future actions CARB can take to reduce vehicle $NO_x$ and $PM_{2.5}$ emissions and actions needed to lower GHGs to meet climate goals (California Air Resources Board, 2021d).[8]

**Diesel Risk Reduction Plan**. Adopted in 2000, it identified emissions control measures to cut cancer risk associated with diesel particulate matter and set a goal of reducing diesel PM emissions 75% by 2010 and 85% by 2020 (California Air Resources Board, 2000). This plan led to an in-use truck and bus regulation requiring the retrofit of PM filters on older trucks and the accelerated turnover of diesel trucks to 2010 models or newer.

**Sustainable Freight Action Plan**. A 2016 plan brought together all state agencies to increase freight sector efficiency, increase competitiveness, and transition freight vehicles and equipment to zero or near-zero emissions (State of California, Office of the Governor, 2006).[9]

**Zero-Emission Vehicle Market Development Strategy**. Adopted in 2021 by the Governor's Office of Business and Economic Development, the strategy builds on three previous ZEV action plans. With the market for ZEVS rapidly expanding,

6 An update is planned for 2022.

7 An updated plan will be issued in 2022.

8 This describes a planned revision to the current 2016 strategy that will be considered by the Board at the end of 2021.

9 The zero-emission targets in this report have been supplanted by more recent and aggressive direction from the governor, as previously described.

the plan provides a framework for aligning vehicles and zero-emissions refueling infrastructure with private investment, end users and workforce development equitably for all California residents (California Governor's Office of Business and Economic Development, 2021).

# 4. NEW DIESEL EMISSION STANDARDS – $NO_X$ AND $PM_{2.5}$

**Objective.** Reduce emissions using technology-forcing standards for new heavy-duty vehicles and engines that are based on the best emission control technologies expected to be available in future years. CARB's priority is on reducing $NO_x$ and $PM_{2.5}$ emissions from diesels because the two pollutants contribute to exceeding ozone and fine particle ambient air quality standards, because diesel PM is considered a carcinogen, and because diesel vehicles are relatively low emitters of volatile organic compounds and carbon monoxide. Reducing GHG emissions for heavy-duty trucks is discussed in Section 8.

## 4.1. EMISSION STANDARDS FOR NEW ON-ROAD DIESEL TRUCKS AND ENGINES

**Background.** Emission standards and requirements for new heavy-duty truck engines began with 1974 models in California, regulating $NO_x$, hydrocarbons, and smoke opacity. The first PM mass-based standard did not go into effect until 1987, following the development and use of a new transient engine test in 1985 and the growing evidence of diesel exhaust emission carcinogenicity (California Air Resources Board, 2021e). In the 1990s CARB aligned its standards with those of the EPA, except for transit buses, creating nationwide standards.

A new test cycle (RMC-SET) was later adopted to better represent steady-state suburban and highway operation, and a Not-To-Exceed (NTE) test and standard that could be easily duplicated in-use was added to ensure emissions control at any mode of operation outside the transient engine test.[10] The new tests resulted from a 1998 enforcement action that found engine manufacturers were increasing $NO_x$ during sustained steady-state driving, a mode of operation not well represented in the transient emission certification test. This is an example of how testing and evaluation of on-road trucks and engines can result in regulatory improvements that better ensure compliance and reduce in-use emissions (see Section 5.1.4).

In the years following the enforcement action, periodic lowering of the $NO_x$ and PM standards resulted in the widespread use of new technologies such as electronic control of engine parameters in the early 1990s, particulate filters in 2007, and selective catalytic reduction (SCR) for $NO_x$ control in 2010. Ultra-low sulfur diesel fuel was also required statewide beginning in 2006 to protect the new aftertreatment devices. A $NO_x$ standard for idle emissions was also adopted.

Since the beginning, all heavy-duty truck engines have been required to demonstrate emission durability for the useful life (UL) of the engine before initial sale is allowed, to comply with emission standards for their UL, and to warrant emission controls against defects.[11]

CARB also adopted on-board diagnostic (OBD) requirements for heavy-duty truck engines beginning with 2008 models. For 2013 model engines, the requirements were

10 Detailed test and compliance procedures for the RMC-SET can be found at 40CFR 86.1362, and at 40CFR Part 86 Subpart T and 40CFR 86.1370 for the NTE test. Note that CARB no longer believes the NTE test is effective and has changed to the 3B-MAW test beginning in 2024. See section 5.1.1 for discussion of the new test.

11 "Useful life" is a term defined by regulation and is less than the average life of an engine. It is currently 435,000 miles for a large diesel truck engine, which is about half the time to engine rebuild or replacement. The regulatory trend is to increase the useful life closer to the actual life for all types of vehicles. The recently adopted omnibus heavy-duty extends the useful life to 600,000 miles for 2027 model year engine and 800,000 miles fo 2031 model engine.

significantly expanded to monitor the performance of nearly all emissions-related hardware including the PM filter and SCR system. CARB also requires the engine to reduce its power and eventually not restart if the diesel exhaust fluid (urea required to reduce $NO_x$ in the SCR catalyst) tank is empty (it requires periodic refilling) or if the system that injects the fluid into the catalyst has failed or been tampered with.

Figure 4 illustrates the progress made in reducing $NO_x$ and PM emissions from new on-road heavy-duty diesel engines.

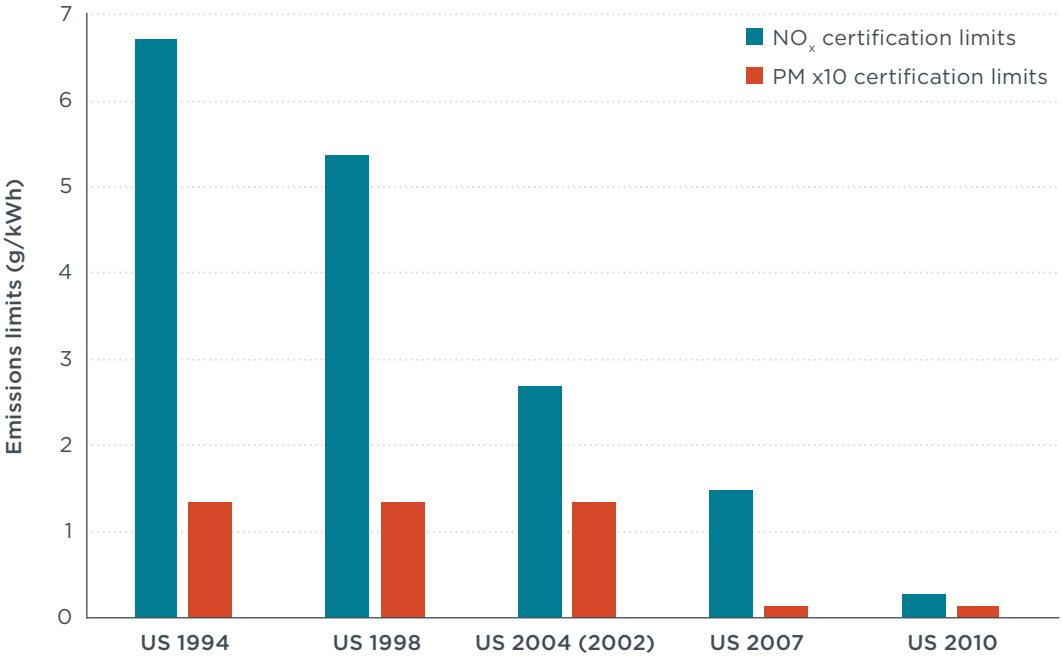


**Figure 4.** $NO_x$ and PM emission standards for new on-road heavy-duty diesel engines. *Source:* Posada, Chambliss, & Blumberg, (2016).

**Status and future.** In 2020 CARB adopted new, more-stringent emission standards and certification requirements for new heavy-duty trucks (California Air Resources Board, 2020e). New $NO_x$ standards go into effect in 2024 requiring reductions of 75%, increasing in 2027 to 90% (see Table 2). The $NO_x$ standard at idle—an alternative to the use of a timer shutting off the engine after five minutes at idle, declines from 30 to 10 grams $NO_x$ maximum per hour for 2024 to 2026 model year engines and to 5 grams $NO_x$ maximum per hour for 2027 and later models. All engine manufacturers have complied with the idle emissions limit. Each truck displays a label stating its compliance with the idle standard, which facilitates enforcement.

In-use truck testing has identified that the SCR catalyst loses effectiveness due to low exhaust temperature when the engine is operated at low load and speed, as may commonly occur in urban driving. To address this source of excess $NO_x$ emissions, a new low-load test cycle was adopted with an accompanying $NO_x$ standard. This will ensure that emission controls remain highly effective in urban driving. Table 2 shows the revised emission standards.

**Table 2.** Future year emission standards for heavy-duty on-road truck engines

| Model Year | Transient test g/bhp-hour | | Low load test g/bhp-hour | Idle standard g/hour |
|---|---|---|---|---|
| | $NO_x$ | PM | $NO_x$ | $NO_x$ |
| **Current** | 0.20 | 0.01 | — | 30 |
| **2024** | 0.050 | 0.005 | 0.200 | 10 |
| **2027** | 0.020 | 0.005 | 0.050 | 5 |

*Note:* g/bhp-hour= gram per brake horsepower-hour

Certification requirements have been revised to include a longer UL, the period during which compliance with emission standards is required. The revised UL is set at 94% of the average mileage when an engine rebuild or replacement occurs, and the warranty period is increased to 75% of the UL from 50% as current requirement.[12] The new useful life and warranty requirements are shown in Table 3.

**Table 3.** Future year durability and warranty requirements, trucks >33,000 lbs. GVWR

| Model year | Compliance period (UL) | | Warranty | |
|---|---|---|---|---|
| | Years | Miles | Years | Miles |
| **Current** | 10 | 435,000 | 5 | 100,000 |
| **2022** | 10 | 435,000 | 5 | 350,000 |
| **2027** | 11 | 600,000 | 7 | 450,000 |
| **2031** | 12 | 800,000 | 10 | 600,000 |

The procedures for demonstrating durability before certification are also strengthened. For example, the SCR aging procedure is being lengthened, and each manufacturer will be required to collect and report emissions-related parameters from the electronic control unit (ECU) of 20% of the engines sold throughout their useful life to better identify potential deterioration. The objective is to reduce the occurrence of in-use failures that are not showing up in the certification durability demonstration program.

The expected fleetwide reduction of $NO_x$ emissions in California as a result of the new emission standards and compliance requirements is shown in Figure 5. The reductions will also contribute to lowering ambient ozone and fine particulate nitrates (California Air Resources Board, 2020d). Note that the lower PM emissions standard is not expected to directly decrease emitted diesel PM because certified emissions rates are currently below the current and future new standard.[13]

12 Percentage increases in UL and warranty are based on survey data on when engines are rebuilt or replaced, which is defined as the actual life of the engine. Data shown are for the 2031 model year for engines used in heavier trucks (>33,000 pounds GVWR). Smaller increases go into effect in 2027. The percentage increases for medium and lighter heavy-duty truck engines are similar.

13 The purpose of increasing the stringency of the PM standard is to prevent any future increases in exhaust PM that might result from control techniques used to meet the new $NO_x$ standards.

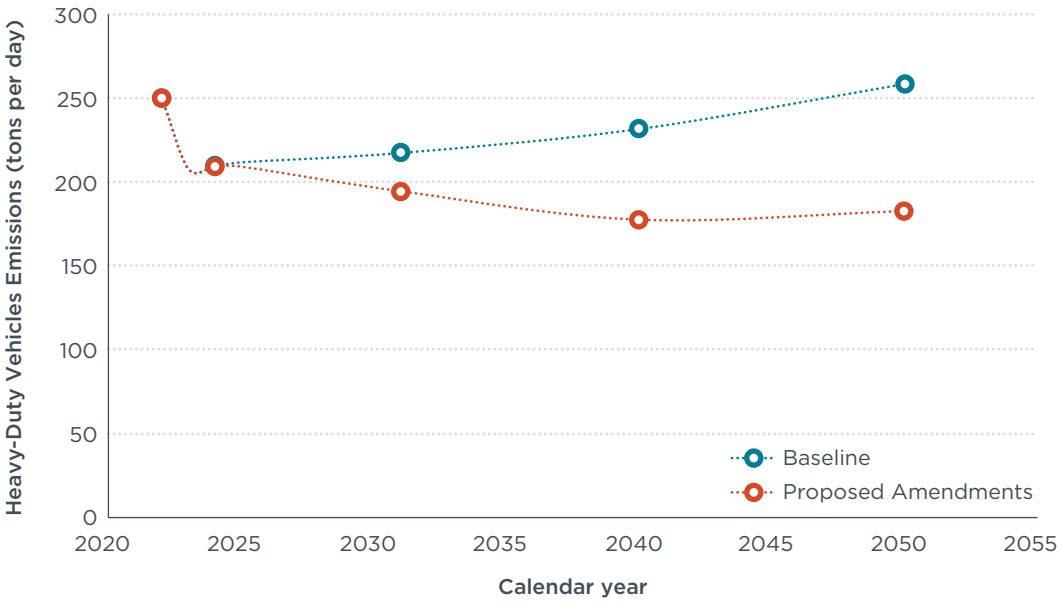


**Figure 5.** $NO_x$ emission reductions under new heavy-duty truck engine standards.
*Source:* California Air Resources Board (2020e)

The monetized health benefits of the new standards exceed the cost of compliance by a ratio of 8.2 to 1.

## 4.2. EMISSION STANDARDS FOR NEW DIESEL OFF-ROAD EQUIPMENT AND ENGINES

**Background.** CARB adopted the first emission standards for new off-road diesel engines greater than 130 kW effective with 1996 models. The federal Clean Air Act of 1990 prohibits California from regulating new off-road diesel engines of less than 130 kW. The standard reduced $NO_x$ emissions by about 50%. CARB also adopted more-stringent standards, called Tier 2 standards, effective with the 2000 model year. In 1998 the EPA adopted Tier 2 and 3 standards starting with the 2001 model year, which were more stringent than CARB's. The agency aligned its standards with those of the EPA, creating a single set of emission limits for off-road diesel engines sold in the U.S. Standards and implementation dates vary by engine power. Most Tier 2 and 3 engines meet the standards for HC, CO, $NO_x$, and PM without the use of exhaust aftertreatment systems. Current certification requirements such as durability demonstration and warranty are similar to those that currently apply to on-road heavy diesel engines. A summary of emission limits by engine size is presented in Table 4.

**Status and future.** CARB and the EPA adopted Tier 4 emission standards that were phased in between 2008 and 2014, again varying by engine size. A new transient test was phased in between 2011 and 2013, excluding the largest engine class. Engines must meet the standards on both the transient and steady-state tests. An NTE test was added with a standard of 1.5 times the steady state standard to help evaluate in-use compliance. Since the Tier 4 standards are of similar stringency as the current on-road diesel engine standards, most off-road engines have been complying with the standards using exhaust aftertreatment, although some engines comply using only a filter or only an SCR catalyst.

**Table 4.** CARB and EPA emission standards for new off-road diesel engines

| Engine rating kW | Engine rating hP | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P < 8 | P < 11 | | | | | 8.0 / (10.5) / 1.0 | | | | | 8.0 / (7.5) / 0.8 | | | 8.0 / (7.5) / 0.4[a] | | | | | | | | | | | | |
| 8 ≤ P < 19 | 11 ≤ P < 25 | | | | | 6.6 / (9.5) / 0.8 | | | | | 6.6 / (7.5) / 0.8 | | | 6.6 / (7.5) / 0.4 | | | | | | | | | | | | |
| 19 ≤ P < 37 | 25 ≤ P < 50 | | | | 5.5 / (9.5) / 0.8 | | | | | 5.5 / (7.5) / 0.6 | | | | 5.5 / (7.5) / 0.3 | | | | | 5.5 / (4.7) / 0.03 | | | | | | | |
| 37 ≤ P < 56 | 50 ≤ P < 75 | | | - / - / 9.2 / - 5.0 / (4.7) / 0.4 | | | | | | 5.0 / (7.5) / 0.4 5.0 / 0.19 / 2.3[c] / 0.02 5.0 / 0.19 / 0.40 / 0.02 | | | | 5.0 / (4.7) / 0.3[b] | | | | | 5.0 / (4.7) / 0.03 | | | | | | | |
| 56 ≤ P < 75 | 75 ≤ P < 100 | | | | | | | | | | | | | 5.0 / (4.7) / 0.4 | | | | 5.0 / 0.19 / 2.3c / 0.02 | 5.0 / 0.19 / 0.40 / 0.02 | | | | | | | |
| 75 ≤ P < 130 | 100 ≤ P < 175 | | - / - / 9.2 / - | | | | | | 5.0 / (6.6) / 0.3 | | | | 5.0 / (4.0) / 0.3 | | | | | | | | | | | | | |
| 130 ≤ P < 225 | 175 ≤ P < 300 | 11.4 / 1.3 / 9.2 / 0.54 | | | | | | | 3.5 / (6.6) / 0.2 | | | 3.5 / (4.0) / 0.2 | | | | | 3.5 / 0.19 / 2.0[d] / 0.02 | | 3.5 / 0.19 / 0.40 / 0.02 | | | | | | |
| 225 ≤ P < 450 | 300 ≤ P < 600 | 11.4 / 1.3 / 9.2 / 0.54 | | | | | 3.5 / 6.4 / 0.2 | | | | | | | | | | | | | | | | | | | |
| 450 ≤ P < 560 | 600 ≤ P < 750 | 11.4 / 1.3 / 9.2 / 0.54 | | | | | | 3.5 / (6.4) / 0.2 | | | | | | | | | | | | | | | | | | |
| P ≥ 560 | P ≥ 750 | | | | | 11.4 / 1.3 / 9.2 / 0.54 | | | | | | 3.5 / (6.4) / 0.2 | | | | | 3.5 / 0.4 / 3.5 / 0.10[e] | | | | 3.5 / 0.19 / 3.5 / 0.04[e] | | | | | |

| Pollutant key (g/kWh) CO / HC / $NO_x$ / PM CO / (HC+$NO_x$) / PM | Unregulated | Tier 1 / Stage I | Tier 2 / Stage II | Tier 3 / Stage IIIA | Tier 4i / Stage IIIB | Tier 4f / Stage IV |
|---|---|---|---|---|---|---|

CARB is also likely for the first time to set OBD requirements for new diesel off-road engines, similar to the current OBD requirements for on-road engines.

The agency is preparing a revision to its Mobile Source Strategy that evaluates potential actions CARB could take to further reduce $NO_x$ and PM emissions to attain clean air everywhere in California and to achieve the state's climate goals. The current draft of the strategy indicates that more-stringent Tier 5 diesel emission standards for new off-road engines could be adopted to provide 50% to 90% additional reduction per piece of equipment starting in 2028–2030 (Figure 6) (California Air Resources Board, 2021d).

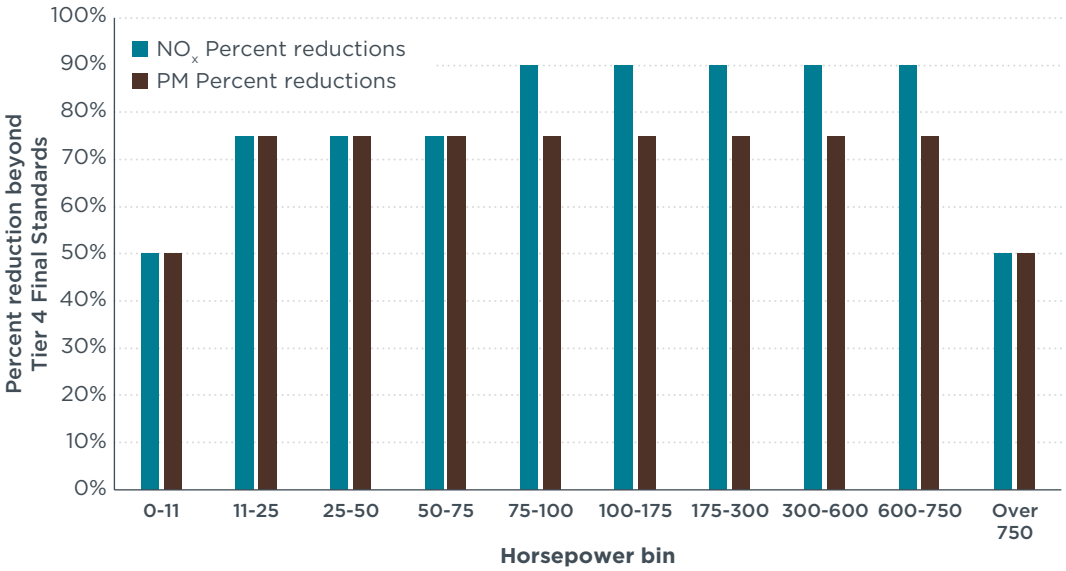


**Figure 6.** Potential Tier V $NO_x$ and PM standards for off-road diesel engines.
*Source:* California Air Resources Board (2021d)

## 4.3. EMISSION STANDARDS FOR NEW COMMERCIAL HARBOR CRAFT ENGINES

**Background.** Harbor craft include ferries, excursion vessels, tugboats, pilot vessels, tow and push boats, crew and supply vessels, barges, and dredge vessels used within 24 miles of the California coast. Commercial fishing boats are excluded. Harbor craft total about 3,100 vessels, many of them using multiple diesel engines.

Since 2009, CARB requires that new harbor craft use marine engines that meet EPA standards for the year the vessel is acquired, when Tier 2 and Tier 3 were in effect.[14] Considering that no exhaust aftertreatment was needed, all new ferries sold before Tier 4 engine availability are required to add a particulate filter, as Tier 4 generally requires the use of a particulate filter and SCR catalyst. CARB also requires new and existing harbor craft to use diesel fuel that meets CARB on-road specifications, which are more stringent and result in lower $NO_x$ emissions than diesel fuel sold elsewhere in the U.S.

**Status and future.** CARB is developing additional requirements for new harbor craft engines. New short distance ferries covering less than 3 nautical miles will be required to have zero-emission propulsion systems as of 2026. New excursion vessels must use zero-emission-capable hybrid systems starting in 2025, though clean back-up diesel engines will be allowed. CARB may also propose that all vessels use a drop-in renewable diesel fuel (ASTM D975) that early testing indicates would slash $NO_x$ by 12% and PM by 27%.

This proposed regulation also specifies requirements to replace older engines with newer, low- emission engines, discussed in section 6.4.

14 The engine standards are structured in Tiers 1 through 4. The EPA diesel marine engine standards and tiers are too complicated to list here. A complete list can be found at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZP4H.pdf. Note that 90% of California harbor craft are in Category 1.

# 5. EMISSION COMPLIANCE AND ENFORCEMENT

**Objective and background.** The CARB program to achieve emissions compliance has three parts. The first is pre-sale certification, with a goal of assuring that the design of an engine or vehicle and its emissions control system have been thoroughly demonstrated by the manufacturer to be capable of meeting emission standards throughout their useful life. CARB requires an application for certification from the manufacturer for each unique engine and vehicle for sale in California. In reviewing a manufacturer's application for certification, CARB staff focuses on evaluating high sales-volume engines and vehicles, engine and emission control designs that have had compliance issues in the past, and engines relying on new technologies. Another high priority is identifying possible defeat devices that allow increased emissions on the road but not during compliance testing. OBD also receives intense scrutiny to ensure that it will properly identify engines and vehicles that develop high emissions in use. Staff will approve applications for certification and issue an executive order only when all regulatory requirements have been met. Until this occurs the engine or vehicle cannot be sold, and there is a mandatory fine if a new engine or vehicle is sold without such an order, as discussed in Section 2.

The objective of the second part of emissions compliance is assuring that each engine or vehicle that rolls off the assembly line is identical to the certified version and meets emission standards. In the past this involved pulling engines or vehicles off the assembly line and repeating the certification test to validate that production engines were meeting standards. As manufacturing quality improved, the number of failures just off the assembly line decreased. Currently OBD checks at the end of assembly for motor vehicles so equipped have reduced the need for assembly-line testing.

The third part is to make sure that certified engines and vehicles remain in emissions compliance throughout their useful life. CARB has learned that without in-use programs to verify emission compliance and enforcement for noncompliance, higher-than-expected in-use emissions nearly always occur. This part of the compliance program is receiving greater attention because in-use vehicles with higher-than-planned emissions still occur, contributing to violations of ambient air quality standards and to excessive pollution exposure for residents living near highways and freight distribution centers with high diesel traffic.

Every type of mobile source engine is required to complete the first compliance step each year:  applying for certification and receiving an executive order before beginning sale of a new model-year engine or vehicle. Manufacturers of heavy-duty engines and passenger vehicles are required to actively engage in all three parts of the compliance process. Smaller sources of mobile emissions may not be required to perform post-sale compliance testing and warranty reporting, but they remain obligated to meet emission standards for the engine or vehicle's useful life. CARB may perform random in-use compliance testing or respond to information suggesting noncompliance, and it will take enforcement action if indicated.

## 5.1. ASSURING IN-USE COMPLIANCE OF HEAVY-DUTY DIESEL TRUCKS.

The three-part compliance process for heavy-duty engines and vehicles is shown in Figure 7.[15]

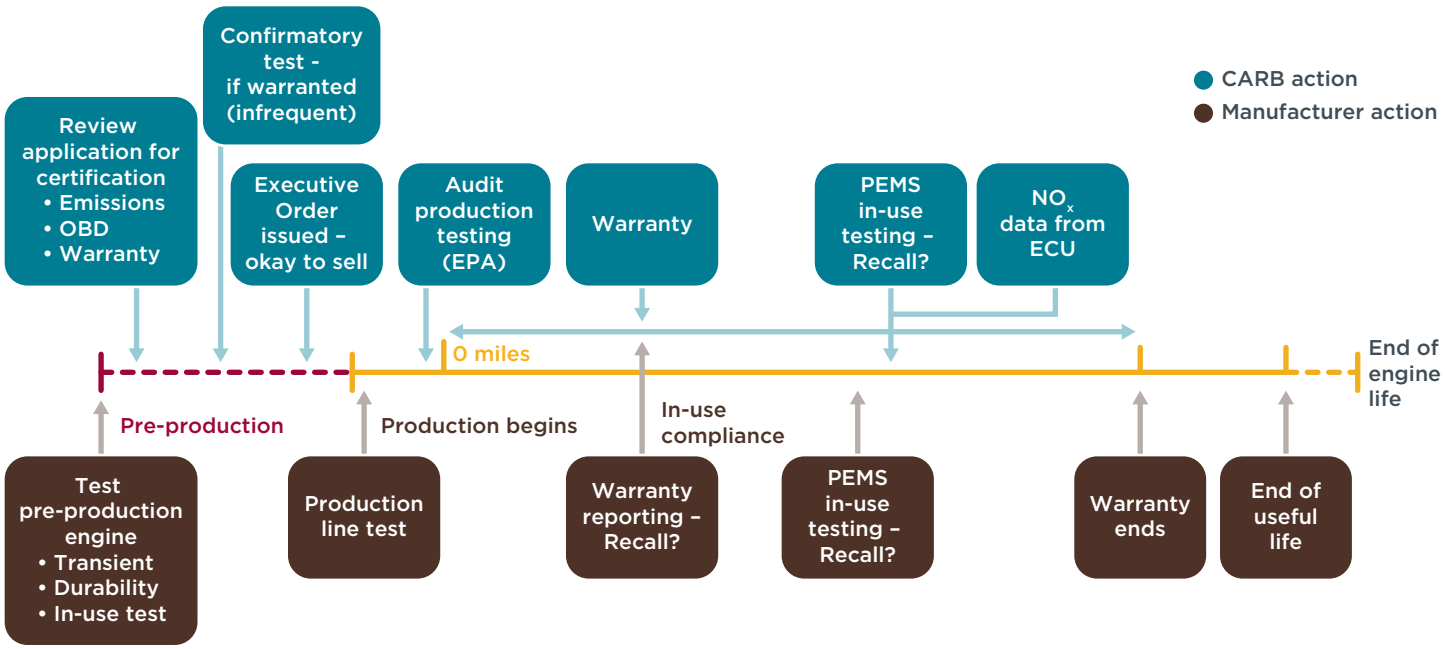


**Figure 7.** Shared responsibilities for assuring compliance with emission standards

CARB has four complementary approaches that gather data to determine whether heavy-duty trucks are complying with emissions standards and other regulatory requirements throughout their useful life. The four are:

- Testing in-use trucks to identify emission control devices or systems that have failed or perform poorly.
- Manufacturer reporting of warranty claims that may suggest systemic emissions control parts failures.
- Identifying individual trucks with excessive emissions using smoke tests and periodic inspections.
- Random testing to determine the overall effectiveness of the diesel emissions control program.

The first three approaches incorporate mandatory repairs to remedy excessive emissions, which may be the responsibility of the engine or truck manufacturer, or the individual truck owner, depending on the cause. The fourth approach identifies opportunities to improve overall program implementation by revising regulatory requirements.

15 This figure includes changes that will become effective in 2024 and 2027 such as longer warranty and useful life, and collection of real-time $NO_x$ and other critical parameters required to be stored in the engine ECU.

### 5.1.1. Identifying engines that are not durable and exceed emission standards in-use

The goal is to confirm that diesel engines certified by the engine manufacturer as complying with standards continue to do so for their useful lives. If testing reveals that emissions of several engines in a small sample of an engine family exceed standards or if a specific emissions control device is found to have the same design or manufacturing defect, CARB requires that the engine manufacturer identify the problem and remedy the noncompliance. The remedy may involve a recall of all the engines in the engine family or an extended warranty for the truck owners. Sometimes a fine is also imposed.

Historically, to determine in-use compliance, a sample of engines were removed from in-use trucks and tested in a laboratory using the same trial as during certification. This process is expensive, and in-use engines are difficult to obtain, so the number of engines that could be routinely tested was limited.

An enforcement action in 1998 found widespread use of defeat devices on many early 1990s heavy-duty engines that was not revealed during manufacturer certification testing . In response, the EPA and CARB began requiring additional tests that covered a much broader set of operating conditions. This new NTE test could also be duplicated to determine compliance in-use without removing the engine. Emissions during the NTE test must be less than 1.5 times the certification test standard. This test was the first attempt to establish a practical and effective compliance check of in-use emissions of heavy-duty diesel engines.

CARB and the EPA also adopted a regulation placing some of the burden and expense of in-use compliance testing on engine manufacturers—the Heavy-Duty In-Use Test program. Each year the agencies select 25% of the engine families produced by each manufacturer for the program. Manufacturers must procure five well-maintained in-use trucks from each engine family, equip the trucks with portable emission measurement systems (PEMS), and record emissions during a full day of regular operation. Based on the data, each manufacturer identifies operational events that are consistent with monitoring specifications of the NTE test and reports whether any valid NTE events exceeded the limit. Such testing began in 2007, the year when new diesel engines were first equipped with particulate filters. CARB can confirm manufacturer submissions with its own PEMS testing as part of its Heavy-Duty In-Use Compliance program.

CARB's analysis of the manufacturer NTE in-use test results found that it is not effective in determining noncompliance. The problem is that the monitoring conditions governing whether such a test is valid do not occur frequently because of the highly transient operation of diesel trucks. This was demonstrated by manufacturer-submitted in-use data showing many instances where $NO_x$ emissions exceeded the standard by 10 times or more, but the test results were not considered valid because specific monitoring conditions were not met. Only 5% of the manufacturer-submitted NTE test data was considered valid (California Air Resources Board, 2020d). Some manufacturers submitted monitoring data that contained no valid NTE events despite days of data collection. The few valid tests submitted by manufacturers resulted in only one recall over 10 years through 2017 (California Air Resources Board, 2017c).[16]

16 Presentation includes more details on the HDIUT program.

To correct this problem, CARB is revising the program by replacing the NTE test with a modified version of a more effective procedure used in the European Union. The modified version, known as the 3-Bin Moving Average Window, will be used starting with 2024 models (California Air Resources Board, 2020e). It has been shown to produce valid in-use data much more frequently than the NTE test, as shown in Figure 8.[17]

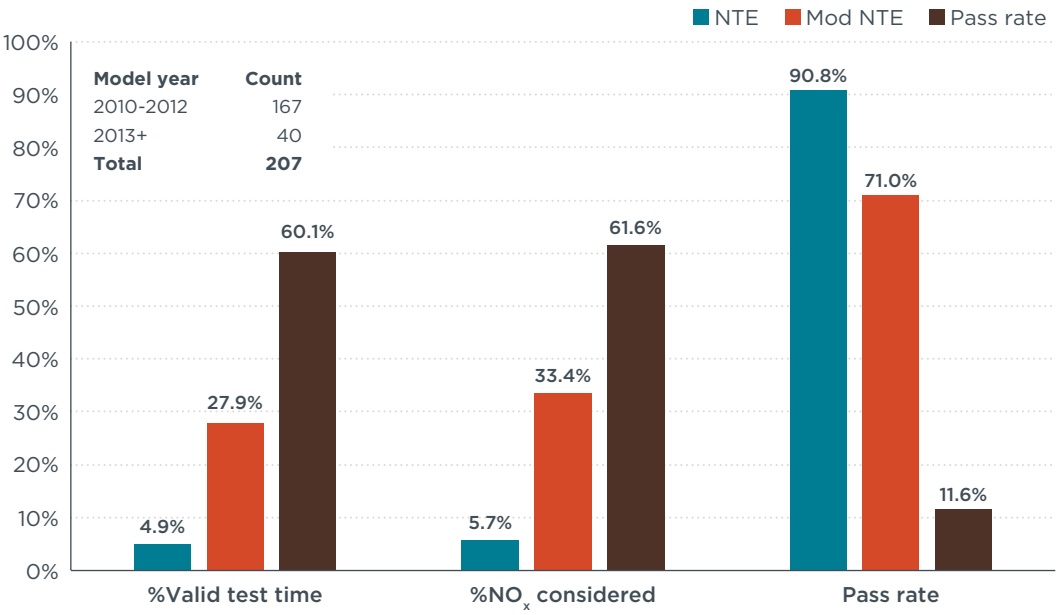


**Figure 8.** Effectiveness of three in-use emission tests.
*Source:* California Air Resources Board (2020e)

The emission standard will remain at less than 1.5 times the closest related engine test standard (idle, RMP-SET, LLC and transient FTP).

In 2016 CARB increased the use of PEMS tests to evaluate in-use heavy-duty diesel truck emissions. The goals are to verify manufacturer in-use testing results and to expand the number of engine families evaluated each year. Although the frequency of directly determining compliance using PEMS is reduced by the limitations of the current NTE test, PEMS testing can also shed light on the overall emissions performance of in-use heavy-duty trucks. For example, CARB PEMS testing of Cummins diesel engines identified widespread failure of the SCR catalyst. The CARB test results were the basis for recalling 500,000 trucks with Cummins engines nationwide for SCR replacement. CARB's new emissions laboratory (as Shown in Figure 3) will further expand the amount of PEMS testing, and its new heavy-duty chassis and engine test cells can be used to resolve any questions on validity of the results.

### 5.1.2. Identifying high failure rates of emission control devices through warranty reporting

This program also encourages engine manufacturers to produce emissions-durable engines. CARB requires heavy-duty engine manufacturers to warrant engine and emissions control systems against failure or excessive emissions. The current warranty period is five years or a specified mileage, whichever comes first. The mileage period

17 Data from California Air Resources Board. (2020e). The Mod NTE shown was an attempt to improve the existing NTE test by changing test parameter restrictions.

varies by truck size and ranges from 110,000 miles for trucks 14,000 to 19,500 pounds GVWR to 350,000 miles for trucks over 33,000 pounds GVWR. A recently adopted CARB regulation increases the warranty period to seven years for 2027 models and 10 years for 2031 models. The warranty mileage period also increases, for example to 600,000 miles for Class 8 trucks.

CARB requires engine manufacturers to keep records of the number of warranty claims for each emissions-related part. Once a warranty claim rate for an emissions-related part reaches 1%, a manufacturer must begin reporting the claim rate quarterly to CARB. The OBD light is often what triggers a warranty claim because the truck owner knows it will pay no cost for the repair. When the number of valid warranty claims exceeds 4%, the need for a remedy is indicated, and CARB evaluates whether it should be an extended warranty or a recall of a defective part. CARB has found that auditing of warranty records is necessary to ensure that manufacturers report faithfully and accurately. Reporting ends when the warranty period expires. This program will have much more value once the new, longer warranty periods go into effect (see Section 4.1).

### 5.1.3. Identifying individual in-use trucks with excess emissions

This program focuses on the truck owner or operator rather than the engine manufacturer. The goal is to identify individual trucks whose engines are high emitters. The program has four sub-elements:

- Random smoke testing and CARB inspections of tampering and OBD performed in the field.
- A requirement that California fleets periodically self-test trucks for excessive smoke and keep records.
- A remote sensing program just beginning implementation that measures nitric oxide, black carbon emissions, and OBD status for trucks so equipped.
- A planned periodic inspection and maintenance program for heavy-duty diesel trucks.

These inspections can identify individual trucks whose owners have not maintained them, have illegally removed emission controls, or whose truck has a failed emissions control device. A discussion of each program element follows.

**Random smoke testing and inspection of tampering and OBD.** CARB for years has performed random smoke tests and inspections of tampering and OBD on diesel trucks at highway weigh stations generally located on the edge of urban areas. CARB also performs random smoke testing of trucks on urban streets and at fleet businesses. The smoke test is a snap idle, which involves a rapid increase in engine speed with the transmission disengaged. Smoke is measured by an opacity meter. The test takes only a few minutes. Opacity limits vary by truck model year. For example, a 2007 or newer truck equipped with a particulate filter fails the test if opacity exceeds 5%, which may indicate a failure of the filter. Older trucks fail if opacity exceeds 20% to 40%, which is visible smoke, with the standard depending on the model year. The test procedure is SAE J1667. (See Table 5.)

**Table 5.** Smoke opacity standards

| | |
|---|---|
| **Engines equipped with a diesel particulate filter (DPF)** | |
| 5% Opacity limit | |
| **Pre-2007 model year (MY) engines without a DPF** | |
| 1997-2006 MY engines | 20% Opacity limit |
| 1991-1996 MY engines | 30% Opacity limit |
| Pre-1991 MY engines | 40% Opacity limit |
| **Engines equipped with a Level 2 Verified Diesel Emission Control Strategy (VDECS)** | |
| 20% Opacity limit | |

An illuminated OBD warning light is also considered a failure. The OBD light will also indicate whether the proper urea needed by the SCR catalyst to reduce $NO_x$ is present and in use (California Air Resources Board, 2019b).

The current failure rate is 4% (California Air Resources Board, 2020a). Failure of the smoke test results in a $300 fine, which increases to $800 if proof of repair is not provided to CARB within 45 days. Multiple failures or unpaid fines can result in the truck being removed from service by the California Highway Patrol. The random inspections and fines provide an effective deterrent to operating a truck with excessive smoke or a defective or tampered-with emissions control device. This program affects all diesel trucks over 6,000 pounds GVWR, including those licensed in other states or bordering countries.

**Smoke testing by fleets.** A complementary Periodic Smoke Inspection Program requires that California-licensed fleets of two or more diesel trucks perform annual smoke tests and maintain records for audit and inspection. The program helps ensure that urban trucks, which may not regularly pass highway inspection stations, don't emit excessive smoke. CARB randomly audits fleet owner records (California Air Resources Board, 2020d). Those found in noncompliance receive fines. CARB staff also investigates citizen complaints of smoky trucks as do local government agencies.

**Remote sensing.** Remote sensing of on-road diesel truck emissions has been pilot-tested and will be expanded statewide over the next few years. CARB has developed an overhead remote sensing device that can be placed at high throughput facilities such as highway weigh stations and border crossings. The device can measure nitric oxides and black carbon (a surrogate for PM emissions) and read license plates. The database of license plates of high-emitting trucks can be used to select vehicles for further CARB inspections or fleet audits. The first of these devices, shown in Figure 9, has been collecting data on 10,000 trucks a month since 2019.

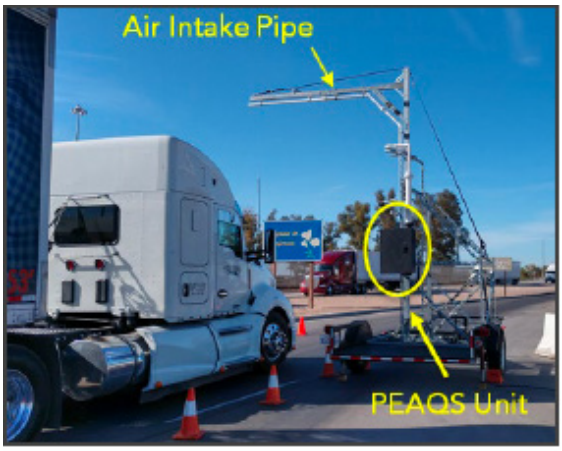


**Figure 9.** CARB's remote sensing system for diesel trucks.
*Source:* California Air Resources Board (2021d)

**Planned periodic in-use inspection program.** CARB's mobile source inventory model projected that in 2031 a small percentage of trucks that are malfunctioning or poorly maintained will account for 65% of $PM_{2.5}$ and 47% of $NO_x$ emissions from the entire on-road truck fleet. For example, if a particulate filter that is 99% effective fails or is removed, emissions from that truck can increase by two orders of magnitude. The impact of malfunctions on fleet emissions is illustrated in Figure 10 (California Air Resources Board, 2021d).

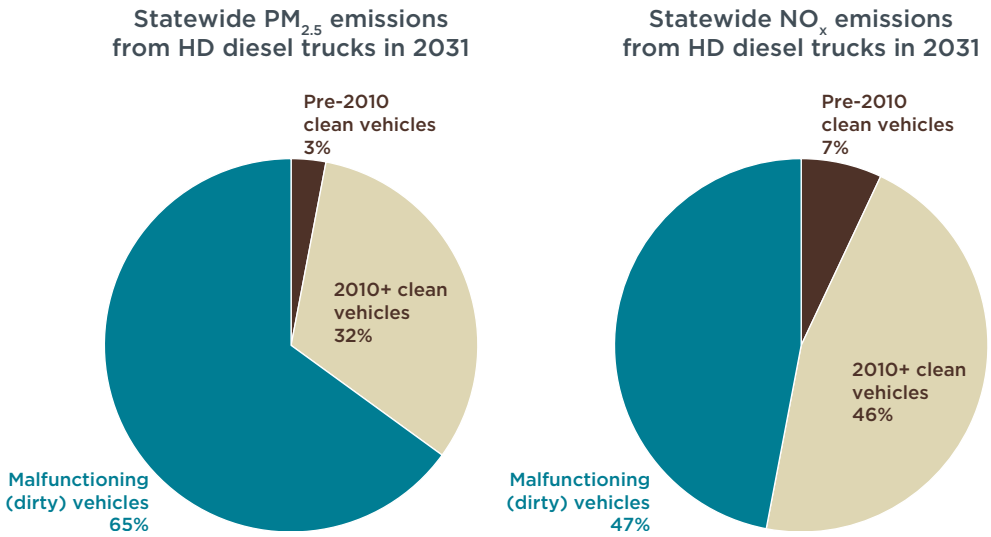


**Figure 10.** PM emissions due to malfunction.
*Source:* California Air Resources Board (2021d)

To reduce these excessive emissions by identifying and repairing high-emitting trucks, a new periodic in-use heavy-duty diesel truck inspection and maintenance program is being developed. Once approved by the CARB board—expected in late in 2021—full implementation will begin as early as 2024.[18]

18 Progress in developing this inspection program can be found at: California Air Resources Board, *Heavy-Duty Inspection and Maintenance Program: Meetings & Workshops*, https://ww2.arb.ca.gov/our-work/programs/inspection-and-maintenance-program/Meetings-and-Workshops

In-use heavy-duty diesel trucks of 14,000 pounds GVWR and above, including those from other states and Mexico and Canada, will be required to register with CARB and obtain a compliance certificate indicating successfully passing several emission inspections per year.

The type of inspection will vary by model year. Trucks of model years 2012 and older will be required to obtain a smoke test and visual inspection of the emissions control system twice a year. The inspections would be obtained from private, state-certified inspection stations similar to those used in California's Smog Check program for passenger vehicles. Trucks of model years 2013 and newer are equipped with OBD. Instead of obtaining inspections at private stations, OBD-equipped trucks will have the option of using remote transmitting devices to report the status of the OBD system through a third party to CARB. Trucks with transmitting devises will also be exempt from the fleet smoke inspection program.

If the remote test indicates high emissions or if a truck has not been registered with CARB or does not have a current compliance certificate, the owner will be sent a notification requesting proof of compliance. Enforcement for noncompliant California-licensed trucks will be by denial of registration and possible fines.[19] Fines will be imposed on trucks registered out of state that are out of compliance, and CARB staff will cross-check the agency's database for noncompliance during periodic inspections at weigh stations or other locations.

### 5.1.4. Determining the effectiveness of CARB's diesel emissions control program

This program's goal is to determine whether the diesel truck emissions control program is achieving the expected emission reductions and whether improvements need to be made. CARB regularly performs random testing of in-use trucks using PEMS to help determine the program's effectiveness. This testing has several objectives. It can be used to estimate the areawide emission contributions of diesel trucks and create or improve upon an emissions inventory. It can also be used to compare on-road test results with expected emission reductions and identify where improvements may be needed. For example, CARB's on-road PEMS testing of diesel trucks that use selective catalytic reduction (SCR) to control $NO_x$ showed that the catalyst was not effectively lowering such emissions at low loads and speeds. This resulted in the adoption of an additional compliance test and $NO_x$ standard to ensure that engine makers design control systems that remain effective under these conditions.

## 5.2. ASSURING IN-USE COMPLIANCE OF DIESEL OFF-ROAD ENGINES.

CARB adopted EPA standards for new off-road diesel engines of 175 hp (130 kW) or greater.[20] The agency retains compliance and enforcement authority and can recall engines for noncompliance. CARB has relied on the EPA for in-use compliance and enforcement of new engine standards and requirements. A new CARB laboratory opening in 2021 has engine dynamometers capable of testing large diesel engines, and the agency has an expanded program to test in-use trucks and equipment using PEMS. CARB does not require reporting of warranty claims as it does for on-road engines. Neither does it plan to adopt a periodic inspection program for diesel off-road engines as for on-road diesel trucks.

19 California Vehicle Code §4000.17.

20 Federal law preempts states including California from adopting emission standards for new off-road engines used in construction and farm equipment that are less than 175 horsepower.

# 6. IN-USE DIESEL EMISSIONS REDUCTION PROGRAMS, INCLUDING MARINE VESSELS

**Objective.** Accelerate the retirement of older, high-emitting diesel trucks, off-road equipment, and harbor craft engines and replace them with lower-emitting or zero-emission engines or vehicles. Reduce emissions from ocean-going vessels.

**Background.** In the early 1980s, California began a program to identify the health impacts of air pollutants besides those already subject to an ambient air quality standard such as ozone or nitrogen dioxide. The concern was that more air pollutants might be toxic and cause cancer or other severe health effects. Many of the substances CARB has listed as toxic—such as methylene chloride, asbestos, and benzene—are directly emitted by industrial sources, while others come primarily from mobile sources. Diesel PM was listed in 1998 as a toxic air contaminant that may cause cancer (California Air Resources Board, n.d. b).

The local air pollution agency for the greater Los Angeles area conducted monitoring in 2000 of more than 30 chemicals present in ambient air and found that diesel particulates accounted for more than 70% of the cancer risk of breathing air in the Los Angeles area.[21] There was growing evidence that diesel PM contributed to more than half the total air cancer risk in Los Angeles of roughly 750 in 1 million over a lifetime. This prompted CARB to publish a Diesel Risk Reduction Plan in 2000. One recommendation was to adopt new retrofit requirements for existing on-road, off-road, and stationary diesel engines when technically feasible and cost-effective (California Air Resources Board, 2020f).[22] This started CARB's efforts to clean up in-use diesel engines with retrofit PM filters or accelerated replacement of older engines with new ones that meet much more-stringent PM emission standards. The need to slash $NO_x$ emissions from diesel engines to meet the ambient ozone standard was also part of the plan.

Growing evidence that $PM_{2.5}$ causes premature deaths from strokes and heart attacks and growing awareness that low-income and minority residents living near areas of heavy diesel truck traffic are exposed to disproportionally high air pollution further raised the priority of replacing older, high-emitting diesel trucks and equipment with cleaner engines.

## 6.1. ACCELERATE REPLACEMENT OF OLDER, HIGH-EMITTING IN-USE DIESEL TRUCKS.

In 2008, CARB adopted a comprehensive regulation requiring the reduction of emissions of $NO_x$ and $PM_{2.5}$ from in-use on-road heavy diesel trucks. The regulation is referred to as the Truck and Bus Regulation and was controversial because it affected many people and businesses. More than 170,000 fleets and nearly 1 million trucks are subject to the regulation.

The regulation required older trucks to be retrofitted with diesel particulate filters (DPF) by 2014. Over a schedule extending to 2023, nearly all trucks older than 2010

21 The latest monitoring results show the cancer risk of breathing Los Angeles air for a lifetime dropped 54% between 2012 and 2018. Diesel PM still contributes 50% of the cancer risk. See: South Coast Air Quality Management District, *Executive summary: Multiple Air Toxics Exposure Study V* (Figure ES-3), http://www.aqmd.gov/docs/default-source/planning/mates-v/draft-mates-v-executive-summary_v2.pdf?sfvrsn=6.

22 In addition to retrofit of existing on-road diesel engines, the plan called for a 90% reduction in the emission limits for new engines and reduction of sulfur in diesel fuel to 15 ppm.

were to be replaced with newer trucks that met the 2010 new diesel engine standards using a DPF and $NO_x$ aftertreatment to reduce pollutants by 90% or more. Transit buses are subject to a separate rule, and reflecting a lack of funding, replacement of school buses is limited to 1977 models and older.

The recession of 2008–2009 affected the transportation sector, and as a result CARB revised the Truck and Bus Regulation in 2014. The revisions relaxed and delayed the DPF retrofit requirements to reduce compliance costs for small businesses and to reflect the failure of some DPFs that occurred due to poor engine maintenance. The revisions also extended to 2023 the date for replacement of older trucks with 2010 or newer ones. The estimated emission reductions of the 2014 revised regulation are shown in Figure 11.

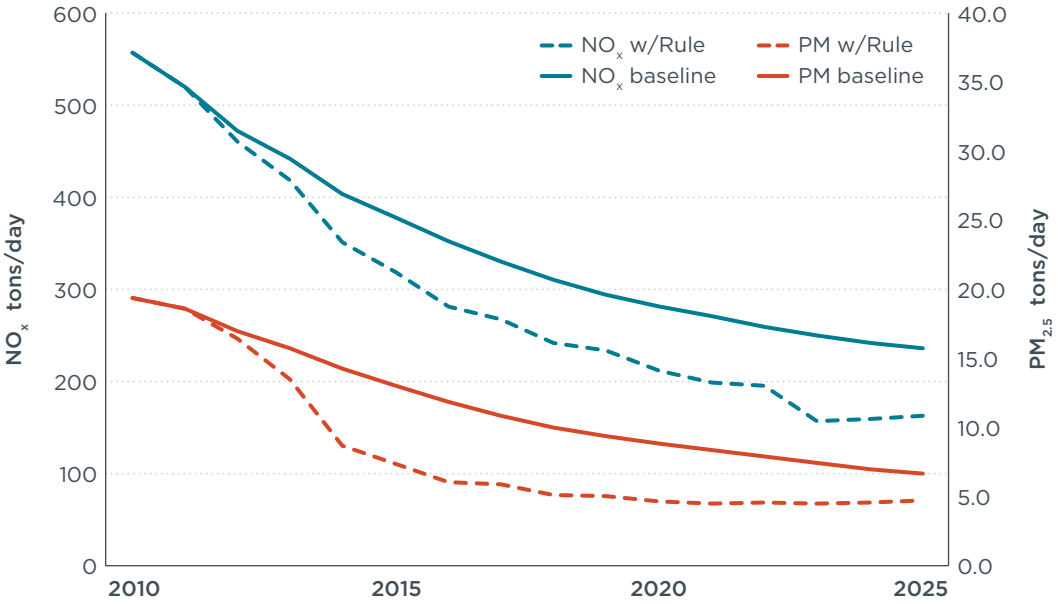


**Figure 11.** Emission reductions under Truck and Bus Regulation.
*Source:* California Air Resources Board (2014)

Enforcement of the regulation is based on reports required to be filed by fleets on their status, truck inspection, and other data to identify fleets that are suspected of being out of compliance. Fleets that don't provide information demonstrating compliance are issued notices of violation with penalties, and a hold is placed on registration. In 2018 and 2019, 23,000 fleets failed to demonstrate compliance and were denied registration, and more than $5 million in penalties were collected. The overall compliance rate increased to 88% in 2019 from 77% in 2017, showing the value of an effective compliance and enforcement program (California Air Resources Board, 2020a).

**Status and future.** The Truck and Bus Regulation will be fully implemented in 2023, and few trucks will be operating on California highways that are not capable of much lower emissions of $NO_x$ and $PM_{2.5}$. However, a strong in-use compliance and enforcement program is necessary to remedy the disproportionate amount of excess $NO_x$ and PM emissions caused by a relatively few high-emitting trucks.

Beginning in 2024, a growing percentage of new-truck purchases by California fleets and truck owners will have to be zero-emission vehicles. That will continue to reduce $NO_x$, PM, and GHG emissions (see Section 9).

## 6.2. ACCELERATE REPLACEMENT OF OLDER, HIGH-EMITTING OFF-ROAD DIESEL EQUIPMENT.

In 2007 CARB adopted a program requiring fleets using off-road diesel equipment with more than 25 horsepower to retrofit engines with particulate filters or replace them with newer, lower-emitting engines. Soon after, the global recession decreased off-road diesel equipment construction activity by more than 50% and new equipment purchases by 90%. The recession caused CARB to reevaluate and revise the program. In 2010 CARB provided a new compliance option that avoids the use of retrofit particulate filters because of challenges in applying them to off-road engines and delayed the start of program implementation until 2014, allowing time for economic recovery.[23]

The revised program affects more than 150,000 pieces of diesel equipment owned by thousands of fleets, ranging from lawn-care tractors to road graders. It does not affect agriculture equipment, marine vessels, locomotives, or recreational vehicles. Requirements vary by fleet size. Large fleets began implementation in 2014, medium-size fleets in 2017, and small fleets in 2019. The smallest fleets have to retire only their dirtiest equipment (Tiers 0 and 1).[24]

Fleets must meet horsepower-weighted emission targets that become more stringent each year. If a fleet cannot meet an emissions target, it must meet a Best Available Control Technology (BACT) requirement. The BACT requirement involves turning over about 10% of the fleet weighted by horsepower each year, though turnover rates vary. [25]

With large-fleet requirements are fully implemented in 2024, the in-use, off-road diesel program will reduce PM emissions by 21% and $NO_x$ by 17% (California Air Resources Board, 2010). Enforcement is based on regular mandatory reporting by fleets on equipment and steps taken to comply. CARB staff audits the reports and confirms them with on-site visits. In 2019, 4,291 off-road diesel-powered vehicles and pieces of equipment were inspected, with an 11% noncompliance rate and collection of $23,700 in penalties (Calfornia Air Resources Board, 2020a).

**Status and future.** The in-use, off-road program will be fully implemented by 2024 for large fleets and 2029 for small fleets.

CARB has begun developing a proposal to increase the program's stringency. The concept under development would require turnover of the remaining Tiers 0–2 engines by 2033 with much-cleaner Tier 4 engines, as presented in Figure 12. A final proposal will go to the CARB board for approval near the end of 2022 (California Air Resources Board, 2021b).

23 The CARB staff report discusses the rationale for the program delay and revision and provides details of the program now in place in California. See: California Air Resources Board. (2010).

24 See Section 4.2 for a description of the engine Tiers and their emission rates.

25 Turnover means purchase new or newer equipment, or repower existing equipment with a newer engine that meets a higher (cleaner) Tier number, or retrofit with a diesel particulate filter.

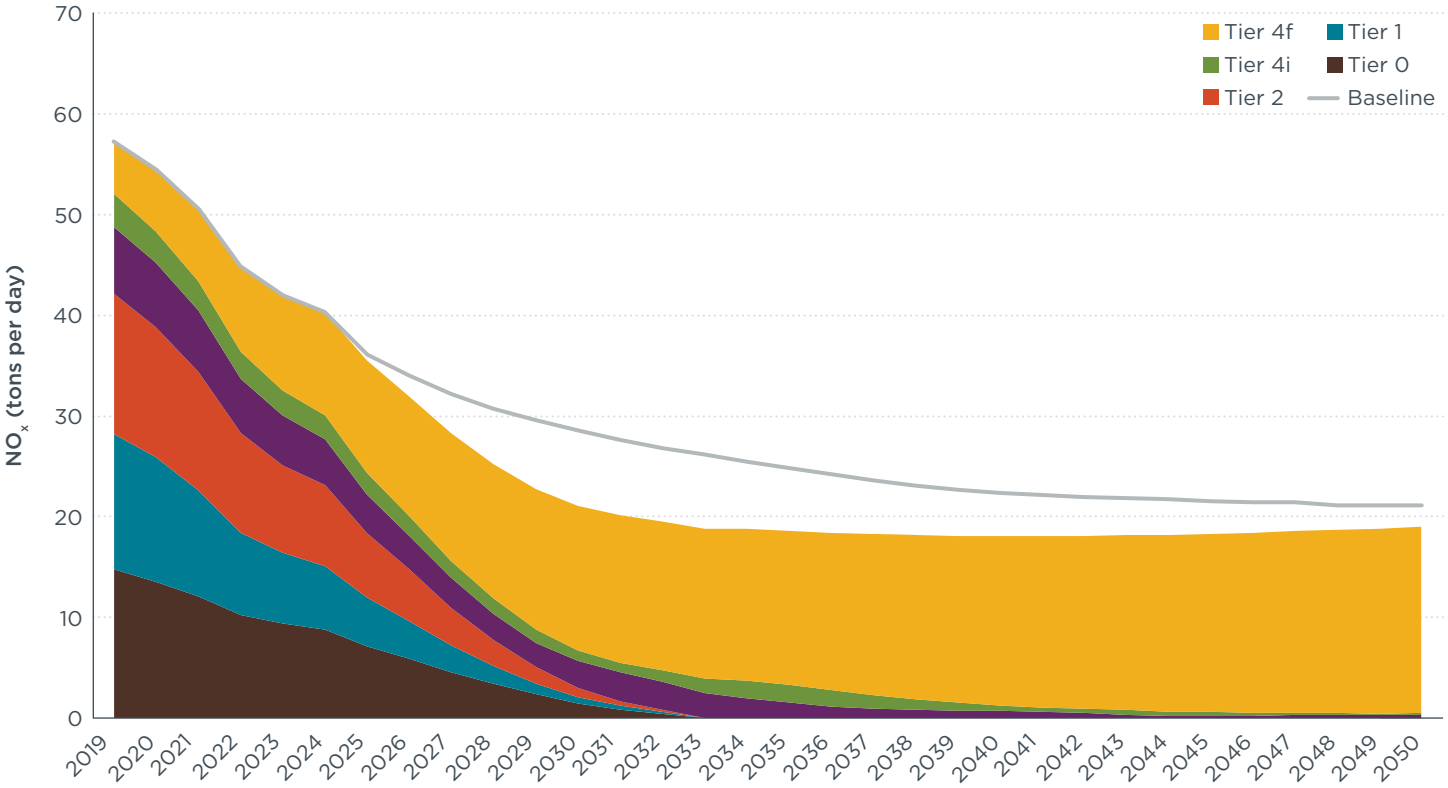


**Figure 12.** Proposed accelerated turnover to cleanest off-road engines.
*Source:* California Air Resources Board (2021d)

## 6.3. ACCELERATING REPLACEMENT OF DIESEL TRANSPORT REFRIGERATION UNITS

**Background.** Diesel-powered transport refrigeration units (TRUs) cool or heat cargo in trucks, trailers, railcars, and shipping containers. New TRUs are subject to existing off-road equipment emission standards for $NO_x$ and PM, which for TRUs greater than 25 horsepower require PM aftertreatment or equivalent technology. Smaller TRUs have a laxer standard.

The program went into effect in 2008 with a goal of accelerating the turnover of higher-emitting TRUs with equipment meeting the lowest off-road PM emissions standard. The lowest PM standard is 0.02 grams per brake horsepower-hour (g/bhp-hour). In simplest terms, when a TRU is 7 years old (the average useful life is 10 years) it must be replaced with a new one meeting the most stringent standard available. The regulation applies to any diesel TRU that operates in California, not just those on trucks and trailers licensed there.

All TRUs are required to register with CARB, which enables the agency to inspect the equipment. Enforcement occurs by inspection of trucks with TRUs, often done at highway weigh stations where CARB already performs smoke inspections. In 2019, CARB inspected 2,064 TRUs and issued 933 citations, reflecting 45% noncompliance which indicates CARB's targeted enforcement was effective. A total of $322,474 in penalties were collected (California Air Resources Board, 2020a). Increased enforcement to reduce the noncompliance rate is needed.

**Status and future.** Since 2020, TRU upgrades to the current off-road standards are largely complete.

CARB staff is evaluating further requirements to reduce $NO_x$, PM, and GHG emissions from TRUs. Such gear on trucks without trailers would have to be replaced by zero-emission units at a rate of 15% per year beginning with the 2023 model year so that all straight-truck TRUs would be zero-emission by 2030. Figure 13 presents the impacts on $NO_x$ from TRU's rapid electrification, with zero-emission units increasing from 10% in 2024 to 100% in 2034. To further reduce PM and $NO_x$ emissions, 2023 and newer diesel TRU engines used in trailers, domestic shipping containers, railcars, and TRU generator sets, including those with less than 25 horsepower, would have to meet the most the most stringent EPA standards.

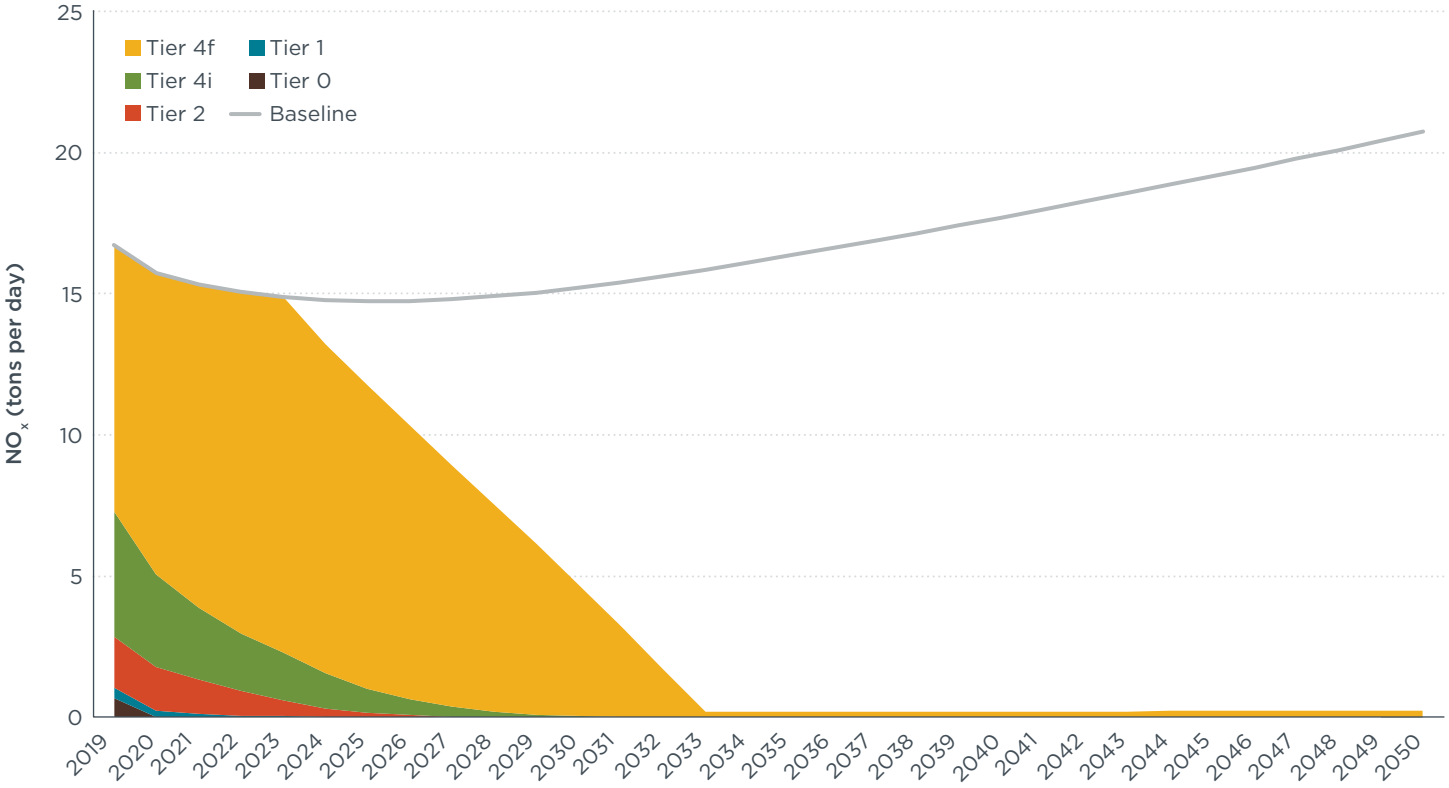


**Figure 13.** Projected impacts of $NO_x$ emissions from accelerating turnover to zero-emission TRUs.
*Source:* California Air Resources Board (2021d)

All newly manufactured TRUs would also have to use a refrigerant with a global warming potential of 2,200 or less, with a goal of phasing out the usage of high-GWP refrigerant such as hydrofluorocarbons (HFCs). This proposed regulation may be considered for adoption by the board at the end of 2021.[26]

26 Follow development of this proposed regulation at: California Air Resources Board, *Transport Refrigeration Unit*, https://ww2.arb.ca.gov/our-work/programs/transport-refrigeration-unit

## 6.4. ACCELERATING REPLACEMENT OF OLDER COMMERCIAL HARBOR CRAFT ENGINES

**Background.** CARB's harbor craft regulation, adopted in 2007, requires many types of harbor craft using Tier 1 or older engines to update with newer, lower-emitting power plants. (Requirements for new harbor craft are discussed in Section 4.3, including a reference listing the tiers and emission standards). Any replacement engine must be Tier 2 or 3. Most types of harbor craft must also replace an older engine with a Tier 2 or 3 engine according to a schedule based on the age of the high-emitting engine. Mandatory upgrades started in 2009 and will be fully implemented by 2022; the deadline was 2020 for vessels with home ports in the Los Angeles area.

Owners of harbor craft are required to file reports describing their fleets and proposed compliance plans. CARB staff may audit and inspect harbor craft to verify compliance. In 2019 CARB staff inspected 315 harbor craft and settled two citations for $143,000.

**Status and future.** Most uncontrolled or Tier 1 harbor craft engines have been replaced or will soon be replaced with cleaner Tier 2 or 3 engines to comply with current regulations. Harbor craft with Tier 4 engines equipped with exhaust aftertreatment have begun to appear. CARB estimates that the current regulation will result in a 75% reduction in PM and a 60% reduction in $NO_x$ from harbor craft in 2025 compared with 2004 (California Air Resources Board, 2016).

Figure 14 shows that most future-year $NO_x$ emissions will still come from Tier 3 engines, which lack exhaust aftertreatment, suggesting that regulatory updates could further reduce emissions (California Air Resources Board, 2021d). The agency is studying the feasibility of requiring upgrades to Tier 4 engines and proposing Tier 5 standards that use exhaust aftertreatment to further reduce the $NO_x$ emissions (Moorhead, Storz, & Pinisetty, 2019). But even without addressing the Tier 3 issue, $NO_x$ emissions by 2030 would fall by almost half from 2020 levels.

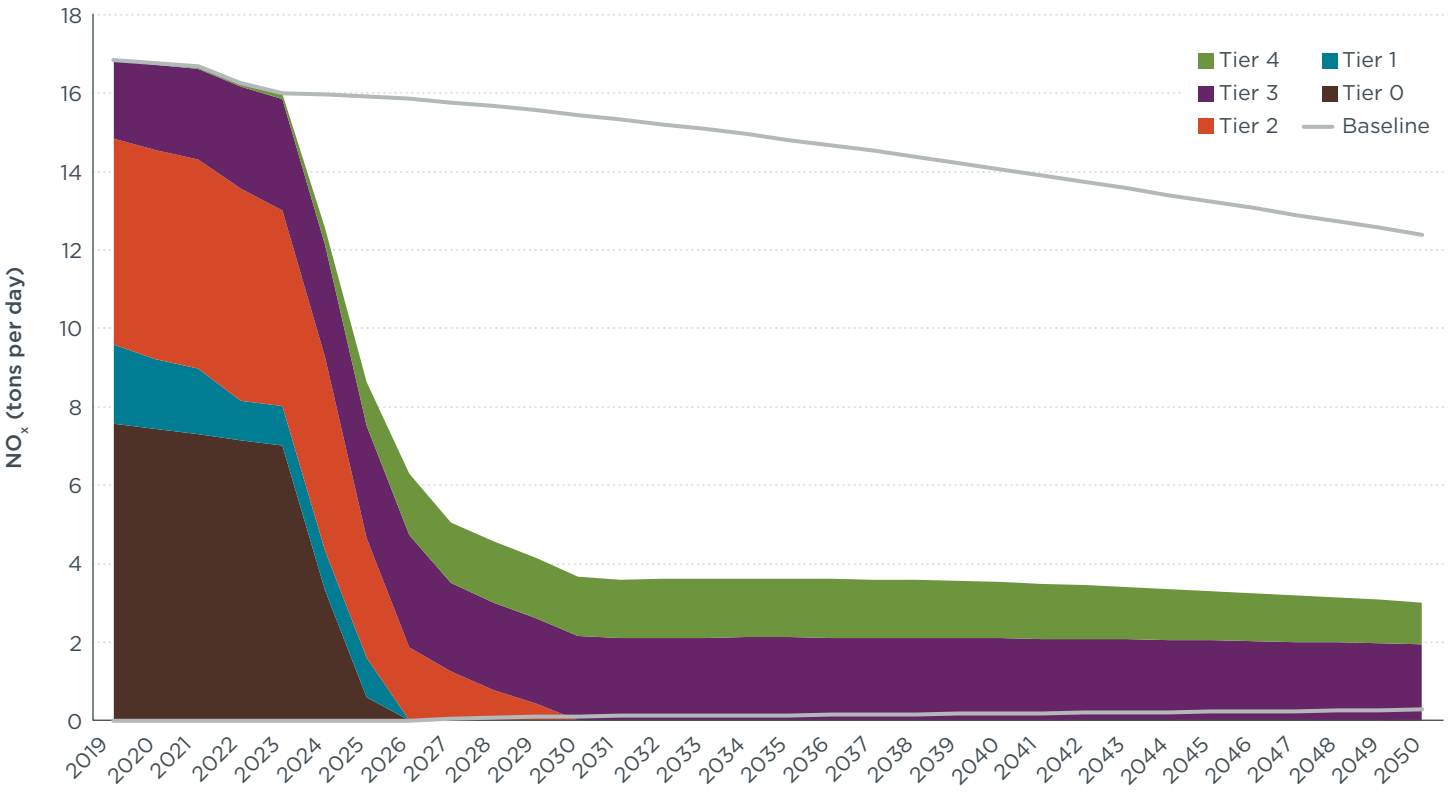


**Figure 14.** $NO_x$ emissions from harbor craft engines by regulatory tier.
*Source:* California Air Resources Board (2021d)

CARB has begun the process of identifying additional actions that could further reduce $NO_x$ and GHG emissions from harbor craft. These include expanding the types of vessels subject to in-use engine upgrades, retrofitting with diesel particulate filters, and eliminating the exemption for engines with less than 50 horsepower. In-use short-run ferries would be required to convert to zero-emission power beginning in 2028 (Moorhead, Storz, & Pinisetty, 2019).

## 6.5. REDUCING EMISSIONS OF EXISTING OCEANGOING MARINE VESSELS

**Background.** CARB defines oceangoing vessels (OGVs) as large commercial ships designed for deep-water navigation, more than 400 feet in length, with a carrying capacity of 10,000 gross tons or more, propelled by combustion-ignition diesel engines of displacement equal to or greater than 30 liters per cylinder. OGVs include tankers, bulk carriers, car carriers, and passenger cruise ships.

These ships and their associated activities in ports and terminals are a large source of $NO_x$, PM, $SO_x$ and toxic emissions that disproportionally affect the health of residents living nearby and downwind. At the Ports of Los Angeles and Long Beach, the largest ports in the U.S., OGVs alone cause 64% of port $NO_x$ emissions (South Coast Air Quality Management District, 2018).

Direct emissions of ships are regulated by the International Marine Organization (IMO), and the sulfur content of fuel is limited. There are three tiers of $NO_x$ standards, which apply to vessels new in 2000, 2011, and 2016. The Tier 2 standards reduce $NO_x$ by about 20% compared with Tier 1. The 2016 Tier 3 standards reduce $NO_x$ by an

additional 75% compared with Tier 2, but only for ships operating in emission control areas (ECAs), such as the North American ECA established in 2010. The IMO has not established a PM standard for new vessels.

Lacking the authority to require emission controls on OGV engines, CARB adopted a different approach. The agency established a requirement—fully implemented in 2014—that ships operating within 24 miles of California must use distillate fuel with no more than 0.1% sulfur by mass. That compares with 3.5% sulfur content allowed by the IMO at the time. Lower-sulfur fuel reduces particle sulfate formation, and the IMO has since reduced allowable sulfur content to 0.5% globally. Enforcement occurs within California waters and may involve boarding ships to sample the fuel being used and its quality. Compliance in 2019 was about 99%, based on 536 inspections. The six violations were settled for $172,500 in penalties (California Air Resources Board, 2020a). CARB staff is evaluating remote sensing technologies that may allow it to expand enforcement more cost-effectively.

CARB also adopted a regulation to reduce emissions of auxiliary engines that provide power while vessels are at berth. The regulation applies to container and refrigerated vessels that dock at California ports 25 times or more per year and cruise ships that make five or more visits. These vessels must turn off auxiliary engines and plug in to the grid to provide power during 80% of their visits. CARB performed 38 inspections, and two citations were settled for $997,005 (California Air Resources Board, 2020a).

In 2001, CARB signed a memorandum of understanding (MOU) with the Ports of Los Angeles and Long Beach, the EPA, the South Coast Air Quality Management District, the Steamship Association of Southern California, and the Pacific Merchant Shipping Association for a voluntary vessel speed reduction program. Within 40 nautical miles of the ports, vessels would slow to 12 knots and in return would receive a reduction in docking fees. Compliance has been above 90%. A recent study reported that at the lower speed, $NO_x$, PM, and $CO_2$ emissions were reduced by 50%–60% per nautical mile (Miller, Yusufkhan, Ranganathan, Welch, & Cocker, 2012).

**Status and future.** In 2020 CARB revised the regulation requiring at-berth engine shutdown to include automobile carriers and tankers and to require the use of shore power for every visit (California Air Resources Board, 2020c). Automobile carriers and tankers contribute about half of the OGV PM emissions at port, and the use of shore power will reduce the emissions by more than 90%. The more-stringent requirements will apply in 2023 to vessels currently subject to the rule, and the automobile carriers and tankers will comply in 2025.

CARB is also beginning to evaluate further changes to the OGV regulation to reduce emissions. One approach would be to incentivize vessels that have Tier 3 engines, or Tier 2 engines with retrofit $NO_x$ controls such as water injection or SCR catalysts, to preferentially use California ports. CARB also is working with the EPA and other partners to urge the IMO to adopt a Tier 4 new-vessel standard by 2028. The current OGV Tier 3 $NO_x$ standard for emission control areas is about 10 times higher than the standard for on-road or off-road heavy-duty truck engines. A particulate standard has not been adopted because the level of sulfur in marine diesel oil is too high to ensure PM filter reliability. A maximum sulfur content closer to 15 ppm (0.0015%) would be required. The potential emission reductions that could be realized from implementing this strategy are shown in Figure 15 (California Air Resrouces Board, 2021d). By 2031, $NO_x$ emissions could fall by more than 80% compared with the baseline trend.

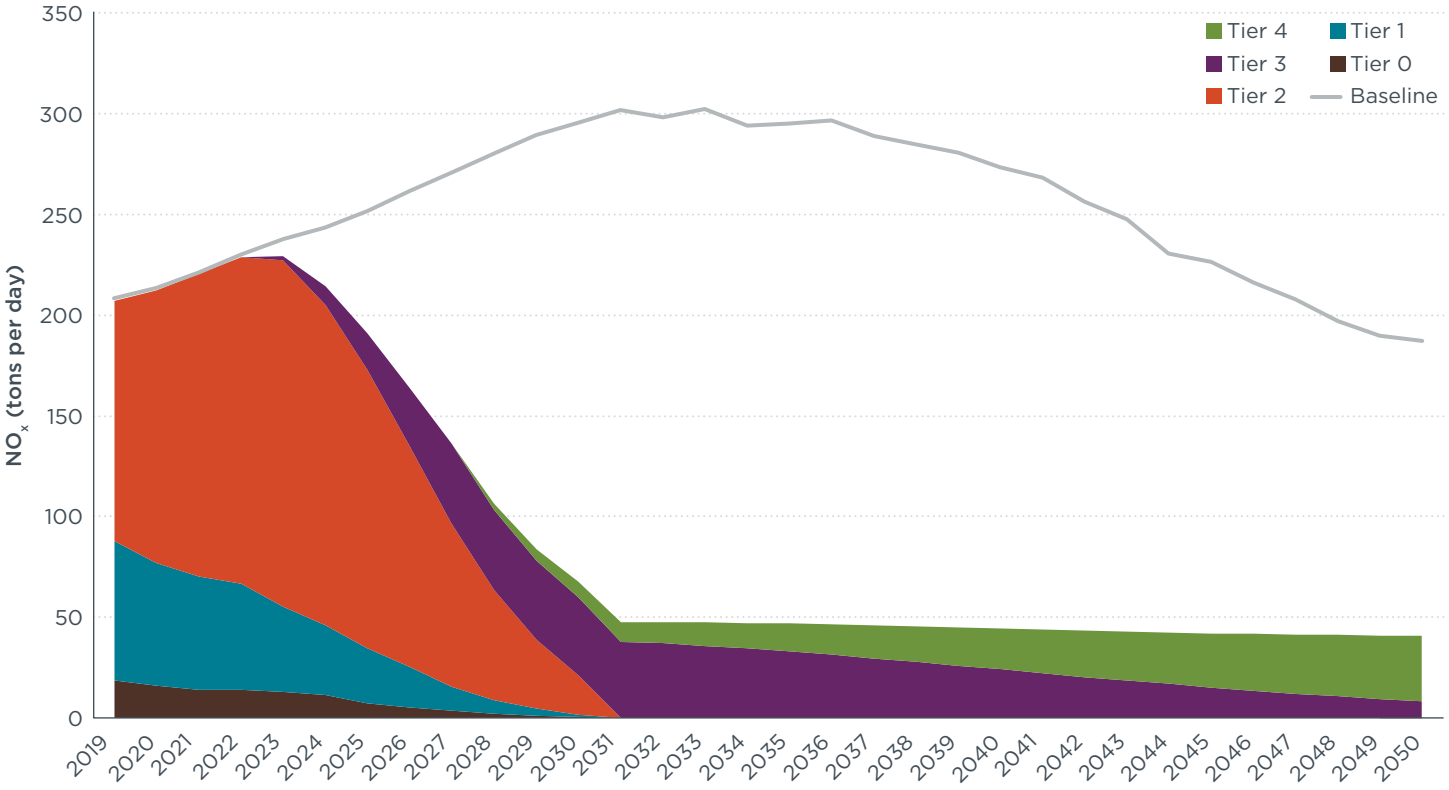


**Figure 15.** $NO_x$ emissions from OGVs by regulatory tier.
*Source:* California Air Resources Board (2021d)

## 6.6. REDUCING IN-USE LOCOMOTIVE EMISSIONS

**Background.** The EPA's emission standards for new and remanufactured line haul locomotives are listed in Table 6, showing that the $NO_x$ and PM limits were reduced by more than 80% between 1992 and 2015 while allowable smoke fell by a third.

**Table 6.** EPA emission standards for new line haul locomotives in g/bhp-hour

| Tier | Model years | $NO_x$ | PM | Smoke steady state |
|---|---|---|---|---|
| **0** | 1973-1992 | 8.0 | 0.22 | 30 |
| **1** | 1993-2004 | 7.4 | 0.22 | 25 |
| **2** | 2005-2011 | 5.5 | 0.10 | 20 |
| **3** | 2012-2014 | 5.5 | 0.10 | 20 |
| **4** | 2015 or later | 1.3 | 0.03 | 20 |

*Note:* Standards for switch locomotives are slightly higher. Standards for HC, CO, and smoke at other than steady state (SS) are not shown. See: https://dieselnet.com/standards/us/loco.php

The federal government preempted states from adopting emission standards for new locomotives and engines. CARB and other agencies petitioned the EPA in 2017 to adopt national lower-emitting Tier 5 standards for new and remanufactured locomotives. The petition suggested that emission levels of 0.2 g/bhp-hour $NO_x$ and <0.01 g/bhp-hour PM and a 10%–25% GHG emission reduction were feasible, as was requiring locomotives be capable of zero-emission operation when in heavily populated areas. As of mid-2021, it is not apparent that the EPA started the requested Tier 5 rulemaking effort.

In the absence of direct regulatory authority, CARB has resorted to in-use emission reduction strategies. The agency negotiated a nonregulatory MOU in 1998 with the state's two class 1 (interstate) railroads to preferentially operate cleaner locomotives in the greater Los Angeles area (California Air Resources Board, 1998). By 2010, the average locomotive $NO_x$ emissions, based on energy used in greater Los Angeles, will be 5.5 g/bhp-hour or less. The MOU contains penalties of $5,000 a day for failure to report and $100,000 for each 0.1 g/bhp-hour of annual emissions above the $NO_x$ limit. The 2019 report shows that both railroads met the $NO_x$ target (California Air Resources Board, (n.d. c). Although available since 2015, operation of Tier 4 locomotives in 2019 was less than 5%.

A second MOU in 2005 with the same railroads resulted in the installation by 2008 on all locomotives in California of automatic idle reduction systems that shut off engines if idled for more than 15 minutes. The MOU also contained an agreement that at least 80% of locomotive fuel used in California beginning in 2007 would be ultra-low sulfur diesel fuel and that the railroads implement a visible smoke inspection and repair program for engines with smoke opacity greater than 20%. This MOU resulted from increased public complaints about locomotive pollution and a concern of disproportionate exposure of residents living near railyards to locomotive emissions (California Air Resources Board, 2005).

**Status and future.** CARB is considering banning locomotives older than 23 years from operating in California beginning in 2030. This would result in mostly Tier 4 locomotives and zero-emission locomotives operating in the state (California Air Resources Board, 2021c).

To facilitate a transition to the 2030 ban, CARB is considering a novel approach to accelerate a transition to the cleanest locomotives. Each locomotive operated in California would be assessed an annual fee based on the emission rate of $NO_x$ and PM for that locomotive and the total amount of operation that occurred in the previous year within the state, measured in megawatt-hours. The fee would be deposited into a savings account for the railroad owning the locomotives. The saved funds could be spent only on purchasing the cleanest locomotives and zero-emission locomotives. Fees could be reduced by purchasing zero-emission locomotives, with extra credit if the zero-emission locomotive is operated in disadvantaged communities whose residents are exposed to the worst air pollution. This concept is an indirect way of incentivizing the accelerated purchase of new, cleaner locomotives. The fee could also be reduced if the operator prioritized its cleanest locomotives for use in California. This would affect both line haul freight and passenger locomotives traveling into and out of California, which account for more than 90% of locomotive emissions within the state.

These approaches are still under development and are scheduled to go the CARB board for consideration in 2022 (California Air Resources Board, 2021d). Figure 16 shows the projected impact of retiring older locomotives in the greater Los Angeles area. By 2030, $NO_x$ emissions from such diesel engines would plunge by 75% from the current projected trend without instituting the requirements, and the decline would be close to 80% by 2050.

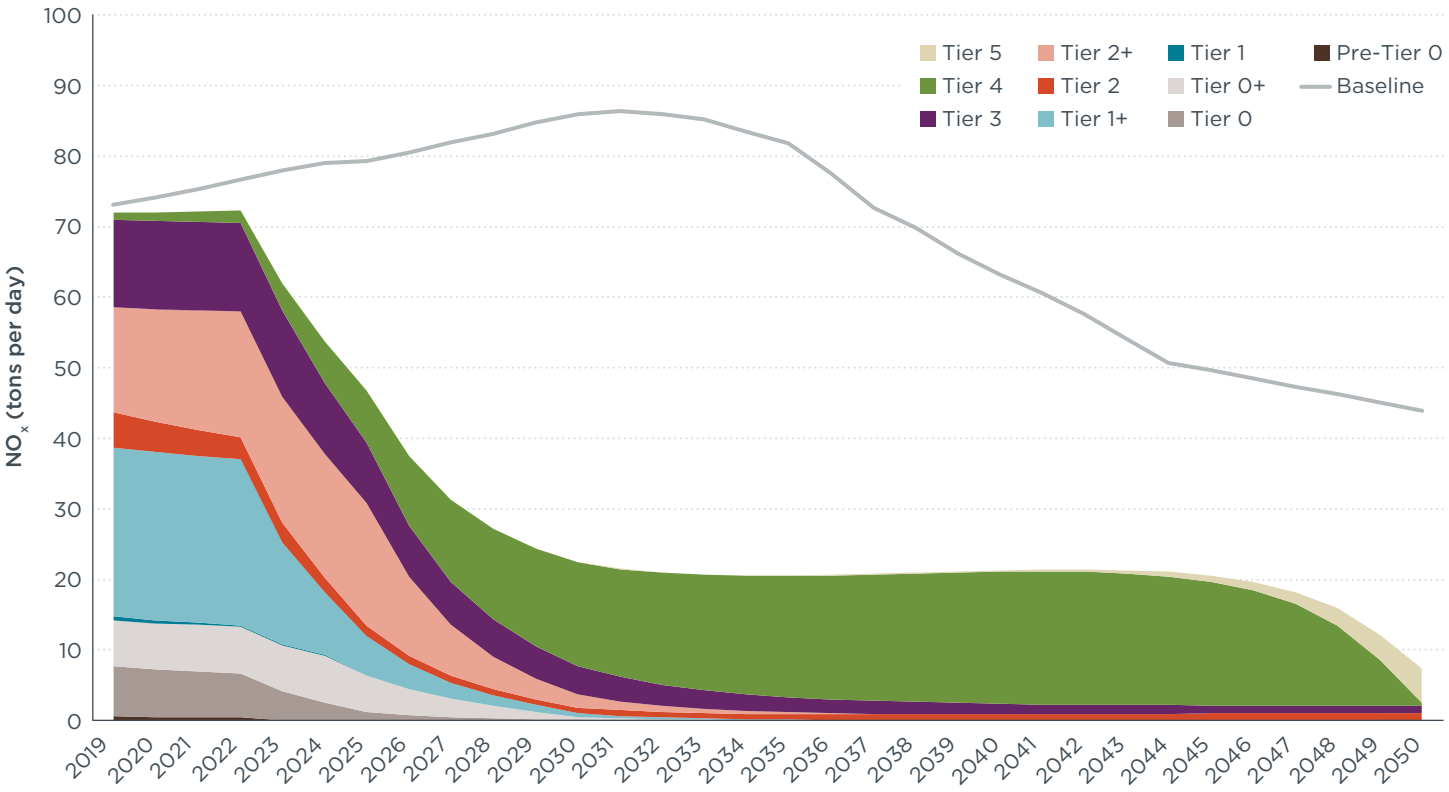


**Figure 16.** Effect of accelerated turnover of older locomotives.
*Source:* California Air Resources Board (2021d)

# 7. DIESEL FUEL

## 7.1. SPECIFICATIONS AND ALTERNATIVES

Background. CARB established specifications for diesel fuel for on-road trucks beginning in 1993. Sulfur content was set at 500 ppm, and aromatic content was reduced from 30% to 10%. The 500 ppm sulfur limit reduced sulfur dioxide emissions by more than 80%. The lowered aromatic limit cut $NO_x$ by 7% and PM from engines not equipped with filters by 25% (California Air Resources Board, 2003a). The emissions of the toxic compounds benzene and polynuclear aromatic hydrocarbons also declined. CARB allows the use of alternative diesel fuel formulations that have been demonstrated to be as effective at reducing emissions as the 10% aromatic specification, and most producers have used that option.

Following adoption of the Diesel Risk Reduction Plan in 2000, CARB further lowered the sulfur standard to 15 ppm effective in 2006 to allow for effective operation and regeneration of diesel filters that were necessary to meet the PM standard for new 2007-model diesel engines. The agency also included a lubricity specification. Sulfur emissions declined by an additional 90%, and PM emissions by 4% more (California Air Resources Board, 2003b). The required use of CARB diesel fuel was expanded to include off-road equipment, locomotives, harbor craft, and stationary engines, many of which had not been using CARB diesel fuel. The specifications for CARB diesel fuel are shown in Table 7:

**Table 7.** CARB diesel fuel specifications

| Specification | Value | ASTM test method |
|---|---|---|
| **Sulfur content** | 15 ppm | D5453-93 |
| **Aromatic hydrocarbon content** | 10% volume | D5186-03 |
| **API gravity** | 39.6° minimum | D287-82 |
| **Lubricity** | 520 microns | D6079-02 |

*Note:* Additional details and the requirements for alternative formulations, which most refiners use, can be found at California Air Resources Board, "CARB Diesel Fuel Specifications and Test Methods," (revisied March 4, 2014), https://ww2.arb.ca.gov/sites/default/files/2020-03/dieselspecs.pdf.

The EPA also adopted a 15 ppm sulfur limit nationwide effective in 2006 but did not implement the other CARB specifications. The absolute $NO_x$ emissions benefit of CARB low aromatic diesel fuel compared with EPA-specification diesel fuel will decrease as trucks and equipment that rely on highly effective aftertreatment for $NO_x$ control continue to enter the fleet (Hajbabaei, Johnson, Guthrie, & Durbin, (2012). The aromatic standard will continue to provide $NO_x$ benefits from diesel equipment that does not use aftertreatment such as locomotives and harbor craft.

Natural gas-fueled engines have become a popular alternative to diesel engines, particularly in transit buses and urban delivery vehicles. Natural gas engines offer lower PM emissions than pre-2007 heavy-duty engines that do not use a particulate filter and lower $NO_x$ emissions than current diesel heavy-duty engines. CARB established fuel specifications for compressed natural gas used in vehicles as shown in Table 8. The global standards organization ASTM International is establishing natural gas specifications that may replace CARB standards.

**Table 8.** CARB compressed natural gas specifications for vehicles

| Specification | Value, mole % | Test method |
|---|---|---|
| **Methane** | 88% minimum | ASTM D 1945-81 |
| **Ethane** | 6.0% maximum | ASTM D 1945-81 |
| **C3 and higher** | 3.0% maximum | ASTM D 1945-81 |
| **C6 and higher** | 0.2% maximum | ASTM D 1945-81 |
| **Hydrogen** | 0.1% maximum | ASTM D 2650-88 |
| **Carbon monoxide** | 0.1% maximum | ASTM D 2650-88 |
| **Oxygen** | 1.0% maximum | ASTM D 1945-81 |
| **Sum of $CO_2$ and $N_2$** | 1.5%–4.5% range | ASTM D 1945-81 |
| **Sulfur** | 16 ppm by volume maximum | Title 17 CCR Section 94112 |

*Note:* Complete specification can be found at: § 2292.5. Specifications for Compressed Natural Gas, (CARB, 5, article 3), https://www.arb.ca.gov/regs/title13old/2292.5.pdf.

**Status and future.** The diesel specification has not changed since 2006, and there is no current plan to revise it.

## 7.2. CALIFORNIA LOW-CARBON FUEL STANDARD

CARB adopted the low-carbon fuel standard (LCFS) in 2009. Its goal is to reduce the carbon intensity (CI) of the pool of transportation fuel sold in California by 20% by 2030. CI is a measure of the amount of GHG resulting from the production, distribution, and consumption of a fuel, including the indirect effect of land use change for crop-based biofuels.

A fuel producer or distributor generates deficits or credits based on its transportation fuel's CI. Fuels such as gasoline and diesel have CIs greater than the standard and generate deficits. For 2022 the standard requires a 10% reduction from the CI of petroleum fuels. The percentage of reduction increases annually through 2030 as show in Figure 17, with a 6.25% reduction in carbon intensity relative to 2010 in the 2019 and then increasing linearly to a 20% reduction in 2030 (California Air Resources Board, n.d. a).

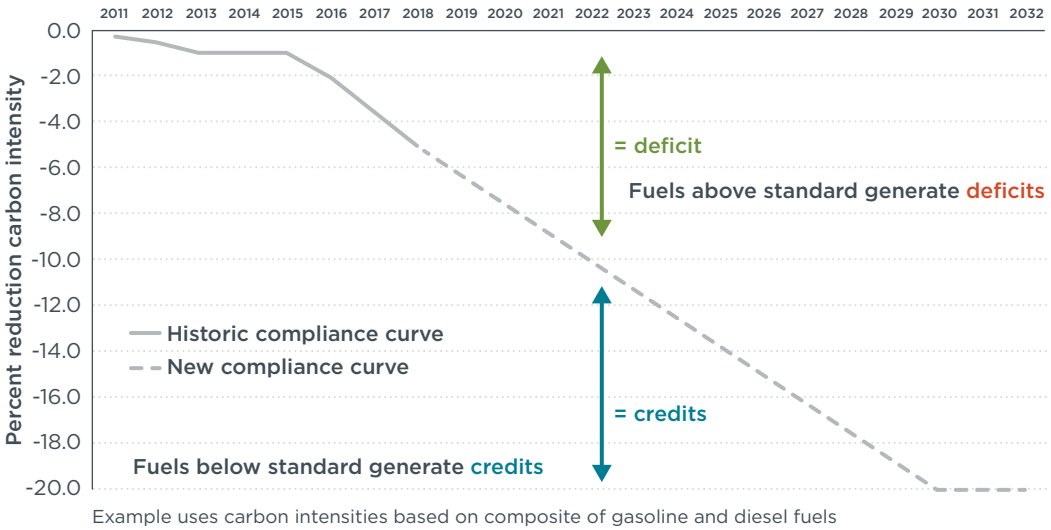


**Figure 17.** Declining carbon intensity requirement for transportation fuels.
*Source:* California Air Resources Board (n.d.a)

A producer or distributor of transportation fuels that has generated deficits—with a CI lower than the standard—must obtain credits to offset the deficit. For example, the fuel producer could earn credits by distributing lower-CI fuels or by purchasing credits from producers or users of transportation fuel whose CI is below the standard, such as electricity used for zero-emission vehicle charging. The credit can be claimed at the fuel distribution point, which could be the fueling infrastructure owned by a fleet. It could also be reflected as a lower fuel price by the distributor at a public vehicle fast charger or hydrogen dispensing station.

Lower-CI fuel producers have generated about $3 billion in revenue under to the LCFS. The LCFS allows unused credits to be banked, and between 2011 and 2019 a reserve of credits has built up. In 2020 the credits generated by low-CI fuels roughly equaled the demand of producers with deficits. The top producers of low-CI fuel credits, in order, are bio/renewable diesel, ethanol, electricity, and biomethane.

**Status and future.** The current value of the LCFS credit to truck operators can be seen by comparing the credit's value with diesel fuel cost. For example, at the current credit price of just below $200 per metric ton, which has been stable for the past two years, a gallon of low-CI renewable diesel generates $1.69 in credit value, making it $0.25 cheaper to market than conventional diesel fuel in California (U.S. Department of Energy, 2021). As a result of the LCFS, bio/renewable diesel has captured 24% of the California market. Electricity provided to an electric truck has a credit value of $0.17/kilowatt-hour, which could offset the typical off-peak price of electricity in California, depending on location (California Air Resources Board, 2021a). Thus, a fleet user of electric trucks could have near-zero to zero fuel cost. Similar LCFSs have been adopted in Oregon, Washington, and British Columbia.

For more detail, the reader can download **LCFS Basics** and the complete regulation (California Air Resources Board, n.d. a; California Air Resources Board, 2020g).

## 8. GREENHOUSE GAS EMISSION REDUCTION

**Background.** Around the turn of the century, growing concern about the impacts of climate change on the health and welfare of California residents resulted in legislation directing CARB and other agencies to take actions to reduce climate emissions. In 2002, the legislature voted for CARB to adopt GHG standards for new passenger vehicles, which it did in 2004. Passenger vehicles are the largest source of GHG emissions in the state.

In 2006 the legislature passed the Global Warming Solutions Act (AB32), establishing a comprehensive planning process to address climate change and requiring statewide GHG emissions to return to 1990 levels by 2020, a 15% reduction. The legislation ordered CARB to adopt regulations that achieved the maximum technologically feasible and cost-effective reduction in GHG emissions. AB32 also directed CARB to adopt a market-based program establishing annual aggregate declining emission limits for sources or categories of sources that emit GHGs, such as motor vehicle fuel production. Other bills and executive orders added specific deadlines for addressing climate goals, such as an executive order that all heavy-duty vehicles and equipment be zero emissions by 2045 where feasible.

The 2018 inventory of California GHG emissions, shown in Figure 18, illustrates that heavy-duty trucks are the second-largest source of transportation GHG emissions (California Air Resources Board, 2020b). CARB and the EPA recognized the need to reduce heavy-duty truck GHG emissions in the first decade of this century and began developing regulations to cut them.

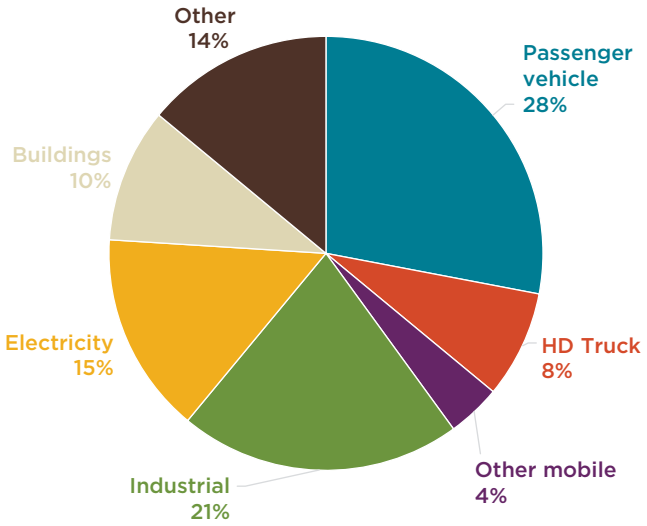


**Figure 18.** California 2018 GHG inventory by sector.
*Source:* California Air Resources Board (2020b)

**Status.** CARB and the EPA worked together to adopt nationally uniform $CO_2$ emission standards for new on-road heavy-duty engines and trucks in two phases, beginning with the 2014 model year and fully implemented by the 2027 model year.[27] In the

27 Standards for other GHGs such as methane and nitrous oxide were also established, mainly to prevent any future increases as technology changes. A standard limiting leakage of air conditioning refrigerant (HFC 134A) was also established, but no requirement was adopted to limit the global warming potential of the refrigerant, as was done with passenger cars.

second phase, the EPA also adopted $CO_2$ emission standards for trailers. CARB adopted both phases of the EPA standards to allow the state to enforce them in California and to ensure it will have a role in any future EPA revisions.

**Diesel engine $CO_2$ standards.** The $CO_2$ standards for new diesel trucks apply separately to the engine and the entire vehicle. The engine standards are based on technologies that improve the efficiency of the diesel engine. These standards, shown in Table 9, vary by the weight of the truck in which the engine is used. The standard is work-based, and emissions are measured using the transient and steady-state (SET) dynamometer engine test for vocational trucks and only the SET for tractor engines. These are the same test procedures used to measure $NO_x$ and other pollutants.

**Table 9.** Diesel engine $CO_2$ emission standards (g $CO_2$/bhp-hour)

| Engine model year | Vocational trucks | | | Tractors |
|---|---|---|---|---|
| | LHD Class 2b-5 | MHD Class 6-7 | HHD Class 8 | HHD Class 8 |
| **2014** | 600 | 600 | 567 | 475 |
| **2017** | 576 | 576 | 555 | 460 |
| **2021** | 563 | 545 | 513 | 447 |
| **2024** | 555 | 538 | 506 | 436 |
| **2027** | 552 | 535 | 503 | 432 |

The percentage reduction of diesel engine emissions by 2027 from 2014 ranges from 8% to 11%, illustrating the limits on improving $CO_2$ and the efficiency already achieved by diesel engines.

**Diesel truck $CO_2$ standards.** The $CO_2$ standards for new diesel trucks are based on drivetrain efficiency improvements, reduction in aerodynamic drag, lower tire rolling resistance, truck weight reduction, and other factors affecting $CO_2$ emissions. The requirements are not based on anticipated use of electric or hybrid electric trucks, which at the time of adoption was uncertain.

Because there are too many truck variations to require whole-vehicle testing, truck $CO_2$ emissions are determined using a computer program known as GEM, for greenhouse gas emissions model. The most recent version of GEM accepts inputs such as a manufacturer's engine fuel map, transmission characteristics, technologies used such as idle reduction and tire pressure systems, aerodynamic drag and tire rolling resistance, and other truck characteristics such as weight and gearing. GEM then calculates the expected $CO_2$ emissions for three pre-defined drive cycles: The CARB HHDDT cycle, the 55 and 65 miles per hour cruise cycles, and for vocational trucks, emissions while parked idling and idling in traffic. The results are weighted for the different cycles and compared with the $CO_2$ standard to determine compliance. One disadvantage of this approach is that enforcement is limited to finding discrepancies with the manufacturer-supplied inputs to the model, since there is no actual $CO_2$ compliance test to compare with in-use $CO_2$ measurements.

Truck $CO_2$ standards vary by truck type, truck use, and for tractors, the cab height. Shown in Table 10 are the $CO_2$ standards for vocational trucks. The full set of standards,

including lighter trucks and heavier tractors, and a description of the GEM model, can be found in the reference.[28]

**Table 10.** Diesel vocational truck $CO_2$ emission standards ($gCO_2$/ton-mile)

| Model year | Vocational truck category and type of truck use (2021+) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LHD Class 2b-5 | | | MHD Class 6-7 | | | HHD Class 8 | | |
| **2014** | 388 | | | 234 | | | 226 | | |
| **2017** | 373 | | | 225 | | | 222 | | |
| | **Urban** | **Multi-** | **Regional** | **Urban** | **Multi-** | **Regional** | **Urban** | **Multi-** | **Regional** |
| **2021** | 424 | 373 | 311 | 296 | 265 | 234 | 308 | 261 | 205 |
| **2024** | 385 | 344 | 296 | 271 | 246 | 221 | 283 | 242 | 194 |
| **2027** | 367 | 330 | 291 | 258 | 235 | 218 | 269 | 230 | 189 |

**Trailers.** CARB adopted a regulation effective in 2010 that requires most in-use box trailers 53-feet long and longer be equipped or retrofitted with aerodynamic devices that reduce fuel consumption by at least 5% (typically side skirts). The regulation requires trailers and the tractors that pull them to use low rolling resistance tires. These requirements apply to most long box trailers that operate on California's roads. While enforcement has been minimal, observation indicates most trailers are now equipped with side skirts or other aerodynamic drag-reducing devices.

Subsequently, the EPA adopted a rule requiring 2018 and newer model box trailers of various lengths sold nationally to meet a $CO_2$ g/ton-mile standard. The limits become more stringent with time. Compliance with a $CO_2$ standard for box trailers is based on the GEM model, using as inputs a standard tractor pulling the trailer with inputs for various trailer $CO_2$ reducing technologies such as side skirts, low rolling resistance tires, rear door fairings, and tire pressure monitoring or automatic inflation systems. The performance standards for new box trailers are shown in Table 11 (California Air Resources Board, 2017).

**Table 11.** $CO_2$ standards for box trailers

| Model year | Full-aero dry trailers | | Partial-aero dry trailers | |
|---|---|---|---|---|
| | **Short, ≤ 50 feet** | **Long, > 50 feet** | **Short** | **Long** |
| **2018-2020** | 125.4 | 81.3 | 125.4 | 81.3 |
| **2021-2023** | 123.7 | 78.9 | 123.7 | 80.6 |
| **2024-2026** | 120.9 | 77.2 | 123.7 | 80.6 |
| **2027+** | 118.8 | 75.7 | 123.7 | 80.6 |

Partial-aero trailers are those that have a working device or protrusion that restricts the use of side or rear fairings such as lift gates or belly boxes. Refrigerated trailers have slightly higher numerical standards than shown in the table because the refrigeration unit on the front of the trailer restricts the use of aerodynamic devices. Other types of trailers such as tankers or container carriers are subject to design standards requiring the use of low rolling resistance tires and tire pressure monitors or automatic inflation systems.

28 A full description of all the $CO_2$ standards for Phase I can be found at: https://ww2.arb.ca.gov/sites/default/files/classic/regact/2013/hdghg2013/hdghg2013isor.pdf, and for Phase II at: https://ww2.arb.ca.gov/sites/default/files/classic/regact/2018/phase2/isor.pdf. Note that the units in Table II-12 of this reference are in error and should be g/bhp-hr.

CARB has aligned its regulation with that of the EPA but retains the requirement that all trailers using California's roads—not just new trailers—use specified $CO_2$ reducing devices.

**Emission reductions.** Table 12 shows the emission reductions and cost of compliance per vehicle or trailer in percent for Phase 2 compared with Phase 1 (U.S. Environmental Protectional Agency, 2016).

**Table 12.** Emission reduction and cost per vehicle of EPA Phase 2 GHG regulation

| GHG reduction | GHG reduction and vehicle price increase, % | | |
|---|---|---|---|
| | MY 2021 | MY 2024 | MY 2027 |
| **Tractors** | 13 | 20 | 25 |
| **Trailers** | 5 | 7 | 9 |
| **Vocational trucks** | 12 | 20 | 24 |
| **Pickups and vans** | 2.5 | 10 | 13 |
| **Price Increase** | | | |
| **Tractors** | 6 | 10 | 12 |
| **Trailers** | 3 | 4 | 4 |
| **Vocational trucks** | 1 | 2 | 3 |
| **Pickups and vans** | 1 | 2 | 3 |

CARB calculated the expected $CO_2$ emission reductions in California for both phases of the regulations combined, including all affected vehicle and trailer types, compared with a no-regulation baseline. The $CO_2$ reduction in 2030 in California would be 23%, and in 2050 34% (California Air Resources Board, 2017a). Figure 19 shows that the impacts of Phase 1 and Phase 2 regualtons on GHG emissions from targeted vehicles, indicating that Phase 2 is much needed to reduce $CO_2$ emissions while keep the vehicle miles traveled (VMT) growth in California.

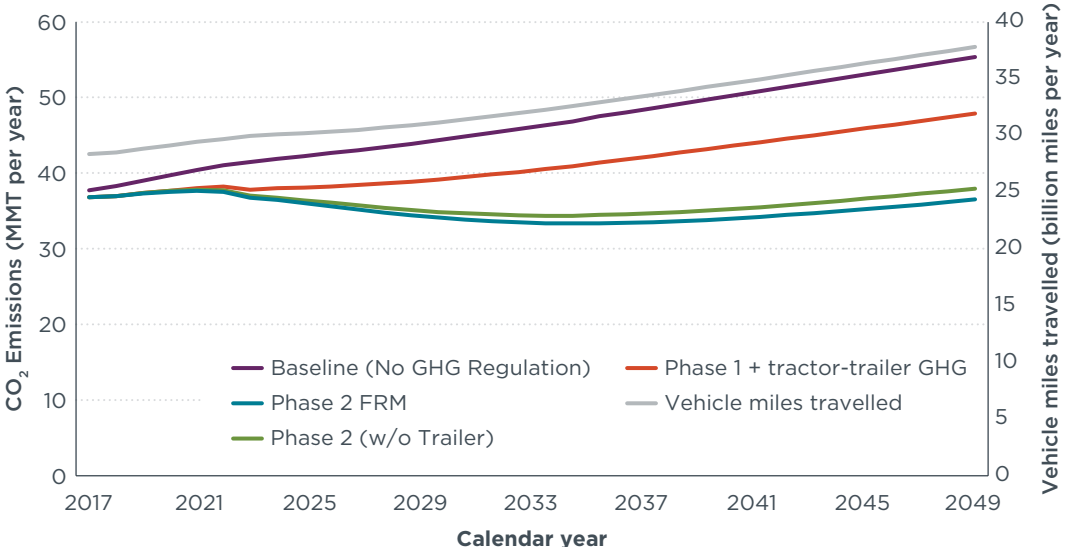


**Figure 19.** California on-road $CO_2$ emissions from truck and trailer-regulated vehicles.
*Source:* California Air Resources Board (2017a)

**Future.** While the emission reductions are significant, they are largely offset by projected increases in truck VMT as the economy grows. In 2050, $CO_2$ emissions would be about the same as they were in 2017. This is because diesel engines are already quite efficient, and further opportunities to improve engine efficiency are limited. Likewise, further improvements to the aerodynamics of box-shaped trucks are relatively small as are gains in tire rolling resistance.

The National Academies of Sciences confirms this finding in a 2017 report reflecting its assessment of technologies and approaches to reducing fuel consumption and GHG emissions from medium-and heavy-duty vehicles beyond the reductions expected from the Phase 2 emission standards. The assessment concludes that $CO_2$ emissions from some diesel engines may be reduced beyond levels required to meet the 2027 EPA standards (National Academies of Sciences, Engineering, and Medicine, 2020).

However, neither the current standards nor their tightening provide large enough GHG emission reductions to begin lowering diesel truck emissions anywhere near zero. This points to the need for more aggressive actions, specifically a transition to zero-emission trucks, as discussed in the next section.

# 9. ZERO-EMISSION PROGRAM

**Background.** California has positioned itself as a world leader in addressing climate change. As part of this commitment, Gov. Newsom issued an executive order in September 2020 (State of California, 2020) directing CARB to take the following actions related to diesel vehicles and equipment:

- Develop and propose medium- and heavy-duty vehicle regulations requiring increasing volumes of new zero-emission trucks and buses sold and operated in the state toward the target of 100% of the fleet transitioning to zero-emission vehicles by 2045 everywhere feasible and for all drayage trucks to be zero-emission by 2035.
- Develop and propose strategies in coordination with other state agencies, the EPA, and local air districts to achieve 100% zero emissions from off-road vehicles and equipment operated in the state by 2035.
- CARB, the Energy Commission, the Public Utilities Commission and other relevant state agencies are to use existing authority to accelerate deployment of affordable fueling and charging options for ZEVs in ways that serve all communities and in particular low-income and disadvantaged communities, consistent with state and federal law.

Consequently, CARB initiated two regulations that start on-road trucks on a path to zero emissions. The number of zero-emission trucks in all weight classes is growing. More than 100 models are available for sale in North America, and there is the expectation of a lower total cost of operation compared with diesel, which supports the practical and economic feasibility of zero-emission trucks.

## 9.1. INCREASING THE SALE AND USE OF NEW ZERO-EMISSION MEDIUM- AND HEAVY-DUTY TRUCKS

**Status and future.** Accelerating the transition of diesel trucks to zero emissions is necessary to provide the $NO_x$ and $PM_{2.5}$ emission reductions needed to attain ambient air quality standards in greater Los Angeles by the mid-2030s. The transition to zero-emission trucks is also essential to meeting the economywide net-zero carbon goal established by the governor because medium- and heavy-duty trucks account for a significant 8% of all GHG emissions in California. CARB plans two new regulations that will help achieve the transition of diesel trucks to zero emissions.

In June 2020, CARB adopted the first rule, the Advanced Clean Trucks regulation. It requires each heavy-duty diesel truck manufacturer doing business in California in 2024 to begin selling new zero-emission trucks of 8,501 pounds GVWR and greater, assuring a wide range of available truck models.[29] The regulation applies to trucks sold and registered in California, which typically means trucks used in urban areas with relatively short mileage averaging 100 miles a day. In the U.S., long-haul interstate trucks are typically registered under an international registration plan rather than state by state and are not subject to this regulation.

29 The original staff proposal was revised at a hearing of the board to increase the required percentage of ZEV trucks to be sold. The revisions made by the board can be found at https://ww3.arb.ca.gov/regact/2019/act2019/30dayattb.pdf. The original proposal, which contains many of the other details of this regulation, can be found at https://ww3.arb.ca.gov/regact/2019/act2019/isor.pdf.

Figure 20 shows the increasing percentage of new heavy-duty truck sales in California that will be required to be zero-emission, by weight class.[30] Classes 2b and 3 include large pickups and vans, and classes 4–8 include delivery trucks, large box trucks, buses, and dump trucks, as examples. The sales-weighted requirement in 2035 will be 58%.

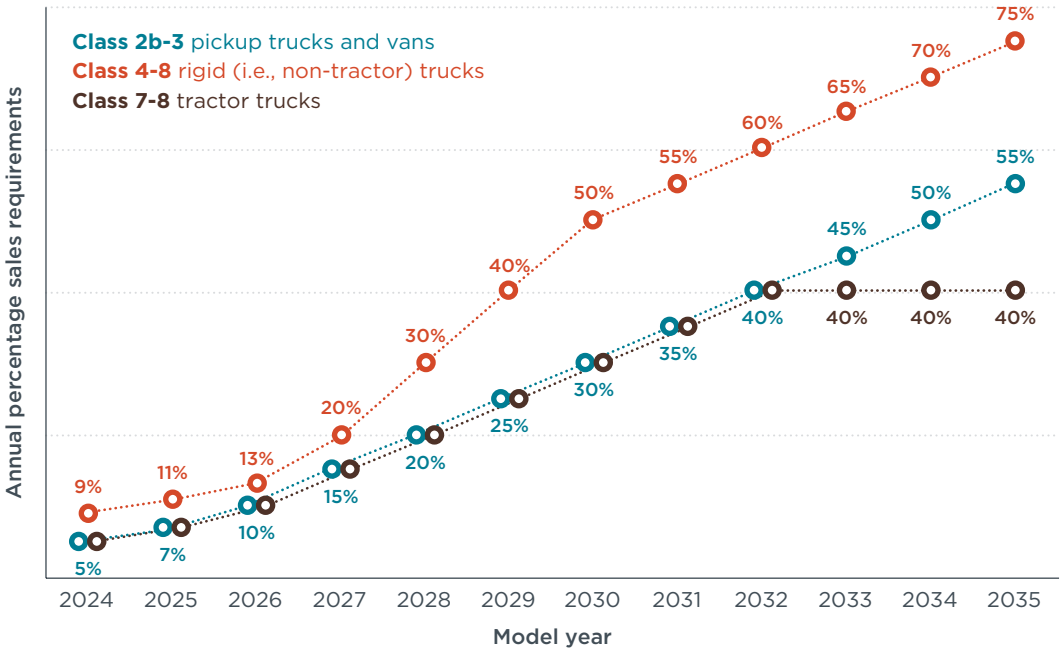


**Figure 20.** Required sales of zero-emission trucks under Advanced Clean Trucks regulation. *Source*: Buysse & Sharpe (2020)

To ensure there are enough purchasers for zero-emission trucks, CARB is developing a second regulation requiring public fleets, high priority fleets, federal fleets and drayage fleets to purchase specified numbers of trucks.[31] This demand-side regulation is expected to be considered for adoption by the board in mid-2022.[32]

CARB's analysis indicates that before the end of this decade the total cost of ownership of most zero-emission trucks will be lower than that of diesel trucks as the price of zero-emission vehicles declines (California Air Resources Board, 2019). Independent studies have confirmed the finding (ICF, 2019). The main reason for the declining ZEV cost of ownership is that the cost of electricity is much lower than cost of diesel fuel. Fuel savings can thus offset the higher capital cost of new trucks over time. The LCFS credit for electricity used as a transportation fuel further reduces the cost of ownership (see Section 7.2). An example of fuel savings that may not offset the higher cost of a new ZEV is school buses, which accumulate low annual mileage and fuel use and are not part of this proposed regulation. The state is funding the transition

30 The truck class definitions in pounds GVWR are: 2b/3: 8,501–14,000; 4–8: 14,001 and up; 7–8 tractors: 26,001 and up.

31 Public fleets refer to all California publicly-owned fleets regardless of size, excluding federal fleets; High priority fleets refer to fleets with more than 50 vehicles or more than $50 million in revenue; Drayage trucks refer to any drayage trucks added to the state registry starting in late 2023, regardless of fleet size.

32 The rule is still under development. To track progress, see https://ww2.arb.ca.gov/our-work/programs/advanced-clean-fleets/advanced-clean-fleets-meetings-events

of older school buses to zero-emissions to protect children from being exposed to diesel emissions.

The reason for CARB to consider both a supply-side and a demand-side regulation stems from several factors. One is that the break-even point where the total cost of ownership of a new zero-emission heavy duty truck is less than that of a diesel truck is not expected until after 2030. Thus, without the regulation, the ramp-up of sales of zero-emission trucks may fall short of the production requirements imposed on truck manufacturers. Waiting for production and sales to balance naturally is not an option because reductions of $CO_2$ emissions are needed now, and the expected price decline of new zero-emission trucks will occur only if sales volumes increase. The demand-side regulation helps ensure market growth.

There are mitigating factors to reduce the cost to fleet operators while accelerating sales of zero-emission trucks. Besides the much lower cost of electricity, financing a new truck purchase spreads the capital cost over multiple years, and in many cases the lower fuel operating cost will offset higher monthly loan payments. California electric utilities are covering the cost of installing electric infrastructure up to the actual charger—such as transformers, conduit, and cables—reducing truck owners' outlays. CARB is providing purchase incentives to encourage early adopters and small businesses, as discussed in the following section.

CARB is developing several fleet-specific regulations that require a faster transition to ZEVs than required by the Advanced Clean Trucks regulation. The agency adopted a clean transit regulation requiring transit districts to begin buying zero-emission buses in 2023 and to purchase only zero-emission buses from 2029 on (California Air Resources Board, 2019a). These can be battery or fuel-cell powered.

Airport shuttles, including diesel buses, are also required by regulation to replace their entire fleets with ZEVs by 2035. The other fleet-specific zero-emission regulations under development are listed in Table 13.

**Table 13.** Zero-emission truck and bus purchase requirements for specific fleets

| Fleet Type | Rule adopted or planned | 100% ZE new purchase or 100% fleet requirement |
|---|---|---|
| **Transit** | Adopted 2018 | 2029 new |
| **Airport shuttles** | Adopted 2019 | 2035 entire fleet |
| **Drayage** | Planned 2022 | 2023 new, entire fleet 2035 |
| **Publicly owned fleets** | Planned 2022 | 2027 new, entire fleet 2035 |
| **Box trucks; yard trucks** | Planned 2022 | Entire fleet 50% 2031, 100% 2035 |
| **Work trucks; day cabs** | Planned 2022 | Entire fleet 50% 2033, 100% 2039 |
| **Sleeper cabs** | Planned 2022 | Entire fleet 50% 2036, 100% 2042 |

*Note:* For all the planned fleet rules, the compliance dates are staff suggestions. Staff is also suggesting some interim requirements that are not listed. The requirements would apply only to vehicles purchased in California, and the caveat "where feasible" has been used to acknowledge that there may be applications where ZEVs are not available or viable. The rules may apply to all vehicles in the fleet, not just diesels.

## 9.2. INCREASING THE SALE AND USE OF NEW ZERO-EMISSION OFF-ROAD VEHICLES AND EQUIPMENT

The governor directed CARB to work with local governments and the EPA to develop strategies to achieve a full turnover of diesel off-road equipment in California to zero-emissions by 2035. A comprehensive strategy is at an early stage of development by CARB staff, although strategies requiring zero-emission transportation refrigeration units (TRUs) used on straight trucks, forklifts, and cargo handling equipment are further along. Zero-emission propulsion for other sectors such as harbor craft is being evaluated. It is important for government to support the introduction of zero-emission off-road equipment where possible now to help stimulate early market development. For example, local governments may create demand by requiring use of zero-emission equipment in construction projects they fund.

## 9.3. REFUELING INFRASTRUCTURE FOR ZERO-EMISSION ON-ROAD TRUCKS

California has led the way in establishing plug-in electric charging stations for passenger vehicles. Most charging is done at home, but a growing number of fast-charge stations are being installed to support electric vehicle owners who live in multi-family buildings where garage charging is not available and to support recharging for high-use vehicles such as taxis or for inter-city trips. Most of the fast-charge stations have been installed by private companies. However, the growing number of plug-in electric vehicles is outpacing the availability of fast-charging stations, and state incentive funds are being made available to help match demand.

For heavy-duty trucks used in urban areas, charging at night where trucks are parked will be common. Larger battery sizes and multiple trucks needing overnight charging in one spot can result in the need for substantial infrastructure investment. California's three investor-owned utilities have committed more than $700 million to provide electric infrastructure upstream of the meter, such as transformers and conduit, to stimulate the initial growth of the electric truck market. As this market expands, installation of public fast chargers for trucks will be needed for trucks used extensively during the day and to allow regional use of trucks where a return to the home base for overnight recharging is not possible. By 2030, 157,000 chargers are needed to support the 180,000 medium- and heavy-duty zero-emission trucks projected (California Energy Commission, n.d.). The state has established a planning and support group involving 29 state agencies and departments to ensure that the charging infrastructure meets the growing demand for ZEVs of all sizes. One challenge is coordinating the installation of charging stations at truck fleet facilities with the planned purchase and delivery of new zero-emission trucks. Currently, charging infrastructure installation at a multi-truck fleet facility can take more than a year because of planning and permitting—a delay that needs to be reduced.

## 10. INCENTIVE PROGRAMS

**Background.** Since the 1990s, CARB has used financial incentives to help encourage the demonstration and early commercial introduction of cleaner vehicles and equipment. Research and early development of more-effective engines and emission controls have been left primarily to the private sector and the federal government. Funds for incentives are usually generated from fees associated with vehicles rather than the state's general fund.

The first funding program, named the Carl Moyer Program in honor of the late Dr. Carl Moyer for his contribution in developing creative solutions to California's ari quality challenges, began in 1998. It focused on achieving lower $NO_x$ and PM emissions to attain ambient air quality standards by subsidizing the purchase of vehicles that were cleaner than required by regulations, such as natural gas-fueled heavy-duty vehicles. It continues to provide about $90 million in subsidies per year and is implemented through local air pollution control districts.

In 2009 a new fund called the Air Quality Improvement Program was authorized and funded at $25 million to $30 million a year. The fund has a broader goal of reducing climate emissions as well as $NO_x$ and PM by improving access to the cleanest technologies. Recently it funded a truck loan program for owners of small fleets who are unable to qualify for traditional financing for the purchase of cleaner trucks.

A one-time opportunity to fund the purchase of cleaner trucks occurred as a result of CARB's settlement with VW for equipping diesel cars and SUVs with devices that illegally increased $NO_x$ emissions. To offset the air-quality damage caused by its cars, VW paid more than $400 million to reduce $NO_x$ emissions in California by replacing older heavy-duty trucks, buses, and equipment with cleaner models. Other enforcement settlements have also provided funds to support clean technologies. VW agreed to install new electric charging infrastructure at a cost of $800 million. Funds from penalties paid to California are deposited in a fund that can be used only to improve air quality. The expenditure of these funds must be approved by the legislature.

As authorized by AB32, the Global Warming Solutions Act of 2006, CARB adopted a cap-and-trade program that requires major emitters of GHGs to lower emissions each year or provide offsets or purchase emission-reduction credits from the state. A portion of the revenue from the purchase of state credits was provided by the legislature to CARB to implement a Low Carbon Transportation Program.[33] Of the nearly $500 million made available annually in recent years, the majority is used to provide purchase incentives for new zero-emission cars and zero- and near-zero emission trucks. The portion of the funds for heavy-duty trucks and off-road equipment is typically about $200 million annually, with the majority going to provide purchase incentives for zero-emission trucks under the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP). About half of the funds are spent in areas that benefit low-income residents. In 2020, the HVIP provided incentives to buyers of 1,200 medium- and heavy-duty zero-emission trucks.

33 As an example, the funding plan for FY2019/20 can be found at: https://ww2.arb.ca.gov/sites/default/files/2019-09/fy1920fundingplan.pdf.

The entire incentive portfolio including several other funds and how the funds are used is shown in Figure 21.[34]

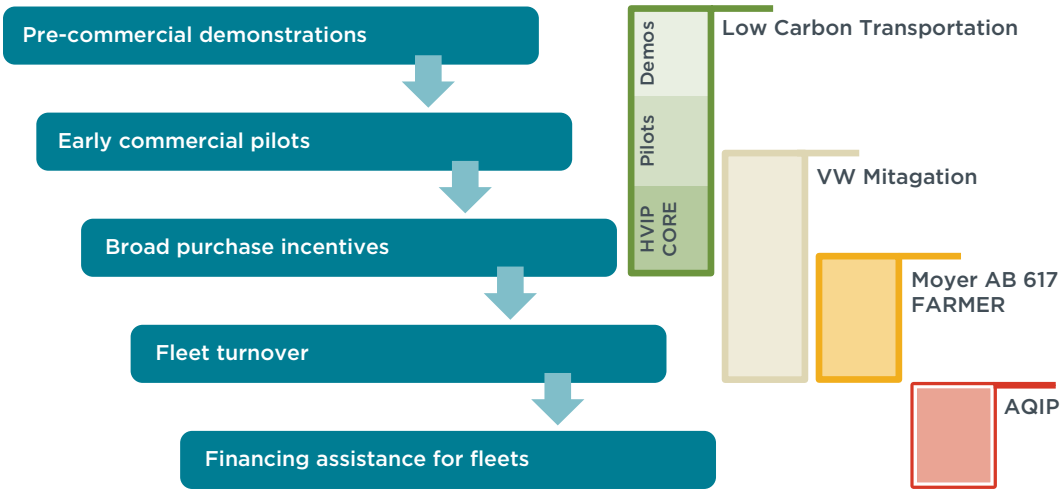


**Figure 21.** CARB's incentive portfolio and its use

**Status and future.** Most of the incentive programs are funded by fees. The cap-and-trade program is authorized through 2030. The exceptions are the VW and other enforcement settlement funds that occur sporadically. Depending of the air quality damage that occurred from the violation and the pollutants affected, funds may or may not be directed to support diesel reduction programs.

These funding programs have been and continue to be important in stimulating the early adoption of new technologies, especially zero-emission trucks that have a high initial cost at the early stage of commercialization. However, as sales of these trucks increase, government funds will at some point become insufficient to continue providing purchase incentives. At this point it is expected that further development and higher production volumes will bring zero-emission truck prices closer to or below the prices of conventional trucks, and with lower operating costs the total cost of ownership of zero-emission trucks will be less than for diesel trucks.

34 Programs shown in the chart that are not specifically discussed in the text are the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) which provides purchase incentives, FARMER (grants to purchase cleaner farming equipment) and AB617 (grants to support development of plans to reduce emissions in disadvantaged communities).

# 11. CONCLUSIONS

California began to adopt programs to reduce diesel emissions in 1974, and the effort will not be complete until 2040 at the earliest. Understanding the mass of emissions and their impact on public health took decades of research. The technologies to reduce emissions had to be invented and proven effective, requiring additional time. As more-advanced emission control technologies have to be integrated with engine design, retrofit of existing engines with emission controls is difficult. Thus, it is taking several decades for high-emitting diesels to be replaced with cleaner ones. The exception is that cleaner diesel fuel immediately reduces emissions from all diesel engines, old or new, on-and off-road.

For governments that have begun more recently or are just starting to develop diesel emission control programs, the path to eliminating the adverse health effects of diesel emissions can be shorter because many of the steps California, the EPA, and the European Union have already taken can be skipped, and programs can focus on requiring use of the most advanced technologies.

Based on CARB's experience reducing diesel and other mobile sources of emissions, the following lessons were learned and are relevant to current and future emission control efforts.

**An effective emission control program requires clear legal authority.** A single implementing agency needs to be empowered to take actions to achieve a goal. The goal must be clearly stated, such as meeting health-based air quality standards, and reduce climate emissions by a specified percentage or the maximum amount feasible. Goals must include dates by which they must be achieved. Other agencies will need to be involved, but it needs to be clear that the same goals apply to their actions and that they must work with the lead agency.

**Legal authority to enforce regulations and impose fines is necessary.** A regulation or requirement that is not enforced will not be an effective or fair regulation. Those that expend resources to comply need to know that those that don't will face strong penalties. Those that comply become a good source of noncompliance information. CARB's unwritten rule is that if a regulated party violates a rule, a monetary fine will be part of the settlement. The amount of the penalty needs to be enough to deter others that fail to comply. This is important because it is unlikely that an agency will have sufficient resources to determine the compliance status of all sources. The deterrent effect of noncompliance settlements is more effective if penalties and settlements are made public, which CARB does for every settlement.

**A skilled staff with the resources to independently develop data is essential.** Successful development of regulations and requirements to reduce emissions is usually an adversarial process. It requires an exchange of information between agency staff and businesses and other stakeholders that may be affected, particularly on critical issues such as technology feasibility and cost. For example, CARB has found that regulated industries sometimes fail to disclose the latest information on technologies or their cost. Agency staff needs the skills to independently make these assessments and the laboratory equipment to test the emission performance of vehicles and the latest technologies. Having the capability to test in-use vehicle emissions is also critical to effective enforcement. Independently generated emissions data has proven to be CARB's most powerful tool in developing successful emissions control programs.

**Technology-forcing emission standards for new vehicles are effective.** Technology-forcing regulation challenges engine and vehicle manufacturers and developers of emission control technologies to invent and demonstrate the feasibility of the most effective systems. Such requirements also establish the necessary lead time to commercialize new technologies. For example, CARB staff worked with Southwest Research Institute to assess, develop, and test engine and emission control systems that reduce heavy-duty diesel engine $NO_x$ emissions by 90%. This study became the technology assessment that justified the 2020 CARB adoption of the 0.02 g/bhp-hour $NO_x$ standard for the 2027 model year. No engine manufacturer acknowledged that this was possible until the study and testing showed otherwise. Almost all motor vehicle emission regulations have been based on this process, and nearly all have been successfully implemented. In those few instances where problems with implementation occurred, the affected manufacturer and CARB were able to develop a solution, most often by allowing more time for development rather than weakening the emissions standard.

The standard-setting process is more effective if it is transparent. Public workshops to obtain ideas and comments from stakeholders and the ability of stakeholders to comment on final regulations before adoption reduces the adversarial nature of the process. Stakeholders value to ability to present their views, even if they are not accepted by the staff or the board.

**Treat the engine and its fuel as a system.** A lower limit on sulfur content of diesel fuel was adopted to reduce diesel particulate emissions, and lower aromatics to reduce $NO_x$ emissions. Sulfur was reduced again to allow the use of diesel filters and $NO_x$ catalysts while also reducing particulate emissions from existing diesel vehicles and equipment not so equipped.

**Focus on opportunities to achieve large reductions in emissions.** Early efforts to reduce heavy-duty diesel $NO_x$ emissions resulted in standards for new truck engines changing in multiple steps of 6 to 5 to 4 g/bhp-hour. These changes in standards were important because they advanced emissions control technology. However, the reduction in each step provided relatively small improvements at a substantial cost to engine manufacturers. By adopting standards that forced the commercialization of exhaust aftertreatment technology, both $NO_x$ and PM emissions were decreased by 90% or more in one iteration of the standards. And recently CARB was able to revise the $NO_x$ standard to require another 90% reduction.

**On-board diagnostics is the unsung hero of emissions control.** OBD has done more to improve emissions control durability and increase in-use emissions compliance than any other regulation. A comprehensive set of diagnostic monitors has been on all 2013 and newer model year on-road diesel engines since 2013. It facilitates warranty claims, protecting the truck owner, and incentivizes engine manufacturers to improve durability to reduce warranty costs. It is becoming an efficient way of identifying individual on-road high-emitting trucks by a quick inspection or remotely. By monitoring the diesel exhaust fluid system, which requires periodic refilling by the truck driver, OBD ensures that this critical system for $NO_x$ control is functional and forces truck shutdown if it is not. Having staff that has a thorough understanding of OBD is necessary to ensure the systems meet all requirements before a truck is approved for sale.

**An active in-use compliance program is essential.** Manufacturers successfully comply with new engine and vehicle emission standards and are permitted to sell their

products. However, the actual reduction of emissions on the road usually falls short of expectations. Several reasons for this are related to the engine manufacturer and include design flaws not identified during development and emission certification. In addition, emissions are higher in certain operating modes that are not emphasized during pre-sale compliance testing. A solution to these causes is an active compliance program based on testing in-use vehicles. A portable emissions monitoring system (PEMS) recording vehicle emissions while a truck is in operation can identify engine families suspected of poor emissions-control durability and may lead to a recall. Installation on a random sample of trucks can identify operational modes where emissions are high and lead to regulatory improvements. This type of testing recently identified high $NO_x$ emissions of diesel trucks operating at low loads and speeds and led CARB to adopt a new low-load test procedure and emission standard that will soon become a requirement for pre-sale certification, improving the effectiveness of the regulation.

Another reason for an active in-use compliance program is owner-related actions such as lack of maintenance and tampering with emission controls. The aftertreatment technologies on modern diesels have reduced a heavy-duty truck's emissions by more than 90%. Owner actions such as tampering with or disabling aftertreatment devices can increase a truck's emission of $NO_x$ and PM tenfold or more. Thus, only a small percentage of mal-maintained or tampered-with trucks can greatly increase overall emissions. An active in-use compliance program aimed at identifying high-emitting trucks and requiring their repair can dramatically reduce emissions. Periodic and random inspection programs and the use of remote sensing of emissions and the OBD system can help ensure that the lowest emissions are realized.

**Accelerate turnover of old diesel vehicles for new, low-emission vehicles.** The adverse effects of diesel pollution on public health, especially for those living adjacent to or near areas of high truck traffic, need to be remedied sooner, not later. One way of accomplishing this is to adopt programs that incentivize or require retiring older vehicles and replacing them with new ones. As current-model trucks are more than 90% cleaner, turnover can quickly reduce emissions and improve air quality. CARB has used both incentives, such as grants to help reduce the price of new trucks, and a requirement that in 2023 no truck operating in California can be older than a 2010 model. A similar program requiring turnover of older diesel off-road equipment is in place. Both programs are enforced, and compliance is high.

An alternative or complement to accelerated turnover is retrofit of pollution-control devices on older diesel trucks. CARB implemented a requirement that older diesel trucks install verified particulate filters unless the truck is upgraded to a newer model equipped with a filter. Verified retrofit filters were made available for sale for most older-model engines. Some filter failures occurred when older vehicles suffered fuel injection failures. One major filter manufacturer had to recall its filters and went out of business. As a result, CARB provided extended deadlines and new options favoring turnover. The lesson learned is that while retrofits can accelerate emission reductions, installing a retrofit device on an old engine can create problems. If feasible, the accelerated-turnover approach is more beneficial to the truck owner due to improved reliability and fuel efficiency.

**Programs are working. Diesel $NO_x$ and PM emissions are declining rapidly.** Emissions from heavy-duty diesel trucks and equipment are declining rapidly in California but

have a long way to go before reaching zero.[35] (See Figure 22.) The more gradual decline in off-road equipment emissions points out that more efforts are needed to reduce these emissions.

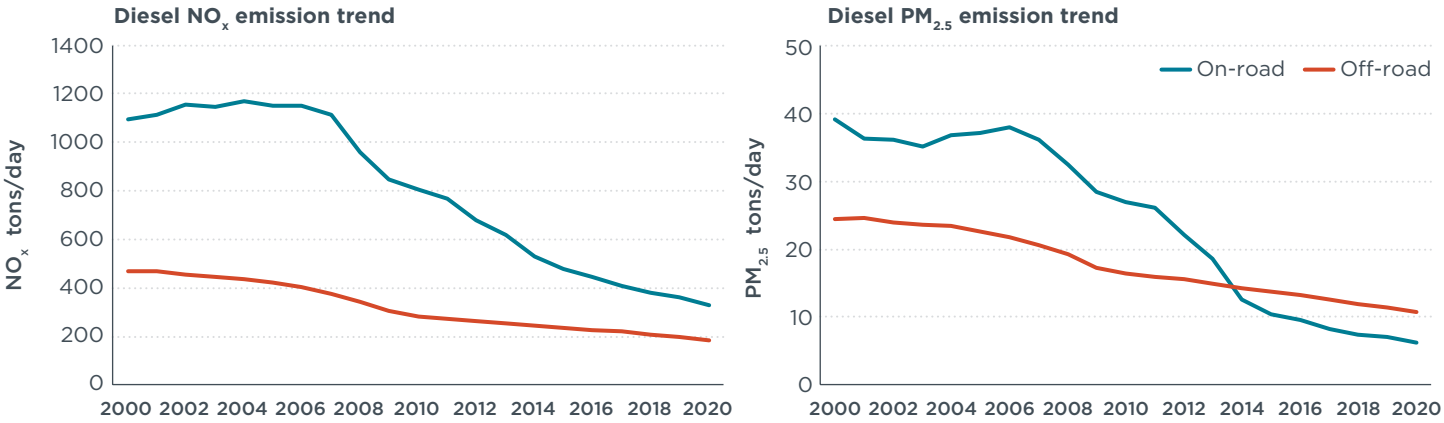


**Figure 22.** Heavy-duty diesel emissions are decreasing.
*Source:* California Air Resources Board (2018b)

**Climate priorities change everything: Zero emissions are essential.** Along with most of the world, California recognizes that successfully abating climate change requires GHG emissions to rapidly approach zero. For mobile sources, CARB has concluded that ZEVs such as battery electric and hydrogen fuel cells are the best approach to addressing the climate problem. They are also the ultimate solution to eliminating urban pollutants. However, the full transition to zero-emissions will take several decades, so efforts to reduce combustion-engine $NO_x$, PM, and $CO_2$ emissions need to continue.

The transition to zero-emissions transportation requires careful planning. CARB adopted a Mobile Source Strategy in 2016 to guide its efforts and is updating the strategy for board adoption at the end of 2021 (California Air Resources Board, 2021d).[36] The draft update identifies actions necessary to meet both urban air quality and climate goals. The plan draws heavily on the lessons learned from past actions that successfully reduced urban pollution from mobile sources. In summary, they are:

- Adoption of technology-forcing standards for new vehicles.
- Programs to ensure in-use compliance.
- Programs to accelerate turnover of older vehicles and equipment to newer, cleaner ones.
- Initiating the transition to ZEVs and technology now.

Figure 23, from the draft update to the Mobile Source Strategy, illustrates the multi-pollutant emission reductions achievable. The strategy also points out that additional actions such as reducing vehicle traffic, supporting walking and bicycling, and shifting to more-efficient movement of goods will also be needed to achieve the state's goal of net-zero carbon emissions by 2045.

35 See CEPAM: 2016 SIP - Standard Emission Tool, https://www.arb.ca.gov/app/emsinv/fcemssumcat/fcemssumcat2016.php

36 The draft plan also reviews implementation progress of the recommendations included in the 2016 plan.

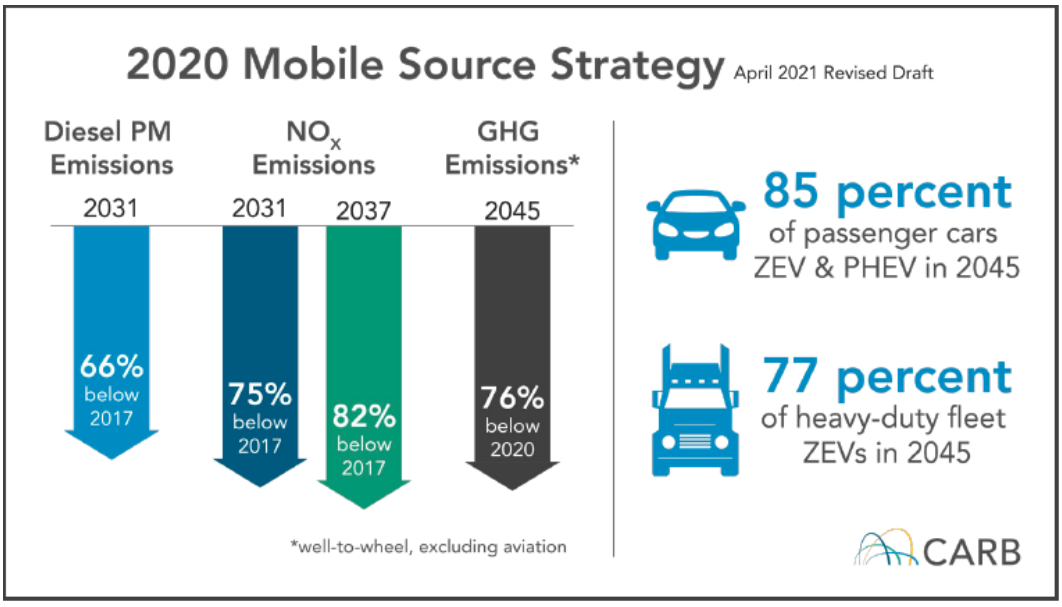


**Figure 23.** Next actions to reduce mobile source emissions toward zero.
*Source:* California Air Resources Board (2021d)

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