Guidance on Quantifying NOx Benefits for Cetane Improvement Programs for Use in SIPs and Transportation Conformity

United States
Environmental Protection
Agency

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Transportation and Climate Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

United States Environmental Protection Agency

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Section 1. Introduction

Note: As used in this document, the terms “you” and “your” refer to a state or states and the terms “we,” “us” and “our” refer to the Environmental Protection Agency (EPA).

1.1 What is the purpose of this document?

The purpose of this document is to provide an update to EPA’s guidance on the emissions reductions attributable to programs that control the cetane level in diesel fuel. In June 2004, EPA issued the original guidance on (the “2004 Guidance”).[1] This update maintains much of the 2004 Guidance, such as program design considerations, use of emission reductions for state implementation plans (SIPs) and transportation conformity, and how to calculate NOx emissions reductions. However, certain aspects of the 2004 Guidance need to be updated to reflect changes in fleet composition and control technology that have occurred since it was released, resulting in a significant decline in the emission reductions from cetane programs. For example, the 2004 Guidance contains information on calculating emission reductions from highway diesel engines for years through 2020 and indicates that increased cetane levels may reduce emissions from all nonroad engines in use in 2004.

Specifically, this update of the 2004 Guidance provides information on how to calculate emissions reductions in 2021 and beyond from both highway engines and nonroad engines. As discussed in the 2004 Guidance, cetane improvement programs only provide emission reductions from pre-2003 model year heavy-duty diesel highway vehicles and nonroad diesel engines that are sensitive to cetane enhancement, which are generally pre-Tier 3 nonroad diesel engines. This update reflects the significant decrease in the number of these highway and nonroad diesel engines that will benefit from a cetane improvement program as pre-2003 highway diesel engines and nonroad diesel engines that may benefit from a cetane improvement program (i.e., pre-Tier 3 engines) make up much smaller portions of the in-use population than they did 15 to 20 years ago. Therefore, we are providing this update to the 2004 Guidance as the number and use of such highway and nonroad diesel engines and the benefits of cetane improvement programs has substantially decreased and will continue to decrease in the future. Appendix 5 contains a sample calculation of the emission reductions from a cetane improvement program for a hypothetical Severe ozone nonattainment area for the 2008 ozone national ambient air quality standard (NAAQS). The example shows that for the hypothetical area with 30 tons/day of nitrogen oxide (NOx) emissions from all highway diesel engines in regulatory classes 41-49 in 2026, a cetane improvement program may reduce NOx emissions by 0.07 tons/day.

This guidance should help state and local air quality agencies that have either existing cetane improvement programs approved in their state implementation plans (SIPs) or may be considering adopting similar programs. Metropolitan planning

[1] *Guidance for Quantifying NOx Benefits for Cetane Improvement Programs for Use in SIPs and Transportation Conformity*, June 2004, EPA420-B-04-005.

organizations (MPOs) for nonattainment and maintenance areas where such programs have been included in the SIP should also use this guidance for calculating emissions reductions in 2021 and beyond for transportation conformity analyses. At this time, cetane improvement programs are approved in SIPs in two states, California and Texas. States considering adopting new cetane improvement programs should be aware of the significant decrease in potential reductions as well as the limitations of adopting such fuel programs due to changes in CAA preemption requirements since 2004, as discussed further in Section 1.3. This guidance updates and supersedes the 2004 Guidance.

1.2 What is a "cetane improvement program"?

A cetane improvement program calls for the use of cetane additives in diesel fuel to increase the cetane number. Generally, increases in the cetane number result in reduced emissions of NOx from certain heavy-duty highway diesel engines and certain diesel powered nonroad engines. For heavy-duty highway diesel engines, the emission reductions are attributable to pre-2003 model year engines. For nonroad diesel engines, the emission reductions are attributable to engines that are certified to pre-Tier 3 emissions standards. Cetane improvement additives include 2-ethylhexylnitrate and di-tertiary butyl peroxide used at diesel fuel concentrations of generally less than 1 volume percent (or 1 vol%). The numerical standard of such a program can take one of three different forms:

Type 1: Total cetane number standard:

This type of standard sets a per-gallon minimum value for the sum of natural (base) cetane number and the increase in cetane number due to additives. An example might be 50 or 55. For areas where the natural cetane has historically been low (e.g., 42), this type of standard could require significantly more additives and thus produce significantly more benefits than for areas where the natural cetane has historically been high (e.g., 47). As a result, the NOx benefits of this type of program could vary substantially from one area to another depending on the historical natural cetane.

Type 2: Cetane number increase standard:

This type of standard sets a per-gallon minimum value for the increase in cetane number due to the use of additives. An example might be 5 or 10. Although the NOx benefits of this type of program are also dependent on the natural cetane which varies by area, this type of program generally produces similar levels of benefits from one area to another as the relative increase in total cetane would be the same.

Type 3: Cetane additive concentration standard:

This type of standard sets a per-gallon minimum value for the concentration of a particular type of cetane improver additive. An example might be 0.15 volume percent of 2-ethylhexylnitrate, or 0.20 volume percent of di-tertiary butyl peroxide. This type of program uses a "proxy property" to represent the true cetane number increase, and the increased uncertainty associated with proxy properties may reduce the NOx benefits that can be claimed from this type of program. See Section 4 below for more details.

The standard set under a cetane improvement program should generally be on a per-gallon basis. Standards that apply on an average basis may be acceptable if appropriate compliance and enforcement mechanisms are established.

1.3 How would "federal preemption" apply to state adoption of cetane improvement programs?

In general, the Clean Air Act (CAA) provides that states are preempted from adopting their own fuel control requirements with respect to a fuel characteristic or component that EPA has regulated unless it is identical to the federal requirements.[2] However, EPA may waive preemption under certain circumstances, as discussed below.

State adoption of motor vehicle fuel requirements is controlled by CAA section 211(c)(4). Section 211(c)(4)(A) prohibits States from prescribing or attempting to enforce any "control or prohibition respecting" a "characteristic or component of a fuel or fuel additive" if EPA has promulgated a control or prohibition applicable to such characteristic or component under section 211(c)(1).

In 1989, EPA promulgated regulations requiring diesel fuel to meet a maximum aromatics level of 35 percent or in the alternative a minimum cetane index specification of 40.[3] This requirement provides the context for evaluating whether state cetane improvement programs are preempted. Determining whether a state cetane improvement program is preempted will depend in large part on the specific details of the state program. For instance, a state cetane improvement program could be structured around increases in the cetane number rather than changes to the cetane index or aromatics content. While the cetane number of unadditized diesel fuel has an impact on the cetane index of that fuel, increasing the cetane number using additives would not necessarily affect either the cetane index or aromatics level. Thus, a state program structured to increase the cetane number without affecting cetane index or aromatic levels is less likely to be considered preempted, while a state program that does affect cetane index or aromatic levels is more likely to be preempted.

Section 211(c)(4)(C) also provides a mechanism for obtaining a waiver from this prohibition for a nonidentical state standard contained in a SIP where the standard is "necessary to achieve" the primary or secondary NAAQS that the SIP implements. Specifically, EPA can approve such a SIP provision as necessary if the Administrator finds that "no other measures that would bring about timely attainment exist," or that "other measures exist and are technically possible to implement, but are unreasonable or impracticable."

However, states considering adopting a new cetane improvement program should be aware that Congress amended the fuel preemption requirements in CAA section 211(c)(4)(C) in 2005. This CAA amendment required EPA to determine the number of fuels approved into SIPs

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[2] Pursuant to CAA section 211(c)(4)(B) California "may at any time prescribe and enforce, for the purpose of motor vehicle emission control, a control or prohibition respecting any fuel or fuel additive."

[3] *Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and Later Calendar Years*, Final Rule, 54 FR 35276 (August 24, 1989). See also, 40 CFR 1090.305.

as of September 1, 2004, and to publish a list of such fuels in the *Federal Register*. The published list included the state in which the fuel has been approved into the SIP and the Petroleum Administration Defense District (PADD) in which the fuel is used. The CAA amendment prohibits EPA from increasing the number of SIP-approved fuel programs above the number that existed on September 1, 2004. EPA published the required list of SIP-approved fuel programs on December 28, 2006 (78 FR 78192).[4] In that notice, EPA stated that:

> *We (EPA) cannot approve a state fuel into a SIP unless the fuel is already in an existing SIP within that PADD, with the exception of a 7.0 psi RVP fuel.*[5] (71 FR 78193)

EPA also stated in that notice that:

> *if there is 'room on the list,' we (EPA) could approve for states within PADD 5 a fuel program that is in California's SIP, without violating the PADD restriction. CARB fuels are approved into California's SIP.* (71 FR 78196)

Two states -- California, which is in PADD 5, and Texas, which is in PADD 3 -- have SIP-approved cetane improvement programs.[6] The CAA's PADD restriction (as noted above) means that states in PADD 3 could adopt a new cetane improvement program, identical to the SIP-approved Texas low emission diesel program, and states in PADD 5 could adopt a cetane program identical to California's SIP-approved cetane improvement regulations provided that states in these PADDs meet all other requirements for SIP-approved fuels in CAA sections 211(c)(4)(C)(i) and 211(c)(4)(C)(v). EPA could not waive preemption under CAA section 211(c)(4)(C)(i) and approve a cetane improvement program into a state's SIP if the state is in PADDs 1, 2 or 4.

1.4 Who can I contact for more information?

A state or local agency with specific questions about an approved cetane improvement program or about incorporating such a program into its SIP should contact its Regional Office. You can find a list of EPA Regional Office contacts at https://www.epa.gov/transportation-air-pollution-and-climate-change/office-transportation-and-air-quality-contacts in Section 16.2 at the end of the document.

A state or local agency with specific questions about including emission reductions from a cetane improvement program in a transportation conformity determination should contact its Regional Office. You can find a list of EPA Regional Office transportation conformity contacts at: https://www.epa.gov/state-and-local-transportation/epa-regional-contacts-regarding-state-and-local-transportation.

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[4] On December 4, 2020, EPA published in the *Federal Register* an updated listing of the fuels approved in SIPs. (See 85 FR 78412.)

[5] See CAA section 211(c)(4)(C)(v)(V).

[6] The states in PADD 3 are: Alabama, Arkansas, Louisiana, Mississippi, New Mexico, and Texas. The states in PADD 5 are: Arizona, California, Nevada, Oregon, and Washington.

For general questions about this guidance, please see the Office of Transportation and Air Quality Contacts by Topic document available at https://www.epa.gov/transportation-air-pollution-and-climate-change/office-transportation-and-air-quality-contacts. A contact person is listed under "Cetane Improvement Programs".

Additional information regarding state and local transportation air quality planning resources can be found on EPA's website at: https://www.epa.gov/state-and-local-transportation.

1.5 Does this guidance create new requirements?

This guidance does not create any new requirements. The CAA and the regulations described in this document contain legally binding requirements. This guidance is not a substitute for those provisions or regulations, nor is it a regulation in itself. Thus, it does not impose legally binding requirements on EPA, states, or the regulated community, and may not apply to a particular situation based upon the circumstances. EPA retains the discretion to adopt approaches on a case-by-case basis that may differ from this guidance but still comply with the statute and applicable regulations. This guidance may be revised periodically without public notice.

Section 2. Federal Criteria for SIPs and Transportation Conformity

2.1 What are the basic criteria for using emission reductions in SIPs?

In order to be approved as a control measure which provides additional emission reductions in a SIP, a cetane improvement program would need to be consistent with SIP reasonable further progress (RFP), attainment, or maintenance requirements and other CAA requirements, as appropriate. The program must provide emission reductions that meet the basic SIP requirements described below. SIP requirements are mandatory requirements under CAA section 110.

Quantifiable –

SIP Requirement: The emission reductions are quantifiable if they are measured in a reliable manner and can be replicated (e.g., the assumptions, methods, and results used to quantify emission reductions can be understood). Emission reductions must be calculated for the time period during which the reductions will occur and will be used for SIP purposes.

When quantifying the emission reductions from a cetane improvement program, you will need to document the emission reductions and provide all relevant data to EPA for review. Sections 3 through 5 of this document provide a recommended method for quantifying emission reductions.

Surplus –

SIP Requirement: Emission reductions are considered "surplus" if they are not otherwise relied on to meet other applicable RFP, attainment, or maintenance requirements for that particular NAAQS pollutant (i.e., there can be no double-counting of emission reductions). In the event that the cetane improvement program is used to meet such air quality related program requirements, they are no longer surplus and may not be used as additional emission reductions. Emissions from the vehicles, engines, or equipment subject to the cetane improvement program must be in the applicable mobile source emissions inventory before the emission reductions from such a program can be used for RFP, attainment or maintenance in a SIP.

Federally Enforceable –

SIP Requirement: A SIP project must be enforceable. Depending on how the emission reductions are to be used, control measures must be enforceable through a SIP. Where the emission reductions are part of a rule or regulation for SIP purposes, they are considered federally enforceable only if they meet all of the following criteria:

- Emission reductions are independently verifiable.
- Violations are defined, as appropriate, e.g., an example of a violation is failing to implement as required by the regulation.
- The state and EPA have the ability to enforce the measure if violations occur.
- Those liable for violations can be identified.

- Citizens have access to all the emissions-related information obtained from the responsible party.
- Citizens can file lawsuits against the responsible party for violations.
- Violations are practicably enforceable in accordance with EPA guidance on practicable enforceability.
- A complete schedule to implement and enforce the measure has been adopted by the implementing agency or agencies.

Permanent –

SIP Requirement: The emission reductions from the cetane improvement program must be permanent throughout the time period that the reductions are used in the applicable SIP.

Adequately Supported –

SIP Requirement: The state must demonstrate that it has adequate funding, personnel, implementation authority, and other resources to implement the project on schedule.

2.2 What should be considered when estimating emission reductions for SIP purposes?

For SIP RFP, attainment or maintenance strategies, the emission reductions which are produced from the cetane improvement program can be estimated by applying the following criteria:

- Where necessary, emission reductions need to account for seasonality. For example, if a control measure is only applied during the summer ozone season, then only reductions which take place during that season may be credited in a SIP.
- Emission reductions would be commensurate with the number of and activity from onroad and nonroad diesel engines using fuel from a cetane improvement program for a given analysis year. As noted earlier, the number of such engines from older fleets has significantly declined since the release of the previous 2004 Guidance.

As required by Clean Air Act section 172(c)(3) and EPA's regulation at 40 CFR 51.112(a), States must use the latest planning assumptions available at the time that the SIP is developed to estimate emission reductions attributable to the cetane improvement program. State and local agencies should contact their EPA Regional Office for any specific questions regarding an area's cetane improvement program. Contact information may be found in Section 1.4 of this guidance.

2.3 What should a State submit to EPA to meet the criteria for incorporating a cetane improvement program in a SIP?

The state should submit to EPA a written document which:

- Identifies and describes the cetane-related control measure and its implementation schedule to reduce emissions within a specific time period;

- Contains estimates of emission reductions attributable to the measure, including all relevant technical support documentation for the estimates. The state must rely on the most recent information available at the time the SIP is developed pursuant to CAA section 172(c)(3) and 40 CFR 51.112(a);

- Contains federally enforceable procedures to implement, track, and monitor the measure as applicable;

- Enforceably commits to monitor, evaluate, and report the resulting emission reductions of the measure as applicable;

- Meets all other requirements for SIP revisions including under CAA sections 110, 172 and 175A, as applicable; and

- In the case of a cetane improvement program which is federally preempted, meets the requirements of CAA section 211(c)(4)(C).

2.4 What are the basic criteria for using emission reductions in transportation conformity determinations?

The transportation conformity rule describes the specific requirements for including emission reductions from onroad mobile control measures in a transportation conformity determination. Transportation conformity is required under CAA section 176(c) (42 U.S.C. 7506(c)) to ensure that federally supported highway and transit project activities are consistent with ("conform to") the purpose of the SIP. EPA's transportation conformity rule (40 CFR Parts 51.390 and Part 93, Subpart A) establishes the criteria and procedures for determining whether transportation plans, transportation improvement programs (TIPs) or projects conform to the SIP.

If the emission reductions from a cetane improvement program have been accounted for in the SIP's motor vehicle emissions budget ("budget"), the MPO would also include the emission reductions from the program to the extent it is being implemented, when estimating regional emissions for a transportation conformity determination.[7]

To include the emission reductions from a cetane improvement program in a conformity analysis, the appropriate jurisdictions must have made the appropriate level of commitment to the measure, as described in 40 CFR 93.122(a). The appropriate level of commitment varies according to the requirements outlined in 40 CFR 93.122(a), and under those provisions, for a cetane improvement program that requires a regulatory action to be implemented, it can be included in a conformity determination if one of the following has occurred:

- The regulatory action for the program is already adopted by the enforcing jurisdiction (e.g., a state has adopted a rule to require the cetane improvement program);

[7] The terms motor vehicle emissions budget and metropolitan planning organization (MPO) are defined the transportation conformity regulations. (*See* 40 CFR 93.101.)

- The program has been included in the approved SIP; or
- There is a written commitment to implement the program in a submitted SIP with a motor vehicle emissions budget that EPA has found adequate.

Note that 40 CFR 93.118 describes the process and criteria that EPA considers when determining whether submitted SIP budgets may be found adequate and used for transportation conformity purposes prior to EPA's final action on the submitted SIP.

Whatever the case, any emission reductions can only be applied in a transportation conformity determination for the time period or years in which the cetane improvement program will be implemented. Written commitments must come from the agency with the authority to implement the cetane improvement program as required by 40 CFR 93.122(a)(3)(iii). The latest emissions model and planning assumptions must also be used when calculating emission reductions, according to 40 CFR 93.110 and 93.111.

The interagency consultation process must be utilized (as required by 40 CFR 93.105) to discuss the methods and assumptions used to quantify the reductions from the cetane improvement program. Sections 3 through 5 of this document describe how to quantify emission reductions.

2.5 How should states enforce a cetane improvement program?

The state should design a compliance and enforcement program to ensure that fuel with cetane improvement additives is being provided to and sold within the designated geographic boundaries of the mandated program area. The assurance of NOx benefits being generated within the program area depends on the rigor of this compliance and enforcement program. This guidance does not specify all elements of such a program that might be necessary, but instead lists several areas that should be considered.

The compliance and enforcement program associated with a cetane improvement program should be designed generally to provide a high degree of confidence that the diesel fuel with a specified amount of improvement in cetane number due to the use of additives is actually sold to end users within a pre-specified geographic area. To accomplish this, mechanisms may need to be instituted to track where the cetane improver is being added to the fuel and subsequently what avenues that fuel takes (pipelines and delivery tanker trucks, for example) in order to be delivered to final dispensing stations within the mandated area. Mechanisms that might be necessary to achieve confidence that this is occurring could include:

- Batch-by-batch tracking of volumes
- Segregation of additized fuel from nonadditized fuel
- Detailed recordkeeping requirements, including Product Transfer Documents
- Periodic reporting requirements
- Requirements for sampling and testing of fuel before and after cetane improver is added
- Surveys of fuel quality within the mandated area

A compliance and enforcement program may also include requirements that particular approved sampling methods be used and may also specify the liability provisions applicable to all parties in the fuel distribution system and the penalties associated with noncompliance with the established cetane standard.

Finally, a cetane improvement program is most easily enforceable if the standard it establishes can be checked against any given batch of fuel. Generally, this means that the standard should be set on a per-gallon basis, not an averaging basis. If a state wishes to set an average standard, it should design a compliance and enforcement program that adequately deals with the inherent and additional uncertainty associated with average standards.

2.6 What types of penalties can be assessed for not complying with SIP requirements?

Use of this guidance does not relieve the obligation to comply with all otherwise applicable CAA requirements, including those pertaining to the crediting of emission reductions for SIPs, including attainment or maintenance strategies. Violations of SIP requirements are enforceable by the State. Additionally, violations of SIP requirements are subject to federal administrative, civil, and/or criminal enforcement under CAA section 113, as well as to citizen suits under CAA section 304. The full range of penalty and injunctive relief options remain available to the federal or State government (or citizens) bringing the enforcement action.

Section 3. Per-vehicle or Per-engine NOx Benefits of Cetane Improvement Additives

3.1 Overview

In order to estimate the NOx benefits of cetane improver additives for an in-use fleet, you should first have an estimate of the NOx benefits for a single highway vehicle or nonroad engine using cetane-enhanced diesel fuel. The fleet-wide NOx benefits may differ from the per-vehicle or nonroad engine benefits due to such issues as migration of vehicles into and out of the cetane program area, the use of proxy fuel properties, etc. These issues are addressed separately in Section 4 below.

The per-vehicle NOx benefits of cetane improver additives are generally represented as a percent reduction in NOx emissions for a given increase in cetane number. There are several potential sources for these benefit estimates, including testing completed under Environmental Technology Verification (ETV) protocols, independent data sets (as reviewed and approved by EPA), and EPA technical reports.[8] This report provides estimates of per-vehicle NOx benefits using the following equation, which we will refer to as (EQ 1):

$$(\%NOx)_{pv} = k \times 100\% \times \{1 - \exp[\ -0.015151 \times AC + 0.000169 \times AC^2 + 0.000223 \times AC \times RC]\} \qquad \textbf{(EQ 1)}$$

Where:

$\mathbf{(\%NOx)_{pv}}$	= Per-vehicle percent reduction in NOx emissions[9]
k	= Constant representing fraction of NOx inventory associated with cetane-sensitive diesel trucks or nonroad engines, as described later in this section
AC	= Additized cetane; the increase in cetane number due to the use of additives
RC	= Reference cetane; the natural (unadditized) cetane number of the fuel prior to implementation of the cetane program

The EPA Technical Report from which equation (EQ 1) is taken contains a detailed description of the data on which the analysis was based and the associated methodology. The Technical Report also contains a discussion of the explanatory power of equation (EQ 1) through comparisons to alternative models, correlating predicted and observed values, and estimating model uncertainty.

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[8] For example, The Effect of Cetane Number Increase Due to Additives on NOx Emissions from Heavy-Duty Highway Engines - Final Technical Report (EPA-420-R-03-002, February 2003).

[9] Although equation (EQ 1) is written for highway vehicles, this same equation can be used for calculating per-engine NOx benefits of cetane improver additives for nonroad diesel engines.

The per-vehicle NOx benefits of cetane improver additives for diesel highway vehicles (or per-engine NOx benefits for nonroad engines) can be estimated from equation (EQ 1) if you have values for k, additized cetane, and reference cetane. The specific values will depend on the cetane additive program being implemented, the fleet mix in the program area, and the quality of diesel fuel prior to program implementation. Guidelines for determining values for k, additized cetane, and reference cetane follow. Note that states should perform separate calculations for highway and nonroad NOx emissions reductions.

3.2 How is the constant 'k' calculated for highway vehicles?

States, including states that currently have cetane improvement programs approved in their SIPs, should calculate area-specific "k" values for highway vehicles for each ozone nonattainment area where a cetane improvement program is or may be implemented and for each relevant year. For example, if a state has a SIP-approved cetane improvement program that is implemented in an area that is classified as Severe for the 2008 ozone NAAQS and the state plans to include emissions reductions from the cetane improvement program in the RFP plans and the attainment plan for that area, the state should calculate an area-specific "k" value for the base year, if the cetane improvement program was in effect in the base year, the RFP and the 2026 attainment year.

The state should calculate area specific "k" values by determining the total amount of vehicle miles traveled (VMT) in the area in the relevant analysis year (e.g., 2026 for a Severe nonattainment area for the 2008 ozone NAAQS) attributable to heavy-duty diesel highway engines of all ages in regulatory classes 41-49 and the total amount of VMT in the area in the same years attributable to heavy-duty diesel highway vehicles that are model year 2002 and older in regulatory classes 41-49. The constant "k" for the area for that year for highway vehicles would then equal:

$$k_{\text{onroad area}} = VMT_{\text{HD Diesel MY2002 and older}} / VMT_{\text{HD Diesel All MY}}$$

Where:

$\mathbf{k_{onroad\ area}}$	= the constant "k" for the specific area and year.
$\mathbf{VMT_{HD\ Diesel\ MY2002\ and\ older}}$	= the VMT attributable to heavy-duty diesel highway vehicles (regulatory classes 41-49) in the area and in the analysis year that are MY 2002 or older.
$\mathbf{VMT_{HD\ Diesel\ All\ MY}}$	= the VMT attributable to all heavy-duty diesel highway vehicles (regulatory classes 41-49) in the area and in the analysis year.

This calculation will result in values of "k" that decrease over time due to fleet turnover, resulting in a corresponding decrease in NOx emission reductions over time.

3.3 How is the constant 'k' calculated for nonroad diesel engines?

States, including states that currently have cetane improvement programs approved in their SIPs, should calculate area specific "k" values for nonroad diesel engines for each ozone nonattainment area where a cetane improvement program is or may be implemented and for each relevant analysis year. For example, if a state has a SIP-approved cetane improvement program that is implemented in an area that is classified as Severe for the 2008 ozone NAAQS and the state plans to include emissions reductions from the cetane improvement program in the RFP plans and the attainment plan for that area, the state should calculate an area-specific "k" value for nonroad diesel engines for the base year, if the cetane improvement program was in effect in the base year, the RFP years, and the 2026 attainment year.

NOx emissions controls such as exhaust gas recirculation and selective catalytic reduction, which are insensitive to increases in cetane levels, became prevalent with the introduction of engines certified to Tier 3 and Tier 4 emissions standards. One way to calculate an area specific "k" for nonroad diesel engines is to calculate the fraction of pre-1988 through Tier 2 engines remaining in the fleet in the subject area in the given analysis year. For example:

$$k_{\text{nonroad area}} = (f_{\text{Diesel pre-1988}} + f_{\text{Diesel Tier 0}} + f_{\text{Diesel Tier 1}} + f_{\text{Diesel Tier 2}})/f_{\text{Diesel Total}}$$

Where:

$\mathbf{k_{nonroad\ area}}$ = the constant "k" for nonroad diesel engines for the specific area and year.

$\mathbf{f_{Diesel\ Tier\ X}}$ = the number of nonroad diesel engines certified to pre-1988, Tier 0, Tier 1 and Tier 2 emissions standards in the area in the analysis year.

$\mathbf{f_{Diesel\ Total}}$ = the total number of nonroad diesel engines in the area and analysis year

This calculation will result in values of "k" that decrease over time resulting in a corresponding decrease in NOx emission reductions over time. To assist states, EPA has provided information on the national fractions of nonroad diesel engines certified to each Tier of emissions standards (see Appendix 1) and similar information broken down by sector (e.g., construction and lawn and garden) (see Appendix 2).[10] The information is available for 2025, 2026 and 2030. Based on this national information, EPA estimates that in 2026, the national average "k" for nonroad diesel engines certified to pre-Tier 3 emission standards equals 0.14. States should consider local information on the number pieces of diesel powered nonroad equipment certified to each Tier of emissions standards in the area because these fractions will vary with location. States should also consider whether to estimate emission reductions from all nonroad diesel engines or from individual sectors of diesel engines that utilize the cetane improvement program. Finally, the value of "k" will continue to decrease over time as diesel engines certified to pre-Tier 3 emission standards are retired.

3.4 How is the reference cetane (RC) calculated?

This is the average natural (unadditized) cetane number of diesel fuel prior to implementation of the cetane improvement program for highway vehicles or nonroad engines. RC does **not** represent the cetane number of the unadditized base fuel **after** the program has been

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[10] Information on the fraction of nonroad diesel engines certified to various Tiers is from a national run of the MOVES3 nonroad module. Additional information on the fleet turnover algorithm in the nonroad module is available at: https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10081RV.pdf.

implemented (referred to here as BC: Base cetane), because refiners may change the quality of the unadditized fuel if they are required to use cetane improver additives, or the natural cetane may change incidentally as a result of compliance with ultra-low sulfur standards. The value of RC for highway diesel fuel should be determined and specified separately from that for nonroad diesel fuel. There are three options for specifying a value for RC for use in the equation above:

1) In areas for which pre-existing survey data is available, you may use an average from the most recent year prior to program implementation as the default value for RC.

2) You may conduct a survey of diesel fuel parameters in the program area prior to the implementation of the cetane improvement program.

3) You may use a default RC value of 47 to represent highway diesel fuel. For nonroad diesel fuel, you may use a default RC value of 45 through calendar year 2007, and a default RC value of 47 thereafter.

Survey data may provide values for total cetane number that are composed of contributions from both natural (unadditized) cetane and a pre-existing cetane improver additive. Since RC is intended to only represent the unadditized portion of total cetane number, any contributions to the total cetane number from cetane improver additives should be separated out and accounted for separately when using equation (EQ 1). See further discussion below. If the default value for RC is used or if the available survey data does not permit quantification of the amount of cetane improver additives already in the fuel, 1 cetane number could be assumed to have resulted from the presence of pre-existing cetane improver additives.

3.5 How is additized cetane (AC) calculated?

This is the increase in cetane number that results from the addition of cetane improvers to an unadditized base fuel for highway vehicles or nonroad engines. However, in order for the NOx emissions effect equation (EQ 1) above to represent the cetane program correctly, the value for AC should be corrected for any changes in the natural cetane prior to and after program implementation. Additized cetane should thus be calculated from the following equation (EQ 2) once the program has been implemented:

$$AC = AC_m + BC - RC \qquad \textbf{(EQ 2)}$$

Where:

AC = Value of additized cetane used to calculate $(\%NOx)_{pv}$ via equation (EQ 1)

AC_m = Value of additized cetane actually measured after program implementation; generally total cetane of additized fuel minus BC, but can also be measured using additive concentration as a proxy property (see Section 4.4)

RC = Reference cetane; the natural (unadditized) cetane number of diesel fuel **prior to** implementation of the cetane program (see discussion above)

BC = Base cetane; the cetane number of the unadditized base fuel **after** implementation of the cetane program

Prior to program implementation, there are no measurements of AC_m or BC. Thus, for SIP planning purposes prior to program implementation, BC can be assumed to be equal to RC. If the fuel contained no pre-existing cetane improver additives prior to implementation of the program, then the value of AC is determined by the type and level of standard set by the state:

Program type	Description	How to determine AC prior to the start of the program
Type 1	Total cetane number standard	Standard minus RC
Type 2	Cetane number increase standard	Standard
Type 3	Cetane additive concentration standard	Convert standard into a cetane number increase using cetane response functions (see Appendix 3)

Once the program has been implemented, the value of AC should be determined from equation (EQ 2) as a part of the in-use enforcement program. The values of AC_m and BC can be measured using a variety of techniques involving some combination of direct measurements of cetane number and indirect measurements of fuel properties. However, indirect measurements of fuel properties (i.e., proxy properties) introduce additional uncertainties which may reduce the fleet-wide NOx benefits that can be claimed (see Section 4.4 below).

As described above, diesel fuel may already contain some cetane improver additives prior to implementation of a cetane improvement program. In such cases the calculation of $(\%NOx)_{pv}$ requires an additional step. Instead of simply using equation (EQ 1) once, equation (EQ 1) should be used twice. The first application of equation (EQ 1) would use a value for AC representing the pre-existing cetane improver additives prior to implementation of the program, while the second application of equation (EQ 1) would use a value for AC representing the total amount of cetane improver additives in the fuel after implementation of the program (pre-existing additives plus any additional additives resulting from the program). The difference between these two applications of equation (EQ 1) would provide an estimate of $(\%NOx)_{pv}$ that best represents the NOx benefits of the cetane improvement program. Mathematically, this process would appear as follows:

$$[(\%NOx)_{pv}]_B = k \times 100\% \times \{1 - \exp[- 0.015151 \times AC_B + 0.000169 \times AC_B^2 + 0.000223 \times AC_B \times RC]\}$$

$$[(\%NOx)_{pv}]_A = k \times 100\% \times \{1 - \exp[- 0.015151 \times AC_A + 0.000169 \times AC_A^2 + 0.000223 \times AC_A \times RC]\}$$

$$(\%NOx)_{pv} = [(\%NOx)_{pv}]_A - [(\%NOx)_{pv}]_B$$

Where:

AC_B	=	The increase in cetane number due to the use of additives before implementation of the cetane improvement program
AC_A	=	The total increase in cetane number due to the presence of all additives after implementation of the cetane improvement program
$[(\%NOx)_{pv}]_B$	=	Per-vehicle[11] percent reduction in NOx emissions due to the use of additives before implementation of the cetane improvement program
$[(\%NOx)_{pv}]_A$	=	Per-vehicle percent reduction in NOx emissions due to the presence of all additives after implementation of the cetane improvement program

If a cetane response function is used to determine increases in cetane number as a function of cetane improver concentration as described in Section 4.4 and Appendix 3, the presence of any pre-existing cetane improver additives must also be taken into account. See Appendix 3.

[11] Although equation (EQ 1) is written here and described for highway vehicles, this same equation can be used for calculating NOx benefits of cetane improver additives for nonroad diesel engines.

Section 4. Calculating in-use Fleet-wide NOx Benefits

4.1 Overview

As described in Section 3, you should first have an estimate of the NOx benefits for a single vehicle or engine using diesel fuel with cetane improver additives before you can estimate the NOx benefits for the in-use fleet for onroad or nonroad diesel sources. The in-use fleet of highway vehicles consists of pre-model year 2003 highway vehicles in regulatory classes 41-49, and the in-use fleet of nonroad engines consists of pre-Tier 3 engines. The per-vehicle benefit is the value $(\%NOx)_{pv}$ calculated from equation (EQ 1), and this equation can also be used for calculating nonroad benefits.

If the cetane additive program applies to both onroad and nonroad diesel engines, then equations 3 (EQ 3) and 4 (EQ 4), discussed below should each be used twice to calculate NOx emissions reduced separately for both highway vehicles and nonroad engines.

The fleet-wide NOx benefits may differ from the per-vehicle benefits due to a variety of programmatic issues. In order to account for these issues, the fleet-wide NOx benefit should be calculated from the following equation, which will be referred to as (EQ 3):

$$(\%NOx)_{fw} = (\%NOx)_{pv} \times F_1 \times F_2 \times F_3 \times F_4 \qquad \textbf{(EQ 3)}$$

Where:

$\mathbf{(\%NOx)_{fw}}$	= Fleet-wide percent reduction in NOx emissions
$\mathbf{(\%NOx)_{pv}}$	= Per-vehicle percent reduction in NOx emissions from equation (EQ 1)
$\mathbf{F_1}$	= Program factor representing 2-stroke engines
$\mathbf{F_2}$	= Program factor representing nonroad fuel
$\mathbf{F_3}$	= Program factor representing vehicle migration
$\mathbf{F_4}$	= Program factor representing the use of proxy fuel properties

Each of the program factors accounts for a specific element of the program design. The following subsections describe how to determine the value of each of the program factors for use in equation (EQ 3).

4.2 How is program factor F1 calculated?

As described in the original Technical Report, equation (EQ 1) does not apply to 2-stroke engines. Thus 2-stroke engines are assumed to receive no NOx benefit from the use of cetane improver additives. For general distribution of a cetane improver additive, the in-use fleet can be assumed to be comprised of only a negligible fraction of 2-stroke engines. However, if cetane improver additives are being used in identifiable, centrally-fueled fleets and those fleets have a non-negligible fraction of 2-stroke engines, the NOx benefit should be adjusted downward accordingly.

Conditions for determining the default value of program factor F_1

Condition	Default value of F_1
General distribution of cetane improver additives through the system of terminals, pipelines, and service stations	1.0
Use of cetane improver additives in a centrally-fueled fleet with an identifiable and measurable number of 2-stroke and 4-stroke engines	(number of 4-stroke engines)/(number of 2-stroke and 4-stroke engines)

4.3 How is program factor F2 calculated?

Cetane improver additives can be used in nonroad engines in addition to highway engines, and nonroad engines are likely to produce some NOx benefits as a result. However, as described in the original Technical Report, equation (EQ 1) was based entirely on emissions data collected on highway engines. A qualitative argument can be made that nonroad engines will respond to cetane in the same way that highway engines do, particularly for nonroad engines of a similarly rated horsepower to highway engines, but there is little analysis to prove this assertion. In addition, a large fraction of diesel fuel designated as "nonroad" is used in residential and industrial heaters instead of diesel engines. There is no information to suggest that these heaters will produce any NOx benefits from the use of cetane improver additives.

In order to account for the paucity of data on NOx benefits for nonroad engines and the fact that heaters also consume some nonroad diesel fuel, an appropriate value for factor F_2 should be chosen. Additional emissions data on the effects of cetane improver additives on nonroad engines may be necessary. For instance, data can be generated under the EPA's Emission Test Verification Program.[12]

Program factor F_2 may need to be set at zero if insufficient data on the potential emission benefits of cetane improver additives in nonroad engines is available.

[12] See fuel additive testing information at: https://www.epa.gov/ve-certification/evaluation-program-aftermarket-retrofit-devices.

Conditions for determining the default value of program factor F_2

Condition	Default value of F_2
Use of cetane improver additives in highway diesel fuel	1.0
Use of cetane improver additives in off-highway diesel fuel, where the NOx benefits of cetane improver additives on nonroad engines has been measured and used to estimate a value for $(\%NOx)_{pv}$ that supersedes equation (EQ 1)	(volume of off-highway fuel used in nonroad engines) / (volume of off-highway fuel used in nonroad engines and heaters)[13]
Use of cetane improver additives in off-highway diesel fuel, where the NOx benefits of cetane improver additives on nonroad engines has not been estimated	0.0

4.4 How is program factor F3 calculated?

Many highway diesel vehicles travel long distances on a single tank of fuel. As a result, many vehicles that refuel within the geographic boundaries of a cetane improver program will quickly travel outside of those boundaries, while many other vehicles that have refueled outside of the program boundaries will subsequently travel into the program area. As a result of this vehicle migration, the total NOx benefits of a cetane improver program will actually occur in a region that includes but extends beyond the geographic boundaries of the covered program area. The actual NOx benefits occurring within the program area will be less than the total NOx benefits produced. The fraction of total NOx benefits occurring within the program area is generally proportional to the geographic size of the program area.

Some segments of the diesel engine fleet may travel shorter distances than the average highway diesel vehicle, and therefore may not contribute to migration. For instance, nonroad engines generally do not travel long distances from their refueling locations like highway vehicles do. Also, some centrally-fueled fleets may use vehicles that only travel within a small region and thus do not contribute to migration. The State may account for such centrally-fueled fleets if it can provide supporting data. Finally, truck operators who actively avoid higher-priced fuel could cause an additional reduction in the NOx benefits of a cetane improver program. The effects of this "price aversion" as estimated from available data are small relative to the impacts of vehicle migration and are here considered to be covered by the default values for program factor F_3 shown below.

[13] "Heaters" include any fuel combustion unit designed to produce heat instead of work, including residential heating units, industrial boilers, etc

Conditions for determining the default value of program factor F_3

Condition	Default value of F_3
Use of cetane improver additives in nonroad engines	1.0
Use of cetane improver additives in highway engines, where the total square mileage of the area within which the mandated cetane improver additive program applies is:	
Less than 50 mi^2	0.3
51 - 300 mi^2	0.5
301 - 1200 mi^2	0.6
1201 - 2800 mi^2	0.7
2801 - 7800 mi^2	0.8
7801 - 70,000 mi^2	0.9
Above 70,001 mi^2	1.0

The state may propose alternative values for factor F_3 if it can provide supporting area-specific vehicle trip length or migration data.

4.5 How is program factor F4 calculated?

Equations 1 and 2 (EQ 1, EQ 2) require measurements for natural cetane number and additized cetane number. Generally, this would require the use of ASTM test procedure D613 twice:

- Once to measure the cetane number of the fuel prior to addition of cetane improver
- A second time to measure the cetane number of the fuel after the cetane improver has been added

The first measurement provides a value for BC in equation (EQ 2), while the second measurement minus the first measurement provides a value for AC_m.

However, a state may wish to permit the use of alternative methods for estimating the values of natural and additized cetane numbers in order to reduce costs, increase the number of samples that can be taken, or to simplify the compliance process. The use of these "proxy properties" introduces additional uncertainties and potential bias into the calculation of $(\%NOx)_{pv}$. Thus, the fleet-wide NOx benefits should be adjusted to account for the use of proxy properties.

The two primary proxy properties available to states include the following:

Cetane index (ASTM D4737)

Used to estimate the natural cetane number. Requires the measurement of fuel distillation properties T10, T50, and T90, and measurement of fuel density. Cetane index is then calculated from the following equation:

$$
\begin{aligned}
CI = \; & 45.2 \\
& + 0.0892 \times (T10 - 215) \\
& + \{0.131 + 0.901 \times [\exp(-3.5 \times (D - 0.85)) - 1]\} \times (T50 - 260) \\
& + \{0.0523 - 0.420 \times [\exp(-3.5 \times (D - 0.85)) - 1]\} \times (T90 - 310) \\
& + 0.00049 \times [(T10 - 215)^2 - (T90 - 310)^2] \\
& + 107 \times [\exp(-3.5 \times (D - 0.85)) - 1] \\
& + 60 \times [\exp(-3.5 \times (D - 0.85)) - 1]^2
\end{aligned}
$$

Where:

CI	= Cetane index
T10	= Distillation property via ASTM D86: temperature in ^{o}F at which 10vol% has evaporated
T50	= Distillation property via ASTM D86: temperature in ^{o}F at which 50vol% has evaporated
T90	= Distillation property via ASTM D86: temperature in ^{o}F at which 90vol% has evaporated
D	= Density in g/ml at 15 ^{o}C, via ASTM D1298

In order to use cetane index to represent the natural cetane number of a fuel, any biases between CI and actual measured natural cetane values should be addressed. Appendix 4 provides a default correlation that can be used for this purpose. Cetane index can only be used to estimate the cetane number of unadditized fuel, or the natural (not total) cetane number of fuel containing a cetane improver additive.

Additive concentration

Along with a cetane response function such as those in Appendix 3, additive concentration can be used to provide an estimate of the increase in cetane number due to the use of cetane improver additives.

There may be other means for generating proxy properties that avoid the use of ASTM test procedure D613. If these means of generating proxy properties have not been peer reviewed in a public process, then their accuracy and precision as predictors of cetane number cannot be confirmed. As a result, allowing their use as compliance tools in a cetane improver additive program could compromise the NOx benefits of that program. Since the benefits of a cetane improvement program must be quantifiable and surplus, potential bias in cetane number predictions for these proxy properties requires an adjustment to the claimable fleet-wide NOx benefits. Choosing an appropriate value for program factor F_4 may be an appropriate means for mitigating bias introduced through the use of proxy properties.

Although equations (EQ 1) and (EQ 2) would normally require measurements for natural cetane number and additized cetane number using ASTM test procedure D613, the simplest possible compliance scheme would involve measurements of additive concentration and only an assumption regarding the natural cetane of the base fuel [BC in equation (EQ 2)]. For instance, the value of BC could be assumed to be equal to RC, the natural cetane number of diesel fuel prior to implementation of the program. If a cetane improvement program permits this compliance approach, the fleet-wide NOx benefits are much more uncertain. As a result, they should be adjusted downward by choosing an appropriate value for program factor F_4.

Conditions for determining the default value of program factor F_4

Condition	Default value of F_4
Program requires the use of ASTM test procedure D613 for measuring base cetane number (BC) and additized cetane number (AC_m)	1.0
Program allows the use of cetane index (including Appendix 4 correlation) and/or additive concentration (with a known response function) as proxy properties for representing cetane number measurements via ASTM D613	1.0
Program allows regulated parties to avoid measuring the base cetane number (BC) by assuming that BC is equal to RC. RC > 47 44 = RC < 47 RC < 44	 0.8 0.9 1.0
Program allows the use of other proxy properties whose measured values are corrected for known bias in comparison to D613 cetane number and whose uncertainty is established to be equivalent to D613	1.0

Section 5. Calculating Tons of NOx Reduced

The reduction in NOx emissions that results from the cetane improvement program depends broadly on the percent reduction in NOx and that portion of the program area's NOx inventory that is affected by cetane improver additives. Mathematically, this is represented by the following equation, which will be referred to as (EQ 4):

$$\text{NOx tons reduced} = \text{Diesel NOx inventory} \times (\%\text{NOx})_{fw} \times \text{Volume fraction affected} \qquad \textbf{(EQ 4)}$$

Where:

NOx tons reduced	= Daily or annual tons of NOx reduced within the geographic boundaries of the cetane improver program area
Diesel NOx inventory	= Total daily or annual tons of NOx generated by diesel engines within the geographic boundaries of the program area, assuming the cetane additive program is not in effect
$(\%NOx)_{fw}$	= Fleet-wide percent reduction in NOx from equation (EQ 3)
Volume fraction affected	= Fraction of the diesel fuel volume which contains cetane improver additives within the program area

The calculation of NOx emissions reduced using equation (EQ 4) may need to take into account other factors depending on the form of the cetane improver program. For instance:

- If the cetane improver program only applies for a portion of the year (e.g., summer months only), then the "Diesel NOx inventory" should likewise represent only that same portion of the year.

- If the cetane improver additive program applies to both highway and nonroad engines, then equation (EQ 4) should be used twice to calculate NOx tons reduced separately for both highway and nonroad, and the results summed.

- If the cetane improver additive program applies to specific centrally-fueled fleets, then the "Diesel NOx inventory" in equation (EQ 4) should represent those specific fleets.

The "volume fraction affected" will generally be equal to 1.0 if the cetane improver additive program applies to all fuel within specified geographic boundaries. In this case the "Diesel NOx inventory" should represent that same area. However, if the program does not apply to all fuel within specified geographic boundaries, or if the "Diesel NOx inventory" must necessarily represent an area that extends beyond the program area, then the "volume fraction affected" will be less than 1.0.

Conditions for determining a value for "Volume fraction affected" in equation (EQ 4)

Condition	Volume fraction affected
Cetane improver additive program applies to all fuel within area X and "Diesel NOx inventory" also represents area X	1.0
Cetane improver additive program applies to all fuel within area X and "Diesel NOx inventory" represents larger area Y	Fuel consumed in area X ÷ Fuel consumed in area Y
Cetane improver additive program applies to specific fleets within area X	Fuel consumed by fleets ÷ Fuel consumed in area X

For highway diesel vehicles, the fuel consumed within a given area can be calculated from the diesel engine VMT associated with that area and fuel economy rates for each diesel vehicle weight class for the calendar year being modeled.

Appendix 1. National Average Distribution of Nonroad Diesel Engines by Certification Tier

Year	Engine Technology	Diesel Engine Population	Total Diesel Engine Population	Tier Distribution
2025	Baseline Pre-1988 Diesel	31404	7378923	0.004
2025	Tier0 Diesel	132355	7378923	0.018
2025	Tier1 Diesel	413170	7378923	0.056
2025	Tier2 Diesel	587042	7378923	0.080
2025	Tier3 Diesel	227160	7378923	0.031
2025	Tier3 Transitional Diesel	87925	7378923	0.012
2025	Tier4 Final Diesel	4295589	7378923	0.582
2025	Tier4 Transitional Diesel	1604279	7378923	0.217
2026	Baseline Pre-1988 Diesel	26078	7433763	0.004
2026	Tier0 Diesel	114620	7433763	0.015
2026	Tier1 Diesel	359047	7433763	0.048
2026	Tier2 Diesel	532660	7433763	0.072
2026	Tier3 Diesel	208629	7433763	0.028
2026	Tier3 Transitional Diesel	81293	7433763	0.011
2026	Tier4 Final Diesel	4513385	7433763	0.607
2026	Tier4 Transitional Diesel	1598051	7433763	0.215
2030	Baseline Pre-1988 Diesel	10669	7707325	0.001
2030	Tier0 Diesel	64809	7707325	0.008
2030	Tier1 Diesel	180919	7707325	0.023
2030	Tier2 Diesel	310606	7707325	0.040
2030	Tier3 Diesel	139022	7707325	0.018
2030	Tier3 Transitional Diesel	55275	7707325	0.007
2030	Tier4 Final Diesel	5379900	7707325	0.698
2030	Tier4 Transitional Diesel	1566125	7707325	0.203

Appendix 2. National Average Distribution of Nonroad Diesel Engines by Certification Tier and Equipment Sector

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
2025	Agriculture	Baseline Pre-1988 Diesel	13175	2110033	0.006
2025	Agriculture	Tier0 Diesel	35810	2110033	0.017
2025	Agriculture	Tier1 Diesel	145741	2110033	0.069
2025	Agriculture	Tier2 Diesel	225858	2110033	0.107
2025	Agriculture	Tier3 Diesel	159126	2110033	0.075
2025	Agriculture	Tier3 Transitional Diesel	32256	2110033	0.015
2025	Agriculture	Tier4 Final Diesel	1211733	2110033	0.574
2025	Agriculture	Tier4 Transitional Diesel	286334	2110033	0.136
2025	Airport Support	Tier0 Diesel	8	20937	0.000
2025	Airport Support	Tier1 Diesel	95	20937	0.005
2025	Airport Support	Tier2 Diesel	236	20937	0.011
2025	Airport Support	Tier3 Diesel	1210	20937	0.058
2025	Airport Support	Tier3 Transitional Diesel	200	20937	0.010
2025	Airport Support	Tier4 Final Diesel	16723	20937	0.799
2025	Airport Support	Tier4 Transitional Diesel	2464	20937	0.118
2025	Commercial	Baseline Pre-1988 Diesel	7596	1465110	0.005
2025	Commercial	Tier0 Diesel	36730	1465110	0.025
2025	Commercial	Tier1 Diesel	81782	1465110	0.056
2025	Commercial	Tier2 Diesel	153174	1465110	0.105
2025	Commercial	Tier3 Diesel	14800	1465110	0.010
2025	Commercial	Tier3 Transitional Diesel	21044	1465110	0.014
2025	Commercial	Tier4 Final Diesel	571771	1465110	0.390
2025	Commercial	Tier4 Transitional Diesel	578214	1465110	0.395
2025	Construction	Baseline Pre-1988 Diesel	8430	2316576	0.004
2025	Construction	Tier0 Diesel	41332	2316576	0.018
2025	Construction	Tier1 Diesel	146813	2316576	0.063
2025	Construction	Tier2 Diesel	133289	2316576	0.058
2025	Construction	Tier3 Diesel	37144	2316576	0.016
2025	Construction	Tier3 Transitional Diesel	25193	2316576	0.011
2025	Construction	Tier4 Final Diesel	1619064	2316576	0.699
2025	Construction	Tier4 Transitional Diesel	305312	2316576	0.132
2025	Industrial	Baseline Pre-1988 Diesel	940	828857	0.001
2025	Industrial	Tier0 Diesel	6425	828857	0.008
2025	Industrial	Tier1 Diesel	13216	828857	0.016
2025	Industrial	Tier2 Diesel	21035	828857	0.025
2025	Industrial	Tier3 Diesel	5479	828857	0.007

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
2025	Industrial	Tier3 Transitional Diesel	4083	828857	0.005
2025	Industrial	Tier4 Final Diesel	641599	828857	0.774
2025	Industrial	Tier4 Transitional Diesel	136081	828857	0.164
2025	Lawn/Garden	Baseline Pre-1988 Diesel	994	508235	0.002
2025	Lawn/Garden	Tier0 Diesel	6832	508235	0.013
2025	Lawn/Garden	Tier1 Diesel	19587	508235	0.039
2025	Lawn/Garden	Tier2 Diesel	35665	508235	0.070
2025	Lawn/Garden	Tier3 Diesel	4673	508235	0.009
2025	Lawn/Garden	Tier3 Transitional Diesel	4974	508235	0.010
2025	Lawn/Garden	Tier4 Final Diesel	163698	508235	0.322
2025	Lawn/Garden	Tier4 Transitional Diesel	271812	508235	0.535
2025	Logging	Tier2 Diesel	1	15534	0.000
2025	Logging	Tier3 Diesel	135	15534	0.009
2025	Logging	Tier3 Transitional Diesel	7	15534	0.000
2025	Logging	Tier4 Final Diesel	15292	15534	0.984
2025	Logging	Tier4 Transitional Diesel	100	15534	0.006
2025	Oil Field	Tier0 Diesel	0	46829	0.000
2025	Oil Field	Tier1 Diesel	188	46829	0.004
2025	Oil Field	Tier2 Diesel	983	46829	0.021
2025	Oil Field	Tier3 Diesel	2376	46829	0.051
2025	Oil Field	Tier3 Transitional Diesel	24	46829	0.001
2025	Oil Field	Tier4 Final Diesel	38566	46829	0.824
2025	Oil Field	Tier4 Transitional Diesel	4691	46829	0.100
2025	Railroad	Baseline Pre-1988 Diesel	142	14466	0.010
2025	Railroad	Tier0 Diesel	525	14466	0.036
2025	Railroad	Tier1 Diesel	1324	14466	0.092
2025	Railroad	Tier2 Diesel	2201	14466	0.152
2025	Railroad	Tier3 Diesel	1133	14466	0.078
2025	Railroad	Tier3 Transitional Diesel	99	14466	0.007
2025	Railroad	Tier4 Final Diesel	7335	14466	0.507
2025	Railroad	Tier4 Transitional Diesel	1708	14466	0.118
2025	Recreational	Baseline Pre-1988 Diesel	124	42323	0.003
2025	Recreational	Tier0 Diesel	4367	42323	0.103
2025	Recreational	Tier1 Diesel	4425	42323	0.105
2025	Recreational	Tier2 Diesel	4907	42323	0.116
2025	Recreational	Tier3 Diesel	1084	42323	0.026
2025	Recreational	Tier3 Transitional Diesel	45	42323	0.001
2025	Recreational	Tier4 Final Diesel	9808	42323	0.232
2025	Recreational	Tier4 Transitional Diesel	17563	42323	0.415
2025	Underground	Baseline Pre-1988 Diesel	3	10022	0.000

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
	Mining				
2025	Underground Mining	Tier0 Diesel	326	10022	0.033
2025	Underground Mining	Tier2 Diesel	9694	10022	0.967
2026	Agriculture	Baseline Pre-1988 Diesel	11017	2101965	0.005
2026	Agriculture	Tier0 Diesel	30550	2101965	0.015
2026	Agriculture	Tier1 Diesel	127170	2101965	0.061
2026	Agriculture	Tier2 Diesel	208322	2101965	0.099
2026	Agriculture	Tier3 Diesel	149893	2101965	0.071
2026	Agriculture	Tier3 Transitional Diesel	30006	2101965	0.014
2026	Agriculture	Tier4 Final Diesel	1270101	2101965	0.604
2026	Agriculture	Tier4 Transitional Diesel	274906	2101965	0.131
2026	Airport Support	Tier0 Diesel	4	21289	0.000
2026	Airport Support	Tier1 Diesel	71	21289	0.003
2026	Airport Support	Tier2 Diesel	160	21289	0.008
2026	Airport Support	Tier3 Diesel	947	21289	0.044
2026	Airport Support	Tier3 Transitional Diesel	143	21289	0.007
2026	Airport Support	Tier4 Final Diesel	17635	21289	0.828
2026	Airport Support	Tier4 Transitional Diesel	2330	21289	0.109
2026	Commercial	Baseline Pre-1988 Diesel	6340	1494890	0.004
2026	Commercial	Tier0 Diesel	31506	1494890	0.021
2026	Commercial	Tier1 Diesel	72813	1494890	0.049
2026	Commercial	Tier2 Diesel	140642	1494890	0.094
2026	Commercial	Tier3 Diesel	14368	1494890	0.010
2026	Commercial	Tier3 Transitional Diesel	19898	1494890	0.013
2026	Commercial	Tier4 Final Diesel	617017	1494890	0.413
2026	Commercial	Tier4 Transitional Diesel	592306	1494890	0.396
2026	Construction	Baseline Pre-1988 Diesel	6910	2313640	0.003
2026	Construction	Tier0 Diesel	36129	2313640	0.016
2026	Construction	Tier1 Diesel	126166	2313640	0.055
2026	Construction	Tier2 Diesel	116758	2313640	0.050
2026	Construction	Tier3 Diesel	30248	2313640	0.013
2026	Construction	Tier3 Transitional Diesel	22677	2313640	0.010
2026	Construction	Tier4 Final Diesel	1681646	2313640	0.727
2026	Construction	Tier4 Transitional Diesel	293105	2313640	0.127
2026	Industrial	Baseline Pre-1988 Diesel	788	859850	0.001
2026	Industrial	Tier0 Diesel	5765	859850	0.007
2026	Industrial	Tier1 Diesel	11716	859850	0.014

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
2026	Industrial	Tier2 Diesel	19410	859850	0.023
2026	Industrial	Tier3 Diesel	4522	859850	0.005
2026	Industrial	Tier3 Transitional Diesel	3555	859850	0.004
2026	Industrial	Tier4 Final Diesel	677377	859850	0.788
2026	Industrial	Tier4 Transitional Diesel	136716	859850	0.159
2026	Lawn/Garden	Baseline Pre-1988 Diesel	801	512345	0.002
2026	Lawn/Garden	Tier0 Diesel	6061	512345	0.012
2026	Lawn/Garden	Tier1 Diesel	15949	512345	0.031
2026	Lawn/Garden	Tier2 Diesel	30030	512345	0.059
2026	Lawn/Garden	Tier3 Diesel	4547	512345	0.009
2026	Lawn/Garden	Tier3 Transitional Diesel	4852	512345	0.009
2026	Lawn/Garden	Tier4 Final Diesel	174780	512345	0.341
2026	Lawn/Garden	Tier4 Transitional Diesel	275325	512345	0.537
2026	Logging	Tier2 Diesel	0	15362	0.000
2026	Logging	Tier3 Diesel	84	15362	0.005
2026	Logging	Tier3 Transitional Diesel	4	15362	0.000
2026	Logging	Tier4 Final Diesel	15218	15362	0.991
2026	Logging	Tier4 Transitional Diesel	56	15362	0.004
2026	Oil Field	Tier1 Diesel	142	47289	0.003
2026	Oil Field	Tier2 Diesel	777	47289	0.016
2026	Oil Field	Tier3 Diesel	1844	47289	0.039
2026	Oil Field	Tier3 Transitional Diesel	16	47289	0.000
2026	Oil Field	Tier4 Final Diesel	41193	47289	0.871
2026	Oil Field	Tier4 Transitional Diesel	3316	47289	0.070
2026	Railroad	Baseline Pre-1988 Diesel	114	14508	0.008
2026	Railroad	Tier0 Diesel	475	14508	0.033
2026	Railroad	Tier1 Diesel	1196	14508	0.082
2026	Railroad	Tier2 Diesel	2068	14508	0.143
2026	Railroad	Tier3 Diesel	1110	14508	0.076
2026	Railroad	Tier3 Transitional Diesel	98	14508	0.007
2026	Railroad	Tier4 Final Diesel	7771	14508	0.536
2026	Railroad	Tier4 Transitional Diesel	1676	14508	0.116
2026	Recreational	Baseline Pre-1988 Diesel	105	42663	0.002
2026	Recreational	Tier0 Diesel	3872	42663	0.091
2026	Recreational	Tier1 Diesel	3824	42663	0.090
2026	Recreational	Tier2 Diesel	4792	42663	0.112
2026	Recreational	Tier3 Diesel	1067	42663	0.025
2026	Recreational	Tier3 Transitional Diesel	44	42663	0.001
2026	Recreational	Tier4 Final Diesel	10646	42663	0.250
2026	Recreational	Tier4 Transitional Diesel	18315	42663	0.429

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
2026	Underground Mining	Baseline Pre-1988 Diesel	2	9961	0.000
2026	Underground Mining	Tier0 Diesel	258	9961	0.026
2026	Underground Mining	Tier2 Diesel	9701	9961	0.974
2030	Agriculture	Baseline Pre-1988 Diesel	4567	2065696	0.002
2030	Agriculture	Tier0 Diesel	17430	2065696	0.008
2030	Agriculture	Tier1 Diesel	65026	2065696	0.031
2030	Agriculture	Tier2 Diesel	113645	2065696	0.055
2030	Agriculture	Tier3 Diesel	103926	2065696	0.050
2030	Agriculture	Tier3 Transitional Diesel	17339	2065696	0.008
2030	Agriculture	Tier4 Final Diesel	1548337	2065696	0.750
2030	Agriculture	Tier4 Transitional Diesel	195426	2065696	0.095
2030	Airport Support	Tier0 Diesel	0	22757	0.000
2030	Airport Support	Tier1 Diesel	15	22757	0.001
2030	Airport Support	Tier2 Diesel	54	22757	0.002
2030	Airport Support	Tier3 Diesel	362	22757	0.016
2030	Airport Support	Tier3 Transitional Diesel	40	22757	0.002
2030	Airport Support	Tier4 Final Diesel	20348	22757	0.894
2030	Airport Support	Tier4 Transitional Diesel	1936	22757	0.085
2030	Commercial	Baseline Pre-1988 Diesel	2589	1622342	0.002
2030	Commercial	Tier0 Diesel	16578	1622342	0.010
2030	Commercial	Tier1 Diesel	37103	1622342	0.023
2030	Commercial	Tier2 Diesel	94206	1622342	0.058
2030	Commercial	Tier3 Diesel	12475	1622342	0.008
2030	Commercial	Tier3 Transitional Diesel	16155	1622342	0.010
2030	Commercial	Tier4 Final Diesel	807664	1622342	0.498
2030	Commercial	Tier4 Transitional Diesel	635574	1622342	0.392
2030	Construction	Baseline Pre-1988 Diesel	2872	2337054	0.001
2030	Construction	Tier0 Diesel	20698	2337054	0.009
2030	Construction	Tier1 Diesel	62300	2337054	0.027
2030	Construction	Tier2 Diesel	64099	2337054	0.027
2030	Construction	Tier3 Diesel	13990	2337054	0.006
2030	Construction	Tier3 Transitional Diesel	15143	2337054	0.006
2030	Construction	Tier4 Final Diesel	1885374	2337054	0.807
2030	Construction	Tier4 Transitional Diesel	272579	2337054	0.117
2030	Industrial	Baseline Pre-1988 Diesel	328	996971	0.000
2030	Industrial	Tier0 Diesel	3599	996971	0.004

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
2030	Industrial	Tier1 Diesel	5416	996971	0.005
2030	Industrial	Tier2 Diesel	12241	996971	0.012
2030	Industrial	Tier3 Diesel	1911	996971	0.002
2030	Industrial	Tier3 Transitional Diesel	2110	996971	0.002
2030	Industrial	Tier4 Final Diesel	819636	996971	0.822
2030	Industrial	Tier4 Transitional Diesel	151730	996971	0.152
2030	Lawn/Garden	Baseline Pre-1988 Diesel	233	529307	0.000
2030	Lawn/Garden	Tier0 Diesel	3738	529307	0.007
2030	Lawn/Garden	Tier1 Diesel	8584	529307	0.016
2030	Lawn/Garden	Tier2 Diesel	11936	529307	0.023
2030	Lawn/Garden	Tier3 Diesel	3858	529307	0.007
2030	Lawn/Garden	Tier3 Transitional Diesel	4357	529307	0.008
2030	Lawn/Garden	Tier4 Final Diesel	211435	529307	0.399
2030	Lawn/Garden	Tier4 Transitional Diesel	285166	529307	0.539
2030	Logging	Tier2 Diesel	0	15053	0.000
2030	Logging	Tier3 Diesel	7	15053	0.000
2030	Logging	Tier4 Final Diesel	15037	15053	0.999
2030	Logging	Tier4 Transitional Diesel	9	15053	0.001
2030	Oil Field	Tier1 Diesel	31	49586	0.001
2030	Oil Field	Tier2 Diesel	237	49586	0.005
2030	Oil Field	Tier3 Diesel	612	49586	0.012
2030	Oil Field	Tier3 Transitional Diesel	1	49586	0.000
2030	Oil Field	Tier4 Final Diesel	47755	49586	0.963
2030	Oil Field	Tier4 Transitional Diesel	950	49586	0.019
2030	Railroad	Baseline Pre-1988 Diesel	36	14838	0.002
2030	Railroad	Tier0 Diesel	305	14838	0.021
2030	Railroad	Tier1 Diesel	662	14838	0.045
2030	Railroad	Tier2 Diesel	937	14838	0.063
2030	Railroad	Tier3 Diesel	908	14838	0.061
2030	Railroad	Tier3 Transitional Diesel	89	14838	0.006
2030	Railroad	Tier4 Final Diesel	10340	14838	0.697
2030	Railroad	Tier4 Transitional Diesel	1560	14838	0.105
2030	Recreational	Baseline Pre-1988 Diesel	44	44056	0.001
2030	Recreational	Tier0 Diesel	2383	44056	0.054
2030	Recreational	Tier1 Diesel	1782	44056	0.040
2030	Recreational	Tier2 Diesel	3665	44056	0.083
2030	Recreational	Tier3 Diesel	973	44056	0.022
2030	Recreational	Tier3 Transitional Diesel	41	44056	0.001
2030	Recreational	Tier4 Final Diesel	13973	44056	0.317
2030	Recreational	Tier4 Transitional Diesel	21194	44056	0.481

Year	Sector	Engine Technology	Diesel Engine Population	Total Diesel Engine Population By Sector	Tier Distribution By Sector
2030	Underground Mining	Baseline Pre-1988 Diesel	0	9663	0.000
2030	Underground Mining	Tier0 Diesel	77	9663	0.008
2030	Underground Mining	Tier2 Diesel	9586	9663	0.992

Appendix 3. Cetane Response Function

The increase in cetane number that results from the use of an additive depends on the cetane response function for that additive. For the common cetane improver additives 2- ethylhexylnitrate (2-EHN) and di-tertiary butyl peroxide (DTBP), the following response function[14] can be used:

$$CNI = a \times BC^{0.36} \times G^{0.57} \times C^{0.032} \times \ln(1 + 17.5 \times C)$$

Where:

CNI	= Increase in cetane number due to the use of a cetane improver additive
a	= Constant, 0.16 for 2-EHN and 0.119 for DTBP
BC	= Base cetane; cetane number of the unadditized fuel to which cetane improver is added. Equals RC (reference cetane) prior to implementation of the program
G	= API gravity of the fuel to which cetane improver is added. Equals 34.6 prior to implementation of the program
C	= Concentration of the additive in volume percent (equation is valid up to 0.5 volume percent, according to referenced study)

If other cetane improver additives are permitted or required, alternative cetane response functions should be developed.

Where:

$\mathbf{C_B}$	=	The concentration of cetane improver additives before implementation of the cetane improvement program
$\mathbf{C_A}$	=	The total concentration of cetane improver additives after implementation of the cetane improvement program
$\mathbf{[CNI]_B}$	=	Increase in cetane number due to the presence of a cetane improver additive before implementation of the cetane improvement program
$\mathbf{[CNI]_A}$	=	Increase in cetane number due to the presence of all cetane improver additives after implementation of the cetane improvement program

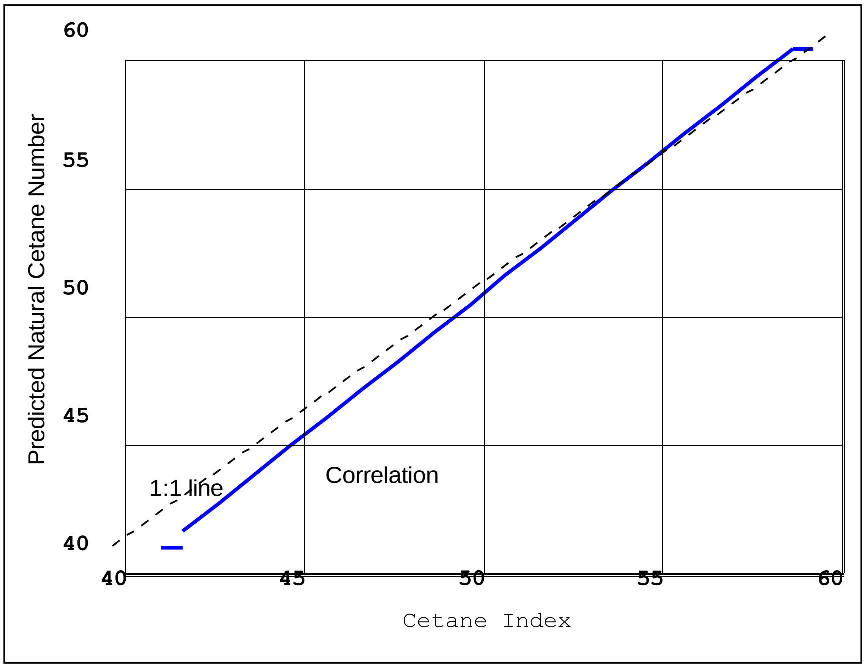
[14] Equation 2 from SAE paper number 972901, "Prediction and Precision of Cetane Number Improver response Equations," Thompson et al.

Appendix 4. Base Cetane Value

Cetane index (CI) is a means for estimating the natural cetane number of a fuel using fuel properties. It allows one to avoid the more costly and involved engine testing required for cetane number under ASTM test method D613. However, there is a measurable bias between CI estimates and actual measurements of natural cetane number made with ASTM D613. A correlation that corrects for this bias for cetane index estimates made through ASTM D-4737 is shown below:

$$\text{Natural cetane number} = 1.107 \times \text{CI} - 5.617$$

This equation can be used to estimate values for the base cetane (BC) in equation (EQ 2).



Appendix 5. Example Emission Reduction Calculation

This appendix provides a hypothetical illustrative example of the calculation of NOx reductions in the context of state-run cetane improvement program in an area that is a Severe nonattainment area for the 2008 ozone NAAQS with an attainment date in July 2027. The values used for the various inputs have been chosen only for purposes of showing how the calculations would be done. The calculated NOx reductions in the area, and thus they are not to be used directly in a SIP or for planning purposes. States that have already example are not indicative of actual reductions that might be expected in a specific nonattainment or maintenance implemented cetane additive programs and states considering implementing cetane additive programs should use values for the requisite inputs that are specific to the program being contemplated.

The example includes the following assumptions:

- Only heavy-duty highway vehicles use cetane improver additives
- Program requirement applies throughout the hypothetical nonattainment area
- Program requirement applies during the months of May through September
- Example calculations represent calendar year 2026. If a cetane additive program is implemented in some other year, both the relevant emissions inventory and the constant 'k' used in equation (EQ 1) would be determined for that year.
- NOx emissions attributable to heavy-duty diesel vehicles in Regulatory Classes 41-49 in 2026 prior to implementation of the cetane improvement program are assumed to be 30 tons per day.

Example

Purpose
Mandatory program for generating emission reductions for the SIP

Program description
Cetane requirement applies to every gallon of diesel sold within the applicable nonattainment area
General distribution of the fuel, not targeted to specific fleets
Minimum total cetane standard of 50

Calculations
Vehicle migration factor: 0.8 (based on an applicable program area of 2804 square miles)
Attainment demonstration in 2026: area specific k-factor = 0.22
Pre-program natural cetane number is 47

$$(\%NOx)_{pv} = 0.22 \times 100\% \times \{1 - \exp[- 0.015151 \times (50 - 47) + 0.000169 \times (50 - 47)^2 + 0.000223 \times (50 - 47) \times (47)]\}$$

$$(\%NOx)_{pv} = 0.27\%$$

$(\%NOx)_{fw} = (\%NOx)_{pv} \times$ vehicle migration factor $(\%NOx)_{fw} = 0.27\% \times 0.8$
$(\%NOx)_{fw} = 0.22\%$

NOx benefits of cetane additive program = Diesel NOx inventory × $(\%NOx)_{fw}$ × Volume fraction affected
NOx benefits of cetane additive program = 30 tons/day × 0.22% / 100%
NOx benefits of cetane additive program = 0.07 tons/day