

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

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

NOTICE

This Technical Report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available.

The purpose in the release of such reports is to facilitate an exchange of technical information and to inform the public of technical developments.

A. Introduction

(Note: As used in this document, the terms “you” and “your” refer to State or States and the terms “we,” “us” and “our” refer to EPA.)

What is the purpose of this document?

This document provides guidance and sets forth the Environmental Protection Agency’s (EPA) policy and interpretation regarding the granting of State Implementation Plan (SIP) credit under section 110 of the Clean Air Act (CAA) for emission reductions attributable to the use of cetane additives in diesel fuel. Cetane improvement programs have the potential to contribute emission reductions needed for progress toward attainment and maintenance of the National Ambient Air Quality Standards (NAAQS). EPA believes that SIP credit is appropriate when there is confidence that cetane improvement programs can achieve emission reductions and meet any other applicable requirements. This document identifies the terms and conditions for establishing and implementing a cetane improvement program and the requirements for approvable SIP submittals and transportation conformity determinations under the Clean Air Act.

This document is intended solely as guidance for SIP credit and does not represent final Agency action. It does not supersede or change any existing federal or State regulations or requirements, including those of an approved SIP. If this guidance is followed, all otherwise applicable CAA requirements pertaining to the crediting of emission reductions for transportation conformity or SIPs apply, including all requirements pertaining to emission reductions for Reasonable Further Progress (RFP) plans, attainment or maintenance strategy. Furthermore, this document does not address the use of NO_x reductions from the use of cetane improvement additives in any form of credit trading program, including programs under EPA’s NO_x SIP call. Additional requirements or limitations may apply in these cases. If information is submitted to EPA that differs from the guidance in this document, EPA will review the information and make a decision as to the appropriateness of its use on a case-by-case basis. This guidance does not prohibit nor substitute for implementation of more stringent requirements if otherwise permitted.

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 cetane number result in reduced emissions of nitrogen oxides. Common cetane improvement additives include 2-ethylhexylnitrate and di-tertiary butylperoxide used at diesel fuel concentrations of generally less than 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 D 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. (See Section G for additional discussion.)

How would "federal preemption" apply to cetane improvement programs?

In general, the 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. However, EPA may waive preemption under certain circumstances, as discussed below.

State adoption of motor vehicle fuel requirements is controlled by section 211(c)(4) of the CAA. 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 40.¹ 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 cetane number rather than cetane index or aromatics. While cetane number of unadditized diesel fuel has an impact on the cetane index of that fuel, increasing the cetane number using additives does not 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. EPA believes there may be State cetane improvement programs that may not be preempted. States should consult with their regional EPA office regarding preemption of specific State cetane programs.

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. 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." EPA has provided guidance on the necessity showing that a State must make in order to meet the preemption waiver requirements of section 211(c)(4)(C). This guidance was distributed in 1997 in the context of State opt-in to RFG and low RVP requirements in ozone SIPs², and readers are referred to that document for more information. States should also consult with their regional EPA office regarding making necessity showings.

A State voluntary or incentive-based cetane control program that did not impose mandatory requirements or obligations on fuel content, typically would not be considered a fuel "control or prohibition." Such a program, therefore, would not be preempted under section 211(c)(4)(A).

¹ 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 § 80.520.

² "Guidance On Use of Opt-In to RFG and Low RVP Requirements In Ozone SIPs," August 1997. <http://www.epa.gov/otaq/regs/fuels/rvpguide.pdf>

B. Federal Criteria for SIPs and Transportation Conformity

What are the basic criteria for using emission reductions in SIPs or transportation conformity?

In order to be approved as a measure which provides additional emission reductions in a SIP or transportation conformity determination, a control measure cannot interfere with other requirements of the CAA, and would need to be consistent with SIP attainment, maintenance, or RFP/ROP requirements. In addition, the control measure would need to provide emission reductions that meet the criteria described below.

(A) **Quantifiable** - The emission reductions from a control measure are quantifiable if they can be reliably and replicably measured. Emission reductions should be calculated for the time period for which the reductions will be used. Sections C through E of this document provide a method which EPA believes is acceptable for quantifying emission reductions.

(B) **Surplus** - Emission reductions are generally surplus and can be used as long as they are not otherwise relied on to meet other applicable air quality attainment, reasonable further progress and maintenance requirements. In the event that the measure is relied on to meet such air quality-related program requirements, they are no longer surplus and may not be used for additional credit.

(C) **Federally Enforceable** - Control measures included in a SIP or SIP revision need to be enforceable. Where the SIP emission reductions are part of a rule or regulation, they are considered federally enforceable if they meet all of the following requirements:

- They are independently verifiable.
- Violations are defined, as appropriate.
- You 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 suits 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.

Specific elements of a compliance and enforcement program associated with a cetane improvement program must normally be approved by EPA's Office of Enforcement and Compliance Assurance. See Section G for additional information.

If a SIP revision is approved under EPA's Mobile Source Voluntary Measures Policy, the State is responsible for assuring that the reductions credited in the SIP occur. The State would need to make an enforceable SIP commitment to monitor, assess and report on the emission

reductions resulting from the voluntary measure and to remedy any shortfalls from forecasted emission reductions in a timely manner. That is, all reductions would need to be achieved by the date the SIP relies on those reductions to meet any attainment, RFP/ROP or maintenance needs. Further, under the policy the total of all voluntary mobile source measures (including cetane-related measures) may not exceed 3 percent of the total reductions needed to meet any requirements for RFP/ROP, attainment or maintenance. In the circumstance where the actual emission reductions achieved are more than the amount estimated in the SIP, you may take credit for the additional emission reductions provided it does not exceed the 3 percent cap on voluntary mobile source measures and meets the other provisions of the Mobile Source Voluntary Measures Policy. If you wish to have a SIP revision approved under the Mobile Source Voluntary Measures Policy consult that policy for further information.³ Additional discussion of a voluntary cetane improvement program can be found in Section F. Please note that the Mobile Source Voluntary Measures Policy is also only guidance and final approval of a program under the policy will be completed through notice-and-comment rulemaking on a SIP submittal.

(D) **Permanent** - The emission reduction would need to be permanent throughout the term that the credit is granted.

(E) **Adequately Supported** – The State would need to demonstrate that it has adequate funding, personnel, and other resources to implement the control measure on schedule.

How can the estimated emission reductions be used for SIP purposes?

For SIP RFP/ROP, attainment or maintenance strategies, the emission reductions which are produced from the cetane-related measure can be used by applying the following criteria:

(A) 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.

(B) 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. In addition, the most recent emissions model approved by EPA should be used in quantifying reductions from SIP control measures that are under development.

³ See "Guidance on Incorporating Voluntary Mobile Source Emission Reduction Programs in State Implementation Plans (SIPs)," Memorandum from Richard D. Wilson, Acting Assistant Administrator for Air and Radiation to EPA Regional Administrators, October 23, 1997. This memo can be found at <http://www.epa.gov/otaq/transp/traqvoldm.htm>.

How can the emission reductions be used for transportation conformity purposes?

EPA's transportation conformity regulation (40 CFR parts 51 and 93) describes the requirements for including emission reductions from on-road mobile control measures in a conformity determination for a transportation plan, transportation improvement program (TIP), or transportation project. If credit is obtained for a cetane improvement measure in a SIP's budget, this does not preclude it from also being recognized in a transportation conformity determination.

To include NO_x emission reductions from a cetane improvement measure in a regional conformity analysis, the appropriate jurisdictions would need to be committed to the measure. The appropriate level of commitment varies according to the requirements outlined in 40 CFR 93.122(a) which are described as follows:

- (A) If the measure does not require a regulatory action to be implemented, it can be included in a conformity determination if it is included in the transportation plan and TIP with sufficient funding and other resources for its full implementation.
- (B) If the measure requires a regulatory action to be implemented, it can be included in a conformity determination if one of the following has occurred:
 - (1) The regulatory action for the measure is already adopted by the enforcing jurisdiction (e.g., a State has adopted a rule to require a control measure);
 - (2) The measure has been included in an approved SIP; or
 - (3) There is a written commitment to implement the measure in a submitted SIP with a motor vehicle emissions budget that EPA has found adequate.
- (C) If the measure is not included in the transportation plan and TIP or the SIP, and it does not require a regulatory action to be implemented, then it can be included in the conformity determination's regional emissions analysis if the conformity determination contains a written commitment from the appropriate entities to implement the measures.

Whatever the case, the emission reductions can only be applied in a conformity determination for the time period or years in which the control measure will be implemented. Written commitments must come from the agency with the authority to implement the measure. The latest emissions model and planning assumptions must be used when calculating emission reductions from the measure, according to 40 CFR 93.110 and 93.111.

Areas should utilize the conformity interagency consultation process to discuss the methods and assumptions used to quantify the reductions from the measure. The conformity determination should include documentation of the methodology, assumptions, and models that were used to calculate emission reductions from cetane improvement measures, as well any commitments that are necessary for implementation, as described above.

What types of penalties can be assessed for not complying with CAA 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 CAA requirements are subject to administrative, civil, and/or criminal enforcement under Section 113 of the CAA, as well as to citizen suits under Section 304 of the CAA. The full range of penalty and injunctive relief options remain available to the federal or State government (or citizens) bringing the enforcement action.

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

The State should submit to EPA a written document which:

- (A) Identifies and describes the cetane-related control measure and its implementation schedule to reduce emissions within a specific time period;
- (B) Contains estimates of emission reductions attributable to the measure, including all relevant technical support documentation for the estimates. States must rely on the most recent information available at the time the SIP is developed pursuant to Clean Air Act §172(c)(3) and 40 CFR 51.112(a);
- (C) Contains federally enforceable procedures to implement, track, and monitor the measure as applicable;
- (D) Enforceably commits to monitor, evaluate, and report the resulting emission reductions of the measure as applicable;
- (E) Enforceably commits to remedy any SIP emission shortfall in a timely manner if the measure does not achieve estimated emission reductions; and
- (F) Meets all other requirements for SIP revisions under sections 110, 172 and 175(a) of the CAA, as applicable.
- (G) In the case of a cetane improvement program which is federally preempted, meets the requirements of section 211(c)(4)(C) of the CAA.

C. Per-vehicle NOx benefits of cetane improvement additives

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 vehicle using cetane-enhanced diesel fuel. The fleet-wide NOx benefits may differ from the per-vehicle 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 issue will be addressed separately in Section D 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. One ready source is the EPA Technical Report entitled, "The Effect of Cetane Number Increase Due To Additives on NOx Emissions from Heavy-Duty Highway Engines."⁴ This report provides estimates of per-vehicle NOx benefits using the following equation, which we will refer to as EQ 1:

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

where

(%NOx)_{pv} = Per-vehicle percent reduction in NOx emissions
k = Constant representing fraction of NOx inventory associated with cetane-sensitive diesel trucks
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.

The per-vehicle NOx benefits of cetane improver additives 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:

⁴ EPA document number EPA420-R-03-002 (February 2003). This document can be downloaded from: <http://www.epa.gov/otaq/models/analysis.htm>. See also EPA document number EPA420-S-03-001 (February 2003), providing a response to comments submitted on the Draft Technical Report by independent peer reviewers.

Constant 'k'

The default values in Appendix A may be used for highway engines. Alternatively, you can generate values specific to the program area by calculating the fraction of the heavy-duty highway diesel NO_x inventory that derives from pre-2003 model year engines for the calendar year of interest. For nonroad engines, constant 'k' is equal to 1.0 until nonroad engines begin to be designed with cetane-insensitive technologies.

RC: Reference cetane

This is the average natural (unadditized) cetane number of diesel fuel prior to implementation of the cetane improvement program. RC does **not** represent the cetane number of the unadditized base fuel **after** the program has been 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 (such as survey data collected annually by the Alliance of Automobile Manufacturers), 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 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.

AC: Additized cetane

This is the increase in cetane number that results from the addition of cetane improvers to an unadditized base fuel. 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:

$$AC = AC_m + BC - RC \quad \text{(EQ 2)}$$

where

- AC = Value of additized cetane used to calculate $(\%NO_x)_{pv}$ 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 D.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 B)

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 fuels properties. However, indirect measurements of fuels properties (i.e. proxy properties) introduce additional uncertainties which may reduce the fleet-wide NOx benefits that can be claimed (see Section D.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 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 D.4 and Appendix B, the presence of any pre-existing cetane improver additives must also be taken into account. See Appendix B.

D. Calculating in-use fleet-wide NOx benefits

As described in Section C, you should first have an estimate of the NOx benefits for a single vehicle using diesel fuel with cetane improver additives before you can estimate the NOx benefits for an entire in-use fleet. The per-vehicle benefit is the value $(\%NOx)_{pv}$ calculated from equation (EQ 1).

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):

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

where

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

1. Program factor F_1

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)

2. Program factor F_2

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 Program⁵.

If the cetane improver additive program applies to both highway and nonroad engines, then equations 3 (EQ 3) and 4 (EQ4, discussed in Section E below) should each be used twice to calculate NOx tons reduced separately for both highway and nonroad, and the results summed. 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.

⁵ See fuels testing protocol at <http://www.epa.gov/otaq/retrofit/retroprotocol.htm>

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 supercedes equation (EQ 1)	(volume of off-highway fuel used in nonroad engines) / (volume of off-highway fuel used in nonroad engines and heaters ⁶)
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

3. Program factor F_3

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 additive 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 additive 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.

⁶ "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 ⁷
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. Program factor F_4

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.

⁷ EPA memorandum of January 28, 2004, from D. Korotney to C. Petti, "Estimation of factors representing vehicle migration for diesel vehicles."

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:

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

where

- CI = Cetane index
- T10 = Distillation property via ASTM D86: temperature in °F at which 10vol% has evaporated
- T50 = Distillation property via ASTM D86: temperature in °F at which 50vol% has evaporated
- T90 = Distillation property via ASTM D86: temperature in °F at which 90vol% has evaporated
- D = Density in g/ml at 15 °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 C 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 B, 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. Examples include Ethyl's proprietary model SPEC and the Petrospec Cetane 2000 Instrument. 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 NO_x 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 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 C 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. $RC \geq 47$ $44 \leq RC < 47$ $RC < 44$	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

E. Calculating tons of NOx reduced

The reduction in NOx tons that results from the cetane improver additive 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):

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

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
$(\% \text{NOx})_{\text{fw}}$	= 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 tons 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. These fuel economy rates can be derived from MOBILE model runs of the area(s) in question.

F. Mobile source voluntary cetane improvement programs

The discussion of quantification of NOx reductions in Sections C, D, and E above presumes that the cetane improvement program has been mandated for a specific geographic area. A State may also establish a mobile source voluntary cetane improvement program. Voluntary measures are discussed generally in Section B in the context of the criteria that programs be federally enforceable. In terms of the quantification of NOx reductions, a voluntary program would be subject to all of the discussion in Sections C through E, with several exceptions.

For instance, equation (EQ 2) is designed to account for the possibility that refiners may lower the natural cetane of their fuel if they know that cetane improvers will be added to the fuel downstream of the refinery. This situation is more likely in the case of a mandatory program than in a voluntary program, since refiners cannot count on the addition of cetane improvers under a voluntary program. Thus if the cetane improver is being added at the terminal level on a voluntary basis, it may be reasonable to avoid measuring the base cetane value BC and simply assume that BC is equal to RC in equation (EQ 2). (However, it may be necessary to measure BC as a means for calculating AC_m , in which case the actual measured value of BC should still be used in equation (EQ 2). See Section D.4 for additional discussion).

Mobile source voluntary cetane improvement programs introduce an additional level of uncertainty associated with projecting the level of future participation. States should follow EPA's Mobile Source Voluntary Measures Policy in making such projections. However, it may be possible to reduce some of the uncertainty in projecting future participation by including certain elements in a mobile source voluntary cetane improvement program. These elements might include specified geographic boundaries within which the cetane improver additives should be used, or a "standard" of Type 1, 2, or 3 as described in Section A.

If the NOx inventory impacts of a mobile source voluntary cetane improvement program are to be measured in real time (for instance, as a check on projections of future participation), then the calculations discussed in Section E may need to be modified. This might be the case if real-time tracking of cetane improver use produces measurements of a specific volume of diesel fuel and a specific increase in cetane number due to the addition of cetane improver to that batch of diesel fuel. The calculation of NOx tons reduced per equation (EQ 4) may require modifications such as the following:

- The replacement of "Diesel NOx Inventory" with values representing fleet-wide grams/gallon factors. Such values could be generated from a combination of MOBILE model output in g/mi for each vehicle weight class and the application of the default fuel economy rates given in Section E. MOBILE model output would necessarily represent the geographic area within which the batch of fuel containing cetane improver additives was needed and was actually used.
- The replacement of "Volume fraction affected" with the volume of the additized batch in question.
- The inclusion of a factor to convert grams into tons

G. Enforcement of cetane improvement programs

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 document does not specify all elements of such a program that might be necessary, but instead lists several areas that should be considered. A State's compliance and enforcement program must normally be approved by EPA's Office of Enforcement and Compliance Assurance as part of the SIP approval process.

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.

With respect to voluntary programs, please consult EPA's Mobile Source Voluntary Measures Policy.

Appendix A

EPA Technical Report EPA420-R-03-002 concluded that many new highway engine designs are largely insensitive to changes in cetane. Cetane improver additives may have no impact on NOx emissions for such engines. To account for this, the Technical Report included a factor 'k' in the equation giving the NOx impact as a function of the increase in cetane number due to the use of additives. This factor 'k' represents the fraction of the highway diesel NOx inventory that derives from cetane-sensitive engines. The Technical Report estimated values for factor 'k' by assuming that 2003 and newer model year highway engines are insensitive to cetane. As a result, the factor 'k' varies by calendar year, as shown in Table A-1. A more complete discussion of how these factors were derived is given in the Technical Report.

Table A-1
Potential yearly weighting factors 'k' for additized cetane model

	Fraction of diesel highway NOx inventory which comes from cetane-sensitive engines
2003	0.93
2004	0.84
2005	0.77
2006	0.70
2007	0.65
2008	0.61
2009	0.57
2010	0.55
2011	0.54
2012	0.53
2013	0.51
2014	0.50
2015	0.48
2016	0.46
2017	0.44
2018	0.41
2019	0.39
2020	0.36

Appendix B

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 function⁸ can be used:

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

where

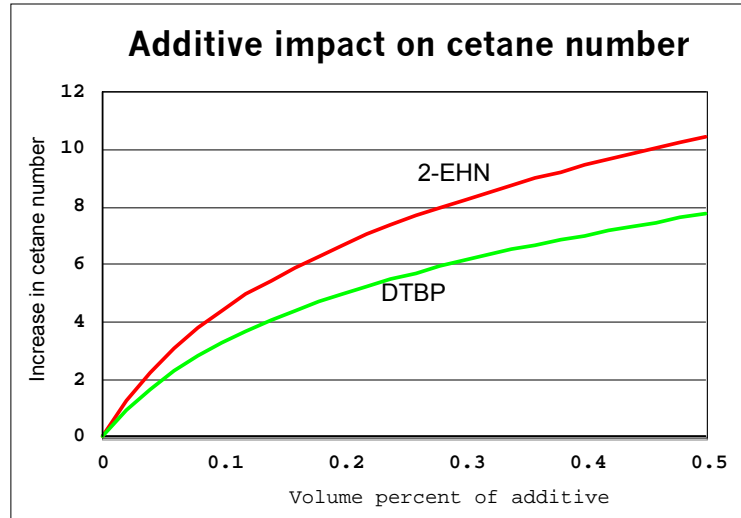
- CNI = Increase in cetane number due to the use of a cetane improver additive
- a = Constant, 0.16 for 2-EHN, 0.119 for DTBP
- BC = Base cetane; cetane number of the unadditized fuel to which cetane improver is added
= RC (reference cetane) prior to implementation of the program
- G = API gravity of the fuel to which cetane improver is added
= 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.

For typical in-use conventional diesel fuel, the response function above generates the following curves⁹:

⁸ Equation 2 from SAE paper number 972901, "Prediction and Precision of Cetane Number Improver response Equations," Thompson et al.

⁹ This graph represents an example of a specific base cetane (BC). The shape of the curve will differ depending on the base cetane of the fuel to which cetane improver is added.



The use of a cetane response function such as that shown above is only valid when a cetane improver is added to a fuel which does not already contain any cetane improver. However, in a cetane improvement program it is possible that cetane improver may be added to a base fuel which already contains cetane improver. In such cases, the use of a cetane response function to predict the incremental increase in cetane number associated with the incremental increase in the concentration of an additive would require two steps.

Using the cetane response function above as an example, the first application of the cetane response function would use a value for the additive concentration C representing the pre-existing cetane improver additives in the fuel, while the second application of the cetane response function would use a value for the additive concentration C representing the total amount of cetane improver additives in the fuel after some incremental amount of cetane improver had been added. The difference between these two applications of the cetane response function would provide an estimate of CNI that best represents the incremental increase in cetane number brought about through the incremental addition of cetane improver. Mathematically, this process would appear as follows:

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

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

$$CNI = [CNI]_A - [CNI]_B$$

where

C_B = The concentration of cetane improver additives before implementation of the cetane improvement program

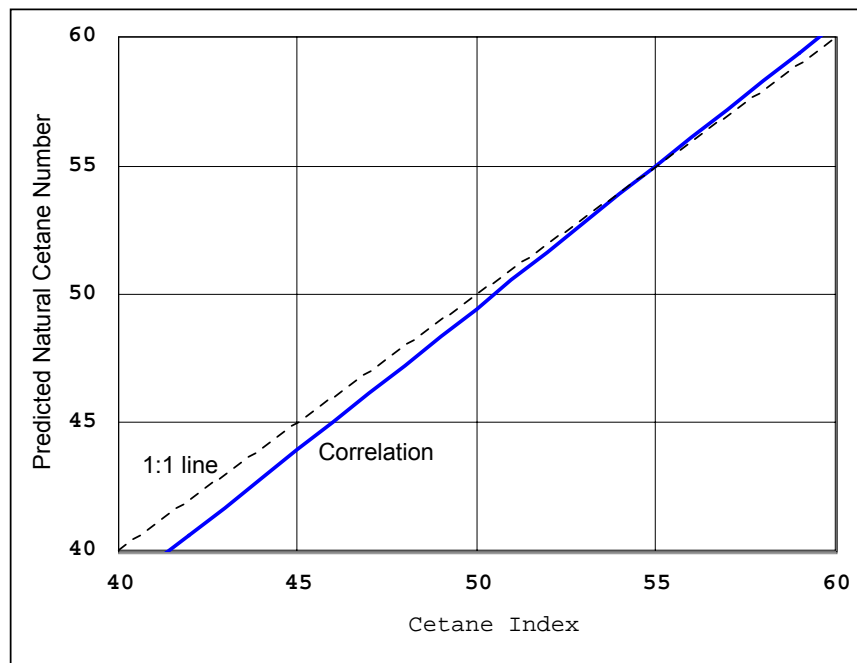
- C_A = The total concentration of cetane improver additives after implementation of the cetane improvement program
- $[CNI]_B$ = Increase in cetane number due to the presence of a cetane improver additive before implementation of the cetane improvement program
- $[CNI]_A$ = Increase in cetane number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

Appendix C

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 D

This appendix provides several illustrative examples of calculations of NO_x reductions in the context of State-run cetane improver additive programs. The values used for the various inputs have been chosen only for purposes of showing how the calculations would be done. The calculated NO_x reductions in these examples are not indicative of actual reductions that might be expected, and thus they are not to be used directly in a SIP or for planning purposes. Parties considering implementing local cetane additive programs should use values for the requisite inputs that are specific to the program being contemplated.

All examples include the following assumptions:

- Only heavy-duty highway vehicles use cetane improver additives
- Programs apply to the State of Tennessee or the five counties comprising the Nashville nonattainment area
- Programs apply during the months of May through September
- Example calculations represent calendar year 2007. 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) must be determined for that year.
- NO_x inventories attributable to heavy-duty diesel vehicles prior to implementation of the cetane improvement program are assumed to be
 - 180 tons per day for the State of Tennessee
 - 30 tons per day for the Nashville nonattainment area

Example D.1

Purpose

Mandatory program for generating SIP credits

Applicable area

Nashville nonattainment area

Program description

Fuel mandate applies to every gallon sold within the applicable counties

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 2007: default k-factor = 0.65

Pre-program natural cetane number is 47

$$\begin{aligned} (\%NOx)_{pv} = 0.65 \times 100\% \times \{ & 1 - \exp[-0.015151 \times (50 - 47)] \\ & + 0.000169 \times (50 - 47)^2 \\ & + 0.000223 \times (50 - 47) \times (47) \} \end{aligned}$$

$$(\%NOx)_{pv} = 0.81\%$$

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

$$(\%NOx)_{fw} = 0.81\% \times 0.8$$

$$(\%NOx)_{fw} = 0.65\%$$

NOx benefits of cetane additive program

$$= \text{Diesel NOx inventory} \times (\%NOx)_{fw} \times \text{Volume fraction affected}$$

$$= 30 \text{ tons/day} \times 0.65\% \times 100\%$$

$$= 0.2 \text{ tons/day}$$

Example D.2

Purpose

Mandatory program for generating SIP credits statewide

Applicable area

State of Tennessee

Program description

Fuel mandate applies to every gallon sold within the State of Tennessee

General distribution of the fuel, not targeted to specific fleets

Minimum total cetane standard of 50

Calculations

Vehicle migration factor: 0.9 (based on an applicable program area of 41,000 square miles)

Attainment demonstration in 2007: default k-factor = 0.65

Absent survey data, pre-program natural cetane number assumed to be 46, with pre-existing additives contributing an additional 1 cetane number, for a total cetane number of 47

$$\begin{aligned} [(\%NOx)_{pv}]_B &= 0.65 \times 100\% \times \{1 - \exp[-0.015151 \times (1) \\ &\quad + 0.000169 \times (1)^2 \\ &\quad + 0.000223 \times (1) \times (46)]\} \quad = 0.31\% \end{aligned}$$

$$\begin{aligned} [(\%NOx)_{pv}]_A &= 0.65 \times 100\% \times \{1 - \exp[-0.015151 \times (50 - 46) \\ &\quad + 0.000169 \times (50 - 46)^2 \\ &\quad + 0.000223 \times (50 - 46) \times (46)]\} \quad = 1.09\% \end{aligned}$$

$$(\%NOx)_{pv} = [(\%NOx)_{pv}]_A - [(\%NOx)_{pv}]_B = 1.09\% - 0.31\%$$

$$(\%NOx)_{pv} = 0.78\%$$

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

$$(\%NOx)_{fw} = 0.78\% \times 0.9$$

$$(\%NOx)_{fw} = 0.70\%$$

NOx benefits of cetane additive program

$$= \text{Diesel NOx inventory} \times (\%NOx)_{fw} \times \text{Volume fraction affected}$$

$$= 180 \text{ tons/day} \times 0.70\% \times 100\%$$

$$= 1.26 \text{ tons/day}$$

Example D.3

Purpose

Mobile source voluntary program for generating SIP credits

Applicable area

Nashville ozone nonattainment area

Program description

Parties may use cetane improver additives at any concentration for any volume of fuel

General distribution of the fuel, not targeted to specific fleets

State has a non-binding commitment from two terminals to use cetane improver additives

- These terminals have historically supplied 20% of Nashville's highway diesel fuel
- These terminals indicate they will additize 80% of their fuel
- The terminals indicate they plan to use 0.05vol% cetane improver additive (2-EHN)

Calculations

Vehicle migration factor: 0.8 (based on an applicable program area of 2804 square miles)

Attainment demonstration in 2007: default k-factor = 0.65

Pre-program natural cetane number is 47

Increase in cetane number assumed to be 3 (based on cetane response function for 0.05vol% of the additive 2-EHN)

$$\begin{aligned} (\%NOx)_{pv} = 0.65 \times 100\% \times \{ & 1 - \exp[-0.015151 \times (50 - 47)] \\ & + 0.000169 \times (50 - 47)^2 \\ & + 0.000223 \times (50 - 47) \times (47) \} \end{aligned}$$

$$(\%NOx)_{pv} = 0.81\%$$

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

$$(\%NOx)_{fw} = 0.81\% \times 0.8$$

$$(\%NOx)_{fw} = 0.65\%$$

NOx benefits of cetane additive program

$$= \text{Diesel NOx inventory} \times (\%NOx)_{fw} \times \text{Volume fraction affected}$$

$$= 30 \text{ tons/day} \times 0.65\% \times (20\% \times 80\%)$$

$$= 0.03 \text{ tons/day}$$