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February 2003

Independent Peer Review of EPA Technical Report EPA420-S-02-012:

“The Effect of Cetane Number Increase Due to Additives on NOx Emissions from Heavy-Duty Highway Engines”

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Peer Reviewers:

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Review Period: September 4, 2002 through November 22, 2002

Assessment and Standards Division
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 the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

Background and Purpose Of This Document

In June of 2002 we released a technical report in draft form for public comment entitled, "The Effect Of Cetane Number Increase Due To Additives on NOx Emissions From Heavy-Duty Highway Engines" (EPA420-S-02-012). Stakeholders were given until July 15, 2002 to provide comments to EPA. After comments were received and reviewed, a number of modifications were made to the technical report. The resulting Revised Draft Technical Report was then given to Drs. Larry Caretto and Nigel Clark to perform independent peer reviews according to the guidelines given in EPA's Science Policy Council Handbook on Peer Review (EPA100-B-00-001). Both of these peer reviews were completed by November 22, 2002, with reports submitted to the EPA.

This document provides a summary of EPA responses to each of the peer reviewers' recommended changes or additions to the technical report or the analyses contained therein. In cases where the technical report has been modified in response to a peer review recommendation, a short description of the modification is given here. Modifications to the technical report itself, however, do not include references to the specific recommendation made by a peer reviewer.

Apart from comparing the responses from the two peer reviews to the four specific questions raised in the original charge, this document does not present or respond to any peer reviewer comments supporting or otherwise agreeing with analyses presented or statements made in the Revised Draft Technical Report. The reader is referred to the peer review reports themselves for these statements of agreement or support. The peer review reports are included at the end of this document.

Table of Contents

Original Charge To Peer Reviewers

Dear Dr. XXXX

This letter serves to establish your intent to be a peer reviewer for the draft EPA technical report entitled, "The Effect of Cetane Number Increase Due To Additives on NOx Emissions from Heavy-Duty Highway Engines." A copy of this report is enclosed. If you agree to perform a review of this document as described in this letter, please indicate so by responding to David Korotney via regular mail or e-mail. Once we receive this response, we will submit the purchase order for your services to our purchasing department. You can begin work after we have informed you that the purchase order for your services has been authorized.

The draft technical report at issue describes an analysis conducted by the Environmental Protection Agency in which existing emissions data from heavy-duty diesel engines was used to determine the degree of correlation between NOx emissions and increases in cetane number brought about through the use of cetane improver additives. The report estimates the percent change in the heavy-duty engine NOx inventory that would be expected to occur if cetane improver additives are used in diesel fuel. These estimates might then be used, for instance, in the context of State Implementation Plans or credit trading programs.

We are submitting this information to you so that we may obtain peer review of the methodology, assumptions, and conclusions we have drawn in this technical report. Your review should make use of your general understanding of the technology used in heavy-duty diesel engines, your statistical expertise, and your knowledge of the relationship between fuel properties, combustion mechanisms, and emissions of regulated pollutants. In your review, you should clearly distinguish between recommendations that are necessary to insure the adequacy of the predictions, and those that you believe should be considered but are not critical. Your comments should be sufficiently detailed to allow thorough understanding by EPA or other parties familiar with the work.

In addition to any issues, comments, or recommendations you include in your review of the draft technical report, you should also address the following specific questions/topics:

1. Is the range of fuels and engines in the database sufficient to form the basis of estimated effects of additized cetane on NOx emissions for the in-use fleet?

2. Is it reasonable to conclude that additized cetane effects on NOx are independent of engine model year?

3. Is it reasonable to assume that all engines sold after 2002 will make use of exhaust gas recirculation?

4. Is there reasonable agreement between the data and the model?

We would appreciate receiving the results of your review within six weeks of start of work. During your review, questions about what is required in order to complete the review or about the draft technical report itself can be directed to the Peer Review Leader via phone, e-mail, or regular mail:

David Korotney
U.S. EPA
2000 Traverwood Dr.
Ann Arbor, Mi 48105
Ph# 734-214-4507
Fax 734-214-4051
korotney.david@epa.gov

Your final review should be provided in written form via regular mail. Your comments should include a cover letter stating your name, the name and address of your organization, what material was reviewed, the number of hours you spent on the review, a summary of your expertise and qualifications, and a statement that you have no real or perceived conflicts of interest. Please also provide an electronic copy of your comments and cover letter, either via e-mail or on a floppy disk included in your submittal via regular mail. The electronic version should be in WordPerfect, MS Word, or some format that can be converted to WordPerfect or MS Word. Please do not provide the draft technical report or your comments to anyone else.

As we have discussed, you will be paid a flat fee of $XXX for this peer review. This fee was calculated based on an estimated XX hours of review time at a rate of $XX per hour. However, spending fewer or more hours than our estimate of XX hours will not affect the fee paid for this work. You may expect to receive payment in full within forty-five (45) days of submitting your invoice and final comments to David Korotney.

Thank you for your time and consideration.

Sincerely,

Chester L. France
Director
Assessment and Standards Division
Office or Transportation and Air Quality

Enclosures

cc: D. Korotney, ASD/NC

Comparison of Answers From Peer Reviewers To The Four Specific Questions Raised In The Charge

Only summaries of the answers from each peer reviewer to the four questions posed in the charge are given here. The reader is referred to the peer review reports for the full answers. EPA responses to any recommendations made by the peer reviewers are addressed in the next section.

1. Is the range of fuels and engines in the database sufficient to form the basis of estimated effects of additized cetane on NOx emissions for the in-use fleet?

Caretto: The range of values for natural cetane and cetane difference are sufficiently broad to form the basis for the resulting regressions. When the database fuels are compared to in-use surveys, the range of the fuels is the same and there should be no significant differences in the additized cetane response for the two sets of fuels. The data on engines built during the 1990's should be representative of the onroad national fleet. The EPA should, however, compare the technology groups of the engines in the database with the engines in the fleet.

Clark: The experimental fuels identified in the SAE papers cover a wider [total] cetane range than is commonly purchased at the pump. This does not diminish the statistical validity of the conclusions. It is probably wise to exclude 2-stroke diesel engines.

2. Is it reasonable to conclude that additized cetane effects on NOx are independent of engine model year?

Caretto: The analysis supports the conclusion that the additized cetane effects are independent of model year.

Clark: I think that the incidence of advanced injection management (such as split injection and rate shaping) may be lower than the report suggests. However, in Figure II.A.2-2 [of the Revised Draft], the range of the NOx response to cetane does shrink for later model years, suggesting that later model year engines exhibit a more precise sensitivity to cetane rating.

3. Is it reasonable to assume that all engines sold after 2002 will make use of exhaust gas recirculation?

Caretto: The conclusion that cetane has no effect on EGR-equipped engines is not supported by tests on different engines. However, engines designed to meet the emission requirements for 2003-and-later will likely be designed so that cetane has no effect on NOx. Therefore, it is still valid to assume that no NOx reduction credit should be given for cetane use in highway engines designed to meet the "2004" emission standards.

Clark: Fearing new EGR tchnology, some line haul companies purchased 2002 technology tractors at a higher rate than predicted, resulting in a lower rate of purchase for 2003+ engines. Thus the rate that EGR-equipped engines enter the fleet may be lower than estimated in the draft report. In addition, it is perhaps not EGR alone, but the complex flow and thermal management schemes, coupled with advanced electronic controls, that change the engine's reaction to fuel properties.

4. Is there reasonable agreement between the data and the model?

Caretto: The small p-values for the regression show a good fit of the model to the data. The wide scatter of individual data points around the 45° line in Figure III.B-2 is typical of such plots when examining the effects of fuels on emissions.

Clark: Even test-to-test variability in transient engine testing is substantial, as evidenced by "round robin" engines tests organized by the EMA.

Peer Reviewer Recommendations and EPA Responses

Recommendation 1: EPA should compare the distribution of engine technology groups in the database with those in the in-use fleet to determine how well the range of engines tested matches those in-use (Caretto)

EPA response to Recommendation 1

Although Figure II.A.2-1 from the Revised Draft Technical Report did present the distribution of engine model years from the database, there was no comparison to the distribution of in-use model years. We have therefore added this comparison to this Figure.

Recommendation 2: Include confidence limits for the final regression equation (Caretto)

EPA response to Recommendation 2

For multi-parameter regression equations of the sort generated by our maximum likelihood curve-fitting approach, there is no straightforward mechanism for combining term-specific standard error estimates into confidence limits. The SAS procedure "proc mix" employed in our analysis does have the capability of generating confidence intervals around every observation in the database, but this falls short of confidence limits around the regression equation itself. In order to generate a quantitative measure of uncertainty, we compared predicted to observed values to estimate the standard error associated with the residuals. A description of this analysis has been added to Section IV.B of the final report, along with a graph illustrating the results.

Recommendation 3: Review evidence for the cause of low cetane sensitivity in engines equipped with EGR. If the lack of a cetane effect is due not just to EGR, revise the report accordingly. (Caretto)

EPA response to Recommendation 3

The evidence identifying a specific cause for lower cetane sensitivity in engines with advanced technology is not conclusive. The primary test program on which our conclusions regarding EGR-equipped engines were based did not include an evaluation of the impacts of injection rate-shaping or other combustion management techniques. In addition, this test program used a prototype, not production, engine with EGR. However, as this peer reviewer pointed out, our assumption of zero-cetane sensitivity for 2003+ model year engines is appropriate regardless of whether that cetane insensitivity is caused by the presence of EGR or some other technology. We have modified the text to highlight this fact. The fact that lower cetane sensitivity in future engines cannot be unambiguously associated with a specific technology does suggest that a future test program is warranted to investigate this issue, but it does not appear to be necessary in order to draw conclusions about additized cetane effects on the in-use fleet.

Recommendation 4: Describe any alternatives to equation (5) that were considered to model the effects of natural cetane changes on NOx (Caretto)

EPA response to Recommendation 4

As described in Section II.B of the final technical report, the high degree of colinearity between natural cetane and other fuel properties presents problems when trying to correlate natural cetane with emissions. In work completed in 2001 and described in the Staff Discussion Document[1], attempts to include natural cetane in correlations between fuel properties and NOx emissions failed - the natural cetane term was not significant, its impact on NOx being surrogated to aromatics and density. The use of additized cetane instead of natural cetane avoids the problems associated with colinearities between fuel properties, and thus results in a less ambiguous and more straightforward correlation with NOx. Given that natural and additized cetane describe overlapping combustion effects, we continue to believe that it is appropriate to use the correlation based on additized cetane to represent the effects of natural cetane on NOx. In addition, we believe that this approach will be environmentally conservative, i.e. result in fewer NOx benefits being ascribed to increases in natural cetane than could actually happen in-use; since changes in natural cetane are usually accompanied by (and in fact usually brought about through) changes in aromatics, NOx emissions from existing engines may be reduced through both the higher cetane and the lower aromatics, resulting in a larger emissions effect than if cetane alone changed. The text in the final technical report has been modified to more clearly state these conclusions.

Recommendation 5: Clarify the policy guidance on the application of this analysis to nonroad engines (Caretto)

EPA response to Recommendation 5

Section I.A was added to clarify that the final technical report is primarily intended to provide the EPA's current understanding of a technical issue. Although the technical analysis contained in the report may be used in EPA policy decisions, those decisions are generally made and applied outside of the technical report proper. Thus the draft technical report's conclusion that "it might be appropriate to apply" the regression equation to nonroad engines was intended to indicate EPA support for this approach on a technical basis while leaving a definitive policy decision to be made at another time or in a more specific context. A sentence has been added to the text indicating that the application of equation (2) to nonroad in any specific context may be

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[1] "Strategies and Issues in Correlating Diesel Fuel Properties with Emissions," Staff Discussion Document, EPA report number EPA420-P-01-001, July 2001

dependent on the availability of supporting data or other relevant factors.

Recommendation 6: Provide the slope and p-value for the comparison between cetane effects on NOx and model year (Caretto)

EPA response to Recommendation 6

Figure III.A.2-2 in the final report has been modified to include the regression lines, and Table III.A.2-1 has been added to show the coefficients and p-values for the least-squares regressions.

Recommendation 7: Provide the actual slope for the regression done on the data shown in Figure III.B-2 [of the revised draft report] as well as the confidence limits. (Caretto)

EPA response to Recommendation 7

Figure IV.B-3 was added to the final report, showing the regression line and the associated confidence interval. The actual slope of the regression line and its p-value have been included in the text.

Recommendation 8: Insert an abstract stating the purpose of the report and the overall conclusions. (Caretto)

EPA response to Recommendation 8

An abstract has been included.

Recommendation 9: The numbering of tables and figures and their associated references must be corrected. (Caretto)

EPA response to Recommendation 9

All the table and figure numbers have been corrected for the final report, along with their associated references.

Recommendation 10: Insert the equation defining the variance inflation factor into the paragraph that introduces this concept. (Caretto)

EPA response to Recommendation 10
The equation defining the variance inflation factor was inserted as suggested.

Recommendation 11: Clarify in the text associated with Figure I.B-1 [of the Revised Draft report] that the data comes from an in-use survey. Clarify that the values in Table I.B-1 are derived from the same in-use survey data shown in Figure I.B-1. Clarify whether the in-use survey data shown in Figure II.A.1-1 is the same as that used in Figure I.B-1. (Caretto)

EPA response to Recommendation 11
Language was added to Section I.B to clarify that the analyses were based on an in-use survey conducted by the Alliance of Automobile Manufacturers in 1999. The in-use surey data shown in Figure II.A.1-1 was collected in 2000, but a review of the 1999 and 2000 surveys indicate that the differences are very minor and would not materially affect the analysis or conclusions. Also, the table and figure numbers were changed in accordance with Recommendation 9.

Recommendation 12: Insert the number of engines at the top of each bar in Figure II.A.2-1. (Caretto)

EPA response to Recommendation 12
The suggested change has been made to Figure II.A.2-1. Also, the figure number was changed in accordance with Recommendation 9. Per Recommendation 1, the same Figure has been used to show the distribution of model years for the in-use 2003 fleet.

Recommendation 13: Indicate somewhere in the report the location of the Web site containing all the background for this report. (Caretto)

EPA response to Recommendation 13
The Web site has been inserted into Section I.B.

Recommendation 14: Correct the spelling of "calendar". (Caretto)

EPA response to Recommendation 14

The suggested change has been made to all occurances in the report.

Recommendation 15: Clarify that "additives" used to increase the cetane number of diesel fuel are limited to peroxides, nitrates, and similar compounds added in very small quantities to specifically and solely affect cetane number. (Clark)

EPA response to Recommendation 15

The text in Section II of the final report has been amended to clarify that other potential bulk blending components such as biodiesel, Fischer-Tropsch diesel, etc. which may increase cetane number were not included in the analysis and thus are not directly represented by the final estimates of additized cetane effects on NOx. The text associate with equation (5) in the final report was also amended to specifically prohibit the application of the correlation to circumstances wherein biodiesel or Fischer-Tropsch fuels are used.

Recommendation 16: Point out that the anticorrelation between additized and natural cetane, as highlighted by the value of -0.35 in Table I.B-2, is due to product requirements rather than properties inherent in the fuel makeup. (Clark)

EPA response to Recommendation 16

The text in Section II of the final report has been amended to highlight this point.

Recommendation 17: Clarify that the following terms are synonomous: additized cetane, additized cetane number, cetane difference, and CETANE_DIF. (Clark)

EPA response to Recommendation 17

These terms are indeed synonomous. The text throughout the final report has been modified to be more consistent in this respect, with "additized cetane" being the primary descriptor. Where necessary, explicit clarifications have been added.

Recommendation 18: Clarify that base fuels in the database had a CETANE_DIF value of zero. (Clark)

EPA response to Recommendation 18

Section III of the final report was amended to clarify this fact.

Recommendation 19: Expound on the impact that repeat measurements have on the database and the subsequent analyses. (Clark)

EPA response to Recommendation 19

Section III.A of the final report states that repeat emission measurements were not averaged nor were they limited in any fashion. The SAS curve-fitting procedure "proc_mix" that was employed in our analysis is able to account for large numbers of repeat observations without allowing them to overly influence the results. This fact has been added to the description of the analysis in Section III.B.

Recommendation 20: Though I understand the argument for log, would a linear fit have changed the conclusions? (Clark)

EPA response to Recommendation 20

The peer reviewer did not advocate a separate analysis to answer this question, and was referring specifically to the use of the natural log of NOx as the dependent variable instead of just NOx. We continue to believe that the primary reason for using the natural logarithm of NOx emissions, i.e. to mitigate the heteroscedastic nature of the NOx measurements, is sufficient to support its use. Besides being a common approach to treating dependent variables in these types of analyses, the use of the natural log also provides the advantage that the conversion of the regression equation to provide the % change in NOx is more straightforward, as described in Section IV.A of the final report. We do not believe that a linear fit would have changed the conclusions. The nonlinearity introduced through the use of the natural log was very minor in the analyses presented in the Staff Discussion Document, and it is unlikely that the very small p-values shown in Table IV.A-2 of the final report would have increased to values at or above 0.10 if a linear fit had been employed. In addition, the use of a log transform for NOx emissions introduces some upward curvature to the correlation which is offset by the existence of the squared cetane difference term in equation (2) which results in an overall downward curvature. If we had used NOx as the dependent variable instead of log NOx, it is likely that the effect of the squared cetane difference term would have been stronger, resulting in effectively the same overall downward curvatuve shown in Figure III.A-1 of the final report.

Recommendation 21: State whether the final estimates of additized cetane effects on NOx apply to locomotives. (Clark)

EPA response to Recommendation 21

The discussion of applicability to nonroad engines in Section IV.C of the final report was amended to specifically exclude locomotives.

Recommendation 22: The draft report indicates that there is also a possibility that natural cetane numbers nationwide will increase with the introduction of ultra-low sulfur highway diesel fuel in 2006. Please indicate whether this result would be due to hydrogenation of the fuel while removing sulfur. (Clark)

EPA response to Recommendation 22
The peer reviewer's understanding is correct, and the text has been modified accordingly.

Recommendation 23: The base level of NOx was not considered in the analysis. It is therefore unclear whether absolute or percent reduction of NOx is more appropriate. (Clark)

EPA response to Recommendation 23
In fact the base level of NOx was included in the analysis. Dummy terms for each engine were included in the regression analysis, and these terms permit each engine to have its own base emissions level. As a result, the percent change estimates provided by equation (4) are apropriately scaled for the base emission level of the engines in the database. In addition, a review of the database indicates that there is no correlation between the cetane impacts on percent change in NOx and the base NOx level of the engine. Thus the percent change values estimated in our analysis should be applicable to engines with any base NOx level.

Recommendation 24: Off-cycle (often steady-state) effects may not have been properly considered. (Clark)

EPA response to Recommendation 24
The peer reviewer cites the exclusion of data collected on the Japanese steady-state cycle as one reason for this concern. In fact that database retained data collected on other steady-state cycles, namely the European R49 cycle. The text in the final report has been amended to highlight this fact. Even so, experience with diesel engine emissions testing strongly suggests that impacts of changes in cetane on NOx emissions are essentially the same for transient and steady-state cycles.

REPORT REVIEW

EPA420-S-02-012 – THE EFFECT OF CETANE NUMBER INCREASE DUE TO ADDITIVES ON NOx EMISSIONS FROM HEAVY-DUTY HIGHWAY ENGINES

Review Prepared for U. S. Environmental Protection Agency
Office of Transportation and Air Quality
Assessment and Standards Division

October 14, 2002

L. S. CARETTO
7805 Cowper Avenue
West Hills, CA 91304

TABLE OF CONTENTS

INTRODUCTION

The U. S. Environmental Protection Agency (EPA) requested an independent peer review of the report entitled “The Effect of Cetane Number Increase Due to Additives on NOx Emissions from Heavy-Duty Highway Engines.” This report, numbered EPA420-S-02-012, is dated June 2002 and is labeled as a revised draft technical report.

The letter requesting the review[1] asked that the following questions be addressed.

1. Is the range of fuels and engines in the database sufficient to form the basis of estimated effects of additized cetane on NOx emissions for the in-use fleet?
2. Is it reasonable to conclude that additized cetane effects on NOx are independent of engine model year?
3. Is it reasonable to assume that all engines sold after 2002 will make use of exhaust gas recirculation?
4. Is there reasonable agreement between the data and the model?

The overall directions for review also call for a clear distinction “between recommendations that are necessary to ensure the adequacy of the predictions and those that [. . .] should be considered but are not critical.”

The body of this review is in the next section. That discussion section presents a brief overview of the report and some general comments. It then addresses the four questions listed above. Finally, additional comments, some simply editorial, are made regarding the report. The recommendations section summarizes the comments and distinguishes between essential recommendations and those that are not critical.

The report draft provided for review was an intermediate draft in which a blank page with the heading “I. EPA Technical Reports” was inserted as a placeholder for material to be added later. Although the remaining sections of the report were renumbered to be consistent with this new section, the tables and figures were not. The discussion in this review of specific report sections, figures, and tables uses the numbers in the draft even though they are not consistent.

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[1] Chester L. France letter to Larry Caretto, August 22, 2002.

DISCUSSION

Scope of the report

The EPA report provides a statistical analysis of existing data on the emission effects of two variables in fuel used in on-highway heavy-duty diesel engines: natural cetane and additized cetane. The latter is defined as the increase in cetane produced by diesel fuel additives designed to increase cetane number.

This report is the result of a process that started in fall 2000 when "EPA voiced concern about the NOx emission reduction credits claimed by Texas [for its low emission diesel (LED) program]." Prior to this report there were meetings with "numerous stakeholders," a July 2001 contractor report by Southwest Research Institute (SwRI),[2] and a July 2001 EPA staff discussion document by EPA.[3] There was also a public workshop held on August 28, 2001. EPA established a web site[4] for this issue that has various reports and memoranda related to this study and stakeholder comments from the public meeting.

The introduction to the report notes that EPA's conclusions on the Texas program were transmitted in a separate memo. It further states that "there is no widely-applicable, EPA-approved model for estimating the emission impacts of more general changes in diesel fuel properties. At this time, EPA has no plans to pursue such a model."

General Comments

In a study like this one, it would be useful to have some quantitative measure of the uncertainty in the results, such as the final regression equation plotted in Figure III.B.1 on page 21. Regression equations by other researchers are shown on the same plot indicating a wide spread in the work of various groups. On this graph it appears that an increase of five in the cetane number due to additives will reduce NOx by about 2% using the regression equation proposed here. However, the other regression equations shown in the figure predict a NOx reduction in the range of 1% to 3% for the same increase in cetane number. Showing the confidence limits on this regression would

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[2] Robert L. Mason and Janet P. Buckingham, "Diesel Fuel Impact Model Data Analysis Plan Review, Draft Final Report, Work Assignment 2-7, EPA Contract 68-C-98-169, Southwest Research Institute, July, 2001.

[3] U. S. Environmental Protection Agency, Strategies and Issues in Correlating Diesel Fuel Properties with Emissions, Staff Discussion Document EPA420-P-01-001, July 2001.

[4] http://www.epa.gov/otaq/models/analysis.htm

give the reader some indication of the reliability of the equation for making predictions. Other areas where confidence limits would add to the report are noted below.

Is the range of fuels and engines in the database sufficient to form the basis of estimated effects of additized cetane on NOx emissions for the in-use fleet?

Fuels

There are two separate questions one can ask regarding the fuels. The question asked here regards the range of fuels. This is separate from the representativeness of the fuels that is addressed in section III.A-1 of the report.

The data to respond to both issues – range and representativeness – are shown in Figures II.A-1 and II.A.1-1 to II.A.1-6 of the report. Figure II.A.1-1 shows a wide range for the natural cetane and cetane differences in the database fuels. This figure shows that the range of values for these properties, which are the ones used in the regressions derived in the report ,are sufficiently broad to form the basis for the resulting regressions.

The issue of representativeness is less certain. Because of the small effect of fuels on emissions (compared to engine effects) and the correlations among various fuel properties, studies of fuel effects on emissions use specially chosen fuels. Such fuels have a wide range in properties to enable effects to be determined with a reasonable number of experimental measurements. In addition, these fuels are often custom blended to avoid collinear effects. This results in experimental fuels that are somewhat different from in-use fuels. This is shown in Figures II.A.1-1 to II.A.1-6 of the report. The distribution of fuel properties, especially sulfur, aromatics, specific gravity and T90, is much narrower in the in-use survey data than it is in the fuels used in the database. Only natural cetane has a similar distribution in both cases.

The report compares the fuel property distributions from the survey data and the report database in terms of the ranges that encompass 90% of the data. This comparison leads the report authors to the conclusion on page 12 that the “database is fully representative of in-use fuels.” This conclusion is correct for the range of properties, but not for the distribution. A more appropriate conclusion is that the fuels in the database have been selected for experimental studies of fuel effects on emissions. Although there are differences in the distribution of properties when the database fuels are compared to in-use surveys, the range of the fuels is the same and there should be no significant differences in the additized cetane response for the two sets of fuels.

Engines

The representativeness of the engines used in the report is analyzed in section III.A.2 in terms of the model year distribution. Twenty-two engines were present in the database with the following model-year distribution: 1991 (5), 1993 (4), 1994 (7), 1996 (5), and 1998 (1). Although the report notes that two-stroke engines and engines with exhaust gas recirculation (EGR) were excluded from the database, there is no analysis of the technology groups to which the remaining engines belong.

Table II.C-2 in the staff discussion document[3] lists of the number of engines and the relative amount of emission data in the various technology groups in the original database. The table shows 73 engines in 16 technology groups in the original database.[5] The technology groups in the original database represent a wide range of in-use engines. Technology groups F and T[6] account for 60% of the emissions data in the original database. When the data for two-stroke engines and EGR-equipped engines are eliminated, there are 65 engines in the original database and groups F and T account for 64% of the emissions data there.

The database-preparation discussion in section III.A of the report refers to the staff discussion document for information about the basic database. The database-preparation procedures were presumably responsible for reducing the number of engines from 73 in the original database to 22 used in this study.

The data on engines built during the 1990s should be representative of the onroad national fleet. In addition, since the proposed final equation allows no credit for engines produced in 2003 and later, the model year mix used for the engines that receive cetane credit will not change significantly as new engines are introduced into the fleet. On this basis, the engines used in the database should be representative.

Because there is no analysis in the report that compares the technology groups of the engines in the database with the engines in the fleet, it is not possible to answer the question of whether or not the range of engines in the database is sufficient. Such an analysis would give a better picture of the similarities and differences between the onroad fleet and the fleet in the database.

On page 23, the report notes that one might use local inventory data on fleet distribution. Urban areas are expected to have a larger proportion of older engines than the national fleet. The regression equation in this report should also be applicable to these areas with the different fleet distributions.

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[5] The text that references this table states that there were 75 engines (some of which were the same engine with different injection timings) in 17 technology groups. The discussion here is based on the data actually in the table.

[6] Both of these technology groups represent turbocharged, direct-injection engines. Group F uses mechanical (inline or rotary) fuel injection and has displacements less than or equal to 9.4 L.. Group T uses electronic unit injection and has displacements greater than 9.4 L.

Is it reasonable to conclude that additized cetane effects on NOx are independent of engine model year?

The report contains an analysis in which the effect of a unit increase in cetane on NOx reduction was analyzed as a function of model year. The data for this analysis are plotted in Figure II.A.2.2 on page 14 of the report. According to the discussion on that page, two separate analyses – one accounting for an engine effect and one without such an effect – showed no statistically significant slope at the $p = 0.1$ level.

This analysis supports the conclusion that the additized cetane effects are independent of model year. However it would be interesting to learn the slope of the regression slope and its p-value.

Is it reasonable to assume that all engines sold after 2002 will make use of exhaust gas recirculation?

The significance of this question is related to the application of the proposed model to the future in-use fleet. The report proposes, in the discussion that begins at the bottom of page 22, that there is no NOx reduction credit for cetane increase in 2003-and-later engines. The absence of cetane effect on 2003-and-later engines is attributed to the presence of EGR on these engines. Because it is not intuitively obvious why EGR should negate the effect of cetane, this review examined the basis for the conclusion about EGR effects.

New emission control technologies are likely to be required to meet the diesel emission standards for 2004. Those standards lower the allowed non-methane hydrocarbons (NMHC) from 1.2 to 0.5 g/bhp-hr, and the current NOx standard of 4 g/bhp-hr will be cut approximately in half.[7] These emission reductions on the diesel engines that have already been subject to significant control will require new control technologies of which exhaust gas recirculation (EGR) is the most likely candidate. The even more stringent diesel emission standards for 2007 will almost certainly require add-on controls for NOx and particulate matter (PM) standards; however, the 2007 standards will continue to require control in the engine itself in addition to the add-on controls.

Under the terms of a 1998 settlement to a civil suit, seven engine manufacturers, who produce nearly all the heavy-duty diesel engines sold in the U. S., agreed to implement the 2004 standards for all engines sold on or after October 1, 2002. Thus, the emission

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[7] There is no actual NOx standard for 2004. Instead, the engine manufacturers must meet a combined NMHC + NOx standard of 2.4 g/bhp-hr; manufacturers can choose to meet an optional NMHC + NOx standard of 2.5 g/bhp-hr combined with a NMHC standard of 0.5 g/bhp-hr.

control technology anticipated for the 2004 standards will be on virtually all heavy-duty diesel engines starting from this October 2002 date. The report uses 2003 and later as the starting point for the installation of technology that meets the new standards.

EPA's relationship with manufacturers regarding future certification plans should give them more data about specific manufacturer's plans regarding future emission control technology than is available to this reviewer. On page 13, the report notes that "there are indications that some manufacturers will not use EGR in their 2002+ engines." Although no quantitative data are presented, there is an implication that the majority of new engines will be using EGR.

Page 15 of the report cites a report by the Heavy-Duty Engines Workgroup (HDEWG) as the "primary source for [EPA's] data on the effects of additized cetane on an EGR-equipped engine." The results from the HDEWG were published in a series of SAE papers in 2000. One paper, which presented the statistical analysis of the study,[8] had the following observations about the effect of cetane:

1. The overall conclusion was that the engine had a "very low sensitivity to cetane number . . . [that] differs from the results of similar experiments in engines that are not equipped with EGR."
2. Table 5 of the paper showed that the regression coefficient for NOx with cetane had a small positive value whose p-value (level of significance) was 0.024.
3. Figure 2 showed that an increase in cetane number from 42 to 52 would *increase* NOx by 1.3%.

The paper reported data with and without EGR, but did not explicitly compare the effects of cetane on NOx, with and without EGR. Table 1, below, is taken from Table 8 of the statistical results paper.[8] The NOx results in this table are the averages of the entries for two fuels with the same cetane number in the original paper. The fuels that have an N in their designation are natural cetane fuels that do not have any additized cetane. *E.g.*, fuels 16 and 16N are both reported as having a "target" cetane level of 52. (The paper contained an analysis that showed the effect of cetane was the same whether the cetane number was produced by an additive or by natural cetane.)

Table 1 – HDEWG Data for Cetane NOx Effect With and Without EGR[8]

Fuels	Cetane	NOx data with EGR			NOx without EGR		
		g/bhp-hr	Percent change		g/bhp-hr	Percent change	
7N+14N	42	2.368	Per step	Initial to final	3.740	Per step	Initial to final
8+8N	47	2.415	2.0%		3.803	1.7%	

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[8] Robert L. Mason *et al*. "EPA HDEWG Program – Statistical Analysis," SAE Paper 2000-01-1859, presented at International Spring Fuel and Lubricants Meeting, Paris, France, June 19-22, 2000.

16+16N	52	2.346	-2.9%	-0.9%	3.684	-3.1%	-1.5%

The results of Table 1 show that the effect of cetane on NOx is similar with or without EGR, for the engine used in the study. In both cases there is an increase of about 2% as the cetane number is increased from 42 to 47 and a decrease of about 3% as the cetane number is increased from 47 to 52. The overall effect of increasing the cetane number from 42 to 52 is a NOx decrease of 0.9% with EGR and a NOx decrease of 1.5% without EGR.

This table shows that the effects of cetane on NOx for this engine are similar with and without EGR. Although the engine has a low sensitivity to cetane, it is likely that this effect is not due to EGR. Instead, it is due to some other differences between this engine and engines tested previously.

One possible explanation may be found in the paper that presents the HDEWG engine test results.[9] Figures 9 to 12 of that paper, and the discussion of those figures, notes that “there is very little premixed burning.” Since the premixed burning phase of diesel combustion is the one that is affected by changes in cetane number, an engine that is designed to nearly eliminate this premixed-burning phase should have a low sensitivity to cetane. The report notes (on page 13) that EPA has “limited information” suggesting that this hypothesis is correct.

According to the full database that EPA used for this study,[10] all the EGR engine data (technology group L) are taken with a single engine, a Caterpillar 3176. Thus the conclusion that cetane has no effect on EGR-equipped engines is not supported by tests on different engines.

This section is supposed to address the following question: is it reasonable to assume that all engines sold after 2002 will make use of exhaust gas recirculation? This question is better restated: Is it reasonable to assume that engines calibrated to meet emission requirements for engines manufactured in 2003-and-later will be designed so that cetane has no effect on NOx emissions?

The answer to the revised question is a guarded “yes.” The only data available for fuel effects on such an engine indicate that cetane will not have a sizeable effect on NOx. (Furthermore the effect of cetane in the one engine tested is a slight – but statistically significant – *increase* in NOx.) A review of the SAE papers discussing the tests on this engine suggests that the explanation for this effect may be the control of the

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[9] Andrew C. Matheaus, *et al*. “EPA HDEWG Program – Engine Tests Results,” SAE Paper 2000-01-1858 presented at International Spring Fuel and Lubricants Meeting, Paris, France, June 19-22, 2000.

[10] This was taken from the Excel file hdd-db7.xls, available at the EPA diesel analysis web site, http://www.epa.gov/otaq/models/analysis.htm.

combustion process to reduce premixed burning rather than EGR. However, this proposed explanation does not change the conclusion of the report that no NOx reduction credit should be given for cetane use in highway engines designed to meet the “2004" emission standards.

The conclusion could be less guarded if data were available in more than one engine designed to meet these standards. However, there are no data that conflict with the observations that one engine calibrated to meet the 2004 emission standards shows a small effect of cetane on NOx emissions and that effect is an increase NOx.

Is there reasonable agreement between the data and the model?

The p-values for the significance of the regression coefficients, shown in Table III.A-2 are all less than 0.0001 except for the natural cetane coefficient which is 0.0057; these small p values show a good fit of the model to the data.

Figure II.B-2 on page 22 shows a comparison of predicted versus observed NOx changes. This plot shows a significant scatter around the 45^o line on which all data should ideally fall. Most of the individual data points lay in a band that is ±2.5 percentage points on either side of the 45^o line. The wide scatter of individual data points around the 45^o line is typical of such plots when examining the effects of fuels on emissions. It would be interesting to know the confidence limits for the mean observed change. The report notes that a regression line through these data had “a slope that is close to 1.0.” The confidence limits on the mean for this regression line would give a quantitative estimate of the agreement between the data and the model.

Although it would be helpful to have the quantitative confidence limit recommended in the previous paragraph, the low p-values for the regression coefficients and the visual comparison of the observed and predicted data in Figure III.B-2 show reasonable agreement between the data and the model.

Other comments

The suggestion on page 25 that a modified version of equation (4) could be applied to changes in natural cetane is not consistent with the equations previously derived. Equation (4) is derived from the percent reduction equation (2). Equation (2) is derived from the basic regression equation (1) by assuming that the percent reduction is due only to additized cetane. The natural cetane of the base fuel and the additized fuel are assumed to be the same. Accordingly, the natural cetane number term drops out of equation (2). If equation (2) were written to consider changes in both additized cetane and natural cetane it would be written as follows.

$$\text{fractional change in NOx} = \exp\{ \begin{aligned}[t] & -0.015151 \, [\, \mathrm{cetDiff}_f - \mathrm{cetDiff}_i \,] \\ & + 0.000169 \, [\, \mathrm{cetDiff}_f - \mathrm{cetDiff}_i \,]^2 \\ & - 0.006014 \, [\, \mathrm{natCet}_f - \mathrm{natCet}_i \,] \\ & + 0.000223 \, [\, (\mathrm{natCet}_f)(\mathrm{cetDif}_f) - (\mathrm{natCet}_i)(\mathrm{cetDif}_i) \,] - 1 \, \} \end{aligned}$$

In this equation natCet_i and natCet_f represent the initial natural cetane number of the initial (base) fuel and natCet_f represents the natural cetane number of the final (modified) fuel. Similarly $\mathrm{cetDiff}_i$ and $\mathrm{cdtDiff}_f$ represent the cetane difference due to additives in the base fuel and the modified fuel, respectively. Equation (5) substitutes the natural cetane terms for the additized cetane terms and does not consider any possible changes in cetane additives between the base and modified fuel.

The discussion of equation (5) implies that the additized cetane equation may be used to estimate, for regulatory purposes, the effects of changes in natural cetane. No reason is given in that discussion for not providing an equation that specifically considers the effects of natural cetane on NOx. Presumably, this was due to the problems associated with modeling natural cetane because of its correlations with other fuel properties. The report should discuss any alternatives to equation (5) that were considered and rejected.

The report could benefit from a brief abstract stating the purpose of the report and the overall conclusions. At present one gets to the bottom of page six before learning that EPA has “determined that correlating of additized cetane with NOx is an appropriate means for providing inventory impact information to anyone considering the use of higher cetane diesel fuel.”

The conclusion near the bottom of page 24 that it “might be appropriate to apply” the regression equation to nonroad engines is not very definitive. Should an area planning a diesel fuel control program claim credit for NOx reductions from nonroad engines? If no policy decision on this issue has been made, the report should say so explicitly. Of course, there are no data on cetane effects in nonroad engines, but one would expect that the NOx effects in nonroad and onroad engines to be similar. A given percent reduction in NOx emissions could become a more significant emission reduction in nonroad engines due to the higher emission rates and longer lifetimes for these engines as compared to highway engines.

Minor editorial comments

The numbering of tables and figures (and the references to these) needs to be redone to reflect the addition of a new section I, EPA Technical Reports. (This section has only its title and a note that the section will be included in the final report.) There are also references to sections that will have to be corrected; *e.g.*, the reference in the next-to-last line on page 12 should be “Section III.B” instead of II.B.

The equation defining the variance inflation factor should be placed in the final paragraph of page 3 where this term is introduced.

The reference for the data in Figure 1.B-1 on page 3 is a 1999 AAM fuel survey. It would be helpful to the reader to indicate briefly in the text, at the point where the reference is made, that the data in the figure come from an in-use survey. This would make it clear that the Figure 1.B-1 and Table 1.B-1 are based on the same data set. At present the mention of in-use survey data, at the top of page 4, is not clear. In addition there is presently a reference to AAM data collected in 2000 on page 9 of the report. Is this a different survey or the same one as cited earlier?

It would be helpful to modify the bar chart in Figure II.A.2-1 on page 13 so that the number of engines for each model year is shown at the top of the bars.

No mention is made of the EPA diesel fuel analysis web site in the report. This is a useful site for anyone who wants to review the background for the present report. This site could be mentioned in the introduction or as a preface to the references section.

The word calendar is misspelled[11] at various places in the report: page 23, last line in both second and third paragraph; page 25, last paragraph, second and sixth lines.

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[11] The spelling used in the report, calender, is allowed by the spell checker in Word Perfect. According to www.dictionary.com, a calender is "a machine in which paper or cloth is made smooth and glossy by being pressed through rollers." This misspelling may be in other places in the report not listed above.

RECOMMENDATIONS

Recommendations necessary to ensure the adequacy of the predictions

The comments in the previous section deal mainly with editorial changes and recommendations for inclusion of more statistical information about existing results. Based on this review there appears no problem with the immediate use of the equations in the report to make useful estimates of the NOx reductions due to the addition of cetane improvers to diesel fuel.

If there is significant use of this approach in future years, the database that justifies the assumption that engines built in 2003-and-later will have no NOx benefit from cetane addition should be based on a larger set of engine data.

Recommendations that should be considered but are not critical

The various recommendations that were made in the previous section are not critical to ensure the adequacy of the predictions. However, these recommendations, summarized below, could improve the usefulness of the report.

- Compare the distribution of engine technology groups in the database with those in the in-use fleet to determine how well the range of engines tested matches those in use.
- Include confidence limits for the final regression equation and the prediction of measured and predicted data.
- Review evidence for cause of low cetane sensitivity in engines equipped with EGR. If you agree that the lack of a cetane effect is not just due to EGR, but to other advanced emission control systems, revise the report accordingly.
- Consider a future test program to verify cetane effects on advanced emission control systems, if cetane increases become a significant NOx control strategy.
- Describe any alternatives to equation (5) that were considered to model the effects of natural cetane changes on NOx.
- Clarify the policy guidance on the application of this analysis to nonroad engines.

PEER REVIEW OF EPA DRAFT TECHNICAL REPORT

"The Effect of Cetane Number Increase Due To Additives on NOx Emissions from Heavy-Duty Highway Engines" (EPA420-S-02-012 / June 2002)

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November 17, 2002; revised December 6, 2002.

PEER REVIEW

The EPA document (EPA420-S-02-012 / June 2002) provides a careful and credible account of the methodology used to arrive at the relationship between diesel fuel cetane number and NOx production for the case of engines that most closely resemble the present day on-highway heavy-duty fleet. The results of this study carefully delineate the different influences of "natural" cetane rating, arising from the gross fuel composition, and of the cetane enhancement arising from the use of fuel additives. The methodology is sound, and the conclusions appear to be reasonable and do not contradict current wisdom on the topic.

On page 3 of the document, the way in which diesel fuel cetane number is attained is categorized into the "natural" and "additized" methods. The report subsequently points out that fuel enhancing additives are used in small quantities in the fuel. However, this report does not allow in its language for the possibility of blending modest quantities of high grade products (such as Fischer-Tropsch paraffinic distillate, or oxygenates) into the fuel. Presumably it is thought that these products would always represent a substantial fraction of the fuel, and therefore be part of the "natural" fuel, but it may prove worth defining the line between additive and blend stock to avoid ambiguity.

The beginning of the report is structured around the relationship between aromatics and cetane number. This relationship is well known, and is usually associated (simplistically) with an aromatic versus straight chain paraffin tradeoff. Presumably the scatter in Figure I.B-1 is due to two factors, namely (i) inaccurate measurement of properties and (ii) the presence of varying quantities of other compounds including olefins and branched species that do not lie directly on the aromatic-straight chain paraffin axis. It is not necessary for clarity of the report to raise this issue, but it does explain the fact that natural cetane and aromatic content enjoy only a 0.57 anti-correlation value in Table I.B-2. I am also told by a refinery expert that many tests and reportings of aromatic content include other compounds with the aromatics. In particular, napthenes may be grouped with aromatics. This will tend to confuse correlations.

An observation, perhaps not central to the document, concerns the strong relationship between T10, T50 and T90 in Table I.B-2. The strength of this relationship may change between the cases of examining only an ensemble of Diesel #2 products, versus an ensemble of a mixture of #1 and #2 products.

The argument on page 5, that the aromatics and specific gravity terms were quite capable of accounting for natural cetane in the NOx model, is clear and credible.

On page 6 it is stated that "Additized cetane is largely uncorrelated with other diesel fuel properties, as shown by the low variance inflation factor in Table I.B-1." However, in Table I.B-2, the value of –0.35 correlating additized cetane and natural cetane is not negligible. This anticorrelation is due to human intervention and the need to enhance fuels with poor natural cetane by using additives to meet cetane minimum standards. As the authors observe later in the document, there is no need to employ additives in a fuel that already has a high natural cetane rating. Perhaps the document could point out that this anticorrelation does exist, but is due to product requirements rather than properties inherent in the fuel makeup. I find it hard to judge how many readers will find this nuance in the statistics obvious, hence my recommendation.

The document needs to be consistent in its meaning of “additized cetane” and “additized cetane number”, and careful in the usage. The footnote to Table I.B-1 provides the definition as a “difference”: are all usages in the text intended to relect difference, or do some reflect the total value? On p.7, in the “Analytical approach” section, the variable CETANE_DIF is mentioned. This is the same as the “additized cetane” defined in the footnote. It would just help the reader to use the same terms, or reference them as the same in the text.

On p.7, presumably a base fuel had a value of CETANE_DIF of zero, and was included. If I am mistaken, the then the text may easily be misread.

Table II.A-1 is very important in showing how the process of eliminating “extraneous” natural fuels separated the natural cetane and additized cetane variables further. However, this separation is merely due to the fact that the experimental fuels identified in the SAE papers cover a wider cetane range than is commonly purchased at the pump. So the database has a range of natural cetane that reflects pump fuel, a range of additized cetane that reflects pump fuels, but a range of total cetane (natural plus additized) that exceeds that of pump fuel. The database range is evidently about 38 to 64 from Figure II.A-1. This does not diminish the value of this review, or diminish the statistical validity of the conclusions: simply put, the motivation for the original research studies differed from the motivation of a refiner blending a product for the market.

On p.8, there is mention that only engines that were tested on both unadditized and additized fuel were considered. When an engine is used to determine emissions using the transient Federal Test Procedure, the engine is first mapped for full torque. Two approaches are possible. Either (i) the engine may be mapped (to determine the torque curve) on a baseline fuel and this one map may be used for generating the test from CFR dimensionless variables for testing and comparing a range of fuels, or (ii) the engine may be mapped on each individual fuel. Essentially, the difference accounts for the de-rating of the engine by some fuels, which may be noticeable with fuels such as diesel emulsions and biodiesel. The influence will usually be greater on PM than NO_X. In this case the mapping issue is not likely to matter much, because fuel density will play the greatest role, and the additives do not change density measurably.

Presumably no test was repeated so many times (see p.8) that the database would be substantially warped by the repeats.

On p.12 the “clean diesel fuel” of California is mentioned. At least one refinery in California still produces a genuine 10% aromatic fuel, but most fuels are “test out” blends, with far higher aromatics. In fact, the issue of using additized test-out fuels in California is precisely the issue being addressed in the present EPA report.

It is probably wise to exclude 2-stroke diesel engines. A few are left in garbage trucks and local dray tractors, but most were used in transit buses and are now being replaced with 4-stroke units.

The authors may be interested to know that Caterpillar used EGR engines to meet California NO_X standards decades ago, but then abandoned the technology. There are very few of these old trucks left in the national fleet, and they differ substantially from advanced electronic EGR engines.

On p.13 the report states “engines built after 1999 will not constitute a majority of the highway engines NO_X inventory for several more years.” Strictly speaking, it is true, but new trucks see the highest VMT, and 2000-2002 trucks already comprise a substantial fraction of the fleet. Also, fearing new EGR technology, some line haul companies purchased 2002 technology tractors at a higher rate than the depressed economy might have predicted (but I have no record of the quantity of these purchases.)

On p. 13 the absence of effect on EGR engines is discussed. This is a very complex issue. It is not perhaps the EGR alone, but the complex flow and thermal management schemes, coupled with advanced electronic controls, that change the engine’s reaction to fuel specifications. Mann et al. (SAE 982486) presented some detail on the interaction of an engine’s fuel injection and control system with fuel parameters. The truth is that the present EPA report is geared to heavy heavy-duty engines with similar unit injector systems and similar injection timing, with turbochargers and intercoolers (that were mimicked in a test cell). Perhaps the largest variation was whether the turbochargers were wastegated or not. It is good that the report examines the influence of the model year on cetane effects. I think that the incidence of advanced injection management (split injection and rate shaping) may be lower in practice than the report suggests, since a 4 g/bhp-hr standard can be met with injection retard, particularly if there is relief through off-cycle operation (see below). What is interesting in Figure II.A.2-2, though, is that the range (and standard deviation) of the response shrinks for later model years, which does suggest a more precise “sensitivity” to the cetane rating.

On p. 14: was a linear fit tried? Engineers tend to be linear people, though I understand the argument for log, and log is often used in emissions work when some higher emitters are encountered. Would a linear fit have changed conclusions? (I am not advocating substantial additional work if this is not known.)

On p.15, it is true that 2-stroke diesels will see little highway use, but they will remain in use in locomotives for some time to come.

On p. 16 “cetane difference” is used: once again, terms should be constant throughout.

The inclusion of the squared terms and interaction term (see p. 16) is important. The interaction term is particularly important, because it will reveal the fact that cetane increases above a certain level are not beneficial. Most NO_X is produced at high load, and hence at high boost, where in-cylinder temperatures are high and promote short ignition delays. These delays become so short in some circumstances, that an increase in cetane number has little effect.

On p. 19, presumably the small increase in natural cetane in 2006 would be due to hydrogenation of the fuel while removing sulfur.

The argument that the turnover is artificial is completely plausible. The “straight line correction” may be needed for “legal defensibility”, but in truth it is not really necessary. No-one is likely to explore fuels above 60 cetane and the turnover is small even up to 65 cetane. The text recognizes this issue.

On p.22 measurement variability is mentioned. Even run-to-run variability in transient engine testing is substantial, as evidenced by “round robin” engine tests organized by the EMA. With small cetane changes, one is fortunate to be able to draw any concrete conclusion.

On p.23, EGR engines are mentioned again. As mentioned previously in this review, EGR is accompanied by other control changes. Pilot (split) injection, with a small pilot quantity, has the potential to eliminate cetane effects almost entirely, except in extreme cold operation cases with poor quality fuel.

In table III.B-1, presumably the high VMT of newer trucks in the fleet has been adequately modeled.

On p. 24, it is argued that off-road engines may benefit according to a similar formula. The exceptions (since 2-stroke technology was excluded) might be GM locomotives, older generator sets (with DDC 71, 92 and 149 series engines) and some marine engines (both GM/DDC and larger bore units). If equation (2) is used for on-road it will at least be conservative (that is, underestimate benefits) because engines with older technology and mechanical injection are likely to be more cetane sensitive. Comments on advanced injection timing presented immediately below are also relevant to the off-road engine issue.

This report specifically excluded engine tests employing the Japanese steady-state cycle. Also, a variable that was not considered in this study was the base level of NOx from the engine. These facts lead to two concerns, namely (i) one can reach different conclusions by considering percent reduction and absolute (brake specific) reduction of NO_X, and (ii) “off-cycle” (often steady-state) effects may not be properly considered. Off-cycle effects are now well understood, and typically lead to an increase in brake-specific NO_X of 2.5 times in the NTE zone for a 5g/bhp-hr. certified engine. Many on-road engines may spend the bulk of their lives emitting at a 12g/bhp-hr level rather than at a transient certification level. It is not clear that cetane enhancement will have the same effect for an advanced injection timing engine as opposed to an engine that has timing set close to TDC. The ignition delay is related to the "integral of the inverse of the exponential function of temperature", and the in-cylinder temperature history will differ for the cases of advanced and TDC timing. The report is predicated on the fact that the FTP represents engine operation and controller (injection timing) behavior, but this might not be so. All of the engines in this study for MY 1990 to MY 1998 will have 4 g/bhp-hr to 6 g/bhp-hr (less safety margin) emissions on the FTP, and the combustion will have a very similar location of peak pressure (as crank angle). Both the off-road engines (which could be 8 to 12 g/bhp-hr engines) and the off-cycle engine operation will not have this constancy. In the case of a 12 g/bhp-hr engine, should one consider absolute or percent reduction of NO_X, and is either truly applicable? This issue goes to the heart of the report, but there is probably little that can be done about it, because few tests will have been performed on US engines with varying cetane rating with non-FTP or steady-state (eg. EURO/OICA) cycles.

Clearly this report cannot deal with all eventualities, but engines under cold start conditions or cold/hot climate operation may deviate from the 68 to 86 degree FTP window of operation and yield different NO_X. In all these cases, correcting using brake specific NO_X rather than percent NO_X would prove conservative.

The last issue that I feel obliged to raise is broader in philosophy than this report addresses. Problems arise in relating emissions and cetane rating because the original definition of cetane number is based on an antiquated engine, with low injection pressure, low in-cylinder charge motion and operating conditions atypical of a present day on-road engine. Fuel providers tailor their product in this regard not to optimize modern engine operation but to cater to this old cetane specification. Cetane may therefore not be correlated unequivocally to ignition delay in modern engines. If cetane rating (by comparison with standards) were measured using a modern engine, with a more meaningful measure of premixed burn, then the difference in effects between natural and additized cetane would be much reduced, and correlations would be superior.

The request for review of this report specifically sought an opinion on whether all post-2002 engines would employ EGR. Most manufacturers have favored the use of EGR to achieve 2003 standards, although there is the option of not meeting standards and absorbing penalties. It is true that EGR technology with present fuel sulfur levels presents materials concerns, and that cooling EGR adds substantial burdens to ultimate efficiency of the engine in vehicle applications. In other words, EGR adds to engine manufacturing cost and complexity, and will detract from fuel economy. It is my opinion that EGR cannot enable 2007-2010 standards without substantial additional engine and controls alterations. It is possible that suggested aftertreatment devices, including SCR catalysts and NO_X adsorbers, will reach a level of success where it is more economical to run a non-EGR engine with aftertreatment rather than an EGR engine with aftertreatment to reach levels below about 0.5g/bhp-hr. of NO_X. In this way, engines in the next decade may not employ EGR, but EGR will predominate over this decade. Also, once engines are fitted with aftertreatment, it is unlikely that the conclusions of this EPA report will be applicable.

In summary, this EPA report has presents a thorough and credible analysis of the effects of additized cetane on NO_X emissions. The assumptions and statistics are reasonable and defensible. The only concerns are that some non-road engines may differ in injection timing and NO_X production from on-road engines, so that the application of this method would be approximate. Also, the reality of off-cycle, high NO_X, operation may not be reflected by FTP tests where timing remains closer to TDC.