UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

August 31, 2018

OFFICE OF
AIR AND RADIATION

Mr. Adam R.F. Gustafson
Boyden Gray & Associates PLLC
801 17th Street N.W., Suite 350
Washington, D.C. 20006

Dear Mr. Gustafson:

This letter is in response to your January 19, 2017, Request for Correction[1] under *the Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by the Environmental Protection Agency* (Information Quality Guidelines).[2] In your Request for Correction (RFC) you raise concerns about the motor vehicle fuel emissions represented in the Motor Vehicle Emissions Simulator model (MOVES2014) and the EPAct/V2/E-89 fuel effects study (EPAct study) on which it is based. EPA has thoroughly reviewed your RFC, and the attached document includes detailed responses to the issues it raised. This letter briefly summarizes EPA's response.

The EPAct study, which provides the data on which the fuel effects for late-model vehicles are based, is a comprehensive and rigorous assessment of the impacts of fuel changes on emissions, including the effects of ethanol blends. This study was a result of EPA's staff experts consulting with other experts in the fields of fuel production and blending, vehicle production, emissions testing, modeling, statistical analysis and design of experiments, along with careful oversight of the testing contractor (an organization with considerable experience and expertise in automotive emissions testing). The EPAct study was objectively designed and appropriately informed by previous research. The EPAct study's test fuels were representative of market fuels, and their blending was appropriate and necessary for a research project designed to study the effects of fuel properties on emissions. The EPAct study also controlled for confounding variables. The fuels selected for speciation reflected important research interests and the selection of pollutants reflected well-established EPA priorities. Following the completion of the study, the design and data analysis were peer reviewed by external experts in emissions measurement and modeling following procedures outlined in EPA's Peer Review Policy and Peer Review Handbook.

[1] RFC 17001, January 2017 https://www.epa.gov/quality/epact-fuel-effects-study-rfc-17001.
[2] *Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by the Environmental Protection Agency,* EPA, 2002. (67 FR 63657).

The EPAct study results are consistent with a broad review of the literature, and the EPAct study results were appropriately implemented in the MOVES model. Experimental results must be interpreted consistent with both the experimental design and analysis method. Many of the concerns expressed in the RFC are based on misunderstanding of the study design and misinterpretation of the results. The RFC focuses entirely on results related to ethanol content, which is just one of several fuel properties included and evaluated in the research and the model. Furthermore, the RFC confounds and conflates the *ethanol content* of gasoline with the *addition of ethanol* to gasoline and all its resulting impacts on other fuel properties. As a result, the RFC misunderstands the complexities involved in applying the EPAct study results and MOVES model to the broad range of market fuels and use cases. The EPAct study results were appropriately incorporated in MOVES. In addition, the MOVES2014 model uses data from four carefully-designed studies (CRC E-65, E-65-3, E-77-2 and E-77-2b) that developed innovative methods to understand fuel property effects on different evaporative emission processes including permeation and vapor venting. EPA believes these studies are unbiased and appropriately control for factors relevant in modeling of permeation and other evaporative emissions.

Based on a detailed review of the RFC, EPA is denying the request to withdraw the results of the EPAct study on exhaust emissions, or CRC studies on evaporative emissions, from MOVES. The current MOVES documentation informs users that ethanol blends above E15 should not be modeled, and the Fuel Wizard interface that adjusts fuel properties to accommodate user inputs will not allow users to input ethanol blend levels greater than 17.5%. To further assure that users do not model emissions beyond the appropriate range when replacing default fuel parameters with local information, we are clarifying the MOVES2014 Technical Guidance as part of the MOVES2014b release. We also plan to include in the next major public update to MOVES a check in the county and project-level Fuel Formulation Importer functions that prevents users from entering gasoline blends with more than 15 percent ethanol.

In addition, as a normal process, EPA will continue to update its fuel effects models, fuel supply databases, and other inputs to MOVES as more data becomes available. EPA recognizes that MOVES needs regular updates as vehicles and fuel supplies continue to evolve, for which reason EPA also regularly updates its emissions model to reflect new scientific information. The EPAct study itself was conducted to update the understanding of gasoline fuel effects on exhaust emissions from vehicles meeting Tier 2 emissions standards, as fuel effects in prior emissions models were based on testing of vehicles employing older technologies. EPA continues to welcome additional high-quality datasets that may provide useful improvements to MOVES.

EPA remains committed to using the best available science when developing or changing regulations, standards, and reports. If you are dissatisfied with this response, you may submit a Request for Reconsideration (RFR). The EPA requests that any such RFR be submitted within 90 days of the date of EPA's response. If you choose to submit an RFR, please send a written request referencing the number assigned to the original Request for Correction (RFC #17001) to the EPA Information Quality Guidelines Processing Staff via mail (Information Quality

Guidelines Processing Staff, Mail Code 2811A, U.S. EPA, 1200 Pennsylvania Ave., N.W., Washington, D.C. 20460) or electronic mail (quality@epa.gov). Additional information about how to submit a RFR can be found on the EPA IQG website (http://www.epa.gov/quality).

Thank you for your interest in EPA's information quality.

Sincerely,

William L. Wehrum
Assistant Administrator
EPA Office of Air and Radiation

cc: Vaughn Noga
Principal Deputy Assistant Administrator
and Deputy Chief Information Officer, OARM

Vincia C. Francis-Holloman
Director, EQMD

Attachment

AGENCY RESPONSE

to

REQUEST FOR CORRECTION OF INFORMATION

PETITION #17001

Concerning the

EPAct/V2/E-89 Fuel Effects Study

and the

Motor Vehicle Emissions Simulator (MOVES2014)

Developed by

The USEPA Office of Transportation and Air Quality

Table of Contents

1 Executive Summary

1.1 General Background on the Request and the Parties Involved

On January 19, 2017, EPA received a Request for Correction of Information, under the Information Quality Act, related to the MOVES (MOtor Vehicle Emission Simulator) model and the Energy Policy Act(EPAct)/V2/E-89 light duty vehicle emissions study. The petitioners submitting the Request are the states of Kansas and Nebraska, the Energy Future Coalition (EFC), and the Urban Air Initiative (UAI) (hereafter collectively "the petitioners"). From 2008 to 2013, EPA/OTAQ, in conjunction with the Department of Energy (DOE) and the Coordinating Research Council (CRC) conducted a large study to assess the impacts of fuel changes on emissions from Tier 2-compliant passenger vehicles. The results of this study, EPAct/V2/E-89 (hereafter "EPAct"), were subsequently incorporated into the 2014 version of the MOVES model ("MOVES2014").

Within the Environmental Protection Agency, the Office of Transportation and Air Quality (OTAQ) is responsible for developing and implementing regulations covering mobile-source emissions, including exhaust and evaporative emissions from cars and trucks. One component of this work is developing and maintaining data and models that estimate emissions from mobile sources, which involves quantifying and modeling the effect of changes in fuel composition on emissions. The MOVES model is a configurable software tool published by OTAQ and used by state agencies, researchers, and others to estimate emission inventories from the mobile-source sector. MOVES generates its outputs from a large database of laboratory and real-world emission observations, as well as a national fuel-property database, both of which are regularly updated to reflect new study results and other data sources. Revised versions of MOVES are released every 2-4 years.

1.2 Brief Summary of Petition Request

The petitioners request that EPA withdraw or substantially revise the EPAct study results and MOVES2014 on the basis that they are erroneous and result in "spurious comparisons between fuels with different levels of ethanol content." Specifically related to the EPAct exhaust emissions study, the petitioners state that the study design was influenced by "financially interested third parties" (namely oil companies, their employees or former employees), used test

fuels unrepresentative of market gasoline, and didn't control for various confounding factors. The petitioners also state that the MOVES model propagates the errors from the EPAct study in estimates of exhaust emissions, and in relating evaporative emissions to fuel properties, relies on prior flawed studies sponsored by "biased third parties," and in addition, contains erroneous information on the national fuel supply.

1.3 Brief Summary of EPA Response

The EPAct study,[1,2] which provides the data on which the fuel effects for late-model vehicles are based, is a comprehensive and rigorous assessment of the impacts of fuel changes on emissions, including the effects of ethanol blends. This study was a result of EPA's staff experts consulting with other experts in the fields of fuel production and blending, vehicle production, emissions testing, modeling, statistical analysis and design of experiments, along with careful oversight of the testing contractor (an organization with considerable experience and expertise in automotive emissions testing). The EPAct study was objectively designed and appropriately informed by previous research. The EPAct study's test fuels were representative of market fuels, and their blending was appropriate and necessary for a research project designed to study the effects of fuel properties on emissions. The EPAct study also controlled for confounding variables. The fuels selected for speciation reflected important research interests and the selection of pollutants reflected well-established EPA priorities. Following the completion of the study, the design and data analysis were peer reviewed by external experts in emissions measurement and modeling following procedures outlined in EPA's Peer Review Policy and Peer Review Handbook.[3]

The EPAct study's results are consistent with a broad review of the literature, and the EPAct study results were appropriately implemented in the MOVES model. Experimental results must be interpreted consistent with both the experimental design and analysis method. Many of the concerns expressed in the Request for Correction (RFC) are based on misunderstanding of the study design and misinterpretation of the results. The RFC focuses entirely on results related to ethanol content, which is just one of several fuel properties included and evaluated in the research and the model. Furthermore, the petitioners confound and conflate the *ethanol content* of gasoline with the *addition of ethanol* to gasoline and all of its resulting impacts on other fuel

properties. As a result, the RFC misunderstands the complexities involved in applying the EPAct study results and MOVES model to the broad range of market fuels and use cases.

The EPAct study's results were appropriately incorporated in MOVES. In addition, the MOVES2014 model uses data from four carefully-designed studies (CRC E-65[4], E-65-3[5], E-77-2[6] and E-77-2b[7]) that developed innovative methods to understand fuel property effects on different evaporative emission processes including permeation and vapor venting. EPA believes these studies are unbiased and appropriately control for factors relevant in modeling of permeation and other evaporative emissions.

Based on a detailed review of the RFC, EPA is denying the request to withdraw the results of the EPAct study on exhaust emissions, or CRC studies on evaporative emissions, from MOVES. The current MOVES documentation informs users that ethanol blends above E15 should not be modeled,[8] and the Fuel Wizard interface that adjusts fuel properties to accommodate user inputs will not allow users to input ethanol blend levels greater than 17.5%. To further assure that users do not model emissions beyond the appropriate range when replacing default fuel parameters with local information, we are clarifying the MOVES2014 Technical Guidance as part of the MOVES2014b release.[9] We also plan to include in the next major public update to MOVES a check in the county and project-level Fuel Formulation Importer functions that prevents users from entering gasoline blends with more than 15 percent ethanol.

In addition, as a normal process, EPA will continue to update its fuel effects models, fuel supply databases, and other inputs to MOVES as more data becomes available. EPA recognizes that MOVES needs regular updates as vehicles and fuel supplies continue to evolve, for which reason EPA also regularly updates its emissions model to reflect new scientific information. The EPAct study itself was conducted to update the understanding of gasoline fuel effects on exhaust emissions from vehicles meeting Tier 2 emissions standards, as fuel effects in prior emissions models were based on testing of vehicles employing older technologies. EPA continues to welcome additional high-quality datasets that may provide useful improvements to MOVES.

2 Actions taken by EPA to Assess Emissions Impacts of Ethanol and other Fuel Properties

Between 2006 and 2013 EPA undertook the design and conduct of several emission test programs (the terms "emission test program" and "emission study" are used interchangeably

throughout this document) as well as collaborated with outside organizations doing similar work, such as the Coordinating Research Council and contractors such as Southwest Research Institute, to generate a large amount of data describing the effects of fuel properties on emissions from gasoline vehicles. This section describes in detail the goals, designs, and procedures used in those studies as background for addressing specific criticisms made by the petitioners.

2.1 Exhaust Test Program

The EPAct study was conducted in three phases, the third and final being the collaborative study undertaken with the National Renewable Energy Laboratory (NREL) and CRC that produced the large database of vehicle and fuel emission test data from which statistical fuel effects models were eventually derived. The overall design of what would become Phase 3 began in 2006 and included two pilot studies, called Phase 1 and Phase 2. These pilot phases ran from May 2008 through February 2009, and tested the full vehicle fleet on three fuels under various conditions to observe general emission trends and evaluate test procedure details. During this time, the formulation (or specification) and blending (or manufacture) of the 27 Phase 3 test fuels was underway. Emission testing for Phase 3 occurred between March 2009 and May 2010. Review, analysis, and publication of the data and results was completed in April 2013 and published in two reports available via the EPA website.[1,2]

2.1.1 Statutory Directive and Program Scope

Prior fuel effects models, such as the EPA Predictive Model and Complex Model, were based on data from 1990s-technology vehicles meeting the Tier 0 and Tier 1 emission standards, with emission levels an order of magnitude higher than Tier 2-compliant vehicles (which began market phase-in in 2004). With the fleet turning over to a new generation of vehicles, the Agency and stakeholders were interested in generating a coherent body of updated fuel effects data on which future policy could be based. Recognizing this issue, the U.S. Congress in Section 1506 of the Energy Policy Act of 2005 instructed EPA to "*develop and finalize an emissions model that reflects, to the maximum extent practicable, the effects of gasoline characteristics or components on emissions from vehicles in the motor fleet during calendar year 2007*." [a] EPA

[a] See also Clean Air Act 211(q)(2) as amended.

fulfilled this directive first by conducting the "EPAct Study" and then incorporating its conclusions into MOVES.

The statutory phrase "*effects of gasoline characteristics or components*" is a fundamental aspect of the work, acknowledging the fact that fuel parameters may vary independently of each other between regions, points in time, or policy scenarios. Thus, the emission test program was to be designed in such a way as to produce emission models able to evaluate as independently as possible the adjustment of fuel characteristics or components thought to have the largest impacts on emissions in market fuels.

2.1.2 Review of Past Studies and Data to Inform Development of New Work

There are hundreds of physical and chemical properties associated with gasoline. Since testing all possible properties would be prohibitively expensive and time consuming, and since not all properties have meaningful impacts on vehicle emissions, the scope of the EPAct test program was narrowed to a manageable level.

EPA considered available data from prior test programs, giving special attention to the expected magnitude of emission changes caused by fuel properties, any evidence of non-linear or interactive impacts with other fuel properties, and whether sufficient data on recent vehicle technologies might already exist. Databases available at the time (2006-7) for estimating the magnitude of emission impacts included those associated with the EPA Complex and Predictive models, the California Air Resources Board Predictive Model, the CRC E-67 and E-74b test programs, as well as the 2005-6 Mobile-Source Air Toxics (MSAT) test program conducted by EPA and several automakers. Table 2-1 lists the parameters initially considered as candidates for study and summarizes selection criteria related to each.

Table 2-1. Fuel Parameters Considered for Study in the EPAct Program.

Fuel Parameter	Data Availability for Tier 2 Vehicles	Anticipated Level of Emission Impact
Aromatics content (% volume)	Little	High
Ethanol content (% volume)	Some	Uncertain
Vapor pressure (psi)[b]	Some	Uncertain
50% Distillation temperature (T50, °F)[c]	Little	Uncertain
90% Distillation temperature (T90, °F)[c]	Little	Uncertain
Sulfur content (% volume)	Some	High
Olefin content[d]	Little	Uncertain
Octane number[e]	Little	Low
Drivability index[f]	Little	Low
Total oxygen content	Little	Uncertain
Polyaromatics content	Little	Uncertain

Initial assessment of costs and program duration suggested it would not be feasible to include more than five fuel parameters and their interactions. Based on assessment of the criteria shown, the first five parameters in this table were chosen as the variables for evaluation in this study. Two other parameters, olefin and sulfur content, were also of interest but were deferred for examination elsewhere. The effect of olefin level was tested in a follow-on study funded by CRC using the same test laboratory and vehicles, with results published by CRC as report E-83.[10] Evaluation of the effect of sulfur required a different program design due its impact on the vehicle exhaust after-treatment catalyst, and during 2009-10 EPA conducted such a test program with a large number of in-use Tier 2 vehicles.[11]

[b] For fuels, the value used is "Reid Vapor Pressure" (RVP), defined as the vapor pressure of the liquid fuel at 100°F.
[c] The 50% and 90% distillation temperatures (or T50 and T90) represent the temperatures at which 50 and 90% of the sample being distilled has been recovered as condensate.
[d] Also known as "alkenes," olefins are defined as hydrocarbon compounds in which two or more carbon atoms are linked by double bonds.
[e] Octane number refers to the susceptibility of a fuel to premature ignition, or "knock," which occurs if the fuel-air mixture explodes under compression before the spark plug fires.
[f] "Drivability index" represents a fuel's performance during cold start and engine warm-up. It is calculated from the fuel's 10%, 50% and 90% distillation temperatures (T10, T50 and T90), and its ethanol content (vol.%).

2.1.3 Selection of Five Gasoline Properties and Their Ranges

The EPAct study was designed to comply with Congress' instructions to create an emissions model that reflects how the individual properties of gasoline affect vehicle emissions (Clean Air Act section 211(q)(2)). Given the unique nature of the roughly 50,000 batches of gasoline produced in or imported into the U.S. each year and the wide range in various fuel properties,[12,13] EPA designed the study's test fuels with certain properties varying in a systematic way across a multi-dimensional matrix so that results could be used for the development of statistical models capable of predicting emissions for the range of in-use fuels without having to measure emissions on each fuel blend separately, which is not feasible.

Fuel parameters may have linear or nonlinear impacts on emissions. To capture a nonlinear impact, three or more treatment levels of a given parameter must be included in the study design. Results from prior work, such as the CRC E-67 study, suggested that ethanol content as well as distillation parameters T50 and T90 (temperatures at which 50% and 90% volume, respectively, of the gasoline has been distilled) may have nonlinear impacts on emissions.[67] Based on this information, EPA originally planned to test three levels of ethanol spanning the range of E0-E10 (10% ethanol being the legal limit for market fuels at that time). In light of a petition from Growth Energy for a waiver for E15 from the "substantially similar" requirements of the Clean Air Act, DOE (via the National Renewable Energy Laboratory (NREL)) offered additional funding for E15 and E20 test fuels to broaden the database to include gasoline-ethanol blends that might be expected to appear in the market in the future.[g] After this adjustment, four levels of ethanol were selected (0%, 10%, 15%, and 20% by volume). Due to the known impact of ethanol on the T50 of gasoline, five levels of T50 were chosen to allow detailed characterization of the impacts of ethanol apart from those of T50 and assess any interactive effects. Finally, to examine potential nonlinear impacts of T90, three levels were tested.[h] The remaining two parameters, aromatic content and Reid Vapor Pressure (RVP) (reported in this program as DVPE[i]), had two levels.

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[g] Letter to The Honorable Lisa Jackson, Administrator of EPA, from General Wesley Clark and Jeff Broin, Co-Chairmen of Growth Energy, March 6, 2009.

[h] The intermediate level of T90 occurs along one edge of the fuel domain in Phase 3. Statistical analysis of any nonlinear T90 effect was intended to rely on a fuel used in Phase 1 of the program as an additional source of data for the intermediate T90 level.

[i] Dry Vapor-Pressure Equivalent.

The parameter ranges to be covered for T50, T90, aromatic content, and RVP were selected to represent the range of in-use fuels based on a review of the Alliance of Automobile Manufacturers' (AAM) 2006 North American Fuel Survey. This database includes several hundred samples taken twice a year from retail outlets in about two dozen cities across the country. The survey is not a statistically representative sample of all gasoline sold, but is large enough that its results agree well with the national averages generated from refinery batch reports submitted to EPA which do include all gasoline produced or imported.[12] The utility of the AAM surveys is the larger number of fuel properties measured compared to EPA batch reports. Since the effect of fuel changes on emissions was expected to be small in comparison to other potential factors (e.g., test-to-test or vehicle-to-vehicle variability), and it was speculated that fuel effects on Tier 2 vehicles might be smaller than those seen in prior test programs on older technology vehicles, the span of fuel parameter ranges was maximized to increase the likelihood of discerning statistically significant results. Test fuel parameter ranges were originally drafted to span roughly the 5^{th} to 95^{th} percentiles of survey results for U.S. gasoline, though some test fuel parameters were outside the range of in-use fuels (e.g., ethanol content above 10 percent) and others were adjusted after the actual blending process began (discussed further below). The intent of collecting data using test fuels that span the range of in-use fuel properties is that the resulting emissions models do not rely on mathematical extrapolation when applied to the broad range of in-use gasolines. Models based only on test fuels with properties near the market average could produce significant uncertainty when applied to fuels different from average.

An intermediate level of T50 in E0 fuels was selected to coincide with the high level of T50 in E10 fuels. Similarly, an intermediate level of T50 in E10 fuels was selected to coincide with the low level of T50 in E0 fuels. For E15 and E20 fuels, the T90, aromatic content, and DVPE ranges selected for E0 and E10 fuels were applied. A single level of T50 was selected for E20 blends based on the information obtained from CRC 2006 CRC Hot-Fuel-Handling Program[14] as well as petroleum industry sources which indicated that it was largely independent of the hydrocarbon fraction of the fuel and would not deviate more than several degrees from 160°F

due to the high fraction of ethanol.[j] Two levels of T50 were selected for the E15 fuels, the low level equal to the lowest T50 assumed for E10 fuels and the high level being a linear interpolation between the highest T50 of E10 fuels and the sole T50 level of E20 fuels. It is important to remember that at the time this fuel matrix was designed, neither E15 nor E20 were commercially available and therefore no information was available on typical distillation properties of these fuels. Table 2-2 shows the levels and range of parameters chosen during the initial design of the Phase 3 fuel set. Some of these parameters were adjusted during subsequent blending steps, as discussed below.

Table 2-2. Fuel Parameters and Ranges Targeted for Study in the EPAct Program.

Fuel Parameter	Number of Levels	Target Values
Ethanol (vol%)	4	0, 10, 15, 20
T50 (°F)	5	150, 160 (E20 only), 190, 220, 240
T90 (°F)	3	300, 325, 340
Aromatics (vol%)	2	15, 40
RVP (psi)	2	7, 10

2.1.4 Use of a Factorial Design to Statistical Modeling of Gasoline Property Effects

Studies involving multiple levels of multiple parameters (variables) are ideally conducted in such a way that each parameter is varied independently through all its levels while the others are held constant, thus generating data from all possible combinations of parameter levels (referred to as a factorial design). Given the number of fuel parameters and their multiple levels outlined above, the Phase 3 fuel set would have required 240 fuels to be blended and tested to examine all points of the factorial matrix. Because this would be burdensome and impractical, an optimized partial factorial design was utilized. This is a widely-used approach that uses a carefully-chosen subset of all the possible fuel blends to allow characterization with statistical confidence of the

[j] As ethanol blend level moves beyond 10 vol%, T50 becomes increasingly correlated (inversely) with ethanol content. At E15, the two can be manipulated independently with some effort within a relatively limited range. At E20, the behavior of the center of the distillation curve (where T50 lies) is dominated by ethanol's boiling point, and thus T50 cannot be moved outside a narrow range around 165°F. Thus, T50 and ethanol should only be understood to be independently blended parameters at E15 and below.

main effects (i.e., the fuel parameters themselves) plus a pre-selected subset of interactions between the main effects. Interactions of interest were chosen based on models from prior studies as well as engineering judgment, and are as follows: ethanol interactions with each of the other fuel parameters, plus T50-squared and ethanol-squared. With the five main effects plus these six interactions, the design was to be optimized for 11 potential terms to be included in the resulting statistical models relating emissions to fuel properties. Selection of the best subset of fuels for a partial factorial design is a computationally intensive process, for which specialized software has been developed. This work was done under contract with experts in the field, statisticians Robert Mason and Janet Buckingham of the Southwest Research Institute (SwRI), and is described in more detail in Appendix A of the testing report.[1]

2.1.5 Partnership with and Technical Support from Coordinating Research Council (CRC)

The Coordinating Research Council (CRC) is a non-profit organization founded in 1942 that funds and publishes engineering and environmental studies related primarily to automobiles and the petroleum products they use. CRC's sustaining funding comes from the American Petroleum Institute (API)[k] and a group of nine automakers. Specific projects may receive support from additional stakeholders, including state and federal agencies wanting to engage in collaborative research. Projects are designed and directed by technical committees made up of representatives of the funding organizations, and the work is typically carried out at contract laboratories.

EPA and the National Renewable Energy Laboratory (NREL) sought to partner with CRC in the EPAct program because of CRC's technical expertise in automotive emissions test programs, as well as its in-depth knowledge of both the vehicles being tested and real-world fuel production and characterization. At several points during the study design, EPA sought the advice of CRC members on details such as the feasibility of achieving certain combinations of T50 and ethanol in test fuel blends, how best to accommodate adaptive combustion controls in test vehicles, and which analytical test procedures should be used in the multi-lab analysis of test fuel parameters. After data collection was complete, EPA hosted several all-day technical sessions where representatives from NREL and CRC discussed the merits of various quality-assurance measures

[k] API is comprised of hundreds of companies, from the largest major oil company to the smallest of independents, representing all sectors of the industry. Members include producers, refiners, suppliers, pipeline operators and marine transportation companies, as well as service and supply companies.

and analytical techniques aimed at producing a final dataset agreed upon by all parties as being of high quality.

2.1.6 Test Fuel Specification and Blending

In addition to the five fuel properties selected as the focus of the program, the test fuel specifications included bounds on a number of parameters for which there was an expectation of possible emission impacts. If such properties were not controlled, incidental changes could confound the primary results. Examples of these properties included olefin (unsaturated hydrocarbons), benzene, and sulfur content. An olefin specification of 7.0 ± 1.5 vol% was used, based on the U.S. average computed from the Alliance of Automobile Manufacturers' 2006 Summer North American Fuel Survey. Because of its important impact on benzene emission performance, the fuel benzene content specification was set at 0.62 ± 0.15 vol%, the level of the refinery average gasoline benzene standard adopted in the 2007 Mobile Source Air Toxics final rulemaking. The sulfur content specification of 25 ± 5 mg/kg (ppmw) was selected to ensure that the level remained within a reasonably narrow range capped by then-current refinery/importer annual average standard of 30 mg/kg. The minimum (R+M)/2 octane specification of 87 was based on minimum requirements of test vehicles selected for the program.

No upper limit was placed on octane number. Both ethanol and aromatics have high research octane number (RON), and since the proportion of each varied independently and widely across the test fuels, controlling octane within a narrow limit was not feasible. At the time of the study design there was also no evidence that octane would affect emissions on the LA-92 test cycle selected for use for this test program, suggesting that it did not need to be controlled for. Indeed, data from a recently-completed study on the current generation of vehicles with engine down-sizing and turbocharging continues to support this conclusion.[15]

Among fuel properties that were held constant, special attention was also paid to the distribution of aromatics by carbon number (molecular size) because of potential impacts on particulate matter (PM) emissions. The ratios of 2:2:2:1 were chosen for C_7:C_8:C_9:C_{10} aromatic hydrocarbons based on speciation data for commercial gasolines available to EPA at the time of

fuel blending.[l] This control of aromatics distribution in the test fuels proved to be very useful after the program was complete and new work by others was being published on the influence of heavy aromatics on particulate matter emissions, such as Honda's "particulate matter index" (PMI).[m,16] It allowed the EPAct study's conclusions about effects of total aromatics and T90 on PM to stand with minimal concern about confounding with uncontrolled changes in the proportion of heavy aromatics. It also allowed analysis and modeling of the data in terms of PMI, since the consistent aromatics distribution produced PMI values for the test fuels that varied systematically within a balanced, rectangular space against other fuel parameters such as ethanol and T50.

The fuel specifications also included limits on T10, final boiling point (FBP), oxidation stability, copper-strip corrosion and solvent-washed gum content pursuant to ASTM D4814 Standard Specification for Automotive Spark-Ignition Engine Fuel. Furthermore, a limit on total content of oxygenates other than ethanol was adopted to safeguard the test fuels against such contamination. Finally, a number of uncontrolled fuel properties used in emissions test calculations were appended to the fuel specification table to make sure they were measured prior to the launch of the emissions test program and in the multi-lab analysis (or "round robin") of test fuels to be conducted. They included carbon, hydrogen and oxygen content, density, and heat of combustion.

All 27 test fuels tested in Phase 3 of EPAct and used to produce the fuel effects models were formulated by EPA in conjunction with Haltermann Products, which was contracted to supply the fuels. To facilitate this process, Haltermann made available to EPA a detailed set of property data for their gasoline blending components, for EPA's use in designing fuels for this program. (These data were designated as confidential business information and were not published in any reports.) The majority of these components were blendstock streams taken from various points in refinery operations (e.g., reformate, alkylate, isomerate, light naphtha), ensuring that the resulting test fuels contained the typical range of components found in actual market fuels. By using a consistent set of blending components for all test fuels, the influence of unknown compounds was minimized relative to using market fuels for some parts of the study.

[l] As a practical matter in meeting the distillation targets, the proportions had to be adjusted to include a greater proportion of C_7 and C_8 aromatics for fuels with a combination of low T90 and high aromatics.
[m] PM Index indicates the relative propensity of a gasoline blend to produce PM, and is a mass-weighted sum of a molecular structure parameter divided by the vapor pressure for each compound in the fuel.

In the development of each test fuel formulation, EPA used a computational blending model to define and adjust the blend recipe from the available component properties while Haltermann prepared and characterized lab-scale hand blends. This process was iterated until the target specifications were met. The distillation parameters, DVPE, as well as the aromatic and olefinic content of hand blends were measured by Haltermann and verified by a third-party laboratory of Haltermann's choice (typically Core Laboratories, Dixie Services, BSI-Inspectorate, or Saybolt). Single measurements were allowed for benzene, sulfur, and ethanol content, as well as MON and RON, though confirmation could be performed at one of the third-party laboratories at Haltermann's discretion. As the development of fuel formulations progressed, it became clear that T50 targets of certain E15 and E20 test fuels were not realistic due to the influence of ethanol's boiling point, so adjustments were made. In addition, a decision was made to reduce the high-level aromatic content target of 40 vol% to 35 vol% to help meet other targets and be more representative of future market fuels. Overall, 21 different blending components were used in this program, between 9 and 16 per fuel, in a manner analogous to how refiners blend their various refinery streams to produce finished gasoline. The process of developing formulations for each test fuel required as many as seven lab-scale iterations in some cases of particularly challenging combinations of fuel parameters. This level of diligence in meeting design targets using a full range of refinery streams is rare in the published literature, especially in studies of this scale, and contributes to our confidence in the results.

Once the design parameter values were met, the final specification for the bulk blend of the fuel was issued by EPA and NREL to produce the quantity needed to complete the emission testing. In each case, the final hand blend results were used as targets for the distillation parameters, DVPE, and the aromatic and olefinic content. These parameters included T30 and T70 distillation points to ensure that the volatility curves of the hand blends were closely reproduced in the bulk blends. During the bulk blending process, distillation parameters, DVPE, MON, and RON as well as the aromatic, olefinic, benzene and sulfur content were measured by Haltermann and another laboratory. Once the bulk blend specification was met, a sample of the fuel was shipped to SwRI for confirmatory testing. If SwRI analytical results fell inside the test method reproducibility limits for the target parameters, EPA and NREL approved the bulk blend for shipment to SwRI. If they fell outside the method reproducibility limits, further tests and/or blend adjustments followed until the requirements of the specification were met. The resulting

fuels were specifically designed and blended to meet specific fuel parameter targets, but yet be representative of in-use fuels (or potential future E15/E20 blends). In theory, it would be possible to find each of these fuel blends in the marketplace by sampling and testing enough samples, but this step would have been prohibitively expensive.

Given that gasoline contains volatile components, it must be handled with care to maintain the intended property specifications. For this reason, test fuels were shipped by Haltermann to SwRI in sealed, epoxy-lined drums and stored on site in a temperature-controlled facility. The storage temperature for unopened drums was 70°F ± 5°F. Any drums that were to be opened (for vehicle fueling or sampling) were cooled to a temperature of <50°F at a dedicated cold-storage facility adjacent to the vehicle refueling area. The temperature of both fuel storage facilities was continuously recorded, and was verified at least once a day.

Upon arrival at SwRI, all fuels received independent identifiers which included the program fuel number, a SwRI fuel code, and a project-specific supplementary three-letter code. All fuel drums and corresponding work requests included all three designators to ensure that the correct fuel was being used at any point in the test program. Additionally, each individual drum received a sequential number. These unique alphanumeric designations assigned to individual drums were recorded and verified by two technicians each time a test vehicle was fueled. Each time a full drum was opened, the properties of its contents were verified using a portable PetroSpec gasoline analyzer. Based on these results, no mislabeling of fuel drums was observed during this program.

The EPAct fuels round robin multi-lab analysis was launched in October 2009 with the support of CRC. Its objective was to supplement the fuel-inspection data previously generated for the drum blends by Haltermann and others with additional results, especially for the target study parameters, i.e. T50, T90, DVPE, ethanol and aromatic content. Participants included BP, Chevron, ConocoPhillips, EPA, ExxonMobil, Marathon, PAC (distillation equipment manufacturer) and Shell. The total number of laboratories which measured the properties of fuels used in this program thus increased to 14. It is worth noting that at least six T50, T90, DVPE, ethanol content and aromatic content results were available for each E0-E20 fuel to ensure accurate quantification of the fuel properties, since otherwise error in test fuel properties could overwhelm the ability to ascertain fuel emission impacts from the test program. Detailed procedures for sampling and handling the fuels, as well as reporting the results, were devised and

distributed to participants. This information, along with a complete list of parameters and the final composite results used in fitting the emission models is available in the study report.[1]

2.1.7 Sizing of Test Fleet and Selection of Vehicles

Proper design of an experimental study should ensure that the effect being investigated has a good chance of being detected if it exists. This likelihood of detection is referred to as the statistical power of a study. Estimation of power requires specification of an effect size deemed to be meaningful, the number of replicate measurements that will be performed, as well as information about the variability or "noise" expected in the measurements. Ideally these inputs are informed by previous experiments or, if no such data are available, they can be chosen based on some assumptions about the behavior of the test subjects. Note that the meaningful effect size used in a power calculation shouldn't be understood as a lower limit on detectable effects, but rather as a maximum acceptable effect size that might escape detection. Once the study is complete, the power is not very meaningful if a statistically significant effect is found, as was the case for many fuel properties in this study. However, in cases where a comparison produces no significant difference and the study design and power are deemed appropriate and sufficient, then the conclusion is that the treatment (such as a fuel change) has no effect.

A power analysis was performed during the initial design of this program to estimate the number of vehicles required to detect a fuel effect of various sizes for both hydrocarbon and NOx emissions. The statistical methods were based on those presented by Snedecor and Cochran, and are consistent with work done for the Auto/Oil Air Quality Improvement Research Program (AQIRP) in the early 1990s.[17,18] Table 2-3 shows estimates of vehicle-by-fuel variability and repeat measurement error derived from data collected in recent emission programs, which are used as inputs to the power estimate.

Table 2-3. Coefficients of Variation (CV, %) Derived from Earlier Studies.[a]

	Study	NO_x	NMHC
Vehicle-by-fuel	CRC E-67	2	18
	2005-6 MSAT	14	13
	Value used	**14**	**18**
Test-to-test	CRC E-67	20	19
	2006 CARB	22	17
	2005-6 MSAT	15	17
	CRC-E74b	22	20
	Value used	**22**	**20**

[a]CV is coefficient of variation, or standard deviation divided by mean. NO_x is nitrogen oxides and NMHC is non-methane hydrocarbons, two important gaseous pollutants typically measured in emission studies.

The prior test programs shown here were conducted in a variety of configurations and were included to give an idea of the range of values expected. CRC E-67 and E-74b represent testing on different vehicles and fuels performed at the same laboratory. The 2005-6 MSAT program tested different vehicles and fuels at different laboratories. The 2006 CARB data represent testing of the same vehicle on the same fuel at different laboratories. Examination of both NOx and hydrocarbon emissions allowed the design to accommodate the more restrictive of the two. Table 2-4 shows an example of the results run for different numbers of replicates and relative differences detectable between two treatments using the variability information gleaned from the earlier studies.

Table 2-4. Results of Power Calculations based on the Results of Previous Studies.

No. of Replicates	Effect Size of Interest	Vehicles Needed at 90% Power
1	5%	614
	10%	155
	15%	70
	20%	40
	25%	26
	40%	11
2	5%	446
	10%	113
	15%	51
	20%	29
	25%	19
	40%	8
3	5%	389
	10%	98
	15%	45
	20%	26
	25%	17
	40%	8

During the design of AQIRP testing a value of 25% was selected as a maximum acceptable fuel effect to escape detection. Using this level of effect for the EPAct study, a design of 19 vehicles with two replicates for each fuel-vehicle combination was originally chosen to meet a 90% study power and a significance level of 0.05 for the statistical tests. A 25% effect seemed large compared to values of 5-10% being reported in other recent programs. However, there was an expectation that through careful design and execution, this program could achieve better measurement variability and repeatability than in earlier programs, which would provide adequate statistical power with smaller sample size. And indeed, this was the case. As will later be explained, the final test fleet was reduced to 15 vehicles but due to reduced measurement variability in the dataset, adequate statistical power was maintained and effects much smaller than 25% were detected with statistical confidence.

The test fleet of 19 vehicles was chosen with the intent of being representative of high-sales-volume light-duty vehicles entering the market at the time the program was being launched. In terms of regulatory standards, the test fleet was to conform on average to Tier-2/Bin-5 exhaust levels, as prior test programs had provided sufficient data on vehicles meeting earlier emission

standards.[n] To ensure the test fleet represented the variety of emission control technologies and approaches employed in the Tier 2 fleet, a range of vehicle sizes and manufacturers was selected. Since various makes and models employ different technologies that react to fuel changes in different ways, failure to have a test fleet representative of the in-use fleet could lead to biased results that could not be generalized. Sales data obtained from EPA certification and commercially-available databases were analyzed to generate a list of high-sales vehicles as candidates for inclusion.[o] Grouping sales data by engine family allowed additional transparency and flexibility in choosing test vehicles that represent a wider group than one specific make and model. The resulting test fleet was used in Phases 1-2 of the program and the engine families represented were expected to cover more than half of new vehicle sales for model year (MY) 2008. No criteria were used to select the individual test vehicles for lease, so sampling within a make/model was effectively random. These steps were taken to ensure that the overall results of the study would be applicable to in-use emissions across the U.S. fleet.[p]

After completion of the pilot phases, a decision was made to reduce the size of the test fleet used in Phase 3 from the original 19 vehicles to conserve sufficient funding to ensure high-quality data collection throughout the program.[q] The primary considerations in deciding which vehicles to retain were prioritizing high-sales engine families and maintaining representation of vehicles, engine sizes, and manufacturers originally selected in order to include a full range of emission control strategies. A list of the 15 Phase 3 test vehicles by make/model is available in the testing report.[1] The reduction in the size of the test fleet did not impair the ability to discern statistically significant test results for the fuel parameters being studied.

A very important aspect of this study is its test fleet of more than a dozen high-sales vehicles representing a broad range of engine and emission control technologies in the market. This feature makes this study much more relevant and useful for estimating fleet-wide emission

[n] Tier 2 emission standards are described in 40 CFR 86.1811.
[o] Engine family (also known as "test group") is a term used in manufacturing and certification to describe a combination of a base engine and after-treatment system that may be used in several vehicle makes and models offered by a manufacturer. An example of such a commercial database is available from Wards.
[p] Note that the EPAct study was intended to give a broad view of how fuels would affect the emissions from the on-road Tier 2 fleet as a whole, rather than being an engineering study of how any particular technology responded to fuel changes.
[q] While a study power analysis repeated using data from 15 vehicles in Phase 1 suggested power in the range of 0.7-0.8, later analysis of Phase 1 data found statistically significant fuel effects smaller than the target effect size of 25%.

impacts than numerous smaller studies. Studies involving one or two vehicles represent a tiny fraction of in-use emissions.

2.1.8 Test Procedures Ensuring High Data Quality

Many factors can affect vehicle emissions performance, with the fuel effect potentially being a relatively small factor. Thus, an important consideration that is often overlooked in fuel effects studies is the need to minimize measurement artifacts, which include variability, error, or bias that are unintended in the design of the study. Any such artifacts become confounded with the fuel effect itself, which can lead to loss of statistical power to resolve an effect or detection of an apparent effect that doesn't exist. As new vehicles have lower and lower emission levels, measurement artifacts have the potential to become more influential in the results of the study. A great deal of effort was taken in the design and execution of this program to minimize artifacts related to procedures, including following a particular sequence of steps in vehicle handling before, during, and between emission tests, as well as use of the same driver and test cell for all emission tests. Some such procedures are highlighted in this section, with more coverage in the testing report.[1]

2.1.8.1 Engine Oil Break-In Period

A study completed by EPA and Lubrizol shortly before the start of this program examined the effect of oil age on emissions.[19] The hypothesis was that fresh engine oil could increase certain emissions, introducing undesired variability into fuel effects tests performed shortly after an oil change. The study involved accumulating 2,000 miles on two low-mileage, Tier-2-compliant vehicles (as would be used in the EPAct study) using a non-ethanol fuel (E0), with emission measurements taken immediately after oil change and at 500, 1,000, and 2,000 miles. Upon completion, the only significant effect of oil age observed was for particulate matter (PM), which dropped by nearly half after 500 miles in one of the vehicles. Both vehicles showed a general trend of PM reduction out to 2,000 miles, though differences between subsequent test intervals were not large or statistically significant. As a result of this work carried out with assistance from Lubrizol, all vehicles in the EPAct study design were run through a 2,000-mile break-in drive after the oil was installed, in order to stabilize emissions.

The study also examined the effect of mileage accumulation with ethanol-blended fuel (E10) on emissions and oil quality. After the initial 2,000-mile accumulation period on E0, the fuel

supply was changed to E10, and another 3,000 miles were accumulated. No significant changes were seen in emissions between the beginning and end of the period, and an analysis of oil quality (including metals, acid and base numbers) done by Lubrizol didn't show oil degradation beyond the normal range for the accumulated mileage.

2.1.8.2 Vehicle Storage Conditions Were Controlled for Stable Performance

Vehicles being actively tested were stored indoors in a temperature-controlled soak area adjacent to the test cell to minimize diurnal fuel weathering and give consistent start-of-test temperatures. All vehicles had batteries trickle-charged for at least 12 hours prior to testing to avoid variation in battery charging loads on the engine during emission tests.

Due to the nature of the randomized test matrix, as well as the incremental addition of test vehicles to the program, certain vehicles were not involved in active testing for several weeks at a time. Those not scheduled to test for more than approximately two weeks were generally stored outdoors in a parking area near the test facility. In an attempt to minimize changes in engine or drivetrain performance due to extended inactivity, those vehicles were operated by an experienced driver once every two weeks over an on-road course around the perimeter of the SwRI campus. Prior to each drive, each vehicle received a brief visual inspection to ensure proper tire inflation and fluid levels. One "lap" was completed, which was approximately 8 miles in length and about 20 minutes in duration. Speed limits ranged from 35 to 45 mph, and the drive included six traffic signals and two stop signs. This task was conducted using a non-ethanol fuel.

2.1.8.3 Fuel Test Sequence Was Randomized to Neutralize Confounding Interferences

The test matrix was designed to test each vehicle/fuel combination in a random order to minimize any effects of biases or artifacts that may not have been addressed through other provisions in design or procedures (e.g., possible effects of season, weather, changes in test fuel properties over time, vehicle or instrument drift, etc.). Randomization of treatments (such as test fuel here) is commonly used in research because it is highly effective at neutralizing potential interferences or unknown confounding factors. During the first nine weeks of testing while test fuels were still being blended and delivered, EPA specified partially randomized vehicle/fuel assignments that alternated between E0 and higher-ethanol blends in an effort to determine the amount of conditioning necessary to allow a vehicle's fuel control system to adapt to a new

ethanol concentration (discussed more in the next subsection). Once the necessary amount of preconditioning was determined, for the remaining 50+ weeks of testing, vehicle/fuel assignments were made using a spreadsheet tool that tracked which combinations had been tested and chose new assignments randomly from the remaining options.

2.1.8.4 Adaptive Fuel Controls Were Monitored to Ensure Stable Performance

The vehicles tested in this program all employed "learned fuel adjustments" (also called fuel trim) to continuously adjust the amount of fuel delivered for proper combustion. Most vehicle manufacturers began using such controls during the 1990s, and today nearly all new vehicles use microprocessor algorithms of varying sophistication to optimize vehicle performance and meet emission standards. When the combustion process requires a change in air/fuel ratio, such as occurs when ethanol blend level changes, the engine controller must adjust the fuel trim to re-optimize engine and emission performance. This "re-learning" process requires operation of the vehicle for a certain period of time in several speed and load modes.

Since this test program used multiple fuels with widely varying properties, vehicles were connected to an on-board diagnostics (OBD) scanner during all preconditioning cycles and emission tests to allow capture and review of certain engine controller settings, including those related to fuel trim. Based on review of OBD data from the initial operation periods on different fuel types, procedures were optimized to ensure fuel trim behavior had stabilized after a fuel change.

2.1.8.5 Established Replicate Repeatability Criteria for Emissions and Cranking Time

Given the inherent variability of chassis dynamometer emissions tests, each vehicle-fuel combination was tested at least twice (so a base dataset goal of 27 fuels × 15 vehicles × 2 replicates = 810 tests), back-to-back, with the second replicate usually performed on the following day. When replicates were split over weekends, an additional prep cycle was conducted so as to maintain a 12-36-hour soak period (meaning time of inactivity between engine operation periods).

Two criteria were used to determine when additional test replicates should be performed. The first was emissions repeatability. After two tests on a given fuel were completed and the acquired data passed all quality control verifications, if the ratio of any of the specified pollutants (THC, NO_X, or CO_2) exceeded the pre-set variability criteria, a third test was conducted and a

note was made in the test log. These repeatability criteria were generated based on variance levels found in Phase 1 data, with a goal of performing a third replicate for approximately 5% of fuel/vehicle pairs in Phase 3 to cover a small number of measurements that might be statistical outliers.

The second criterion was engine cranking time at start-up. Since emissions performance on current technology vehicles is dominated by what occurs shortly after start-up, engine cranking times between replicates were screened for inconsistency. If a test differed in cranking time from a previous replicate by more than one second, its procedure log and emissions data were reviewed by EPA and NREL to determine if an additional replicate should be performed.

In the end, additional replicates were performed for approximately 3% of vehicle-fuel combinations due to repeatability and cranking criteria, as well as a small number of void tests due to procedural issues.

2.1.8.6 Statistical Screening Performed to Detect Chronological Drift in Measurements

Measurements may be affected by any of a variety of sources of "drift," generally understood to be a systematic or progressive shift in results due to vehicle drivetrain wear, sulfur build-up on exhaust aftertreatment catalysts, accumulation of deposits on fuel injectors or valve seats, weathering of stored test fuels, changes in instrumentation calibration, or other unknown factors. Some known sources of potential drift were minimized by procedures such as the dynamometer coastdown checks and gas analyzer zero/span checks against calibration gases. As an additional screen for drift that might affect the program results, each vehicle was re-run on a fuel from early in its sequence again at the mid-point and end of testing. A number of statistical analyses were conducted, including graphical review of emission trends, modeling of measurements as a function of odometer reading as well as time of test (beginning, middle, end). In the end only one pollutant in a single test phase appeared to have any indication of drift over the course of the study, a result that a statistician retained by project partner NREL explained could be expected due to simple chance given the large number of statistical comparisons being performed.[20] Thus, the conclusion was that no meaningful drift in results was observed over the course of the study.

2.1.9 Peer Review of Study Design and Results

Prior to formal peer review of the finished study, as described in Section 2.1.5, EPA sought peer input from subject matter experts at various points during the design process, primarily through CRC, whose membership includes experts with knowledge of fuel production and blending as well as vehicle design and emission testing. Experts in statistical design of experiments were also used to evaluate fuel matrix options and test vehicle fleet sizes. During and after data collection a series of workshop sessions were held with representatives of the project partners (EPA, CRC, and DOE/NREL) to discuss in detail the merits of various approaches and arrive at a consensus on what would constitute the final dataset. From this dataset, the various parties would then go on to perform independent analysis and interpretation.

In October 2011, following completion of data analysis and emission modeling by EPA, the Agency contracted with SRA International to conduct an independent peer review of the study. The scope of the review focused on the statistical methods used to draw conclusions from the data and then asked the reviewers to comment on the study overall. EPA provided SRA with a list of known subject matter experts from academia, consulting, and industry to serve as a starting point for identifying candidate reviewers. SRA selected three independent (as defined in EPA's Peer Review Handbook[3]) subject matter experts familiar with statistical analysis and vehicle emissions. To ensure the independence and impartiality of the peer review, SRA was solely responsible for selecting, directing, and compensating the peer review panel.

A crucial element in selecting peer reviewers was determining whether they had any actual or perceived conflicts of interest or bias that might prevent them from conducting a fair and impartial review. Consistent with the EPA Peer Review Handbook, the peer reviewers were evaluated for independence, potential conflict of interest, and appearance of impartiality before they were selected. SRA required each reviewer to complete and sign a conflict of interest and bias questionnaire, and provided the reviewers a copy of the analysis report and a charge letter containing specific questions EPA asked the reviewers to address in their comments. A report with the peer reviewers' resumes, comments, and EPA's responses is available via the EPA Science Inventory website.[r]

[r] Peer-review documents are available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryID=240069.

As a result of the peer review, additional analyses were performed and a number of substantial modifications to the study report were made to provide additional discussion of points raised by the reviewers, but no significant issues were raised related to the study design and no change in the statistical models or overall results was warranted. For example, quoting a statement from the comments of Dr. Xuming He, a University of Michigan professor of statistics: "Overall, I found the study well designed and carefully analyzed with generally accepted modern statistical tools."

2.1.10 Implementation of the EPAct Study in MOVES2014

Following the steps described above, the statistical models developed from the results of the EPAct study were incorporated into the MOVES model. The statistical models are equations used to calculate adjustments to relate emissions estimates for specific states or counties in specific years to the fuel properties assigned to those locations in the selected years. Adjustments are calculated for emissions of carbon monoxide (CO), total hydrocarbons (THC), oxides of nitrogen (NO_x), and particulate matter (PM). In addition, similar statistical models are used to calculate adjustments for the air toxics such as acetaldehyde, formaldehyde, acrolein, ethanol, 1,3-butadiene and benzene. The application of the EPAct study results in MOVES are documented in the technical report covering the adjustments for fuel properties,[21] as well as the report covering estimation of air-toxic emissions.[22] Relevant portions of these documents underwent an additional round of peer review, with materials also available on the Science Inventory website.[s]

2.2 Evaporative Test Programs

2.2.1 Background on Evaporative Emissions Study Goals and Designs

A series of studies sponsored by the CRC (E-65[4], E-65-3[5], E-77-2[6], E-77-2b[7]) investigated evaporative emissions from in-use vehicles. The goal of these programs was to quantify and analyze the main sources of evaporative emissions with innovative test procedures designed to represent and measure emissions in the "real world." Importantly, these were the first studies that examined specific factors influencing permeation emissions, including fuel system design and fuel composition.

[s] Peer-review materials available at: https://cfpub.epa.gov/si/si_public_record_report.cfm?dirEntryId=263653.

In 2001, the California Air Resources Board (CARB) requested the CRC evaluate the impacts of different types of oxygenated fuels on permeation. Two oxygenates in common use at the time, methyl tertiary-butyl ether (MTBE) and ethanol, were the focus of these studies. In the first study initiated in 2002, CRC E-65 used three typical California in-use fuels: an MTBE fuel, a 5.7% ethanol fuel, and a non-oxygenated fuel. The ethanol fuel was found to have much higher permeation than either of the other fuels. CRC continued to explore these findings with additional fuels and some newer technology vehicles in study E-65-3.

The E-77 series of test programs was initiated in 2005 to examine the effectiveness with age of evaporative emission controls in vehicles employing recent evaporative control technologies, drawing on new measurement approaches and test procedures.

The 2005 Energy Policy Act (via Clean Air Act Section 211(q)(3)(A) as amended) required that the EPA conduct a permeation effects study, specifically requiring that we study "*the effects of ethanol content in gasoline on permeation, the process by which fuel molecules migrate through the elastomeric materials (rubber and plastic parts) that make up the fuel and fuel vapor systems of a motor vehicle*." CAA Section 211(q)(3)(B) required the study "*to include estimates of the increase in total evaporative emissions likely to result from the use of gasoline with ethanol content in a motor vehicle, and the fleet of motor vehicles due to permeation*." The CRC E-77 studies and their incorporation into MOVES2010 with the previous E-65 studies fulfilled these requirements.

2.2.2 Vehicle, Fuel, and Test Procedure Choices

Both the CRC E-65 and E-65-3 test programs measured emissions from fuel systems that had been separated from their respective vehicles. These "rigs," including the tank and all hoses and connections, were used to isolate permeation emissions from other sources of evaporative emissions. The initial program, E-65, used fuel systems from ten vehicles selected to represent the California in-use fleet in the 2001 calendar year, covering model years 1978 to 2001. All vehicles had mileage appropriate to their ages. Two of the vehicles were certified to "enhanced evaporative emissions standards" (phased in during 1996-99), with one additional vehicle employing Onboard Refueling Vapor Recovery (ORVR). The three test fuels were based on commercial fuels with adjustments made to match certain property targets, including RVP, T10, T50 and T90, in that order. One fuel was a non-oxygenated gasoline. Two fuels were

oxygenated, with one containing 11% MTBE (2% oxygen), and the second containing 6% ethanol fuel (2% oxygen).

A follow-up study, CRC E-65-3, tested five vehicles with newer evaporative technology from model years 2001-2005. As with the previous study, two of the vehicles met federal "enhanced evaporative emissions standards,"[23, t] with another two meeting California "Near-Zero" and "Zero" evaporative standards (part of the LEV II program beginning in 2004),[24] and one was a Flexible Fuel Vehicle (FFV). Six test fuels were evaluated for this study: E0, E6, E6 with high aromatics, E10, E20 and E85. All fuels were blended to target "summer" California fuel characteristics, including vapor pressure at 7 psi. The aromatics content and distribution of aromatics types were similar, with the exception of the E85 fuel, which had substantially lower aromatics, and the high-aromatics E6 fuel.

The CRC E-77 studies, which spanned 2005 to 2010, were specifically designed to test aging evaporative emissions controls in vehicles certified to federal "enhanced" standards (phased in between 1996 and 1999). With the development of the MOVES model in the early 2000s, we took a fresh look at evaporative emissions modeling. EPA contracted with Harold Haskew & Associates, who suggested revising our approach and test procedures. The new approach took into consideration lessons learned from CRC E-65 studies regarding distinction of different evaporative emissions mechanisms, and included recommendations for new test procedures. Previously, the measurement and modeling of evaporative emissions mimicked the certification procedures of "hot soak," "running loss" and "diurnal." While the E-65 studies had measured emissions from completely isolated fuel systems, following their removal from the vehicles, the E-77 series tested whole vehicles and developed new test procedures. The new approach, based on first principles focusing on the mechanisms of "permeation," "canister breakthrough," "leaks" (vapor and liquid), and "refueling and spillage," was incorporated into MOVES2010.

[t] Federal enhanced evaporative standards began in 1996 and capped HC emissions at 2.5 g combined diurnal + hot soak test (DHST) for light-duty vehicles (LDVs). A diurnal test measures all vapors from the (non-running) vehicle, including permeation and canister venting, while it is sealed in a chamber being heated and cooled over 48 hours. A hot soak test measures evaporative emissions from the vehicle parked in a sealed chamber for one hour immediately after driving. Federal Tier 2 standards beginning in 2004 reduced this level to 1.2 g per DHST for LDVs. California LEV II standards also began in 2004 and set "near zero" standards at 0.5 g per DHST using the California procedures, which are different from Federal procedures but result in a similar level of control. LEV II "zero evap" standards allowed 0.35 g per DHST for background emissions from non-fuel sources such as foams, plastics, and lubricants. Onboard Refueling Vapor Recovery (ORVR) began in 1998 and required sufficient evaporative control canister capacity to capture refueling vapors. ORVR is not included in a diurnal test.

The first E-77 project was a pilot study to test new procedures. Since new evaporative emission standards had been put into place in 2004 (following the E-65 study), which impacted vehicle designs to control evaporative emissions and permeation emissions in particular, this study included three and six vehicles certified to "pre-enhanced" and "enhanced" standards, respectively, and one vehicle certified to Tier 2 evaporative emissions standards. For the initial effort, only two fuels were used, differing in vapor pressure (7 and 9 psi) and containing no ethanol.

The second effort, E-77-2, was designed to distinguish the effects of RVP and ethanol, by measuring emissions from eight vehicles over five fuels, including three ethanol levels and two volatility levels. The vehicles and fuels were adopted from another project designed to investigate the effect of ethanol on tailpipe emissions (CRC E-74b).[25] The vehicles were selected based on high sales volume to represent the current fleet. Mileages were representative of in-use averages for the model years procured, ranging from 1994 to 2006. Inspections prior to purchase ensured that no prior extensive damage and repair had occurred, especially for the emissions control systems. The eight vehicles were certified to "pre-enhanced" (one vehicle), "enhanced" (five vehicles) and Tier 2 standards (two vehicles). The fuels from E-74b were 7 psi E0 and E10, and 9 psi E20. Small portions of the fuel were blended with butane to achieve the higher vapor pressures of 9 psi for E0, and 10 psi for E10 (to represent the 1 psi waiver for fuels containing 10% ethanol). Fuels were blended in small batches of approximately 50 gallons, by adding small amounts of butane, circulating for a brief period and then re-measuring vapor pressure with a Grabner[u] instrument using ASTM D5191 procedures.

E-77-2b added an additional eight vehicles to the body of data for better statistical power. Five of the vehicles were also owned by CRC and had been used in the E-74b program, and three more were leased for the test program. The five CRC vehicles included two 2002 model year and three 2004 model year vehicles. The same fuels and procedures were used as in E-77-2.

Evaporative emissions testing procedures employed in the E-77 programs were designed to distinguish evaporative emissions mechanisms including Hot Soak, Diurnal, Running Loss and permeation, including a newly developed "Static Test" to isolate permeation. The Static Test

[u] www.grabner-instruments.com MINIVAP VPS /VPSH Vapor Pressure Tester. The portable MINIVAP VPS and VPSH vapor pressure testers are the worldwide accepted standard instruments for the determination of the vapor pressure of gasoline according to ASTM D5191, ASTM D6377, ASTM D6378 and EN 13016 1+2

gave a pure permeation rate over a uniform temperature and also indicated the presence of vapor or liquid leaks. The Static tests were run at 86°F and 105°F in the E-77 Pilot and at 86°F in succeeding programs.

2.2.3 Involvement of CRC and Other Partners

The E-65 studies were initiated by the California Air Resources Board (CARB), with the initial study proposed at a public meeting in Sacramento during June 2001. The CRC offered to support and co-fund the program. They contracted with Harold Haskew and Associates and Automotive Testing Laboratories to run the programs.

The E-77 programs were initiated both to expand upon the E-65 studies, to evaluate the new evaporative emissions test procedures which distinguished the evaporative emissions processes on whole vehicles, and also to meet the EPA's requirements under the Energy Policy Act to conduct research to better understand the effects of ethanol on evaporative emissions. EPA worked with CRC both technically and as co-funders to execute the pilot E-77 and subsequent E-77-2 and E-77-2b test programs. NREL was interested in the effects of 20% ethanol in fuel on evaporative emissions and therefore added and funded E-77-2c.

2.2.4 Brief Overview of Results

The results from the initial program, with older technology vehicles, CRC E-65, showed an average increase in permeation emissions of approximately 50% for the ethanol blend. The corresponding difference for the vehicles with enhanced emission controls was substantially higher, over 100%, a large relative difference, although very small in absolute terms, due to the much lower permeation emissions from the enhanced-evap-control vehicles.

Results from E-65-3 were broadly similar, with E6, E10, and E20 having higher permeation rates than E0 in all fuel systems. However, E85 had lower permeation than E0.

The CRC E-77 series of test programs tested entire vehicles rather than isolated fuel systems as in the E-65 programs. The E-77 Pilot showed that the new procedures developed could distinguish the evaporative mechanisms in whole vehicle testing. E-77-2 and E-77-2b tested 16 vehicles over five fuels varying RVP and ethanol levels. At the higher ethanol level, i.e., 10% in relation to 0%, higher permeation emissions were observed in all these vehicles, with percentage increases that were equal to or greater than those seen in the older technologies tested in E-65; however, the absolute magnitude of the increase was smaller than in the E-65 test programs.

2.2.5 Implementation in MOVES

2.2.5.1 Prediction of Permeation Emissions in MOVES2014

The CRC evaporative emissions studies described above were reviewed for the purpose of updating permeation emissions in the MOVES model (both MOVES2010 and MOVES2014) and determining how to model evaporative emissions for Tier 2 vehicles. While emissions for other evaporative emission modes (particularly vapor venting) decreased for Tier 2 vehicles as compared to enhanced evaporative emissions, the results for permeation were found to be very similar to those from the previous version (MOVES2009) in which model inputs were based on compliance data for enhanced-evap vehicles in model years 1999-2003.

Results from the newly developed "static" permeation test were used to evaluate permeation rates for model years 1999-2003, representing Enhanced Evaporative Emissions Standards, and 2004-2015, representing Tier 2 Evaporative Emissions Standards. Statistically significant differences in the rates between these two groups were not evident; accordingly, the same value for the base rate (0.01 g/hr) used for MY 1999-2003 was retained for MY 2004-15. Finally, as the E-77 programs were not broad enough to investigate the effects of vehicle age on permeation emissions (deterioration), MOVES did not attempt to project increases in base permeation rate with increasing vehicle age for model years after 1998. For MOVES2014, EPA updated the permeation rates described above to reflect new emission standards for future model years. Starting in model year 2016, the permeation rates in MOVES2014 were further reduced to represent the introduction of two additional sets of standards, specifically, "early credit" Federal Tier 3 and California LEV III.

The permeation base rates used in MOVES2014 are presented in Table 2-5. Note that the model projects a steadily declining trend in permeation emissions, as technology and durability improve and as standards become more stringent. For example, the base rate for new vehicles declines over six-fold over the 20-year period between 1996 and 2016.

Table 2-5. Base Permeation Rates at 72°F (g/hr).

Model year group	Age group	Base permeation rate (g/hr)
1971-1977	10-14	0.192
	15-19	0.229
	20+	0.311
1978-1995	0-5	0.055
	6-9	0.091
	10-14	0.124
	15-19	0.148
	20+	0.201
1996	0-5	0.046
	6-9	0.075
	10-14	0.101
	15-19	0.120
	20+	0.163
1997	0-5	0.037
	6-9	0.059
	10-14	0.079
	15-19	0.093
	20+	0.125
1998	0-5	0.015
	6-9	0.018
	10-14	0.022
	15-19	0.024
	20+	0.029
1999-2015	All Ages	0.010
2016-2017	All Ages	0.007
2018-2019	All Ages	0.006
2020-2021	All Ages	0.004
2022+		0.003

2.2.5.2 Modeling Ethanol Effects on Permeation in MOVES2014

Distinguishing permeation emissions from vapor venting (from the fuel tank) allows estimation of ethanol fuel effects specific to permeation. Vapor venting emissions are a much larger portion of the evaporative emissions inventory and are not affected by ethanol.

The ethanol effect in MOVES2014 was estimated by fitting statistical models to the E-77 data, accounting for the effects of evaporative standard, ethanol content, and vapor pressure.

Statistically significant differences were not seen between the two ethanol levels (6% and 10%) at each standard level. Therefore, the results for both levels were pooled into one category of ethanol-containing fuel, which had significantly different emissions compared to E0 fuel. The results also showed a greater relative ethanol effect on permeation in vehicles meeting the Tier 2 and enhanced-evaporative certification standards than vehicles meeting earlier standards. The percent difference between the ethanol rate and the E0 rate is used in MOVES as the ethanol fuel adjustment. Table 2-6 lists the fuel adjustments which came from this analysis and are used for E5 through E85 in MOVES.

Table 2-6. Ethanol Effect (E6-E10 relative to E0) for Permeation Emissions in MOVES2014.

Model Years	Percent Increase
1995 and earlier	65.9
1996	75.5
1997-2000	107.3
2001 and later	113.8

2.2.5.3 MOVES Workgroup and Other Stakeholder Review Processes

The current and previous MOVES Review Work Groups were established by the Mobile Source Technical Review Subcommittee (MSTRS) of the Clean Air Act Advisory Committee (CAAAC). The MOVES Review Work Group provides input to the MSTRS on specific issues related to the development of MOVES. The MSTRS, in turn, provides recommendations to the chartered CAAAC, which deliberates on the recommendations before providing its advice to the EPA. The work group consists of members who have expertise in modeling emissions from highway and nonroad vehicles. The work group is not designed for policy or advocacy, but rather, is a focal point for sharing technical expertise. Following the completion of the EPAct data analysis by EPA scientists, a summary of the study design and its findings, including the emission models, were presented to the Work Group. Materials and minutes from Work Group meetings are available to the public through the MOVES website.[v]

[v] See https://www.epa.gov/moves/moves-model-review-work-group.

3 Response to Specific Points in the Petition

In Section 2 of this document, we have given a thorough account of the course of the EPAct fuel effects study from its design and execution to its eventual applications, and have provided background on studies looking at fuel property effects on evaporative emissions. In Section 3, we offer detailed and specific rebuttals of the main technical issues raised by the petitioners in their request. For convenience, we will refer to the Request for Correction throughout as "RFC."

3.1 The EPAct Study Design Was Objective

As explained in detail in Section 2, the EPAct study was carefully designed to meet EPA's statutory directive in a manner that not only relied on the best available science and data collection methods, but was also responsive to goals related to stewardship of limited federal financial resources, collaboration within the federal government (e.g., DOE); and consultation with external technical experts. Furthermore, the EPAct study was peer reviewed by external, independent experts, [26] consistent with EPA's peer review policy.[3] The scope of the peer review included the appropriateness of the study design as well as the statistical techniques used to draw conclusions from the data. No significant issues were raised related to the study design.

The RFC repeatedly suggests biases were introduced into the design through EPA's consultation with industry experts, especially those who were at the time, or even had once been, employed by a petroleum company. In general, the RFC assumes the worst possible motives in the actions and interactions of partners which would normally be considered good practices for information gathering and collaborative research. In the following subsections, we direct our responses to specific claims in the RFC.

3.1.1 The EPAct Study Design Built on Previous Research

In III.A.1.a, the RFC criticizes the EPAct study because it was ostensibly based on CRC E-67, a study that also employed an experimental matrix of fuel properties. At the time the EPAct study was designed, both EPA staff and their contractors were certainly aware of CRC E-67. Petitioners imply that any similarity to CRC E-67 detracts from the validity of the EPAct study. However, the RFC makes no technical arguments as to why this should be the case, other than to insinuate that any association of the work with the petroleum industry is sufficient to discredit it. The CRC E-67 data collection and analysis was performed by academic researchers, and

reference to it by EPA staff in the context of the EPAct study design process only signifies awareness of it as related research. The EPAct study built upon and expanded previous research, as described at length in section 2.1.2 of this document.

3.1.2 EPA Directed the Design of the Study

In III.A.1.e, the RFC states that "EPA delegated the Design of the EPAct Study to an Oil Industry consultant." This claim is a gross mischaracterization of the interactions that took place. In fact, EPA directed the design of the study throughout, as described fully in Section 2.1. The petitioners' stated concern about an oil industry consultant may have originated with page A-8 of Appendix A to the EPAct Testing Report, where Dr. Robert Mason of SwRI stated that "EPA requested that SwRI work with Mr. Jim Uihlein from Chevron to prepare a 30-fuel experimental design for the Coordinating Research Council."[w] Note that this request did not delegate the development of a new study design to Mr. Uihlein, but suggested that he, as a representative of CRC, provide input on an optional augmentation to the existing 25-fuel matrix design Dr. Mason had produced earlier. The purpose for the modification in question was to investigate a possible nonlinear effect of T90 on emissions (referred to as a T90-squared term), a topic in which CRC and Mr. Uihlein had expressed interest. EPA did not find the idea of a exploring a T90-squared effect unreasonable, but was uncertain that resources would be available to address it.

After evaluation of several options, the matrix shown in Table 8 of Appendix A (Design #4) was proposed by Dr. Mason as the best option. Finally, as outlined in Section 6 of Appendix A, following subsequent review and revision, EPA staff produced the final matrix of 27 fuels (Design #5), meeting constraints related to project budget and limitations of the fuel formulation process. Additional description of the matrix design process can be found in Section 2.1 of the Phase 3 analysis report.[2]

During the design of the study, EPA staff directing the design consulted with parties such as Uihlein and other CRC representatives. However, the process was not consensus-based. EPA staff solicited input on specific technical issues, and exercised judgment in how, if at all, to reflect that input in the final study design. We emphasize that EPA designed and executed the study through our own efforts and those of our contractors. As employees of the contractor

[w] See EPAct testing report (Reference 2), Section 5 of Appendix A.

(SwRI), Dr. Mason and other contractor staff operated under all procedures and constraints applicable to contractors, including disclosure of any potential conflicts of interest.[27] [x]

3.1.3 Changes to Study Design Following Pilot Testing Did Not "Bias" Further Testing "Against Ethanol"

In III.A.1.f, the RFC states that "EPA abandoned test results that challenged its prior assumptions." This claim refers to the fact that during the initial program design it was EPA's intention for data from Phase 1 pilot testing to be included in the final analysis along with results from the main Phase 3 program. However, by the time Phase 3 testing commenced, EPA scientists had made a decision not to include the Phase 1 results in the final fuel effect models for two reasons. One reason was that the Phase 1 test fuels did not meet formulation requirements implemented for Phase 3 fuels, such as the ratios of aromatics by carbon number and limitations on use of pure compounds, which are described in Section 2.1.6. Another reason was that numerous improvements were made to vehicle handling and testing procedures based on observations from the pilot phases. [28] Examples include the requirements for vehicle storage conditions and monitoring of adaptive fuel controls described in Section 2.1.8.

Additional claims that EPA sought to change course after Phase 1 by the addition of ethanol-sensitive test vehicles appear to derive from a briefing outlining discussion between EPA staff and management. This discussion considered options for investigating the situation in which the Phase 1 results appeared inconsistent with prior studies, including doing additional tests using different vehicles, fuel blends, and test cycles. However, the record shows that this discussion resulted in no substantive changes to the project; no "ethanol-sensitive" test vehicles were identified or added to the study as a result of these deliberations. On the contrary, comparing the test fleet of 15 vehicles eventually used in Phase 3 to the 19 used in the pilot as shown on slide 6 of the same briefing document quoted by the petitioners, it is evident that the four vehicles removed from the test fleet for Phase 3 showed above-average NO_x sensitivity to ethanol levels. This outcome means that in fact the Phase 3 test fleet is expected to have been less sensitive to ethanol on average than the pilot fleet. This fact is incidental though, since the Phase 3 vehicle

[x] 48 CFR 1552.209-73(b): "The Contractor agrees to notify immediately the EPA Contracting Officer Representative and the Contracting Officer of (1) any actual or potential personal conflict of interest with regard to any of its employees working on or having access to information regarding this contract… A personal conflict of interest is defined as a relationship of an employee, subcontractor employee, or consultant with an entity that may impair the objectivity of the employee, subcontractor employee, or consultant in performing the contract work."

sample was selected with the goals of prioritizing high-sales engine families and maintaining representation of vehicles, engine sizes, and manufacturers in order to include a full range of emission control strategies (as explained in Section 2.1.7 above) and without regard to ethanol sensitivity.

3.1.4 Design Changes Were Necessary and Reasonable

In III.A.1.g, the petitioners allege that changes made to the EPAct study design throughout were "arbitrary." On the contrary, the changes were necessary and based on objective findings and criteria.

During the planning process, the design was modified through a series of systematic steps, as described and explained in the project reports and summarized in sections 2.1.6 and 2.1.8 of this document. The design was developed "as the result of an iterative process involving balancing among research goals, fuel blending feasibility, and experimental design," as discussed in the project analysis report (page 20).[2]

In the initial step, EPA developed a design covering an ethanol range from 0 to 10%. Following interaction with research partners, the design was expanded in a second step to include fuels up to the 20% ethanol. The ethanol range was expanded to accommodate the research interests of the Department of Energy, as explained in the Program Design report (page 9 at bottom): "During the design process, DOE (via NREL) offered additional funding to add E15 and E20 fuels to … include fuel blends that might be expected [to] appear in the market …"[1]

One specific criticism in III.A.1.g of the RFC is that "EPA arbitrarily raised the T50 of the E15 test fuels from 195°F to 220°F." This change was implemented as a logical and appropriate response to an issue that arose after initial fuel blending had commenced. With respect to the upper end of the T50 range, it is important to note, as discussed in section 2.1.3, that E15 fuels were not commercially available at the time the program was designed, and that the initial value was assumed by interpolating between the values for E10 and E20. Petitioners cite subsequent discussions among the project participants and contractors as to whether the initial target value would prove achievable. However, the internal debate was resolved when new information became available after "initial blending experiments also revealed that the upper T50 limit for E15 fuels was as high as 220°F, considerably higher than the 190°F target assumed in the

absence of relevant information," as described in the EPAct testing report (page 16).[1] Accordingly, the initial assumption was revised based on experimental data.

Additionally, petitioners argue that the "fuel matrix's G-efficiency fell even further … as EPA made a series of arbitrary changes." It is true, as noted by petitioners, that the design efficiency of the fuel sets considered dropped from an initial value of 72.6% initially to a final value of 51.6% for the final fuel set. The main reason for this declining trend in efficiency is that the modifications placed greater analytic demands on the matrix. For example, successive design changes expanded the size and altered the "shape" of the five-dimensional fuel-property region to be covered, or added parameters to the model to be fit to the results, or reduced the numbers of fuels in the matrix.

With respect to design efficiency, two points must be noted. First, the *G*-efficiency does not denote "confidence in the results" as argued elsewhere by petitioners.[y] It simply reflects the anticipated uncertainty in model predictions throughout the five-dimensional space, or in technical terms, "the maximum standard error for prediction over the candidate [fuel] set."[29] In fact, the expert who performed the design work noted that "a design with a G-efficiency greater than 50-60% is considered adequate for prediction purposes."[30]

In the sixth paragraph, RFC section III.A.1.g also highlights what it calls *"last-minute changes"* to test procedures, such as EPA's directive to "begin vehicle testing the fuels as they were available, without fully randomizing all the test fuels." As described in Section 2.1.8.3 of this document, during the initial few weeks of testing EPA specified partially randomized vehicle/fuel assignments to determine the amount of conditioning required for a vehicle's fuel control system to adapt to varying ethanol concentrations. For the remaining 50+ weeks of testing, vehicle/fuel assignments were fully randomized. Then, as described in Section 2.1.8.6, after the program was complete, project sponsors performed a drift analysis to screen for any biases that might have occurred related to timing or order of tests. This analysis found no evidence of drift.

The RFC also states in this same paragraph that "EPA also lowered the number of Phase 3 test vehicles to 10 from an initial fleet of 19, eventually increasing the number to 15 vehicles a

[y] *State of Kansas vs. Environmental Protection Agency*. USCA Case No. 14-1268. (D.C. Cir. 2015). (Petitioners' brief, at 48).

full thirty-seven weeks after vehicle testing had begun." Prior to the launch of Phase 3 testing, EPA staff recommended to their management 15 vehicles as a fleet size likely to meet both statistical and budgetary targets for the program.[z] As a measure of caution, EPA directed the contractor to begin active testing with a block of ten vehicles, with additional vehicles being added later as the project finances were finalized.

3.1.5 Fuel Property Measurements Followed Standard Procedures for Collaborative Analysis

In III.A.1.h, petitioners question the conduct of the inter-laboratory comparison ("round-robin") assessment of the test fuel properties, alleging that the laboratories affiliated with oil companies were "biased market actors," and that "the testing companies were allowed to see how their data compared with the other companies' before it was finalized…," thus opening the "possibility of uncorrected mistakes or even collusion between the various testing companies."

The EPA project report states, "By mid-March 2010, all promised data were received by EPA. Shortly thereafter, a blinded set of round-robin results was made available to all participants … so that each could determine if their data were correctly entered…"[aa] Petitioners characterize this step as improper, but it is consistent with standard practice in reporting draft results to participants, while providing required confidentiality protections. Under the heading of "Collusion," a relevant guidance document from the National Institute of Standards and Technology (NIST) states that such a process is designed to ensure "that the possibility for collusion and falsification is minimized." NIST goes further to add that the coordinator is responsible to "ensure that there is no communication of the assigned values to or among participants until the results … have been collated in a draft report."[31] Thus, it is appropriate to share blinded results in the draft report stage, as was the case for the EPAct study, with no requirement to delay release to a "final" stage, as implied by petitioners. Additionally, a similar guidance document for the International Organization for Standardization (ISO) states that "test reports shall be clear and comprehensive and include data covering the results of all participants."[32] Far from creating the "possibility of uncorrected mistakes," as alleged by petitioners, the sharing of results in the first round facilitates detection and correction of mistakes by participants before the results are finalized.

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[z] EPA staff recommended use of a 15-vehicle test fleet in February, 2009.
[aa] See EPAct testing report (Reference 1), page 29 at bottom.

3.1.6 CRC Purchased EPAct Test Vehicles for Use in Follow-On Studies

Section III.A.1.i of the RFC highlights the fact that CRC purchased the test vehicles when the leases were set to expire during the final weeks of Phase 3 testing (in Spring 2010) and made them available to the testing contractor to complete the study, an arrangement they allege constituted an improper acquisition by EPA. In fact, project conference call agendas (made available to the petitioners as part of a 2016 FOIA release) show that CRC had proposed to purchase the vehicles no later than the previous Fall for use in a follow-on study of their own design regarding fuel olefin content. CRC eventually published the olefin study as project E-83, and then used the vehicles in another study, published as E-98. The conference call agendas, as well as CRC's use of the vehicles in additional work after the EPAct study, support the conclusion that CRC did not purchase the vehicles to solve a problem for EPA related to vehicle lease costs but rather to enable collection of additional data on the same vehicles. Furthermore, CRC was a project partner, and jointly published the dataset and testing report under their own name, an arrangement in which it would not be unexpected for them to provide support to the testing effort, material or otherwise.

3.2 The EPAct Study's Test Fuels Were Representative of Market Fuels

Section III.2 of the RFC contains the petitioners' critique of the fuels designed and blended for use in the EPAct Study. It should be stated at the outset that at the time the EPAct study was designed, commercially-available gasolines included ethanol at levels no higher than 10% by volume (E10). Fuels containing 15% or 20% ethanol (E15, E20) were not commercially available at that time. Even now (2018), E15 and E20 exist only in very limited supply. Consequently, it was unclear what typical properties for these fuels would have been. As discussed in section 2.1.3 of this document, using market data available for E0 and E10, the values of the five fuel properties under study were chosen to bracket the ranges found in market fuel according to survey data available at the time the study was being designed (2006).[bb] The intent was to develop a balanced statistical design that covered the space of in-use fuels, not to make the average parameter values of the test fuels equal those of market fuels. Other fuel

[bb] See EPAct testing report (Reference 1), Section III.A.2 (page 8).

properties that had been shown previously to affect emissions being measured (e.g., sulfur, olefins, MTBE) were specified to remain within a range around a value typical of in-use fuel.[cc]

The petitioners focus on three specific fuel properties for their criticisms that the EPAct test fuels were not representative of market fuels: octane ratings, distillation temperatures, and aromatics levels. We address each of these specifically below in the following sub-sections. Before we do so, we begin by addressing a fundamental argument that the results of the EPAct study are invalid due to the methods used to blend the test fuels.

3.2.1 Fuel Blending in the EPAct Study

A central part of the RFC is the point that the fuels were "match-blended," rather than "splash-blended." This argument is not given its own discrete section heading in the RFC, yet it pervades and informs many of the arguments in the entire document, explicitly or implicitly.

In the introduction to the RFC (page 6), petitioners claim that "EPA could have modeled ethanol's emissions effects by simply adding ethanol to commercial gasoline blendstocks ('splash blending'), or mimicking real-world refinery practices. Instead, the EPAct study's designers created novel fuels through an arbitrary 'match blending' process …" Subsequently, on page 14, petitioners note that "EPA relied on CRC's E-67 study, a 'match-blending' study that found ethanol increases emissions." Additionally, petitioners begin in III.2 with an argument that "…the EPAct study should have included a reference case of splash-blended gasoline-ethanol fuels … Instead, it included only fuels artificially match-blended to predetermined parameters, …" (page 30).

Given the centrality of the distinction between "splash-blending" and "match-blending" practices, Section 3.2.2 defines and explains the meanings of these two terms, and Section 3.2.3 explains the necessity of careful match blending in research.

The RFC's repeated suggestion that comparisons of emissions among sets of fuels developed through match-blending are inherently invalid conflates two arguments: the first concerning whether and how to most closely emulate "real world" fuel blending as practiced by refiners, and the second concerning what is necessary (or useful) in designing a research project to study the effects of fuel properties on emissions.

[cc] See EPAct testing report (Reference 1), Section III.A.4 (page 13).

3.2.2 Match Blending is Consistent with Current Refinery Practice

Historically, the term "splash blending" referred to a practice in which ethanol was added to a finished gasoline that was already legally saleable, producing a new fuel having higher octane, vapor pressure, and oxygen content (as well as changes in other fuel properties).[dd] Ethanol blends were produced this way for many years as a relatively low-volume product in midwestern states where tax credits enabled sale of blends containing up to 10% ethanol at retail prices lower than regular grade. At low volumes, it wasn't economical for refiners to produce and transport a separate base blendstock to capture ethanol's octane blending value.

However, with the widespread ramp-up in ethanol volumes following the enactment of the 2005 Energy Policy Act, refiners could anticipate the blending of ethanol into nearly all their gasolines. With this realization, refinery practices changed, whereby products designated as "blendstocks for oxygenate blending" (BOB) became the vast majority of their output.

The production of a BOB refers to the development of a base hydrocarbon blendstock formulated with the expectation of subsequent ethanol addition downstream at the terminal, such that it will meet multiple predetermined targets for specific properties, such as octane rating or RVP, as defined in the ASTM technical specification for automotive fuels and EPA regulations.[ee] For example, since ethanol has high octane value, refiners can cut back on components that also contribute to the octane rating and blend ethanol into a sub-grade blendstock not otherwise saleable as market gasoline. Ethanol also boosts the vapor pressure of the blend, such that in areas with volatility controls during the summer (reformulated gasoline areas and some other large cities), the base blendstock must have lower volatility than would otherwise be required of gasoline sold without ethanol. In the marketplace, the blending of ethanol happens at terminals downstream of the refinery gate, so refiners produce their unfinished blendstocks in anticipation of the subsequent addition of ethanol to produce a finished, market-ready gasoline. This process involves careful optimization of the properties of the BOB, including but not limited to, octane rating, distillation profile, volatility, and sulfur

[dd] The label "splash blend" was originally associated with the practice carried out prior to terminal modifications in which delivery truck would fill to 90% of its capacity at the gasoline terminal and then fill the remaining 10% at an ethanol storage facility, allowing the fuel to mix while the truck traveled to the retail outlet.

[ee] ASTM D4814 "Standard Specification for Automotive Spark-Ignition Engine Fuel" and Clean Air Act §211(h) as amended in 1990.

content, to produce a fuel that meets market requirements at the lowest cost. Rather than being "unrealistic," as petitioners claim, such "match blending" is actually the norm.

In the RFC, as in previous documents and communications, petitioners refer to "splash blending" in some contexts, as the "simple addition of ethanol to gasoline." This definition corresponds to the definition we have given above for splash blending in the context of blending ethanol into an already finished gasoline. But it does not apply if the "simple addition" is to a BOB designed specifically for the addition of ethanol. In other contexts, they also make the claim that the majority of ethanol-containing gasoline in the U.S. is "splash blended," ostensibly because the addition of ethanol at the terminal is the final step in the process. However, regardless of "match blending" or "splash blending," the ethanol is added at the terminal as a necessary and final step to make the gasoline saleable, so this criterion cannot be used to distinguish the two.

3.2.3 Match Blending is Necessary in Research

In their critique of the EPAct Study and the MOVES model, petitioners imply that comparisons between ethanol blends and their parent gasolines would be the only valid way to "evaluate the effect of ethanol." It is not surprising that petitioners focus exclusively on the evaluation of ethanol. However, we must note that the goals and requirements for the EPAct Study and the MOVES2014 model are much broader in scope.

3.2.3.1 The Goals of the EPAct Study Were Not Limited to Assessing the Effects of Ethanol

Among the fuel properties considered in both the EPAct study and MOVES model, the level of ethanol is only one fuel property among several. Other fuel properties examined in the EPAct study and considered in MOVES include aromatics, vapor pressure and distillation temperatures, all of which are important.

In accounting for several fuel properties, MOVES must make a much broader range of comparisons than simple comparisons between splash blends. Specifically, MOVES must be able to compare any two gasolines. Whether or not one of the fuels was blended from the other is irrelevant. In addition, MOVES must be able to estimate the effects of multiple gasoline properties varied simultaneously.

In the Energy Policy Act of 2005, EPA was directed to develop an "Emissions Model, … that reflects, to the maximum extent practicable, the effect of gasoline characteristics or components

on emissions from vehicles."[ff] This directive does not mention ethanol explicitly, nor does it mandate any specific "characteristics" or "components" to be included in the analysis. These decisions were left to the discretion of the agency, and were carefully considered in the design of the EPAct study, as described in sections 2.1.3-2.1.6 of this document. It is reasonable to conclude that Congress intended that the effect of ethanol be included in the analysis, but not to conclude that ethanol was to be the sole focus.

3.2.3.2 For Purposes of EPAct and MOVES, Comparisons Among "Splash Blends" Would Have Been Inadequate.

To meet the goals of MOVES, as well as the directives of the statute, measurement of emissions on a set of splash blends would not have been adequate, for the reason that many other fuel properties change as a result of the addition of a component such as ethanol. For example, if ethanol is added to gasoline, fractions of aromatics, saturates, and olefins shift, as do vapor pressure and distillation temperatures. If emissions are measured on the original gasoline and the ethanol blend, it is impossible to relate observed changes to any particular property, or to generalize to the broad population of fuels in the market. Furthermore, since emission effects may differ with fuel parameters at different levels, the impact of splash blending ethanol will vary depending on the properties of the base fuel to which it is added.

To generate meaningful answers, it is necessary to develop an approach that allows the researcher to assess the effects of specific fuel characteristics, as though independent of the others. To achieve this goal systematically and with reasonable level of effort and expense, the most logical approach is to develop a rigorous experimental design.

In the experiment, all fuel properties are assigned to multiple levels over their ranges. For example, to assess the effect of ethanol level in relation to that of another component, such as aromatics, it is necessary to estimate the effect of ethanol both at low and high aromatics levels, and vice versa. The use of experimental design prevents the introduction of confounding variables, rather than introducing them, as alleged in the RFC.

Having developed the experimental design, match blending is necessary to generate fuels with properties at the intended points across the design space. The EPAct project is the most recent example of an experimental design involving match blending in a study assessing the

[ff] Energy Policy Act of 2005, Sec. 1506, (q)(1)(B)(2).

effects of fuel properties on emissions. A precedent-setting example was the "Auto/Oil Air Quality Improvement Research Program," sponsored by 14 oil companies and three automobile manufacturers, and conducted during 1989-1995. The final program report points out that "… vehicles were tested using experimental gasolines formulated to provide a wide variation in: total aromatics content, total olefin content, oxygenate … content, sulfur content, vapor pressure …, and 50% and 90% distillation temperatures."[33] The design is a close analog to the EPAct study design, except that EPAct capitalized on improvements in experimental design and analysis methods developed over the intervening 20 years.[34]

Another example, investigating the effects of diesel, rather than gasoline properties, is the "Heavy-Duty Working Group" study, conducted between 1996-1999. The second phase of this study used a statistically designed fuel property matrix which included cetane number, aromatic content and aromatic type.[35,36]

Returning to the question of research design, one cannot envision a "splash-blending" study design that would produce results relevant to the real world. Such a design could compare a market E10 (or E15/E20) fuel and its non-ethanol blendstock, but that particular blendstock would have never been sold without ethanol present. Rather, a different hydrocarbon blend would have been produced to meet market requirements without ethanol. Alternatively, the study could compare a market-legal E0 to a mid-grade E10 splash-blended from it, but that comparison would represent a historical situation that is irrelevant in the marketplace today, as described above. In either case, the difference in emissions between the base fuel and splash blend is academic. To collect relevant and useful data on the effect of ethanol blending (or any other fuel property) on emissions requires a more deliberate design approach as carried out in the EPAct test program.

3.2.3.3 Experimental Results Must Be Interpreted Consistent with the Experimental Design

Having implemented the experimental design, the emissions measurements must be analyzed and results interpreted in a manner consistent with the design. Failure to do so can produce misunderstanding and misinterpretation, which is evident in the RFC.

For example, the RFC appears to assume that subsets of test fuels differing in ethanol level, but consistent in other properties such as aromatics or distillation temperatures, can or must be interpreted as though the fuel with higher ethanol were blended from the fuel with lower ethanol.

However, this is emphatically not the case. Subsets of fuels generated with the study design are not intended to represent sets of splash-blended fuels, and cannot be interpreted as such.

This misunderstanding of the petitioners appears to be the source of much of their perplexity and concern about the EPAct study, including claims such as:

"There is no regulatory, mechanical, or health justification for adding high-boiling point hydrocarbons to test fuel for the purpose of measuring ethanol's effect on tailpipe emissions." [RFC, page 7 at top],

Having misunderstood the design, the petitioners also misinterpret the resulting models. The RFC (bottom of page 6) selectively quotes the EPAct Study Executive Summary[2] with an implication that the study results were incoherent or otherwise uninterpretable:

"The result of this 'match blending' was the EPAct study's conclusion that 'other factors being equal, increasing ethanol is associated with an increase in emissions.' This conclusion is misleading at best, because other factors are never equal in the real world …" [RFC, page 6 at bottom].

In fact, the EPAct Study Executive Summary was making a general point intended to help readers avoid misinterpreting the results, and it went on to provide more specific guidance designed to guide readers in interpreting and applying the results correctly (i.e., model coefficients) (page 3): "It is important to note that the effects of different fuel properties are not cleanly separable. It is difficult to modify one property in an actual fuel without affecting one or more of the others. The study design and analysis … are structured so as to allow assessment of fuel effects as though they were independent of each other. However, in interpreting or applying the models, it is critical to consider the effect of all five fuel properties in conjunction with each other. Consideration of single coefficients in isolation can easily result in misleading conclusions."

The models produced from the EPAct study represent a statistical deconstruction of the emission results, a necessary step to estimate emissions impacts of fuel blends with varying levels of all the parameters tested in the program. How, then, should they be interpreted? As mentioned, they can be appropriately interpreted as though representing comparisons between fuels that differ in one factor, but are similar for the remaining properties.

Model coefficients describe associations between emissions and changes in fuel properties. A positive coefficient for a property indicates that an increase in the property is associated with

an increase in emissions if the remaining four properties remain constant. However, the effects of all the other model coefficients and interactions must be summed to get the overall effect that the modeling results would describe.

The EPAct study models therefore can account for "splash blends" of ethanol into gasoline because they can account for simultaneous changes in multiple properties affecting emissions. For example, when using the model to compare the results of a splash blend of ethanol into a base gasoline, the model will typically show an overall PM decrease due to its lowering of the aromatic content and distillation points relative to the base fuel, even though the effect of the ethanol by itself would be to increase PM by its tendency to slow evaporation of fuel droplets. The EPAct model can therefore be used to model a combination of fuel properties, in isolation or in combination such as in splash blends. However, it is important to note that a test program of splash blends could not be used to compare an ethanol blend to a non-ethanol gasoline potentially sold in its place and having the same RVP or T50 level. This is because the act of splash-blending affects multiple fuel properties simultaneously, preventing the individual effects from being distinguished and the results from being generally applicable.

As a final point, we note that the EPAct models describe associations between emissions and fuel properties. However, we emphasize that the existence of associations does not necessarily imply causative relationships; attribution of causation requires interpretation and the application of engineering and scientific judgment.

3.2.4 Responses to Specific Criticisms of the EPAct Test Fuels

3.2.4.1 The Test Fuels' Octane Levels Were Assigned Consistent with the Study's Objectives

In III.A.2.a of the RFC, petitioners argue that "the EPAct study's test fuel contained unrealistically high levels of octane." It is true that some test fuels had octane levels higher than those typical for many regular-grade fuels. However, petitioners make no arguments as to how the octane ratings, *per se*, might have affected the results.

The octane rating of all test fuels met the minimum value for regular-grade market fuels, but some fuels had higher values in the range of premium grade market fuel. Section 2.1.6 above, and the EPAct study report on design and data collection, explain that narrow limits on octane would not have been possible to meet given other blending priorities, such as aromatics and ethanol targets, which were known to affect emissions.[1] Since there was no evidence that octane

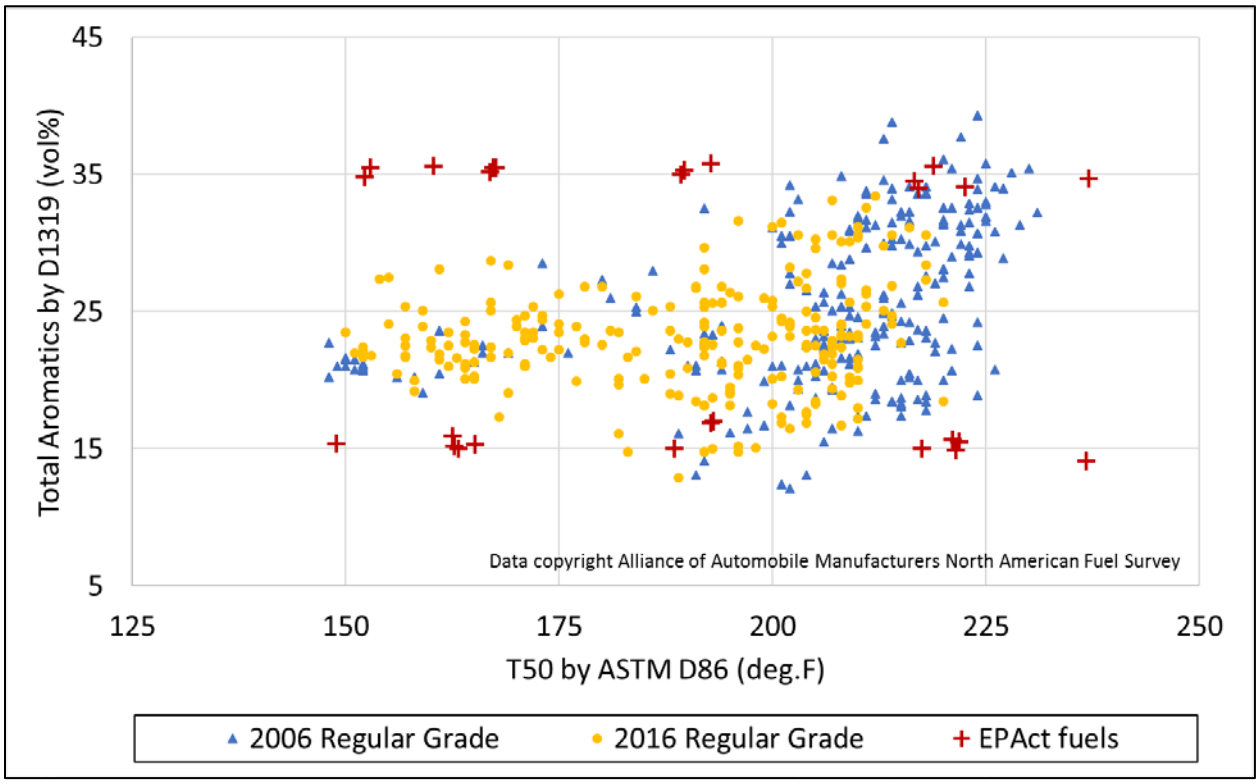
would affect emissions collected in the specified test procedures, allowing octane values above regular grade market fuels was deemed acceptable. Given that data from a recently-completed study on the current generation of vehicles with engine down-sizing and turbocharging continues to support this assumption, the RFC's criticism that "octane levels were skewed high" is of no relevance. [15]

3.2.4.2 The Range in Test Fuel Distillation Temperatures Spanned the Market Range, Allowing for Uncertainty in Future Blending Practices

In III.A.2.b, the RFC criticizes the upper range of T50 distillation temperatures based on the assumption that splash-blending ethanol tends to depress T50 below levels observed for non-ethanol market gasolines. However, as we have described elsewhere, the EPAct study was not a splash-blending study. As discussed in Section 2.1.6, the T50 range of the test fuels was specifically designed to represent the range of in-use fuels at the time the study was designed (2006-7) while still accounting for the distillation impacts of ethanol blending, particularly for the E15 and E20 blends not yet generally available in the market.[1,12] The T50 range of test fuels relative to regular grade market fuels in 2006 and 2016 is depicted in Figure 3-1. This plot shows that the fuel matrix covered the full range of market fuels at the time of the study, and after shifts in these properties over time, this range remains relevant a decade later. This is corroborated by the refinery batch data provided to EPA and summarized in the 2017 EPA Fuel Trends Report.[gg]

[gg] Figures 121-133 in the 2017 Fuel Trends Report show E200 data, which is a mathematical inverse of T50.[12] The values can be converted as follows: T50[as °F] = (147.91-E200[as vol%])/0.49.

Figure 3-1. Total Aromatics Content vs. the T50 Distillation Temperature for EPAct Test Fuels and Market Fuel Surveys.



RFC section III.A.2.b also criticizes the final boiling point (FBP) of the test fuels as being too low compared to market fuels. This was not a parameter used in the design and analysis of the data, primarily because of the variability inherent in the measurement of FBP. Rather, the study controlled the T90 distillation points to be representative of in-use fuels (as described in Section 2.1.3).

3.2.4.3 Test Fuels' Aromatics Levels Spanned the Range for the Majority of Commercial Fuels

The criticism that the EPAct study test fuels' aromatics range exceeds that of market fuels is also without merit. In III.A.2.d, the RFC claims that the aromatics levels used in the study were "skewed high" because "the market includes fuels with aromatics levels as low as 3.9%," and the lower level used in the study was close to 15%. However, as the reports make clear, the study was not designed to span the *entire* range, but rather the 5th to 95th percentiles, which were 16 vol% and 38 vol% for conventional gasoline in 2006, with individual batches exceeding 60

vol%, even higher than the high end of the range for the test fuels (35%).[1,12,hh] The aromatics range of test fuels relative to market survey data in also shown above in Figure 3-1.

In addition, the RFC criticizes the test fuel blending, arguing that some aromatics levels "significantly exceed" target values. The criticism appears to be based on the RFC's erroneous comparison of results generated by ASTM method D6729 with those from method D1319. The EPAct study aromatics specifications were based on D1319 because this the method for which there is the largest body of data for in-use fuels (including the Alliance of Automobile Manufacturers North American Fuel Survey), an important consideration when specifying and blending representative test fuels. Also, the MOVES fuel adjustment algorithms, where the EPAct study results were to be applied, are based on county and regional D1319 data.

These two test methods have different goals, with D1319 being focused on quantifying the proportions of aromatics, olefins, and saturates, and D6729 attempting to quantify the full range of compounds in gasoline. While both methods can produce a total aromatics value, the results often differ for the same fuel sample, typically with the D6729 result being larger. For example, across the EPAct study test fuels the difference between the methods ranges from 0.4 vol% to 6.2 vol% with a median of 2.2 vol%. EPA generated D6729 results for the test fuels after fuel formulation and blending was completed to provide a detailed view of the composition for future reference.

3.3 The EPAct Study Controlled for Confounding Variables

The petitioners contend that the EPAct study failed to disentangle several confounding factors from those being studied, listing specifically octane, drivability, distillation temperatures, aromatics speciation, density, and olefin content. In fact, as described in sections 2.1.3-2.1.6 of this document, one of the strengths of the EPAct study's design was its ability to control for confounding variables. Furthermore, we disagree that those fuel parameters that were uncontrolled have a significant effect on emissions. As discussed in section 2.1.6 of this document, octane has been shown to have no impact on emissions on the subject vehicles over the test conditions evaluated, and therefore should not be considered a confounder. Drivability is a linear combination (a sum, essentially) of distillation points and ethanol level, and therefore

[hh] For a summary of 2006 refinery batch data for aromatics see Figures 66-73 in the 2017 Fuel Trends Report.[12]

cannot be considered an independent factor when those underlying fuel parameters are already accounted for in the study the design. Other factors are discussed in more detail below.

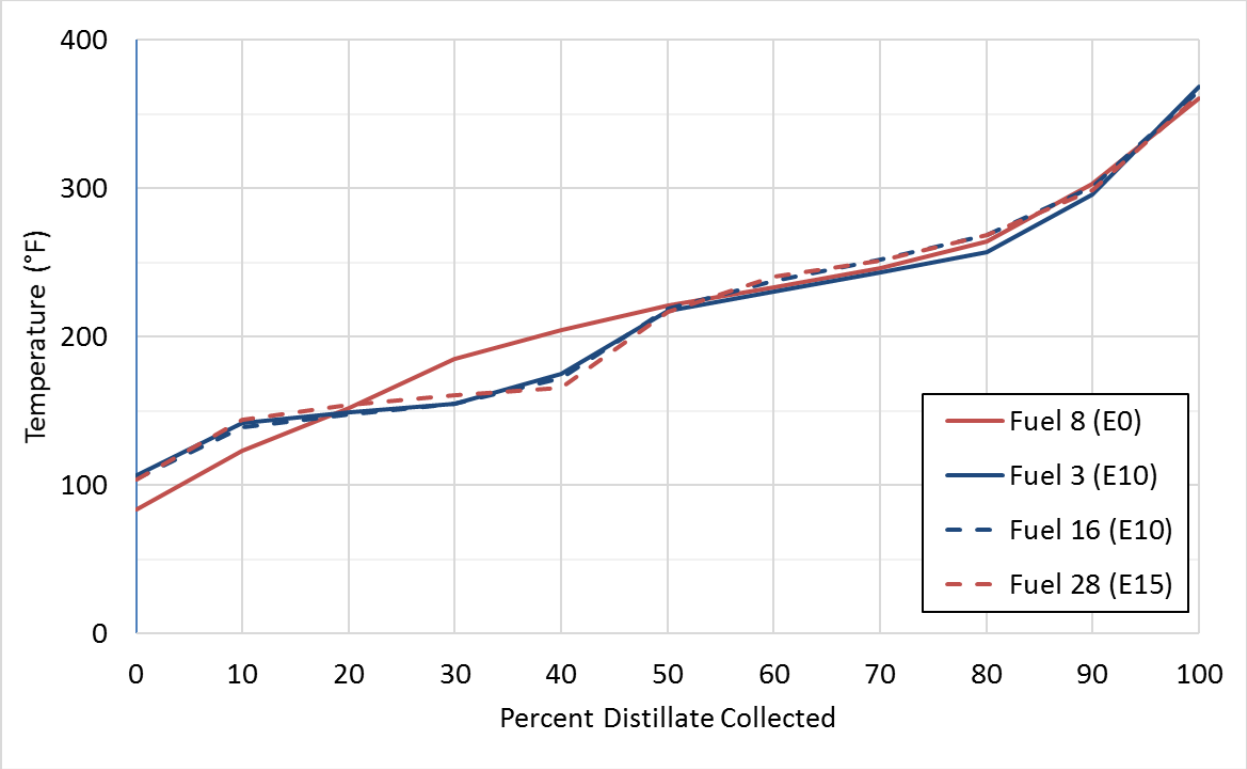
3.3.1 The Distillation Profiles and Hydrocarbon Blending Components of EPAct Test Fuels Are Representative of Market Fuels

The EPAct study appropriately controlled for distillation temperatures. EPA's choice of T50 and T90 as distillation match points was reasoned and appropriate; there was no systematic bias in fuel blending that resulted in ethanol fuels having higher boiling point hydrocarbons which were responsible for ethanol's impacts on PM emissions; and T70 is not an important missing parameter.

T50 and T90 have been used to characterize the upper half of a fuel's volatility profile for decades, and as such they act as a link to many earlier studies and models as well as a vast volume of market fuel data. As discussed in Section 2.1.3, when the EPAct study was being designed it was these prior studies that provided evidence that T50 and T90 could have emission impacts warranting inclusion in the EPAct design. These studies did not highlight other distillation parameters, particularly as replacements for T50 and T90.

Although matching test fuels at the T50 and T90 points does not guarantee that they will have the same distillation profile overall, there was no systematic bias in the fuel blending. The petitioners make the statement: "Within every set of EPAct test fuels with matched T50 and T90, and varying ethanol concentrations, the boiling points of one or more higher-ethanol fuels exceeded those of one or more lower-ethanol fuels for the entire T60-T80 range," which simply means that some fuels had some distillation points higher than some others. And in contrast to Figure 5 in the RFC, the EPAct study includes groups of test fuels with closely matched T60-T80 distillation profiles, as shown in Figure 3-2 of this document.

Figure 3-2. Example of EPAct test fuels with varying ethanol levels but with closely-matched T60-T80 distillation profiles.



Furthermore, high-boiling point hydrocarbons are not required to be added in order to match distillation parameters, and they are not responsible for the emissions impacts observed by the EPAct study. It is possible to match the upper distillation range regardless of ethanol level. Ethanol's influence is limited to the T50 area of the distillation profile near its boiling point; matching upper distillation points only requires adjustment of components near ethanol's boiling range.

EPA performed a subsequent study[37] to explore ethanol's impact on PM in more detail, and this work confirmed the EPAct study's finding that ethanol can reinforce the propensity of gasoline to produce PM. It also confirmed that the upper distillation range can be matched regardless of ethanol level and without adding high boiling point hydrocarbons. Figure 3-3 shows the matched distillation profiles for the two ethanol/non-ethanol fuel pairs in the study. Figure 3-4 illustrates that creating a distillation-matched pair doesn't require the ethanol blend to contain more high-boiling hydrocarbons. The plot shows all fuel components that differed by more than 0.1 weight percent between the ethanol and non-ethanol test fuel, in order of

increasing boiling point from left to right. The large upward bar left of center shows addition of ethanol, while several smaller downward bars nearby it represent removal from the blend of several components in the same boiling (or distillation) range as ethanol in order to match the upper distillation profiles. The absence of upward bars to the right of center indicate no more high-boiling compounds were present in the ethanol blend relative to the non-ethanol fuel.

Figure 3-3. Distillation Profiles of E0/E15 Test Fuel Pairs Showing Closely-Matched Regions Above T60.

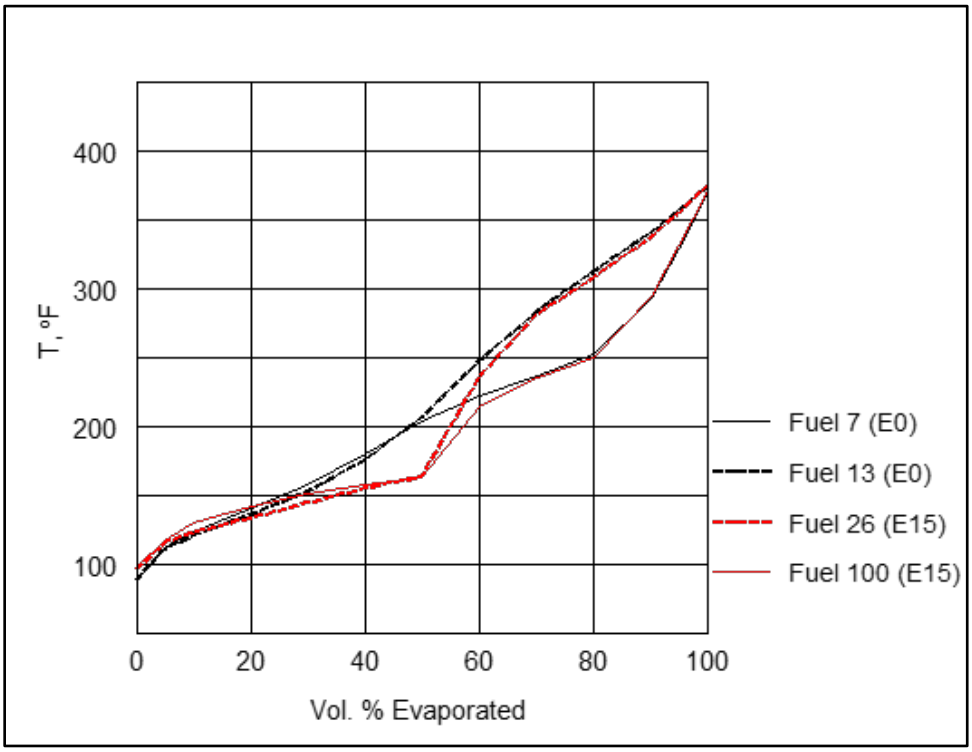
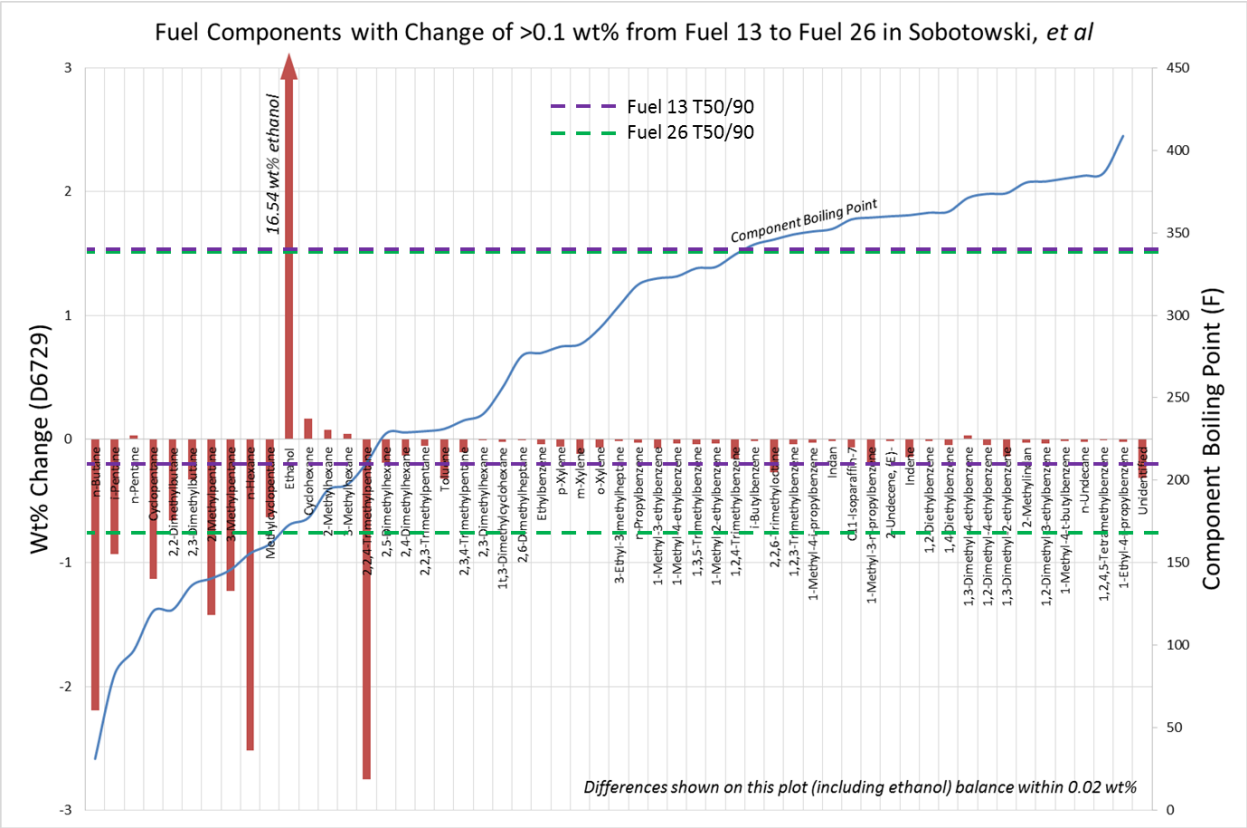


Figure 3-4. Comparison of Differences in Fuel Components for an E0/E15 Fuel Pair with Closely-Matched Distillation Profiles Above T60.



Finally, the assertion that T70 is an important missing model parameter is based on a statistically flawed analysis and is inconsistent with existing evidence. The 2016 Darlington, *et al.*, paper cited in the RFC attempted to re-fit the EPAct study PM models by substituting T70 for the T90 parameter used in the original study design.[38] However, implicit in the process of fitting a regression model is a requirement that the predictors, or parameters, have minimal correlation with each other.[39] As explained in Section 2.1.4, the EPAct fuel matrix was designed around a set of model parameters that would be used in regression of its results, a process that attempted to neutralize the correlation between those parameters. T70 was not a design parameter, and has uncontrolled correlations with other fuel parameters also being included in the models. Furthermore, existing evidence does not support an assertion that T70 is a more important predictor of PM emissions.[15,16,37,40]

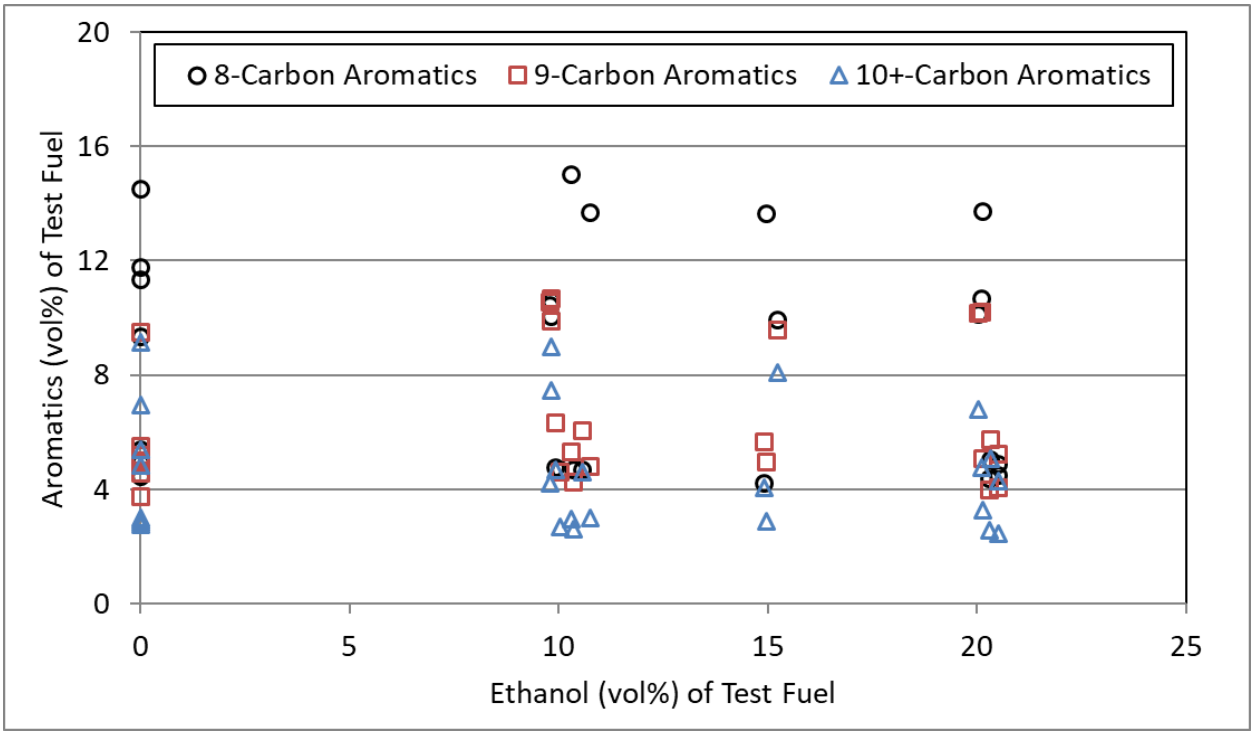
3.3.2 The EPAct Study Specified Balanced Proportions of Aromatics Species to Eliminate Confounding Variables and Ensure Results Were Applicable to In-Use Fuels

Aromatics species in gasoline are comprised of compounds with between 6 and 13 carbon atoms and span the upper half of the distillation range (i.e., above T50). Aromatics have a higher structure-related propensity to form PM than non-aromatics because of their higher carbon-to-hydrogen ratio, and the higher their boiling point (which is closely correlated with their carbon count), the more likely they are to contribute to PM formation via volatility-related mechanisms. This means that high-boiling aromatics, say, those with ≥9 carbons, or boiling above T90, have especially high leverage on PM. Thus, when specifying a total aromatics value as a test fuel (and model) parameter, it is important that the proportions of species by volatility be controlled to resemble in-use fuels (to which the resulting emissions models are intended to apply). This level of specification was not typical (if ever done) in a gasoline fuel effects study prior to EPAct, and it was through the EPAct study and other studies around the same time that gasoline property effects on PM were first being studied in detail.

EPA staff used market gasoline speciation datasets available at the time of the study design to specify proportions of aromatics for the test fuels. Figure 3-5 plots the aromatics species by carbon number for each test fuel, showing relatively straight, consistent, horizontal trends in aromatics type across the ethanol levels. Figure 3-6 shows PM Index (PMI)[ii] by ethanol level for all test fuels, again showing a relatively square rectangle covering the space, indicating the design intended to maintain a consistent PM-forming potential of the fuels across the ethanol levels. The ethanol interaction with PMI was a new finding from the study results, enabled by this careful separation of PMI and ethanol into different dimensions. As described in Section 3.3.1, EPA performed a follow-up study to better understand this ethanol-PMI interaction.

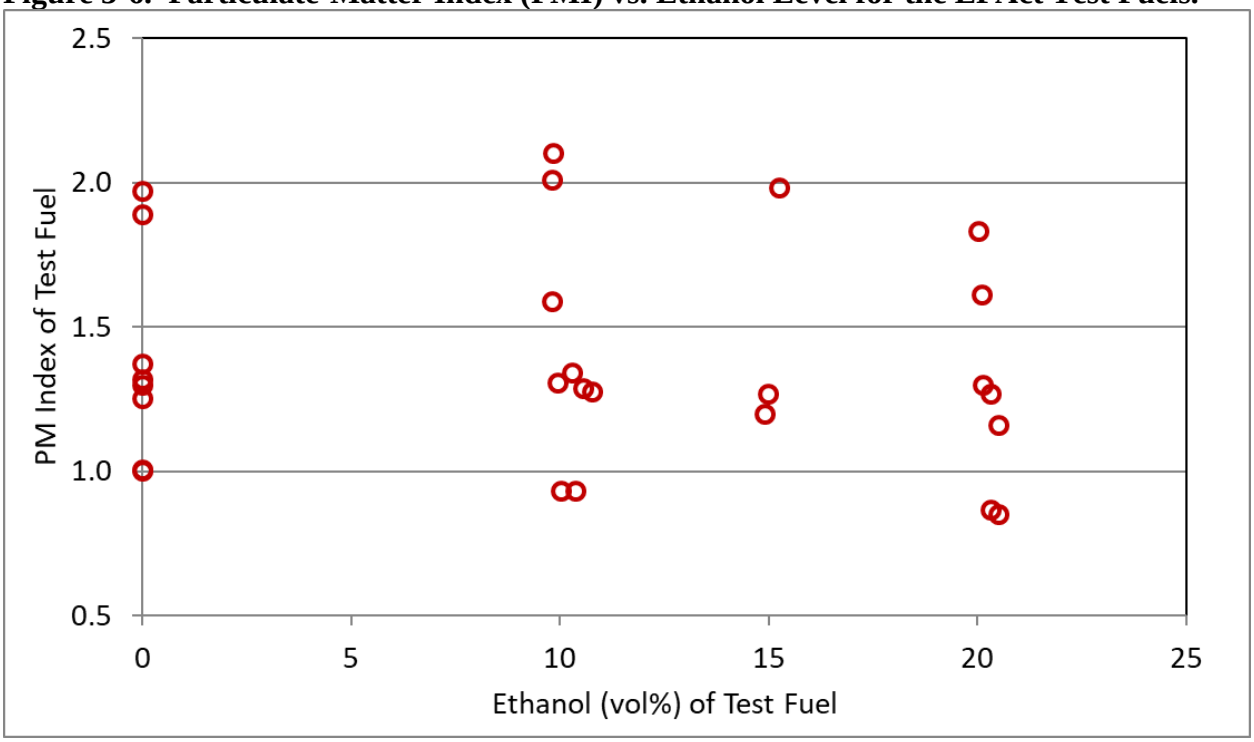
[ii] PM Index (PMI) is an estimate of the relative PM-formation potential of a particular gasoline blend, based on the molecular structure and volatility of its components.

Figure 3-5. Levels of Aromatics by Carbon Number vs. Ethanol Level in the EPAct Test Fuels.*



*Higher-carbon-count aromatics are associated with higher PM emissions. Therefore, their concentration in the test fuels was controlled across ethanol levels to preclude confounding the ethanol and aromatics effects.

Figure 3-6. Particulate-Matter Index (PMI) vs. Ethanol Level for the EPAct Test Fuels.*

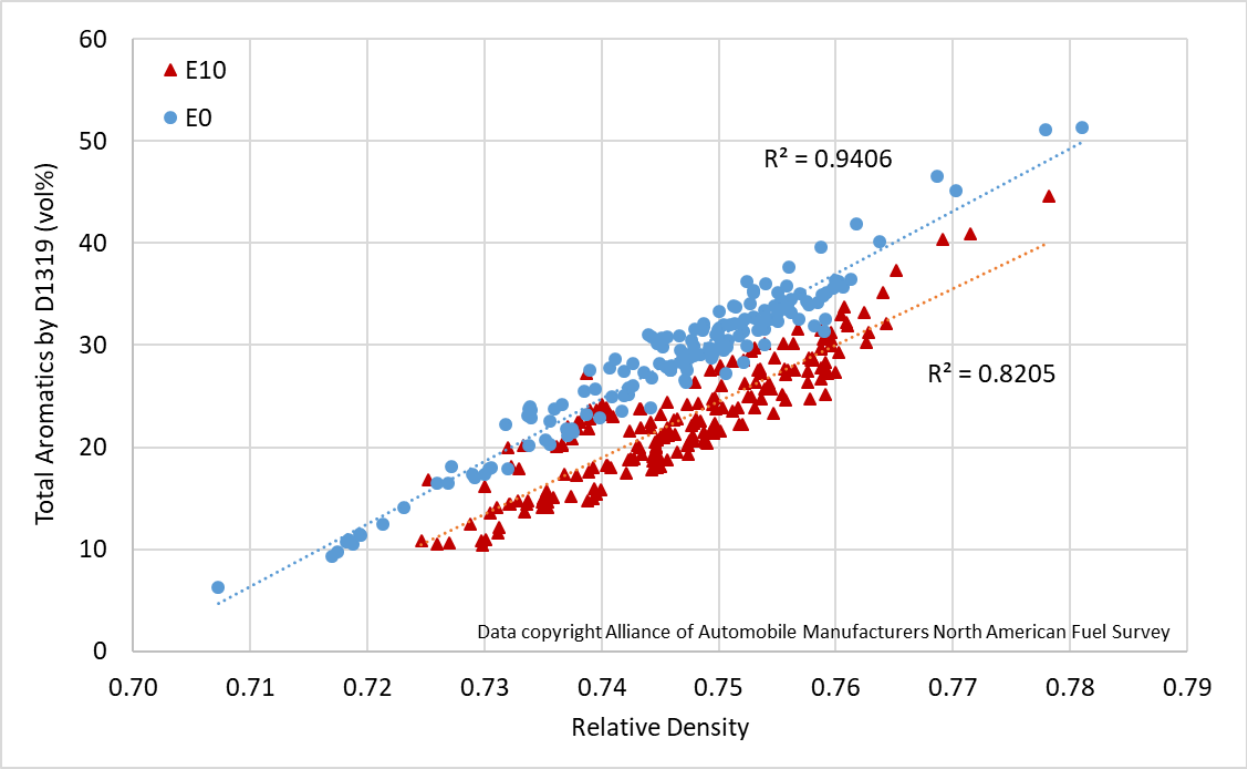


*PM Index (PMI) is an estimate of the relative PM-formation potential of a particular gasoline blend, based on the molecular structure and volatility of its components. Therefore, the PMI of the test fuels was controlled across ethanol levels to avoid confounding the ethanol and PMI effects.

3.3.3 Fuel Density Is Highly Correlated with Aromatics and Ethanol Content, Both of Which Were Carefully Controlled Design Parameters

In III.A.3.d, the RFC claims that the EPAct study did not control for the relationship between fuel density and emissions. However, the RFC cites no evidence of (and we are unaware of studies showing) an emission impact of density itself, independent of hydrocarbon type or volatility, in gasoline vehicles. Density is a fuel parameter that follows, or results from, the proportions of various constituents such as aromatics and ethanol chosen during the blending. As illustrated in Figure 3-7, density is highly correlated with aromatic content at a given ethanol level, and thus did not need to be controlled separately.

Figure 3-7. Correlation Between Aromatics and Density in 2007 Market Fuels.



The petitioners also suggest that blendstock density declined in market fuels over the period when ethanol blending increased, attributing it to ethanol displacing "*higher-density octane additives*". To the extent that a decline in blendstock density has occurred, it is a result of a complex interplay of a number of factors, with the substitution of ethanol for aromatics in meeting octane targets, as suggested by the petitioners, being only one. Another is the increased production of natural gas and its coproducts over the past decade having made catalytic reforming less economically attractive as a source of octane and hydrogen in the refinery. This change has resulted in production of more alkylate (isoparaffins), a high-octane component with lower density than aromatics or ethanol.

In order to understand and model these changes in market fuel over time, the EPAct study required a parametric design including independent adjustment of aromatics and ethanol, as explained in Section 3.2. As part of this process, saturate levels in the test fuels were adjusted to balance changes in other parameters. However, given that olefin, aromatic, and ethanol content were all controlled, saturates were fully defined by mathematical difference. The petitioners suggest that "*high-distillate saturates*" contribute to pollution but were uncontrolled in the study.

In fact, any effect of high-boiling saturates on emissions was accounted for in varying the T90 parameter at a fixed aromatic and ethanol level.

3.3.4 The Study's Olefin and Saturate Specifications Did Not Bias Results

The EPAct study controlled for olefin content (contrary to the RFC's assertion in section III.A.3.e). A fixed olefin content of 7.0 ± 1.5 volume percent was specified for all test fuels, consistent with market fuel averages, as described in Section III of the EPAct study testing report.[1] As explained in Section 2.1.2 of this document, the effect of olefins on emissions was tested in a follow-on study funded by CRC using the same laboratory and test vehicles. Comparing E10 blends with 3% and 18% olefin content, a much larger range than the variance among EPAct study fuels, the study found no statistically significant effects on cycle-composite emissions, and a minor effect on cold-transient test segments (bags) for NOx and CO.[10]

3.3.5 Omission of Detergent Additives from Test Fuels Did Not Affect Results

RFC section III.A.3.f states that EPAct study results were biased against ethanol based on the claims that (1) testing of ethanol blends was delayed relative to the E0 fuels, and since deposit control additives were not used in the test fuels, (2) emission results from ethanol blends were therefore more likely, on average, to be affected by build-up of combustion deposits.

There was no meaningful delay in including ethanol-containing fuels into the test schedule. Review of Table V-1 of the EPAct study testing report shows that ethanol blends were introduced into the test sequence on the fourth week of a test campaign that ran 60 weeks.

In addition, we disagree with the suggestion that there was any measurable emission impact of combustion deposits over the course of the EPAct study. As described in Section 2.1.8.6, the study design included a drift screen that compared emission measurements at the beginning, middle, and end of testing using the same fuel. Any statistically significant effect of deposits on emission performance would have been detected by this analysis. As no such changes were detected, we find no merit in this claim.

Finally, the RFC refers to the CRC E-98 report, which describes a study done by SwRI using the same vehicles as the EPAct study after it was completed. The E-98 study was done more than two years after the EPAct testing was completed, and during that interim period the test vehicles were used in the E-83 study at University of California Riverside, and then spent approximately a year in storage. It is inappropriate to link the vehicles' behavior in the E-98

project to what occurred in the EPAct study. The petitioners state that "when CRC used nine EPAct study vehicles in a subsequent study, most of them had higher emissions than expected based on the initial EPAct study tests." In fact, E-98 used all fifteen EPAct study vehicles, and Section 3.1 of the E-98 report explains that only four were found to have "higher emissions than expected," with no specific emissions thresholds given for flagging the four vehicles.

3.4 The Fuels Selected for Speciation Reflected Important Research Interests

Due to the expense and effort involved in speciation of exhaust emissions, it was not possible to collect this type of data for the full set of emission tests while maintaining the project schedule and budget. The subset for which speciation was performed was carefully selected so as to focus on those areas of most interest to EPA. This included aromatics, given their importance in photochemical modeling. It also included ethanol, which was important from a policy perspective in the context of the directives of the Energy Policy Act of 2005 to assess the impacts of the Renewable Fuel Standard. As a result, fuels selected for speciation emphasized those that allowed for ranges of both ethanol and aromatics.

3.5 The Selection of Air Toxic Pollutants for Speciation Reflected Well-Established Priorities

Petitioners incorrectly claim that EPA "neglected" or "ignored" other toxic compounds, such as polyaromatic hydrocarbons (PAH). The EPAct study measured emissions of over 200 individual hydrocarbon species.[41] In the analysis of the study's Phase 3 results, statistical models were fit for a subset of these compounds, including acetaldehyde, formaldehyde, acrolein, benzene and 1,3-butadiene. These five compounds are identified in previous National Air Toxic Assessments (NATA), which are conducted to identify and prioritize air toxics, emissions sources and geographic locations of greatest potential concern. In the 2005 NATA, formaldehyde and benzene are listed as national and regional "cancer risk drivers," respectively. Acetaldehyde and 1,3-butadiene are listed as national "cancer risk contributors," and acrolein is listed as a national "non-cancer hazard driver."[jj] These and other compounds are included in

[jj] See *Summary of Results for the 2005 National-scale Assessment*, available at: https://www.epa.gov/sites/production/files/2015-10/documents/2005-nata-results-summary.pdf.

development of emissions profiles incorporated into in the SPECIATE database, which is used to produce pollutant inventories and provide input to receptor models.[42,43]

Petitioners also claim that EPA "neglected" ultrafine particles (UFPs) and black carbon. In fact, the EPAct Study collected $PM_{2.5}$ emissions data, which includes both UFPs and black carbon. $PM_{2.5}$ is the appropriate and relevant pollutant to measure for the purpose of the EPAct study, because the National Ambient Air Quality Standards are established for $PM_{2.5}$ and not its component parts in isolation. The 2009 EPA Integrated Science Assessment for PM states that, "Overall, the results indicate that many constituents of PM can be linked with differing health effects and the evidence is not yet sufficient to allow differentiation of those constituents or sources that are more closely related to specific health outcomes."[44] The point was affirmed by the Health Effects Institute Review Panel on Ultrafine Particles in a 2013 publication stating that "toxicologic studies […] and epidemiologic studies to date have not provided consistent findings on the effects of exposures to ambient levels of UFPs, particularly in human populations. The current evidence does not support a conclusion that exposures to UFPs alone can account in substantial ways for the adverse effects that have been associated with other ambient pollutants such as $PM_{2.5}$."[45]

3.6 Study Results Are Consistent with Previous Work

Section III.B of the RFC makes a series of over-simplified and unqualified claims that the findings of the EPAct study are "demonstrably false," and are "refuted by previous studies." The citations from the peer-reviewed literature are selective; a broader review refutes the petitioners' claims and generally supports the EPAct study results. The subsections below respond in more detail to the RFC sections III.B.1-4. Before addressing specific considerations, we can make the following observations about the studies cited in RFC section III.B:

- Most studies are small, involving measurements on only a few (<5) vehicles, on small numbers of fuels (2-8), making it difficult to generalize the results beyond the specific context of the study under consideration.
- Studies vary widely in the reporting of fuel properties, particularly aromatics levels and distillation parameters. Lacking this information, it is difficult or impossible to relate the results to any single fuel constituent or property, as multiple fuel properties that affect emissions performance vary simultaneously. In turn, then, it is very

difficult to reproduce such a study or apply its results to other situations with confidence.

- In small studies, it is common that authors report their results for individual vehicles separately, without averaging or otherwise deriving broader conclusions from their results. It is up to the reader to translate specific findings to a broader context where inferences can be made about real-world emissions, which even if possible, takes expertise and effort.

In combination, these three points greatly complicate the task of assimilating the results of multiple studies over several decades, interpreting them individually and in relation to each other, and generalizing them broadly in a policy-relevant context. The disjointed nature of the research also facilitates the tendency of interested parties to selectively cite, i.e., "cherry pick" the literature for studies with results that apparently favor the position they wish to support.

In section III.B. of the RFC, the petitioners cite small numbers of carefully selected studies. In the material that follows, we present a review of a broader range of published studies, which while scarcely exhaustive, is sufficient to give the reader a better sense of the variability in research methods and results. We present many of the papers cited in the RFC, plus a number of additional papers omitted in the RFC.

3.6.1 The EPAct Study Correctly Reports the Responses of Particulate Matter Emissions to Ethanol and Other Fuel Properties

RFC section III.B.1 opens with the unqualified claim that, "The entire PM formation potential of gasoline comes from aromatics," a statement paraphrased from the abstract of an article reporting the results of smog-chamber experiments conducted 20 years ago.[46] A second unsupported claim immediately follows: "Ethanol, by contrast, does not produce $PM_{2.5}$ … ." The reader is left to conclude that the second statement follows from the first, and that both have a bearing on the findings of the EPAct study.

To see the misleading nature of the first claim, it is only necessary to understand the study more fully and to quote its conclusions in context. The study concerned the formation of "secondary organic aerosol" (SOA) in the atmosphere from "whole gasoline vapor," rather than "primary particulate" emitted in tailpipe exhaust, as estimated in the EPAct study. Thus, "whole gasoline" refers to unburned fuel, and has nothing to do with the generation of particulate through combustion in the vehicle as measured in the EPAct study. The cited study can be more

accurately summarized by quoting its conclusion: "The results of these experiments strongly support the hypothesis that aromatics play the predominant role in SOA formation associated with atmospheric oxidation of unburned gasoline." Thus, the cited article is entirely irrelevant to the findings of the EPAct study.

The second claim is equally misleading and equally irrelevant. The RFC cites the Chapter 7 of the Regulatory Impact Assessment for the Tier 3 Emission Standards (at page 7-72).[47] Again, it is worthwhile to quote that document more fully: "It is unlikely that ethanol would form SOA directly or affect SOA formation indirectly through changes in the radical populations due to increasing ethanol exhaust." This passage concerns the tendency of ethanol to influence SOA formation in the atmosphere through formation of free-radical species. This process is completely independent of any influence ethanol might exert on the formation of primary particulate during combustion in the vehicle, which is the topic of the EPAct study.

Thus, the two studies the petitioners cite to discredit the results of the EPAct study with respect to the effect of aromatics on PM emissions have no relevance to exhaust PM emissions.

The RFC continues to claim that the "reductions of PM emission with the addition of ethanol … has been demonstrated in many studies." While this claim does have some relevance,[48,49,50,51,52,53] it does not conflict with the findings of the EPAct study. The statistical model for exhaust PM that was developed from the EPAct study predicts reductions in PM, particularly for start emissions, for pairs of fuels in which ethanol is added to a gasoline by "splash blending," with concomitant reductions in aromatics and the distillation parameters. This conclusion can easily be verified by application of the EPAct models to such fuel pairs.[kk] However, this question is entirely different from whether the presence of ethanol in a fuel contributes to PM formation during combustion by itself, apart from its impact on other fuel parameters.

We do not dispute the important role of aromatics and other high molecular-weight petroleum constituents in formation of PM. Indeed, results from the EPAct study suggest that aromatics and T90 are important influences in PM formation from combustion of ethanol-gasoline blends. Additional research designed to clarify the findings of the EPAct study has

[kk] See the EPAct emission model calculator, available at: https://www.epa.gov/moves/epactv2e-89-tier-2-gasoline-fuel-effects-study.

confirmed that ethanol can be positively associated with PM emissions, through its interaction with aromatics and other high-molecular-weight constituents.[37]

These findings are clarified by fundamental research into the vaporization behavior of ethanol-gasoline mixtures. In blended fuels, the ethanol and petroleum components interact in ways that differ from either in isolation. For example, experiments have shown that the time required for a fuel droplet to fully vaporize increases when ethanol is added to a hydrocarbon mixture, suggesting that after a given time, droplets in an ethanol-hydrocarbon mixture are larger than in a pure hydrocarbon liquid, leading to incomplete combustion and contributing to higher PM formation.[54, 55] Further work in this area has shown that the presence of ethanol affects the vaporization of aromatics: "… there was a clear effect that as the blended ethanol concentration increased there was an increase in the aromatic concentration in both the vapor and liquid phases towards the later stages of distillation and droplet evaporation - …," with the implication that "… increased ethanol content could be causing regions locally rich in aromatics in direct injection engines which would heighten PM emissions."[56]

Thus, the relationship between primary particulate-matter emissions and ethanol blending is not nearly as simplistic as claimed in the RFC. Emissions of particulate matter are highly variable and depend on multiple factors, including vehicle technology and fuel composition, with ethanol content as one relevant factor.

3.6.2 The EPAct Study Correctly Reports the Responses of Nitrogen Oxide (NO_x) Emissions to Ethanol and other Fuel Properties

The association of ethanol with increases in NO_x emissions, even in splash blends, has been observed in studies since it was first used as a fuel additive more than three decades ago. RFC section III.B.2's discussion of NO_x emissions begins by misstating the results of the EPAct study, apparently confusing positive coefficients in statistical models with a conclusion that "increased ethanol content is correlated with increased emissions of NO_x." This statement fundamentally misinterprets the models and ignores repeated caveats in the EPAct study report that coefficients cannot be taken in isolation to represent the "effect" of any fuel property, including ethanol.

The error in interpretation is then compounded by an implication that ethanol coefficients from the statistical models can be directly compared to results from any individual published study, which is not correct. Applications of the models as a whole can often be compared to

published results, if the relevant fuel property information is reported so as to allow more direct comparisons.

Petitioners follow with a third statement, that ethanol reduces NO_x emissions when "simply splash blended into ordinary gasoline." This statement grossly oversimplifies the evidence accumulated over 25 years. While highly variable and mixed results have been consistently reported in the literature, increased NO_x emissions for ethanol blends have been frequently reported, both in earlier and more recent studies.

In Table 3-1 below, we have summarized the results of a selection of studies published between 1996 and 2014. In addition to the source, we note the model-year range and numbers of vehicles measured, how authors indicated test fuels were blended, and test cycles used. In addition, the table shows the average percent difference in NO_x emissions for comparisons between ethanol blends with 10 or 20% ethanol (E10, E20) and gasolines without ethanol (E0). In addition, maximum and minimum differences are indicated, where reported. Finally, the table indicates the directional differences in aromatics and T50 distillation temperatures between the ethanol blends and the E0 gasolines, as knowledge of these two parameters allows us to relate the published results to the EPAct study.

Table 3-1. Summary of Published Results for Oxides of Nitrogen for Studies Comparing Emissions on Fuels Containing 0 to 20 vol.% Ethanol (*References in italics are cited in the Request for Correction*).

Reference	MY range	Blending[a]	Cycle[b]	n_{veh}	Aro/ T50[c]	comparison	Difference (%)		
							Min.	Mean	Max.
Reuter et al., 1992[59]	1989	match	FTP	20	▼/ ?	E10: E0		+5.1	
Stump et al., 1996[60]	1977-1984	neither	FTP	3	▼/▼	E10: E0	-12	+20	+41
Mulawa et al., 1997[48]	1987-1994	splash	FTP	3	▼/ ?	E10: E0	-7.8	+4.0	+11
Graham et al., 2008[61]	1998-2003	match	FTP	3	▲/▲	E10: E0	-20	+17	+78
			US06	4	▲/▲	E10: E0	-22	+14	+84
Durbin et al., 2007[62]	2001-2003	match	FTP	12	—/var.	E10:E0		+5.3[d]	
Knoll et al., 2009[65]	1999-2007	splash	LA92	16	? / ?	E10: E0		-5.5[e]	
					? / ?	E15: E0		-0.61[e]	
					? / ?	E20: E0		+12.23	
Stansfield et al., 2012[57]	2009	splash	NEDC	1	? / ?	E10: E0		+13.3	
Yassine & La Pan, 2012[58]	2006	splash	FTP	1	? / ?	E10: E0		-57.5	
					? / ?	E20: E0		-57.1	
Maricq et al., 2012[63]	*"truck with GDI"*	*neither*	*FTP*	*1*	▼/▼	*E10: E0*		*-7[d]*	
Aakko-Saksa et al., 2014[51]	2006-2010	match	"Directive 70/220 /EEC"	3	▼/▼	E10: E0	-9.1	+17	+50
Hubbard et al., 2014[66]	*2006*	*splash*	*FTP*	*1*	*? / ?*	*E10: E0*		*-9.1*	
					? / ?	*E20: E0*		*-44*	
Karavalakis et al., 2014[53]	2007-2012	match	FTP	5	▼/▲	E15:E10	-17	+2.1[d]	+26
					▼/▼	E20:E10	-17	+6.3[d]	+40

[a] Fuel-blending method, as reported by authors, or inferred from text. Details of blending typically not reported.
[b] For test cycle, "FTP" = "Federal Test Procedure," reported as composites including start and hot-running phases. "US06" includes only hot-running emissions.
[c] Indicates levels of total aromatics (as % by volume), and T50 (°C or °F) for ethanol blends, in relation to gasolines (without ethanol). "▲" = higher, "▼" = lower, "var." = variable levels studied, "?" = "not reported."
[d] Result is approximate.
[e] Results may have been affected by instrument drift during test sequences.

Examining the table, we see that average NO_x increases of 5-20% were reported in the first five references for vehicles manufactured between 1989 and 2003.[48,59,60,61,62] Note, however, that NO_x reductions have been consistently reported for individual vehicles. For older vehicles, NO_x increases might be related to factors such as the effective enleanment of the fuel-air mixture

by the addition of oxygenate, whereas reductions could be related to the "charge-cooling" effect of ethanol's high heat of vaporization.

For the remaining seven more recent references, which measured emissions primarily for vehicles manufactured since 2003, results are more mixed, with both increases and decreases reported. Of these, two studies report NO_x increases, even between splash-blended fuels, and another reports increases between match-blended fuels where the differences in fuel properties are consistent with splash blending.

The results of studies for which the aromatics and T50 temperatures are reported are worth discussing in more detail, to interpret results and relate them to the EPAct study. Stump et al., 1996 measured emissions on several vehicles manufactured prior to 1985, using two "typical" summer fuels matched closely on vapor pressure and octane rating, but with 0 and 8.8% ethanol, respectively.[60] The ethanol blend also had substantially lower aromatics and T50, which would be expected to reduce NO_x emissions. Despite this fact, NO_x emissions for two of three vehicles were substantially higher (approximately 40%), while those for the third were lower (-12%).

Graham et al., 2008 reported emissions for several vehicles on two cycles differing in driving aggressiveness on "summer" and "winter" "tailor blended" fuels including 0 and 10% ethanol.[61,ll] For the "tailor blended" E10 fuels, both aromatics and T50 were higher than for the E0 fuels, and measured NO_x was also higher on average. The reported NO_x differences are consistent with predicted differences from the EPAct models for these combinations of fuel properties; the EPAct models predict increases of 10-25% for the E10:E0 comparison, depending on the specific characteristics of the blends tested, and the study results reported 14-17%.

Among the reported studies, the project reported by Durbin et al., 2007 is unique in that results were reported for a set of fuels with properties designed (through match blending) to form an experimental matrix (similar to but smaller than the EPAct program) designed to vary distillation parameters (i.e., T50, T90 temperatures) while holding the aromatics level constant.[62] Under these conditions, Durbin et al. reported an apparent interference interaction between ethanol and T50, but an overall average increase in NO_x of approximately 5.0% between E10 and E0 across the entire T50 range.

[ll] Note that these authors also report results for "splash-blended" E10 fuels. We have not included these results, as the combinations of fuel properties for the summer fuel are not consistent with splash blending.

Maricq et al., 2012 measured engine-out (not tailpipe) NO_x emissions on a single truck for a specific E0 fuel and two E10 fuels, designated as "certification" and "pump."[63] For both E10 fuels, aromatics and T50 were lower than the E0 fuel by margins larger than expected in splash blending, which would be expected to lower NO_x emissions. For this truck, NO_x emissions were approximately 6% lower for the E10 relative to the E0 fuels. Depending on how start and running emissions are weighted, the EPAct study models predict small average NOx changes for these fuels, ranging from -1.0 to 2.0%.

Aakko-Saksa et al., 2014 state that their fuels were "match blended" but aromatics and T50 were substantially lower for the E10 fuel than the "fossil" gasoline (E0).[51] Even so, they report NO_x increases for 2 of 3 vehicles measured. For the reported fuel properties, the EPAct study model would report small increases on average, of 0.5-3.0%, again depending on how start and running NO_x were weighted.

Karavalakis et al., 2014 reported small NO_x increases of 2-6% for E15 and E20 blends in relation to E10.[53] Both the E15 and E20 blends had slightly lower aromatics than the E10, and higher and lower T50, respectively. Predicted NO_x differences from the EPAct study models would match these measurements closely.

To summarize, this brief review of peer-reviewed studies refutes the claim of petitioners that NO_x emissions are consistently lower for fuels with higher than lower ethanol levels. Secondly, the EPAct study models can report either increases or decreases in NO_x emissions with ethanol in the fuel, depending on the properties of the fuels being compared, particularly total aromatics and the T50 distillation temperature. Finally, the predictions from the EPAct study NO_x models often match published results reasonably well when accounting for the changes in fuel properties other than ethanol, both in terms of direction and magnitude.

3.6.3 The EPAct Study Correctly Reports Responses in Hydrocarbons to Ethanol and other Fuel Properties

RFC section III.B.3 claims that hydrocarbon emissions are reduced for a fuel created by splash-blending ethanol into a "fixed gasoline," followed by an implication that the EPAct study links ethanol levels to increased hydrocarbons emissions, because the ethanol coefficients in the relevant models are positive. As described in section 3.2 of this document, "splash-blended ethanol into a fixed gasoline blendstock" is not how refiners typically produce marketable fuels

"*in the real world*," and even so, the results of the EPAct study for hydrocarbon species do not conflict with a claim that hydrocarbon emissions decline for a splash-blended fuel.

Table 3-2 below summarizes published results showing differences in hydrocarbon emissions for ethanol blends. Note that the table indicates whether authors reported fuel properties, and if so, directional differences in relevant fuel properties, including aromatics, vapor pressure, and the T50 and T90 distillation temperatures.

Reviewing the table makes clear that reductions in hydrocarbon emissions have frequently been reported in the literature, whether the term "hydrocarbons" refers to "total hydrocarbons" (THC), "non-methane hydrocarbons" (NMHC) or "non-methane organic gases" (NMOG), and whether fuels in particular studies were "splash" or "match" blended. However, we also note that increases are sometimes reported, both for individual vehicles and small sets of vehicles.

The RFC reiterates a misinterpretation of the EPAct study model coefficients that we have mentioned above, taking the ethanol coefficients in the hydrocarbon models as the "effect of ethanol addition" to a base fuel. In doing so, the RFC misinterprets the EPAct study report regarding the correct interpretation of the model coefficients, in which we state that coefficients represent the effect of each fuel parameter "as if the remaining properties could be held constant."

The source of misunderstanding is the erroneous view that the sets of model coefficients represent the "addition of" ethanol. They do not. The models are designed to make comparisons among fuels in which the levels of the five fuel properties differ, and are agnostic as to why the properties differ. There is no assumption that in any comparison among fuels, that any of the fuels necessarily had been blended from one of the others by the addition of ethanol, or for that matter, any other fuel constituent.

In fact, the RFC correctly cites the EPAct study report to effect that "if typical collateral fuel changes (lower T50 and aromatics) are accounted for, we might project that blending ethanol would tend to reduce THC, NMHC and NMOG emissions." The significance of this statement and its implication, which the RFC misses, is that the models are capable of representing the simultaneous changes in fuel properties inherent in splash blending, and do in fact predict reductions in hydrocarbon emissions in cases of splash blending, whether for THC, NMHC or NMOG.

Table 3-2. Summary of Results for Hydrocarbons for Published Studies Comparing Emissions on Fuels Containing 0 to 20 vol.% Ethanol (*Papers cited in the RFC are indicated in italics*).

Reference[a]	Cycle[b]	n_{veh}	Aro/RVP /T50/T90[c]	HC Species	comparison	Difference (%)		
						Min.	Mean	Max.
Reuter et al. 1992[59]	FTP	20	▼/ ?/ ▲/▼	THC	E10: E0		-4.9	
Stump et al., 1996[60]	FTP	3	▼/▬/▼/▼	THC	E10: E0	-51	-8.8	33
Mulawa et al., 1997[48]	FTP	3	▼/ ? / ? / ?	THC	E10: E0	-65	-48	-16
Graham et al., 2008[61]	FTP	3	▲/▬/▲/▲	NMHC	E10: E0	-15	+10	50
	US06	4	▲/▬/▲/▲	NMHC	E10: E0	-43	-21	0.0
Durbin et al., 2007[62]	FTP	12	▬/▬/var./var.	NMHC	E10:E0		+6.8	
Knoll et al., 2009[65]	LA92	16	? /▲ / ? / ?	NMHC	E10: E0		-12	
			? /▲ / ? / ?	NMHC	E15:E0		-11	
			? /▲ / ? / ?	NMHC	E20:E0		-15	
Stansfield et al., 2012[57]	NEDC	1	? /▲ / ? / ?	THC	E10: E0		-9.1	
Yassine & La Pan, 2012[58]	FTP	1	? /▲ / ? / ?	NMHC	E10: E0		-40	
			? /▲ / ? / ?	NMHC	E20: E0		-55	
Maricq et al., 2012[63]	FTP	1	▼/var./▼/▲	THC	E10: E0		+1.6[d]	
Aakko-Saksa et al., 2014[51]	"Directive 70/220 /EEC"	3	▼/▼/▼/▼[e]	THC	E10: E0	-12	-1.9	+7.1
Hubbard et al., 2014[66]	*FTP*	*1*	*? /▲ / ? / ?*	*THC*	*E10: E0*		*-7.5*	
			? /▲ / ? / ?	*THC*	*E20: E0*		*-24*	
Karavalakis et al., 2014[53]	FTP	5	▼/▬/▲/▲	THC	E15:E10	-7.9	+16[d]	+53
			▼/▬/▲/▼	THC	E20:E10	-21	+17[d]	+107

[a] For each reference, "model-year range" and "blending" methods are the same is in Table 3-1.
[b] For test cycle, "FTP" = "Federal Test Procedure," reported as composites including start and hot-running phases. "US06" includes only hot-running emissions.
[c] Indicates levels of total aromatics (wt.%, vol.%), vapor pressure (psi, kPa) and T50 and T90 distillation temperatures (°C, °F): "▲" = higher, "▼" = lower, "▬" = same, "var." = variable levels studied", "?" = "not reported."
[d] Result is approximate.
[e] This paper actually reports T95. Tests run at -7°C.

An example will help to illustrate the point. Table 3-3 shows a set of fuel properties that represent splash blending of an E10 fuel from a base gasoline, adapted from a published source.[64] With respect to hydrocarbon emissions, the important differences are lower aromatics (by 10%), increased vapor pressure (by 1 psi), lower T50 (by 20°F) and lower T90 (by 5°F).

Table 3-4 shows reductions in hydrocarbon species, for start and running emissions, as projected by the EPAct study models. Note that the models predict reductions in the range of the studies summarized in Table 3-2, particularly Knoll et al, 2009,[65] a study with a sample of vehicles comparable to that used in the EPAct study. Note also that the model predictions represent fleet averages, incorporating the fact that some individual vehicles show larger reductions, and others show increases.

Table 3-3. Example Fuel Properties Representing Splash Blending of an E10 Fuel from a Base Gasoline.

Property	E0	E10
Ethanol (vol.%)	0.0	9
Aromatics (vol. %)	33	30
Vapor Pressure (psi)	8	9
T50 (F)	220	200
T90 (F)	320	315

Table 3-4. Average Reductions in Hydrocarbon Species (%), as Projected by the EPAct Models for the Fuel Pair Shown in Table 3-3.

Cycle	THC	NMHC	NMOG
Start	-15.4	-19.2	-13.0
Running	-6.4	-15.0	-6.1

However, the EPAct study models can be applied more generally than shown in this example. They can be used to predict average emissions differences for any two fuels, regardless of whether one of the fuels was blended from the other. We can illustrate by comparing model predictions to published study results summarized in Table 3-2 above, for studies that report fuel properties.

Karavalakis et al., 2014 compared E20 and E15 blends to an E10 blend on a set of five vehicles.[53] However, the differences between the fuels are not consistent with splash blending. For example, the E15 blend has lower aromatics than the E10 (by 11%), the vapor pressure is nearly equal (within 1.5%), and T50 temperature is 9°F higher (rather than lower). As shown in the Table 3-2, the study reports a 16% mean increase in THC on the E10 blend, and the EPAct study THC models predict increases of 15% and 5.5% for start and running emissions, respectively.

Aakko-Saksa et al., 2014 measured emissions for three vehicles on several fuels, including an E0 "fossil" gasoline and an E10 blend.[51] Differences in these fuels were largely consistent with splash blending except that aromatics was 18% lower in the E10, rather than 10% lower, as would have been expected in splash blending. Similarly, the vapor pressure was 1 psi lower in the E10, rather than higher, as would have been expected. In addition, the T50 and T90 distillation temperatures were 32 and ~5° F lower in the E10, respectively. The authors reported small average reductions of approximately 2% in both THC and NMHC. For this fuel pair, the EPAct study models report a small average 3% reduction for THC and a somewhat larger 9% reduction for NMHC, depending on the weighting of start and running emissions.

As the splash-blending example and a review of several studies shows, the RFC's criticism of the EPAct study models' predictions for hydrocarbon emissions is based on a fundamental misunderstanding and misinterpretation of the models and their application. The implicit claim that the EPAct study models predict hydrocarbon increases for splash-blended ethanol-containing fuels is simply false.

3.6.4 The EPAct Study Correctly Reports the Responses of Formaldehyde Emissions to Ethanol and other Fuel Properties

In its discussion of formaldehyde emissions, RFC section III.B.4 again misinterprets the EPAct models, taking the ethanol coefficient as the "effect of adding ethanol" with all of its associated effects on other fuel parameters, as opposed to the presence of ethanol in a fuel. RFC section III.B.4 cites literature purporting to support an argument that levels of ethanol in fuel have no effect on formaldehyde emissions. As with the other emissions, the RFC attempts to buttress oversimplified blanket generalizations with very selective citations to a limited number of published studies. A broader and more impartial reading of the literature does justice to the variability and complexity of the reported results, while showing that increases in formaldehyde emissions for ethanol blends have been widely reported for over two decades, consistent with the findings of the EPAct study. Table 3-5 shows an overview of studies reporting measurements of formaldehyde for gasolines and ethanol blends. As always, emissions are highly variable, and every study cited reported decreases in formaldehyde for some vehicles, as shown by consistently negative values in the "Min." column of the table. However, the means for most studies show a tendency towards increases, on average. However, as the RFC notes, differences are not always statistically significant in all studies.

Table 3-5. Summary of Results for Formaldehyde for Published Studies comparing Emissions on Fuels containing 0 to 20 vol.% Ethanol.

Reference[a]	Cycle[b]	n_{veh}	Aro/RVP /T50/T90[c]	comparison	Difference (%)		
					Min.	Mean	Max.
Reuter et al. 1992[59]	FTP	20	▼/ ?/ ▲/▼	E10: E0		+19	
Stump et al., 1996[60]	FTP	3	▼/▬/▼/▼	E10: E0	-1.3	+32	+57
Graham et al., 2008[61]	FTP	3	▲/▬/▲/▲	E10: E0	-83	-16	+130
Knoll et al., 2009[65]	LA92	16	? /▲ / ? / ?	E10: E0	-35	+25	+85
Aakko-Saksa et al., 2014[51]	"Directive 70/220 /EEC"	3	▼/▼/▼/▼[d]	E10: E0	-13	+15	+33
Karavalakis et al., 2014[53]	FTP	5	▼/▬/▲/▲	E15:E10	-74	-23	+86
			▼/▬/▲/▼	E20:E10	-86	-4.2	+89

[a] For each reference, "model-year range" and "blending" methods are the same is in Table 3-2.
[b] For test cycle, "FTP" = "Federal Test Procedure," reported as composites including start and hot-running phases. "US06" includes only hot-running emissions.
[c] Indicates levels of total aromatics (wt.%, vol.%), vapor pressure (psi, kPa) and T50 and T90 distillation temperatures (°C, °F): "▲" = higher, "▼" = lower, "▬" = same, "var." = variable levels studied", "?" = "not reported."
[d] This paper actually reports T95; tests performed at -7°C.

Among the studies cited in RFC section III.B.4, there are a number of points worth noting. First, although RFC section III.B.4 correctly summarizes the results of Hubbard et al.[66], this study reports results for a single vehicle; the study's results are not sufficient to justify the broad claim made by petitioners.

Second, the RFC's citation of Knoll et al., 2009[65] admits but deemphasizes the finding of statistically significant increases in formaldehyde for ethanol blends relative to E0. More importantly, it fails to note that this study offers an explanation accounting for at least some variability among vehicles in response to ethanol blends. Specifically, the study concludes that vehicles applying "long-term fuel trim" during "power enrichment" are more likely to show increases in formaldehyde emissions than vehicles that do not. This finding is in itself a counterexample sufficient to rebut petitioners' claim that "ethanol blends do not increase formaldehyde emissions in modern vehicles" (RFC, page 47).

Third, RFC section III.B.4 cites the published article by Durbin et al., 2007 to the effect that their statistical analysis did not report a significant regression coefficient for ethanol, in an analysis of composite results on the FTP cycle.[62] However, the RFC fails to mention the additional finding by Durbin et al., not stated in the peer-reviewed article but included in the full

project report, of a significant increase in formaldehyde for the initial cold-start phase of the FTP cycle, i.e., "start" emissions.[67] In fact, every vehicle in the project showed higher formaldehyde during starts on E10 than on the E0 fuel, a result qualitatively similar to the results of the EPAct study.

With respect to studies not cited in the RFC, Aakko-Saksa et al., 2014 reports increases in formaldehyde averaging 15% for E10 relative to E0.[51] For the same fuel properties, the EPAct study models project average increases of 8-10%, demonstrating reasonable agreement in direction and magnitude.

3.6.5 The Nonlinear Effect of T50 Is Statistically Robust

RFC sections III.B.5 and IV.A question the EPAct model's prediction of an increase in PM cold-start emissions when the T50 parameter is shifted either higher or lower than 185°F. This effect reflects the presence of a quadratic term for T50 (T50×T50), in addition to the linear term. The results of the statistical analysis strongly indicate that the inclusion of the quadratic term improves the model fit. However, to investigate the hypothesis that the inclusion of the quadratic term could be an artifact related to the inclusion of the E15 and E20 fuels in the design, we re-fit the PM model using the E0-E10 subset of fuels, which represented a viable study design in its own right. The results showed that both the T50 and T50×T50 terms continued to provide a statistically significant improvement to model fit with this reduced dataset. Since the completion of the EPAct study, EPA is continuing to invest in research to better understand the relationships between fuel properties and PM formation, including aromatics, distillation temperatures, vapor pressure and ethanol level.

3.7 The EPAct Study Made Extensive Use of Peer Input and was Rigorously Peer Reviewed

EPA's Peer Review Handbook notes that peer input can take a number of forms besides formal review, including solicitation of expert advice, and states, "The Agency has significant discretion in deciding on the timing and the frequency of peer review." (p. 21).[3] Throughout the design and execution of the EPAct study, EPA made extensive use of ongoing peer input through consultation with experts in government (DOE/NREL) and the automotive and fuel industries (i.e., CRC representatives), involving "an open exchange of data, insights and ideas." (p. 24)

After the data analysis was complete, the study was formally peer reviewed in accordance with the EPA Peer Review Policy and the EPA Peer Review Handbook (as discussed in more detail in Section 2.1.9 above). This external peer review was facilitated by a contractor, who selected three independent experts familiar with statistical analysis, vehicle emissions measurement and the behavior of fuel properties in ethanol-gasoline blends. In response to the peer review, additional analyses were performed and a number of substantial modifications to the study report were made to address points raised by the reviewers, but no significant issues were raised related to the study design and no change in the statistical models or overall results was warranted. The peer review record, including the peer review comments and the EPA responses, is publicly available at the Agency's Science Inventory website.[68]

3.8 MOVES Appropriately Incorporates the Findings of the EPAct Study

Having responded in detail in the preceding sections to the petitioners' claims and concerns regarding the design and results of EPAct study, we do not feel it necessary further explain that it's reasonable to have incorporated its findings into the MOVES model.

3.9 MOVES Incorporates Appropriate Information about Ethanol's Influence on Evaporative Emissions

RFC sections IV.B.1 and IV.B.2 present claims of bias and error in the studies on which MOVES permeation effects are based. Recurring themes in these claims include fuel properties being biased to produce higher emissions from ethanol blends, citation of studies that were done on piping or other materials not representative of fuel systems, and conflation of permeation and other vapor generation processes. We respond to these claims for each study in the following subsections.

As described in Section 2.2 above, the MOVES2014 model uses data from four carefully-designed studies (CRC E-65, E-65-3, E-77-2 and E-77-2b) that developed innovative methods to understand fuel property effects on different evaporative emission processes including permeation and vapor venting. They were primarily funded through CRC's sustaining contributions from automotive and oil companies, but also included funding and technical oversight from California Air Resources Board and EPA. The projects underwent extensive review during the CRC project review process and the MOVES development process. EPA

believes these studies are unbiased and appropriately control for factors relevant in modeling of permeation emissions.

3.9.1 CRC E-65

The E-65 Study, published in 2004, was designed to investigate the evaporative emissions of gasolines containing ethanol in California as a response to a ban on the use of methyl-tertiary-butyl-ether (MTBE) as a gasoline oxygenate. Permeation and diurnal emissions were measured from the fuel systems of ten vehicles following removal from the vehicle bodies. Separation of the fuel systems from the vehicles allowed better isolation of the effects of interest, and was done in such a way as to not disturb any factory seals or replace any original materials.

Three fuels were acquired for the study from a commercial terminal. One fuel contained 10% MTBE, another had 5.7% ethanol (E5.7), and a third contained no oxygenate (E0). A number of volatility adjustments were made to bring the three fuels into alignment in RVP and distillation points. After more detailed comparison, the E5.7 was adjusted by addition of olefins (alkenes) and a deposit-control additive to make it more comparable to the E0 fuel. The final E5.7 closely matched the E0 in vapor pressure and T10, but had somewhat higher T50 and T90 distillation temperatures, indicating a lower volatility of the fuel overall. It also had slightly lower aromatics and benzene levels.

RFC section IV.B.1.a claims that the fuel modifications had the effect of "further biasing" the study against ethanol, by "artificially" elevating its vapor pressure, with the implication that it would have been "biased against ethanol" even without modification. Had the E5.7 been "splash blended" from the E0, its RVP would have increased, and its T50 and T90 dropped slightly, indicating a higher volatility across the distillation range. However, since the E5.7 was matched on RVP, we can say its RVP was "depressed" rather than "elevated" and that its overall volatility across the distillation range was "reduced" rather than "increased" relative to a splash blend, given its higher T50 and T90. Nonetheless, permeation emissions were 45% higher on average for the E5.7 versus the E0 fuel, including increases of more than double for the two vehicles with enhanced evaporative controls.

We also note that the total aromatics content was somewhat lower in the ethanol blend, including slightly lower benzene and significantly lower toluene, so the claim that greater aromatics content in the ethanol fuel biased the results is questionable.

RFC section IV.B.1.a raises the possibility that the lengthy storage of the ethanol test fuel "may have raised the mass and reactivity of permeation emissions and elevated peroxide levels in the ethanol test fuel." This assertion relies on two assumptions: 1) that fuel storage conditions were such that significant amounts of peroxides were formed, and 2) those peroxides reacted with fuel tank materials in a way that enhanced permeation on a meaningful scale. Both of these assumptions are speculative and unsubstantiated.

3.9.2 CRC E-65-3

The CRC E-65-3 test program, published in 2006, examined permeation emissions in newer vehicles using six test fuels with varying amounts of ethanol and aromatics. RFC section IV.B.1.b claims that the fuels were "unrealistic because refiners lower aromatics content to compensate for the additional of ethanol." Further, petitioners argue that all test fuels except the "E85 and the E5.7 test fuel with highest total volume of aromatics also had higher BTEX levels (high volatility C6 to C8 aromatics) than the E0 fuel." With respect to the first criticism, we emphasize, as we have said elsewhere in this document, that the goal of this study (and of MOVES) is to compare fuel with differing levels of ethanol, not to estimate the effect of the "addition of ethanol" to specific marketable gasolines. Once again, it is necessary to point out the fallacy of the implicit argument in the RFC that any fuel containing ethanol must have lower aromatics than any fuel not containing ethanol.

With respect to the second criticism, we make two additional points. First, the RFC's claim regarding "C6-C8 aromatics" in the test fuels is simply in error. In fact, the "high aromatics" E5.7 fuel did contain slightly higher benzene (C6) than the E0 fuel, as noted in the RFC. However, this same fuel contained lower toluene (C7) and xylene (C8) than the E0 fuel. Nonetheless, the study recorded higher permeation on the E5.7 fuels than on the E0 fuel, calling into question the claim that the permeation from the ethanol blends can be attributed to "unrealistically high" aromatics.

RFC section IV.B.1.b makes another misleading claim regarding the volatile low-molecular weight paraffins in the fuels, stating (correctly) that the "high aromatics" E5.7 fuel had lower pentane content than the "low aromatics" E5.7 blend. However, the RFC fails to mention that the E0 fuel had higher pentane content than any other fuel in the study, including the E10 and E20 blends. Thus, despite having higher pentane and/or lower aromatics, the ethanol blends still

had higher permeation than the E0, making it difficult to accept the RFC's claims that ethanol is completely neutral in regard to permeation.

3.9.3 CRC E-77-2

The CRC E-77-2 study, published in 2010, used test fuels from the CRC E-74b test program on exhaust emissions because they were already well-characterized and met the fuel property objectives for vapor pressure and ethanol.

RFC section IV.B.1.c claims the test fuels had "artificially elevated aromatics content" that "introduced a systematic bias against ethanol." In fact, the aromatics levels of fuels in this study were quite consistent in aromatics levels and lower overall than in the E-65 studies. Specifically, the aromatics were 23.8% in the E0 fuel and just slightly higher at 24.8% in the E10 fuel. However, across the permeation tests the ethanol blend showed emissions increases in the range of 20%-500%. Thus, the large increases in permeation emissions appear out of proportion to the small increase in aromatics level.

The RFC states that a benzene content around 1% exceeds levels in market fuels, citing a 0.62% level described in the EPA Tier 3 and MSAT gasoline regulatory programs. In fact, the 0.62% average level was not required until 2011, while the E-77-2 studies were planned and started in 2007 timeframe. Table 3-16 in the Tier 3 Regulatory Impact Analysis (the same document the RFC cited for the 0.62% benzene figure) shows average market fuel benzene in 2007 was 0.97%.[47] Furthermore, a summary of refinery batch data from 2007 shows conventional gasoline benzene content spanned a 10^{th}-90^{th} percentile range of 0.5 to 2.1%.[12,mm]

RFC section III.B.1.c also confuses and conflates the various sources of evaporative emissions from vehicles, using information about one to support criticisms of another. As discussed in Section 2.2 above, there are entirely different chemical and physical mechanisms at work for permeation than for diurnal emissions. The high diurnal emissions of the Ford Escape mentioned in the RFC were not considered in determining fuel effects on permeation. The Static tests were used to compute the fuel effects on permeation in the mixed model described in Section 2.2.6 of this document. Static tests from both E-77-2 and E-77-2b corrected to 72°F were used in a linear mixed model which included certification level, ethanol and RVP levels. To

[mm] See Figures 44 and 45 in the 2017 EPA Fuel Trends Report.

better understand how the evaporative emissions control system works, see discussion of the DELTA model in the MOVES2014 evaporative emissions modeling report.[69]

3.9.4 CRC E-77-2b

The CRC E-77-2b study, also published in 2010, was a follow-on to E-77-2 that used the same fuels and test conditions but tested additional vehicles. RFC section IV.B.1.d claims that the E-77-2b study's speciation results show that benzene, toluene and xylenes (BTEX) and light paraffins permeated at higher rates than other hydrocarbons, suggesting further that the study "entirely ignored this," and thus "confounded the effect of ethanol with the effect of aromatics and other fuel components." EPA re-examined the study's findings, and it is not apparent that the permeate is "enriched" with light-weight aromatics to a greater extent than other light-weight hydrocarbons, such as ethanol or hexane. Also, our review does not support the RFC's claim that an "effect of aromatics" on permeation was ignored or glossed over.

For additional detail, the reader may refer to Table 3-6, summarizing an analysis of the speciated permeation emissions from CRC E-77-2b and E-77-2c studies, as compiled and applied in MOVES2014.[70] Observing trends across the ethanol levels, we see that the fraction of permeated VOCs comprised of the aromatics toluene, xylenes, and ethylbenzene are relatively constant or even decrease with increasing fuel ethanol level, meanwhile the fraction for ethanol increases markedly.

Table 3-6. Species Fractions Representing Permeation Emissions as Components of Total VOC Emissions, by Ethanol Level (Source: CRC E-77-2b, CRC E-77-2c).

Pollutant	Ethanol Level				
	0.0% (E0)	10% (E10)	15% (E15)	20% (E20)	70-100% (E85)[p]
Ethanol	0.000	0.202	0.2694	0.3296	0. 61042*
2,2,4-Trimethylpentane	0.036	0.024	0.0172	0.0107	0. 00830*
Ethylbenzene	0.003	0.001	0.0017	0.0019	0. 00124*
Hexane	0.050	0.065	0.0472	0.0308	0. 01276*
Toluene	0.110	0.101	0.0666	0.0354	0. 01608*
Xylene(s)	0.016	0.011	0.0127	0.0140	0. 00733*
Benzene	Equation 21		0.0236	0.0244	0. 00664*

Finally, as mentioned in Section 3.9.3 of this document, the RFC confuses the various sources of evaporative emissions. The diurnal emissions from the Nissan Altima were not considered in the analysis of permeation fuel effects.

3.9.5 Evaporative Study Results Were Correctly Implemented in MOVES

Section IV.B.3 of the RFC claims that the MOVES2014 fuel adjustment does not correctly use the data obtained in the CRC E-65, E-65-3, E-77-2 and E-77-2b. The MOVES technical report for evaporative emissions report was peer reviewed and neither reviewer raised concerns with the permeation emissions or the studies on which they were based.[69] In fact, one reviewer stated, "Treatment of the addition of ethanol is straight forward, carefully done and presented, and an important addition." The reviewers were charged to answer both general and detailed questions about the technical approach and data gaps in the model.

Section IV.B.3.b of the RFC criticizes the use of the same adjustment to represent the effect of ethanol on permeation emissions for both Tier 2 as well as Tier 1 vehicles, arguing that this assumption is "not supported by evidence" from the four CRC studies described above. In their argument, the petitioners appear to conflate differences between absolute and proportional differences in emissions between standard levels and between fuels. Of course, in the results for the static permeation tests from E-77-2 and E-77-2b, the absolute permeation rates (mass/time) for Tier 2 vehicles are substantially lower than those from the older Tier 1 vehicles. However, in comparing the results on the E10 fuels to those on the E0 fuels, the proportional differences for the Tier 2 vehicles are not substantially different from those for the Tier 1 vehicles. For this reason, the same ethanol adjustment, applied as a proportional value (i.e., as a percentage), is applied to permeation emissions to both sets of vehicles in MOVES2014.

In IV.B.3.c, the RFC argues that the MOVES model fails to reflect "significant reductions in evaporative emissions" that would be expected to follow reductions in the relevant standards. In making this claim, the RFC focuses on emissions from fuel permeation (e.g., through fuel tanks and lines). However, petitioners fail to recognize that the evaporative emissions estimated by MOVES include vapor losses through all relevant processes, including vapor vented from the tank (through the canister), as well as "hot-running" losses during driving. When all evaporative emissions are considered, permeation accounts for but a relatively small percentage of the total. As petitioners note, the base rate for permeation emissions (0.01 g/hr) does not decline between

the vehicles certified to "enhanced" and "Tier 2" evaporative standards, as described in Section 2.2.5 above. The reason that the base rate does not decline for MY 2004, when the Tier 2 standards became effective, was that in the data reviewed in the development of the rates, no statistically significant difference in permeation rates was evident between sets of vehicles representing different standards. However, contrary to the petitioners' claim, the MOVES model shows overall reductions in total evaporative emissions attributable to the implementation of the Tier 2 evaporative standards.

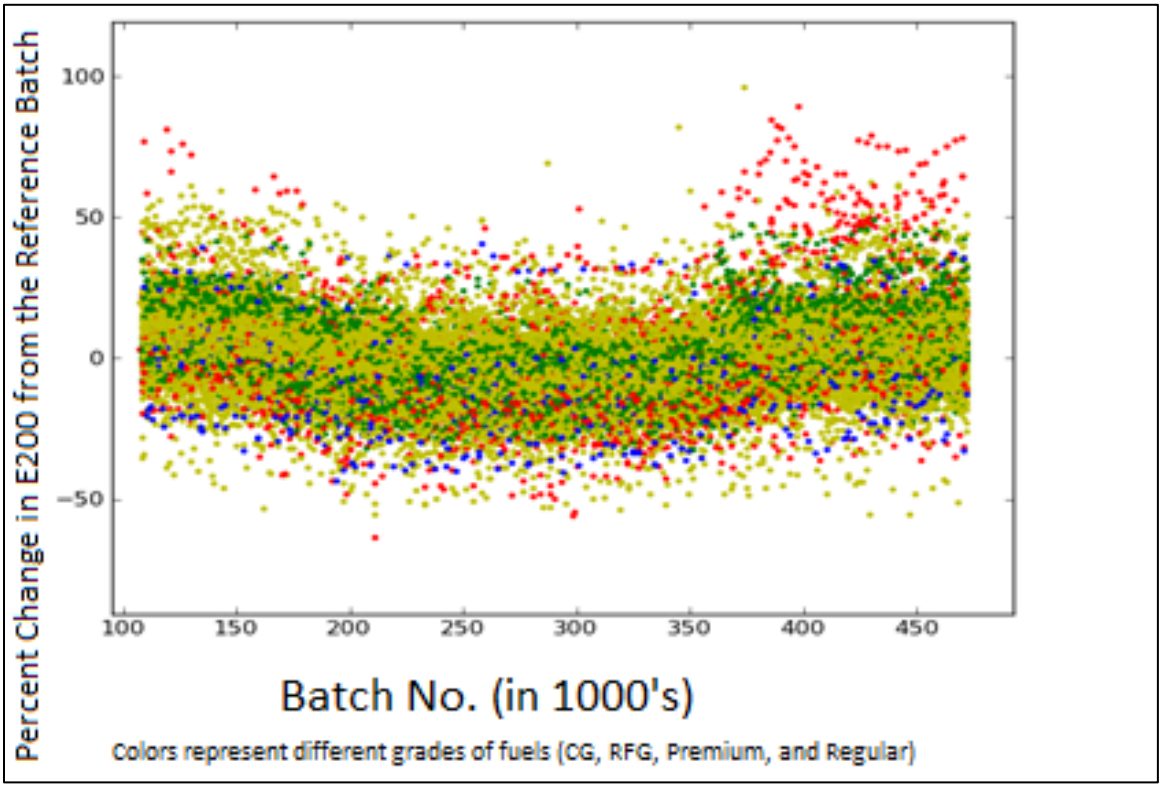
3.10 The MOVES Default Fuel Parameters Reflect Commercially Available Fuels

Section IV.C of the RFC maintains that the default fuel parameters in the MOVES database are "inconsistent with market fuel." In fact, the default fuel parameters reflect a broad and deep review of fuels in the market, drawing on fuel survey data from multiple years, such as the Alliance of Automobile Manufacturers annual market samples (cited in Addendum D of the RFC), as well as a much larger dataset of batch reports that refiners submit to EPA throughout the year. Since the regional fuels in the model are essentially averages over time and geographic area, and fuel properties vary widely in the market, it is hardly surprising that a sample taken at a particular location and point in time can differ in one or more fuel properties from the model default.

The RFC specifically points to the T50 and T90 fuel parameters (as shown in Figure 7 and Figure 8, pages 59-60) in an attempt to identify discrepancies between the MOVES2014 default fuel property values and those of "real-world fuels" in the corresponding counties. However, as seen in those figures, the MOVES2014 defaults are well within the wide variation observed in market fuel surveys, often falling near the center of the observed range. Differences or discrepancies mentioned in the RFC are inconsequential when compared to the variability shown in these figures and as we have mentioned, the samples presented by petitioners do not reflect the expected ranges of geographic or seasonal variability. Figure 3-8 further illustrates the wide variation in T50 values (shown as E200 values[nn]), used to construct the MOVES2014 default fuel parameters.

[nn] "E200" represents the fraction of the fuel evaporated at 200°F, a value that is inversely related to T50 and can be derived from it mathematically.

Figure 3-8. Variation in E200 (a function of T50) fuel batch property data used in the construction of MOVES2014 default fuel properties.



EPA agrees that "the model cannot provide accurate results unless the accompanying changes in fuel properties with increasing ethanol content… are properly taken into account." The default fuel parameters for E0, E10 and E15 fuels provided in the MOVES2014 database were initially developed in support of the Tier 3 rulemaking. The differences in fuel properties in relation to ethanol level in the default fuel supply and in the Fuel Wizard were generated using refinery modeling, as noted by petitioners. The refinery modeling served to consolidate reported data for petroleum blendstocks, prior to the addition of ethanol, into appropriate regional averages for marketable fuels.[oo] The default fuel parameters are documented in the MOVES2014 Fuel Supply report, which provides the background, basis, and application of the revised fuel supplies and the Fuel Wizard included in MOVES2014.[71]

[oo] These blendstocks are "Blendstocks for Oxygenate Blending" (BOBS), as described in 3.2.2 above.

Nonetheless, the petitioners claim that the Fuel Wizard parameters (and related fuel parameter adjustments for increased ethanol levels) are based on "undisclosed refinery modeling data" (see RFC footnote 344). However, as explained in the Fuel Supply report, the data is derived from batch property reports provided to EPA for compliance purposes. As such, the data is designated as confidential business information (CBI) and cannot be released publicly; however, a summary of these data can be found in EPA fuel trends reporting.[12,13] In addition, the refinery modeling applied to these data is well documented in the Regulatory Impact Analysis for the Tier 3 rulemaking.[47]

The RFC also suggests that "states are at the mercy of the MOVES2014's default fuel parameters" and goes on in a footnote to claim that single or yearly station samples (such as the Alliance of Automobile Manufacturer's North American Fuel Survey) are not allowed for substitution in state SIP analyses. Contrary to the petitioners' claim that "state regulators may not replace" the default fuel parameters, EPA does provide guidance to state and local users that contemplates the possibility of replacing default fuel parameters with local information.[8] For vapor pressure, the guidance encourages users to adopt values that "reflect any specific local regulatory requirements and differences between ethanol- and non-ethanol blended gasoline."[pp] For other fuel properties, substantial effort would be necessary to provide local data that is demonstrably superior to the default values.

As described above, due to the "batch-by-batch" nature of fuel production (and the variation in fuel properties among these batches), it is important to emphasize that single fuel samples do not capture an accurate picture of the range of fuel properties encountered in any given area. Because fuel standards apply not to individual fuel batches but rather to averages of properties over time and space, even highly regulated fuel properties such as sulfur can vary by tens of ppm in a single area from week to week, or even station to station depending on which batch of fuel was received, even if from the same refinery.

3.11 There Is No Requirement to Make MOVES2014 or the EPAct Study Available to the Science Advisory Board

RFC section IV.D claims that EPA was required to make the MOVES2014 model and the EPAct Study available to the Science Advisory Board (SAB) under 42 U.S.C. §4365(c)(1).

[pp] MOVES2014a Technical Guidance,[8] page 45.

However, Section 4365 does not apply. The RFC's claim is based on two arguments, first, that the MOVES2014 model qualifies as a "regulation," and second, that EPA consulted with the Department of Transportation concerning the length of a grace period before use of MOVES was required for analyses for transportation conformity.

The MOVES2014 model, and its predecessors, have been consistently treated as "non-binding technical tools," not "proposed regulations" under the Clean Air Act. Accordingly, the release of MOVES2014 did not trigger a requirement under 42 U.S.C. §4365(c)(1) to "make the model available" to the SAB. Further, the consultation with DOT is not the sort of statutory review-and-comment process that could qualify as "formal review and comment" under 42 U.S.C. §4365(c)(1), and only requires consultation on the length of the grace period before the model applies to transportation conformity determinations, not on the model itself.

In addition, EPA posted both the EPAct Study reports and underlying data for download from the Agency website. The EPAct Study has been available on the website since its posting in April of 2013, and the MOVES2014 model since its release in July of 2014. Having been posted, both the study and the model were "available" to any interested parties.

Finally, page 19 of EPA's Information Quality Guidelines mentions the SAB as one example of a group with which EPA consults, not based on any requirement, but rather to enhance the quality of the information EPA disseminates.

4 Conclusion

The Energy Policy Act of 2005 required EPA to study the "effects of gasoline characteristics or components on emissions," an objective requiring a parametric study design and test fuels where properties were adjusted independently of each other. This is exactly what the EPAct program did. The EPAct study fuel matrix was objectively designed using standard methods familiar to experts in the field, and the emission measurement activities were conducted with the highest attention to detail and technical rigor. Once completed, the study was peer-reviewed by independent experts in emissions testing and statistics, and no concerns were raised about the overall fuel matrix design.

The EPAct study results are consistent with a broad review of the literature. When comparing EPAct study results to other studies, it is important to understand that engine design and calibration can have a significant impact on how fuel properties affect emissions.

Consequently, different test programs can legitimately find conflicting results for similar fuel changes if they are each using a small number of vehicles from different manufacturers or model years. The EPAct study was designed to minimize the impact of any specific vehicle by choosing a large test fleet of high-sales vehicles representative of the in-use market at the time, and then averaging all the results together.

The EPAct study's results were appropriately incorporated in MOVES. In addition, the MOVES2014 model uses data from four carefully-designed studies (CRC E-65, E-65-3, E-77-2 and E-77-2) that developed innovative methods to understand fuel property effects on different evaporative emission processes including permeation and vapor venting. EPA believes these studies are unbiased and appropriately control for factors relevant in modeling of permeation and other evaporative emissions.

Based on a detailed review of the RFC, EPA is denying the request to withdraw the results of the EPAct study on exhaust emissions, or CRC studies on evaporative emissions, from MOVES. Nor will EPA grant the request to "lock the MOVES2014 model's ethanol parameter at 10%." The current MOVES documentation informs users that ethanol blends above E15 should not be modeled,[8] and the Fuel Wizard interface that adjusts fuel properties to accommodate user inputs will not allow users to input ethanol blend levels greater than 17.5%. To further assure that users do not model emissions beyond the appropriate range when replacing default fuel parameters with local information, we are clarifying the MOVES2014 Technical Guidance as part of the MOVES2014b release.[9] We also plan to include in the next major public update to MOVES a check in the county and project-level Fuel Formulation Importer functions that prevents users from entering gasoline blends with more than 15 percent ethanol.

In addition, we will continue to update our fuel effects models, fuel supply databases, and other inputs to MOVES as more data becomes available. EPA recognizes that MOVES needs regular updates as vehicles and fuel supplies continue to evolve, and EPA also regularly updates its emissions model to reflect new scientific information. The EPAct study itself was conducted to update the understanding of gasoline property effects on exhaust emissions from vehicles meeting Tier 2 emissions standards, as fuel effects in prior emissions models were based on testing of vehicles employing older technologies. EPA continues to welcome additional high-quality datasets that may provide useful improvements to MOVES.

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