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PROPOSED ANTI-BACKSLIDING DETERMINATION FOR RENEWABLE FUELS AND AIR QUALITY

Docket ID No. EPA–HQ–OAR–2020–0240

Growth Energy appreciates the opportunity to provide comments for EPA's consideration on its Anti-Backsliding Study[1] and proposed determination that no additional fuel control measures are necessary under Clean Air Act Section 211(v) to mitigate air quality impacts associated with the Renewable Fuel Standard ("RFS") (the "Proposed Determination").[2] Growth Energy is the world's largest association of biofuel producers, representing 103 U.S. plants that each year produce more than 8 billion gallons of cleaner-burning, renewable fuel, 94 businesses associated with the biofuel production chain, and tens of thousands of biofuel supporters. Together, our members are working to bring better and more affordable choices at the fuel pump to consumers and protect the environment for future generations. We are committed to helping our country diversify its energy portfolio to support more green energy small businesses and jobs, sustain family farms, and reduce the costs of transportation fuels for consumers.

Growth Energy strongly supports EPA's Proposed Determination. Below we briefly summarize our view that the Proposed Determination is amply supported by the facts before the Agency and the law. Indeed, our technical analysis is that the Anti-Backsliding Study overstates the RFS' potential adverse impacts on air quality and understates the emissions and air quality benefits of ethanol-blended fuels. Specifically, due to various methodological issues with the fuel properties used in EPA's modeling, as well as the studies underlying the MOVES model, the Anti-Backsliding Study erroneously overestimates even slight increases in certain pollutants (NOx, VOCs, and particulate matter (PM)); at the same time, the Study underestimates the benefits of ethanol-blended fuel in reducing emissions of potent air toxics such as benzene and 1,3 butadiene, as well as PM and carbon monoxide.

We explain these critiques in detail below and in the analysis from AIR, Inc. attached as Exhibit 1 ("AIR Report"). But even if EPA's modeled potential adverse impacts were accurate, we agree with the Agency that its analysis concludes that the impacts are slight and that the Tier 3 Motor Vehicle Emissions and Fuel Standards, 79 Fed. Reg. 23,414 (Apr. 28, 2014), which took effect in 2017 ("Tier 3 Rule"), address any potential impacts such that no additional fuels regulations to mitigate adverse impacts are necessary.

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[1] Clean Air Act Section 211(v)(1) Anti-backsliding Study, EPA-420-R-20-008 (May 2020), https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100ZBY1.pdf.

[2] Proposed Determination for Renewable Fuels and Air Quality Pursuant to Clean Air Act Section 211(v), EPA-420-D-20-003 (May 2020).

In addition to the benefits for air quality discussed below, ethanol-blended fuels provide, at low cost, substantial GHG emissions benefits. Specifically, the U.S. Department of Agriculture found that ethanol reduces greenhouse gas emissions by at least 39% compared to traditional gasoline, and by 2022, the agency anticipates corn ethanol's relative carbon benefits could reach up to 70%, with ongoing innovations in corn cultivation and biorefinery practices.[3] Cellulosic ethanol provides even greater GHG benefits.

We appreciate EPA's consideration of these perspectives and encourage EPA to finalize its Proposed Determination.

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I. Statutory Background and Design of EPA's Anti-backsliding Study

Clean Air Act Section 211(v) tasks EPA with evaluating whether the RFS' required volumes "will adversely impact air quality as a result of changes in vehicle and engine emissions of air pollutants." 42 U.S.C. § 7545(v)(1)(A). Based on its evaluation, EPA then must either (a) "promulgate fuel regulations to implement appropriate measures to mitigate, to the greatest extent achievable, . . . any adverse impacts on air quality, as a result of the renewable volumes required by this section," or (b) "make a determination that no such measures are necessary." *Id.* § 7545(v)(2). EPA appropriately studied, as the statute specifies, air quality impacts specifically associated with vehicle emissions, as opposed to non-vehicle downstream or upstream impacts (e.g., encompassing biofuels manufacturing and refining).

Further, the statute requires EPA to evaluate "different blend levels, types of renewable fuels, and available vehicle technologies." 42 U.S.C. § 7545(v)(1)(B)(i). EPA reasonably selected 2005 and 2016 to model air quality impacts associated with changes in renewable fuel volumes,[4] and evaluated differences in the predominant fuels at those times -- specifically, for

[3] "The greenhouse gas benefits of corn ethanol—assessing recent evidence." BIOFUELS. Jan Lewandrowski, Jeffrey Rosenfeld, Diana Pape, Tommy Hendrickson, Kirsten Jaglo, Katrin Moffroid (2020). 11:3, 361-375, DOI: 10.1080/17597269.2018.1546488; USDA/ICF Study, "A Life-Cycle Analysis of the Greenhouse Gas Emission From Corn-Based Ethanol," (Sep. 2018) https://www.usda.gov/oce/climate_change/mitigation_technologies/LCA_of_Corn_Ethanol_2018_Report.pdf ; Mueller, "Updated Life Cycle Greenhouse Gas Data for Corn Ethanol Production," (Mar. 2016) http://illinoisrfa.org/wp-content/uploads/2017/06/UIC-OIG-3_16_v2-1.pdf; Michael Wang et al., Argonne National Labs, "Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane, and Cellulosic Biomass for U.S. Use," (Dec. 2012) http://iopscience.iop.org/1748-9326/7/4/045905/pdf/1748-9326_7_4_045905.pdf .

[4] For purposes of this comment letter and Exhibit 1, we note that EPA's approach to fulfilling its obligation under section 211(v) was to assume that the RFS volumes are the cause of the increase in renewable fuels over the 2005 to 2016 timeframe. Specifically, Congress instructed EPA to study "whether the *renewable fuel volumes required by this section* will adversely impact air quality." 42 U.S.C. § 7545(v)(1)(A) (emphasis added). At the time, Congress envisioned that the RFS would drive growth in renewable fuels, and the study should have been completed in 2009, preceding implementation of the RFS. *Id.* It is debatable, however, whether the RFS is responsible for the transition from E0 to E10 because, for a variety of market and regulatory reasons, that transition was already underway. *See, e.g.*, 84 Fed. Reg. 26,980, 26,986 (Jun. 10, 2019). Further, given EPA's implementation of the RFS, and in particular its management of the RIN bank and its grant of small refinery exemptions accounting for billions of

the gasoline market, E0 and E10, and for the diesel market, petroleum diesel with no biodiesel and B5. *See* Proposed Determination at 3. The years and blend levels EPA selected are representative of the changes in the fuels market from the pre-RFS period to current day, when the vast majority of gasoline sold in the U.S. is E10. Additionally, EPA's design decision to hold California fuels constant in both the pre-RFS and with-RFS scenarios is a reasonable simplifying assumption based on that state's fuels regulations, as is EPA's assumption that reformulated gasoline areas approximate pre-RFS areas that likely had E10 in 2005. *See* Anti-backsliding Study at 9-11 ("Allocating E10 to RFG areas represents a reasonable approximation of where ethanol was primarily used in this timeframe."); Proposed Determination at 3.

In sum, the scope and general design of the Anti-backsliding Study are consistent with Section 211(v)'s statutory mandate.

II. EPA's Proposed Determination Appropriately Concludes New Fuels Regulations Are Unnecessary.

Growth Energy supports EPA's Proposed Determination that new fuel control measures are unnecessary to address air quality impacts associated with the RFS' required volumes. In fact, there are significant technical issues with the Anti-backsliding Study that overstate potential adverse impacts associated with ethanol-blended fuels, and with E10 in particular, while understating emissions benefits. Correction of the Anti-backsliding Study to address these errors would reinforce EPA's conclusion that new fuel regulations are unnecessary under Section 211(v). In any event, even without such corrections, EPA's existing analysis amply supports that no new fuels regulations are necessary.

a. The Anti-backsliding Study Overestimates Potential Adverse Impacts for Air Quality and Underestimates Benefits of Ethanol-blended Fuel.

Notwithstanding that EPA created a reasonable framework for analyzing E0 and E10's emissions and air quality differences, the Anti-backsliding Study includes two technical errors related to fuel properties and fuel correction factors used in the MOVES model that cause the adverse modeled emissions results to be overstated. As an initial matter, the magnitude of the Anti-backsliding Study's adverse air quality impacts is small, so correcting technical errors readily causes adverse impacts to become favorable instead. Specifically, EPA's air quality results for ozone, PM, acetaldehyde, and formaldehyde reflect very minor (less than 1%) average percentage changes in the "with RFS" scenario on a U.S. county-wide basis. *See* AIR Report at 3. These changes could be considered negligible.

With respect to fuel properties, AIR Inc. evaluated the actual fuel properties of E0 and E10 in conventional gasoline areas based on EPA Fuels Trend data, as contrasted with the E0 fuel properties in MOVES based on confidential refinery batch data. *See* Air Report at 4-6. Significant differences for aromatics, T50, and T90 exist between the two data sets. Specifically,

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gallons of renewable fuels, the RFS does not drive increases in renewable fuel use as Congress intended. *See generally* Growth Energy 2020 RVO Comment Letter. Assuming the transition from E0 to E10 was not due to the statutorily-required "renewable fuel volumes," it is not clear that the RFS itself caused any impacts on air quality at all.

E10's aromatics levels are almost 7 percent lower based on the EPA Fuels Trend data. *Id.* at 7. Using the actual fuel properties of E10 in conventional areas to recreate EPA's emissions analysis results in substantial decreases in NOx, VOC, and PM emissions, as well as even greater reductions in benzene and 1,3 butadiene, both potent air toxics, as well as carbon monoxide. *Id.* at 8. The emissions reductions associated with the replacement of aromatics with ethanol are consistent with a broad body of scientific literature substantiating the emissions benefits of ethanol-blended fuels.[5]

Thus, had EPA used real-world fuels data in the Anti-backsliding Study, the results would have yielded more favorable outcomes for air quality in the "with-RFS" scenario, particularly with respect to ozone and PM.

Second, regarding MOVES' fuel correction factors, EPA developed statistical models using vehicle emissions data collected as part of the "EPAct study" that involved testing of fifteen MY2008 Tier 2 vehicles certified on indolene on a suite of specially-blended test fuels in order to assess the impact of changes in RVP, ethanol and aromatic content, as well as temperatures at which 50 percent (T50) and 90 percent (T90) of a fuel is evaporated. In that study, in order to hold the test fuel's distillation properties constant while increasing ethanol content, certain other constituents had to be adjusted, raising a question of whether the observed small emissions impacts resulted from the increase in ethanol content or the other fuel constituent changes made to hold distillation properties constant. *See* AIR Report at 8-9; *see also* "Review of U.S. EPA's Analysis of the Emissions Impacts of Providing Regulatory Flexibility for E15," Trinity Consultants at 3-5 ("Trinity Report") (Appendix 1 to AIR Report). Contrary to the EPAct statistical models, across a wide range of other studies that evaluated a large subset of Tier 2 and Tier 3 vehicles, E10 does not demonstrate statistically significant adverse NOx or PM impacts as compared to E0. *See id.* We understand EPA is aware of these other studies, but has not yet carried them forward to make the necessary adjustments to the MOVES model.

Taken together, these two issues underscore that the modest adverse emissions impacts modeled in the Anti-backsliding Study represent an unrealistically adverse scenario of the air quality impacts of ethanol-blended fuels. An assessment that incorporated updated real-world fuel properties and addressed MOVES' fuel correction factors would reflect the most current scientific information about emissions and air quality benefits of ethanol-blended fuels, including lower PM emissions and substantially lower air toxics and carbon monoxide.

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[5] UC Riverside Study, "Impacts of Aromatics and Ethanol Content on Exhaust Emissions from Gasoline Direct Injection (GDI) Vehicles" (Apr. 2018); H. Weichang Yuan, et. al, "Comparison of real-world vehicle fuel use and tailpipe emissions for gasoline-ethanol fuel blends," FUEL, Volume 249, Pages 352-364 (2019) doi: 10.1016/j.fuel.2019.03.115; J. Yang, et. al., "Investigation of the effect of mid- and high-level ethanol blends on the particulate and the mobile source air toxic emissions from a GDI flex fuel vehicle" (Dec. 2018) ENERGY FUELS, 2019331429-440 https://pubs.acs.org/doi/10.1021/acs.energyfuels.8b02206; S. Mueller, et. al., "The Impact of Higher Ethanol Blend Levels on Vehicle Emissions in 5 Global Cities" (Nov. 2018) http://www.erc.uic.edu/assets/pdf/UIC5cities_HEALTH_Nov12_Final.pdf.

b. Notwithstanding the Anti-backsliding Study's Technical Issues, the Proposed Determination is Supported by the Record.

Even assuming the Anti-backsliding Study's modest modeled adverse air impacts are accurate, the small and inconsequential nature of those impacts support the Proposed Determination. Section 211(v) requires that EPA "include consideration" of "appropriate national, regional, and local air quality control measures" in its air quality assessment that informs whether new fuel regulations are "necessary." 42 U.S.C. § 7545(v). The Tier 3 Rule is an existing "national . . . air quality control measure." *Id.* Accordingly, the Agency appropriately analyzed the impact of the Tier 3 Rule in proposing that no new regulations are necessary. Proposed Determination at 4-7; *see also Michigan v. E.P.A.*, 135 S. Ct. 2699, 2705 (2015) (referencing EPA's determination in the mercury air toxics standards (MATS) that "regulation [was] 'necessary' because the *imposition of the Act's other requirements* did not eliminate these risks") (emphasis added) (remanding the MATS rule on other grounds).

In other words, in this case EPA appropriately determined that new fuel regulations are not "necessary" under Section 211(v) where existing regulations already address any small potential emissions increases. Specifically, even to the extent EPA's modeled ozone, PM, and formaldehyde impacts are accurate, those impacts are small and are offset by the Tier 3 Rule's stringent fleet-wide exhaust emission standards. *See id* at 6. Finally, we agree with EPA that there are no fuel control measures available to address potential acetaldehyde increases, and that in any event, acetaldehyde emissions are not potent air toxics or carcinogens, unlike benzene and 1,3 butadiene emissions that are reduced substantially in ethanol-blended fuels. Accordingly, the benefits of reductions in benzene and 1,3 butadiene emissions outweigh the impacts of small increases in acetaldehyde emissions.

Exhibit 1

Review of EPA's Anti-backsliding Analysis
AIR, Inc.
July 7, 2020

Introduction

EPA released its Anti-backsliding Study for Renewable Fuels in May 2020.[1] Along with the study, EPA released other supporting materials, including a Proposed Determination document.[2] Upon performing an air quality analysis of the impact of the increase in renewable fuels associated with the RFS, and comparing these emission and air quality changes to the effects of the on-road Tier 3 final rule, EPA concluded that fuel regulations to mitigate any emission increases as a result of the Renewable Fuel Standard (RFS) are not necessary.

We agree with EPA that fuel regulations to mitigate such impacts are not necessary. In fact, due to various methodological issues with the fuel properties EPA used, the study overstates any potential negative air quality effects of the RFS. Specifically, the study overstates ozone and PM impacts, and undercounts the reductions of toxics. When using appropriate fuel properties, hydrocarbon and NOx increases are significantly smaller (leading to lower ozone impacts), PM emissions decline instead of increasing (leading to possible PM air quality benefit for the RFS), and toxics benefits of the RFS are higher.

This document is a review of EPA's emission inventory and air quality analysis performed for the Anti-backsliding Study, which appropriately focused on vehicle emissions pursuant to the Clean Air Act's statutory mandate in section 211(v). The document is organized as follows:

- Brief Summary of EPA's Analysis
- AIR's Comments on EPA's Analysis
- Implications

1. Brief Summary of EPA's Analysis

EPA evaluated two emissions and air quality scenarios, a "with RFS" scenario and a "no RFS" scenario. EPA evaluated both scenarios for calendar year 2016. The "with RFS" scenario used actual biofuel volumes used in vehicles in 2016. The "no RFS" scenario approximated biofuel volumes from calendar year 2005. Emission inventories were evaluated for calendar year 2016 only in conventional gasoline (CG) areas of the U.S., since all RFG areas already had E10 (10% ethanol by volume) in 2005.

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[1] *Clean Air Act Section 211(v)(1) Anti-backsliding Study*, EPA-420-R-20-008, May 2020.

[2] *Proposed Determination for Renewable Fuels and Air Quality Pursuant to Clean Air Act Section 211(v),* EPA-420-D-20-003, May 2020.

Onroad and nonroad emission inventories for the two scenarios were estimated with EPA's MOVES2014 model. EPA did not evaluate potential changes in upstream emissions (transportation and distribution, and refinery and ethanol plant emissions). All conventional gasoline counties have E10 fuel properties for 2016 in MOVES. To evaluate E0 in 2016 (the "No RFS" scenario), EPA made assumptions regarding the properties of a hypothetical E0 used in 2016 based on information from its report on MOVES fuel supply characteristics.[3] In other words, because all areas of the country had E10 in 2016, there was little or no real-world fuel data to evaluate E0 fuel properties on in 2016; thus, E0 fuel parameters in 2016 must be estimated. In particular, EPA used a table from the Fuel Supply Defaults report that illustrates the changes in fuel properties with a change in ethanol. This table is shown as Table 1 below.

Table 1. MOVES Fuel Adjustment Factors for E0 to E10

Fuel	Description	RVP (psi)	Aromatics (vol %)	Olefins (vol %)	E200 (%)	E300 (%)	T50 (F)	T90 (F)
E10 S	Summer E10	1.00	-2.02	-0.46	3.11	0.39	-6.34	-1.77
E10 W	Winter E10	1.00	-3.65	-2.07	4.88	0.54	-9.96	-2.45
E15 S	Summer E15		-3.36	-1.64	9.24	0.91	-18.86	-4.14
E15 W	Winter E15		-5.69	-3.27	11.11	1.01	-22.67	-4.59

The table shows that when moving from E0 to E10, RVP increases by 1 psi, aromatics are 2.02% lower, olefins are 0.46% lower, E200 increases by 3.11%, and E300 increases by 0.39%. T50 and T90 are closely related to E200 and E300. These relationships were developed by EPA from analysis of refinery batch data for the nation (not just conventional gasoline areas) reported from the fuel producers for calendar years 2007, 2009 and 2011. The data contain confidential business information from the refiners, and EPA has never described in detail how this analysis was performed. The fuel parameter relationships, particularly the relationship between ethanol increase, and the change in aromatics and T50, are a critical input to EPA's emission inventory analysis for onroad vehicles, and therefore are a critical input to the Anti-backsliding air quality analysis.

EPA's Modeled Results of the "with RFS" Scenario compared to "No RFS":

- Ozone: a modest ozone (8-hour maximum average ozone) increase across the eastern U.S. and some areas of the western U.S., with some decreases in localized areas[4]
- PM: Relatively unchanged in most areas, with increases in some areas, and decreases in some localized areas.[5]

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[3] *Fuel Supply Defaults: Regional Fuels and the Fuel Wizard in MOVES2014b,* EPA-420-R-18-008 July 2018.

[4] *Anti-backsliding Study*, Page 6.

[5] *Anti-backsliding Study,* Page 6.

- CO: Decreased concentrations across the U.S., and in some areas of the west, with larger decreases in some areas.[6]
- NO_2: Increases across the eastern U.S., and in some areas of the eastern U.S., with larger increases in some urban areas. [7]
- Toxics: Increased concentrations of acetaldehyde and formaldehyde, decreased concentrations of benzene and 1,3 butadiene, and mixed results for acrolein and napthalene.

2. AIR's Comments on EPA's Analysis

As an initial matter, EPA's modeled air quality results must be placed in context. The U.S. county average results for 2016 are shown in Table 2.

Table 2. EPA Estimated County Average Air Quality Impacts of E10 vs E0	
Pollutant	Average % Change
Acetaldehyde	0.4
Acrolein	-0.37
Benzene	-2.64
1,3 Butadiene	-3.07
CO	-1.29
Formaldehyde	0.26
Naphthalene	-0.20
NO_2[8]	1.28
Ozone	0.36
PM2.5	-0.01

EPA's modeling shows an estimated ozone increase is 0.36%. This is very small and could be considered negligible. Of the toxics, acetaldehyde and formaldehyde very slightly increase, but benzene, 1,3 butadiene, and acrolein, and naphthalene are lower. According to the California Air Resources Board's Predictive Model, 1,3 butadiene and benzene are more potent air toxics than formaldehyde and acetaldehyde, thus, their reductions are more significant than the small increases in formaldehyde and acetaldehyde. [9]

Overall, we have two major concerns with EPA's analysis:

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[6] *Anti-backsliding Study,* Page 6.

[7] *Anti-backsliding Study,* Page 6.

[8] There are no nonattainment areas in the U.S. for NO2. See https://www3.epa.gov/airquality/greenbook/ancl.html

[9] California Procedures for Evaluating Alternative Specifications for Phase 3 Reformulated Gasoline Using the California Predictive Model, Last Amended: August 24, 2012, https://ww2.arb.ca.gov/resources/documents/gasoline-predictive-models-and-procedures. The potency weighting factors for toxics from this source are 1,3 butadiene: 1.0, benzene: 0.17, formaldehyde: 0.035, and acetaldehyde: 0.016. The source does not list potency weighting factors for acrolein or naphthalene.

- Fuel properties used in the MOVES model for the "no RFS" (E0) scenario in 2016
- Fuel correction factors used in MOVES model

These concerns are described below.

a. *Effects of Ethanol on Fuel Properties in Conventional Gasoline Areas*

EPA's Anti-backsliding analysis used modeled fuel properties, rather than its real-world fuels data. The modeled properties have a tendency to exaggerate ozone and PM impacts and underestimate toxic reductions. As indicated in Table 1, EPA's analysis of fuel properties from refiners for the U.S. indicates that a 10% increase in ethanol reduces aromatics by only 2% and T50 by 6.3F. This is not consistent with data over the 2006-2016 period in EPA's Fuel Trends Report.

As noted above, to perform the Anti-backsliding analysis, one must have fuel properties for E10 and E0 in 2016. EPA attempted to predict from a fuel modeling analysis what the E0 properties would be in 2016 for E0. An alternative method to discerning the fuel properties of a hypothetical E0 in 2016 is to examine how fuel properties changed between 2006 (when there was plenty of E0) and 2016. As described below, this method reveals that certain fuel properties in EPA's method are unrealistic, and thus distort the air quality results of transitioning from E0 to E10 in the "with RFS" scenario.

Specifically, Table 3 shows fuel properties from EPA's Fuel Trends report for conventional gasoline areas for calendar years 2006 and 2016 – the same areas modeled in the Anti-backsliding Study.[10] Ethanol increased from 0.5% to 9.9% between 2006 and 2016. Aromatics declined by 6.5%. T50 declined by 16.3F and T90 by 13.6F.

Table 3. Fuel Property Trends Between 2006 and 2016 in Conventional Gasoline Areas

	Ethanol (vol %)	Aromatics (vol %)	Olefins (vol %)	E200 (%)	E300 (%)	T50 (F)	T90 (F)	RVP (psi)
2006	0.5	28.5	11	45	82	210.0	334.0	8.4
2016	9.9	22	9	53	85	193.7	320.3	9.3
Difference (2016-2006)	9.4	-6.5	-2	8	3	-16.3	-13.6	0.9

Regarding the aromatics decline, EPA's Fuel Trends report made the following two statements:

[10] *Fuel Trends Report: Gasoline 2006-2016,* U.S. EPA, EPA-420-R-17-005., 2017. The earliest years in the Fuel Trends Report is 2006, so in evaluating fuel properties between 2006 and 2016, we are ignoring potential changes between 2005 and 2006, which we understand to be inconsequential.

- "Ethanol's high octane value has also allowed refiners to significantly reduce the aromatic content of the gasoline, a trend borne out by the data."[11]
- "Aromatics levels in the CG gasoline continued to track lower as ethanol has entered the gasoline pool."[12]

Thus, the Fuels Trends report indicates that ethanol was the major contributor to lower aromatics and T50 levels in conventional gasoline areas. Yet EPA's Anti-backsliding Study used its modeled analysis of refinery batch data on all fuels – conventional <u>and RFG</u> – to determine the impact of ethanol on aromatics. This resulted in aromatics and other fuel parameter changes for its hypothetical E0 in 2016 that were much too low for conventional gasoline areas.

If the refinery batch data were publicly available, we would perform an analysis similar to EPA's just for the conventional areas that are being modeled in the Anti-backsliding Study. Since it is not available, we must infer from the fuel property trends between 2006 and 2016 the effects of ethanol for conventional areas.

First, we must attempt to isolate fuel changes that result from changes other than ethanol volumes. To do this, we evaluate other fuel regulations that can also have an influence on fuel properties. Other than the RFS, three fuel regulations were promulgated by EPA in the approximate 2006-2016 timeframe. The three fuel regulations are the Tier 2/Sulfur regulation[13], the Mobile Source Air Toxics (MSAT) rule[14], and the Tier 3/Sulfur regulation.[15] The Tier 2 sulfur regulation, however, was fully implemented by calendar year 2006, so changes in fuel properties for that rule should not affect fuel properties between 2006 and 2016.[16] The MSAT rule required benzene levels to be reduced starting in 2011.[17] The MSAT rule required the reduction in benzene levels from a baseline of around 0.97% to 0.62%.[18] EPA expected an equivalent reduction in aromatics levels since benzene is an aromatic (a reduction of 0.35% in aromatics).[19] Therefore, we could infer that 0.35% of the 6.5% reduction in aromatics between 2006 and 2016 was due to the MSAT rule. The third regulation was the Tier 3/Sulfur rule, which further reduced sulfur levels to 10 ppm in 2017. Some refiners would have implemented this requirement early to

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[11] *Fuel Trends Report*, Page 8.

[12] *Fuel Trends Report*, Page 61.

[13] *Control of Air Pollution From New Motor Vehicles: Tier 2 Motor Vehicle Emissions Standards and Gasoline Sulfur Control Requirements; Final Rule*, 40CFR Parts 80, 85, 86, February 10, 2000.

[14] *Control of Hazardous Air Pollutants From Mobile Sources; Final Rule,* 40CFR Parts 59, 80, 85, 86, February 26, 2000.

[15] *Control of Air Pollution From Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards; Final Rule,* 40CFR Parts 79, 80, 85, et.al., April 28, 2014.

[16] *Tier 2/Sulfur*, Page 6698.

[17] *MSAT Rule*, Page 8428.

[18] *Control of Hazardous Air Pollutants from Mobile Sources, Regulatory Impact Analysis,* EPA420-R-07-002 February 2007, Page 6-6.

[19] *MSAT RIA*, Page 6-82.

generate credits, however, examination of the Reference and Control fuel properties in the Regulatory Impact Analysis shows little change in fuel properties other than sulfur.[20] Therefore, it is reasonable to attribute most of the fuel property changes between 2006 and 2016 to the expansion of ethanol in conventional areas.

In addition to fuel property regulation, changes in the ratio of gasoline and diesel production can also affect properties such as the E300 level. Specifically, if refiners increase diesel output, they shift some of the higher molecular weight components that are used in gasoline to diesel fuel. This shift can result in a gasoline with higher E300, or lower T90. With regard to E300 trends, EPA's Fuels Trends Report indicated:

- "E200 and E300 are also affected by the addition of ethanol. Ethanol boils below 200 Fahrenheit, and also causes some of the hydrocarbons in gasoline which boil above 200 Fahrenheit to boil below 200 Fahrenheit. Ethanol likely contributed to increased E300 values between 2000 and 2016 as well. However, as discussed above, the modest dieselization trend here in the United States also may have contributed to increased E300 over this time period. "

The MOVES model utilizes the following inputs in estimating fuel correction factors:

- Ethanol
- Aromatics
- RVP
- T50
- T90

Table 4 compares the EPA Anti-backsliding fuel changes to the EPA Fuels Trend Report average levels for 2016 for the five properties used in MOVES.[21]

Table 4. Change in Fuel Properties Due to Expansion from E0 to E10 Fuel in Conventional Areas

Fuel Parameter	EPA Anti-backsliding Study (Summer)	EPA Fuels Trends Report – Conventional Gasoline (Summer)[22]
Ethanol (%)	+10	+9.5
Aromatics (%)	-2.02	-6.5
RVP (psi)	+1.0	+0.9
T50 (F)	-6.34	-16.3
T90 (F)	-1.77	-13.6

[20] *Control of Air Pollution from Motor Vehicles: Tier 3 Motor Vehicle Emission and Fuel Standards Final Rule, Regulatory Impact Analysis,* EPA-420-R-14-005, March 2014. See Tables 7-9 and 7-10.

[21] For purposes of this analysis, we ignored the small effect of the MSAT rule on aromatics.

[22] These were determined by visual observations of the plots in the Trends Report, since the raw data were not available in the report.

While the increase in ethanol and RVP are very close in both cases, the changes in the other fuel properties are very different. Specifically, the changes for the Anti-backsliding Study are much smaller than the actual data of fuel properties in conventional areas.[23] Assuming that most if not all of the fuel parameter changes are due to the expansion of ethanol in conventional areas, the actual values from conventional areas are preferable for modeling the impacts of the RFS than modeled values from all conventional and RFG areas.[24]

Using the more appropriate Fuels Trend data from conventional gasoline areas for E0 in 2006 (with three adjustments – benzene, sulfur, and T90) and E10 in calendar year 2016, AIR estimated the change in annual emissions inventories in conventional gasoline areas using the MOVES model. Fuel property adjustments used in this analysis as compared to the EPA analysis are shown in Table 5 (i.e., the rows called "Data"). For sulfur and benzene for E10, we used MOVES values by county for 2016. For sulfur and benzene for E0, we assumed the same sulfur and benzene levels as for E10.[25] For T90, we assumed that one-half of the change in T90 is due to ethanol blending, and the other half is due to the dieselization trend mentioned by EPA. For example, Table 5 shows that increasing from E0 to E10 reduced aromatics by 6.5%. Therefore, to predict hypothetical E0 aromatics levels in conventional areas in 2016, aromatics is increased by 6.5%.

Table 5. EPA and AIR, Inc. Evaluation of Fuel Properties of E10 relative to E0 in Conventional Gasoline Areas

Season	Source	RVP	Aromatics	Olefins	T50	T90
Summer	EPA	1.0	-2.02	-0.46	-6.34	-1.77
	Data	0.9	-6.5	-2.0	-16.3	-6.8
Winter	EPA	1.0	-3.65	-2.07	-9.96	-2.45
	Data	0.2	-6.0	-2.8	-12.2	-6.8

We compare the percent changes in annual emissions with EPA's Anti-backsliding Study in Table 6. In our emissions analysis, similar to EPA's, we also did not include California.

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[23] If the changes in fuel parameters are not mostly related to the expansion in ethanol, it is critical to explain what factors besides ethanol are influencing these changes. We know it is not the fuel sulfur or MSAT regulations.

[24] EPA based its ethanol impacts on fuel parameters on refinery batch data from 2007, 2009, and 2011 for both RFG and conventional areas. No one outside of EPA has been able to review this analysis in detail. EPA could, at a minimum use, have used a wider range of data (for example, from 2007-2016), and also analyzed conventional areas separately from RFG areas.

[25] Benzene was reduced in the 2012-2016 timeframe, and although Tier 3 sulfur was not reduced until 2017, some reductions could have occurred prior to 2016. Neither regulation had a significant effect on aromatics, T50, or T90 levels, so we assumed the same levels for both fuel properties for E0 and E10.

Table 6. Percent Changes in National On-Road Gasoline Emissions Due to E10 in Conventional Areas (Excludes California)		
	EPA Anti-backsliding	Using Actual Fuel Properties for Conventional Areas
NOx	+6%	+3.1%
VOC	+6.6%	+1.8%
PM2.5	+1.3%	-3.0%
CO	-5.6%	-7.3%
Benzene	-12.4%	-15.2%
1,3 Butadiene	-12.2%	-13.8%
Acetaldehyde	+110%	+79%
Acrolein	+8.5%	+2.1%
Formaldehyde	+7.4%	+7.6%

Table 6 shows that using ethanol effects based on actual fuel properties has a significant effect on the change in emission inventories. VOC, NOx, acetaldehyde, and acrolein increase much less than in the EPA analysis. Fine particulate flips from a 1.3% increase to a 3.0% decrease. Carbon monoxide shows a greater decline. The benzene decline is even more substantial –15.2%. 1,3 butadiene also shows a greater decrease.

These emission inventory changes would alter the EPA air quality analyses as well, although it is difficult to predict whether ozone would increase or decrease. At a minimum, the already very small increase in ozone in the EPA analysis would shrink further. Fine PM may show widespread air quality reductions due to E10.
In sum, as contrasted with real-world fuels data, EPA's Anti-backsliding Study overstates adverse emissions impacts associated with a transition from E0 to E10 and underestimates the benefits for air toxics, particulate matter, and carbon monoxide.

b. *EPA's Fuel Correction Factors in MOVES*

AIR previously outlined its concerns with the EPA MOVES fuel correction factors in an SAE paper. [26] For PM, EPA failed to take into account the influence of the T70 parameter on PM emissions. The EPAct testing program used by EPA to evaluate the MOVES fuel correction factors evaluated T50, T90, aromatics, and ethanol's effects on emissions. The fuels were match-blended in the testing program. Since ethanol affects all of these fuel properties, the test fuel blender adjusted T70 of some of the test fuels in an attempt to get the other distillation properties to match. The T70 values of some of the fuels were outside of the range of properties that would be seen in the U.S. Ignoring T70's effect on PM emissions attributed the T70 effect to

[26] *Analysis of EPAct Emission Data Using T70 as an Additional Predictor of PM Emissions from Tier 2 Gasoline Vehicles*, T. Darlington, D. Kahlbaum, S. Von Hulzen, and R. Furey, SAE2016-01-0996, April, 2016. Available for purchase from SAE at https://www.sae.org.

other fuel properties in the modeling, including ethanol. AIR re-analyzed the EPAct data using T70, and ethanol dropped out of the equation used to predict Bag 1 (cold start) PM emissions. The paper concludes that if T70 were included in the model predicting PM emissions, that E10 would reduce PM emissions instead of increasing PM. AIR recommended including the T70 parameter for PM emissions in MOVES.

If T70 were included in the MOVES fuel correction factors, the modeled PM emissions would be reduced even further from the level shown in Table 5 (see Figure 9 of the T70 report).

Additional commentary on the fuel correction factors in MOVES is addressed in the attached "Review of U.S. EPA's Analysis of the Emissions Impacts of Providing Regulatory Flexibility for E15," Trinity Consultants, previously submitted by Growth Energy on the 2019 E15/RVP Proposed Rule.

3. Discussion

EPA's Anti-backsliding analysis shows that increasing ethanol from E0 to E10 in the U.S. had very little impact on ozone and PM, and reduced the most potent air toxics (benzene and 1,3 butadiene). The emission inventory analysis, which drives the air quality results, hinges on the quality of prediction of E0 properties in calendar year 2016 in conventional gasoline areas, and the MOVES fuel correction factors. EPA's analysis of E0 properties in 2016 is based on an analysis of refiner gasoline batch processing data (also used in MOVES) for conventional and RFG areas. Real data on fuel parameter changes in conventional gasoline areas do not confirm EPA's analysis. Instead, the real fuel trends data in conventional areas show a larger effect of ethanol on key fuel properties such as aromatics, T50, and T90 levels than EPA has estimated and used in the emission inventory analysis. Using real-world fuel properties, emissions associated with E10 vs. E0 are lower across the board, with even more dramatic decreases of potent air toxics and significant CO and PM decreases.

EPA's proposed determination is that it is not necessary to promulgate fuel regulations to mitigate the air quality impacts resulting from required renewable fuels volumes. Although EPA's analysis amply supports this proposed determination, improving the analysis with ethanol fuel effects data and improved MOVES correction factors would show that the modest adverse impacts EPA observed are lessened or entirely absent. An improved analysis based on real fuel data would show ethanol-blended fuels are associated with PM improvements, lower benzene and 1,3 butadiene, and lower carbon monoxide emissions.

Appendix 1

Review of U.S. EPA's Analysis of the Emissions Impacts of Providing Regulatory Flexibility for E15

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SUMMARY

On March 21, 2019, the U.S. Environmental Protection Agency (EPA) published a Notice of Proposed Rulemaking addressing modifications to fuel regulations to provide flexibility for E15.[1] The proposed flexibility for E15 blends involves extending the current 1 pound per square inch (psi) RVP tolerance available for E10 blends[2] to E15. More specifically, the proposed E15 flexibility provisions would revise the current maximum allowable summertime RVP limit of 9 psi for E15 to 10 psi, the same limit that applies to E10 blends.

EPA has proposed, among other things, to modify its interpretation of Clean Air Act section 211(h)(4) as applying the 1.0 psi RVP tolerance to gasoline ethanol blends of 10% or more, and also to update its interpretation under section 211(f)(1) of what is "substantially similar" ("sub sim") to certification fuel utilized in certification to include E15 at 10.0 psi. Specifically, EPA is proposing to find that E15, whether with an RVP of 9 or 10 psi, is substantially similar to the E10 fuel used in the certification of Tier 3 vehicles (which has an RVP specification of 9 psi).

EPA's emissions analysis is comprised of (1) an evaluation of whether E15 is sub sim to E10 certification fuel; and (2) a discussion of the overall impact of the proposed rule. First, in analyzing whether E15 is substantially similar to E10 certification fuel, EPA evaluated the potential impacts of E15 relative to E10 on exhaust emissions, materials compatibility, and driveability. Overall, EPA found that the exhaust emissions impacts of E15 as compared to E10 would be slight, that there would be no impacts on driveability and materials compatibility, and that, consistent with its established practice, a fuel qualifies as sub sim if its volatility meets ASTM specifications. Based on this analysis, EPA concludes that E15 is substantially similar to E10 certification fuel. These findings are also consistent with those made previously by EPA in authorizing the use of E15 in model year (MY) 2001 and later vehicles.[3,4]

Second, regarding the overall emissions impacts of the rule with respect to evaporative emissions, EPA observed that E15 at 10 psi is *less* volatile than E10 at 10 psi, which is the fuel it would likely replace. Therefore, the proposed rule would lower the volatility of in-use gasoline and reduce evaporative emissions. In addition, EPA finds that the additional dilution associated with E15 relative to E10 will reduce evaporative emissions of benzene, a toxic air contaminant. With respect to exhaust emissions, relying on the EPAct models, EPA suggested that E15 blends may result in slightly lower CO emissions, which can play a role in ozone formation, and slightly higher NOx and PM emissions.

This report provides input regarding EPA's technical emissions analyses and conclusions that E15 is sub sim to E10 certification fuel, as well as the overall emissions impact of the proposed rule. The results of the review support EPA's overall findings that E15 is substantially similar to E10 certification fuel and that any impacts of the proposed rule on emissions will be, at most, small. This conclusion that E15 and E10 will have similar emissions effects applies to Tier 3

[1] 84 Fed. Reg. 10,584 – 10,630 (Mar. 21, 2019).
[2] See Section 211(h)(4) of the Clean Air Act.
[3] 75 Fed. Reg. 68,094 (Nov. 4, 2010).
[4] 76 Fed. Reg. 4,662 (Jan. 26, 2011).

vehicles certified using E10 as well as MY 2001 and later gasoline-fueled light-duty vehicles certified using E0. However, due to shortcomings in the EPAct study methodology on which EPA relies, this review also indicates that the small increases in exhaust emissions of some pollutants that EPA reports as possible from the proposed rule are less certain to exist than EPA asserts and may in fact not actually occur—EPA should acknowledge this uncertainty in the final rule. In addition, this review confirms that the reductions in general evaporative emissions as well as evaporative emissions of benzene and emissions of carbon monoxide that EPA suggests will in fact occur.

REVIEW OF EPA'S EMISSIONS ANALYSES

Exhaust Emissions

With respect to both its sub sim interpretive rule and the overall emissions impact of the proposed rule, EPA's analysis of the exhaust emission impacts of E15 relative to E10 relies heavily upon statistical models that were developed using vehicle emissions data collected as part of the "EPAct study." The EPAct study involved testing of 15 MY 2008 vehicles designed with port fuel injection systems (PFI) that were certified using Indolene fuel to Tier 2 emission standards on a suite of specially blended test fuels in order to determine the impact of changes in RVP (or Dry Vapor Pressure Equivalent, DVPE), ethanol and aromatic content, as well as the temperatures at which 50% (T50) and 90% (T90) of a fuel is evaporated.

Based on the statistical models derived from the analysis of EPAct emissions test data and test fuel properties, EPA concludes that the proposed rule could result in slightly lower emissions of carbon monoxide (CO), slightly higher emissions of oxides of nitrogen (NOx) and particulate matter (PM), and small but variable impacts on emissions of non-methane organic gases (NMOG) from vehicles in which E15 has been approved for use, as EPA reports in Table II.E-1. EPA characterizes these impacts as real but relatively small. EPA emphasizes the results from the EPAct statistical models over results from other studies that used different methodologies to evaluate E15's exhaust emissions impacts. The agency also cites results from the MOVES model, Complex Model, and Predictive Model as supporting the conclusions it draws from the EPAct models. [5] As discussed in more detail below, the exhaust emissions impacts of providing E15 flexibility through the proposed action will be at most small.[6] Further, given the results of

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[5] EPA references the Complex Model and the Predictive Model as supportive of these conclusions regarding emissions increases and decreases; however, the ability of those models to accurately show emissions differences between E10 and E15 is limited or nonexistent. EPA developed the Complex Model as part of the Reformulated Gasoline regulations based on testing of vehicles representative of MY *1990* vehicle emission control technology for which use of E15 is not authorized. In addition, the test data used to develop the model were limited to ethanol gasoline blends of up to only E10. Similarly, the Predictive Model developed by the California Air Resources Board is based on test data from blends only up to E10 and addresses impacts from the entire light-duty vehicle fleet, including vehicles for which E15 has not been approved.

[6] It should be noted that the emission impacts presented by EPA from the EPAct models in Table II.E-1 apply only to the MY 2001 and later light-duty vehicles for which E15 use has been approved. The small emission changes noted in the table, even if accurate, should be viewed in light of overall emissions of these pollutants from *all* onroad vehicles, including those that cannot legally use E15 and therefore to which the emissions impacts do not apply. Depending on the pollutant and the year, the contribution of other vehicles to total on-road emissions varies but currently is generally on the order of 50% (NMOG, CO) to 75% (PM, NOx).

other studies and issues with the data that underlie the EPAct models, it is not clear that there will be, in fact, *any* increase in exhaust emissions of NOx, PM, or NMOG associated with the proposed rule.

There has been considerable debate regarding the basis for and performance of the EPAct models, which underlie the MOVES model. Major criticisms of the EPAct models relate to the design of the test fuel matrix for study; the way in which the test fuels were "match blended" in an effort to independently vary certain fuel properties; and the resulting properties of the test fuels, particularly their distillation curves and the amounts and types of aromatic compounds they contain relative to commercial fuels. In addition, EPA assumes that the emission results observed from testing of vehicles certified to Tier 2 standards will also apply to vehicles certified to Tier 3 standards.

Beyond the studies referenced by EPA in its assessment of the proposed rule, there are numerous notable publications that document the debate surrounding the EPAct models with respect to the emissions impacts of ethanol blends and that address issues pertaining to the exhaust emissions impacts of the proposed rule. These include the publications listed below.

- Anderson, J.E., et al., "Issues with T50 and T90 as Match Criteria for Ethanol-Gasoline Blends," Society of Automotive Engineers Technical Paper Series, Paper No. 2014-01-9080.

- Darlington, T.L., et al., "Analysis of EPAct Emission Data Using T70 as an Additional Predictor of PM Emissions from Tier 2 Gasoline Vehicles," Society of Automotive Engineers Technical Paper Series, Paper No. 2016-01-0996.

- Request for Correction of Information, submitted on behalf of the State of Kansas, the State of Nebraska, the Energy Future Coalition, and the Urban Air Initiative, Concerning the U.S. Environmental Protection Agency's EPAct/V2/E-89 Fuel Effects Study and Motor Vehicle Emissions Simulator Model (MOVES2014).[7]

- 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.[8]

- "California Multimedia Evaluation of Gasoline Ethanol Blends between E10 and E30, Tier 1 Report," Submitted by the Renewable Fuels Association and Growth Energy to the California Multimedia Working Group, February 14, 2019. (See excerpt in Appendix A.)

- Clark, N., et al., "Emissions from Low- and Mid-Level Blends of Anhydrous Ethanol in Gasoline," Society of Automotive Engineers Technical Paper Series, Paper No. 2019-01-0997.

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[7] Available at https://www.epa.gov/quality/epa-information-quality-guidelines-requests-correction-and-requests-reconsideration#17001.

[8] Available at https://www.epa.gov/sites/production/files/2018-09/documents/ethanol-related_request_for_correction_combined_aug_31_2018.pdf.

These studies encompass evaluations of the impacts in MY 2001 and later vehicles, including Tier 2 and Tier 3 vehicles. One key concern with the basis for the EPAct models identified in the literature above is how the design of the study sought to independently assess the impacts of ethanol content and T50 on vehicle emissions. As is well-known and documented in detail in the references listed above, addition of 10% or 15% ethanol to a gasoline blend substantially reduces T50, which necessitates the addition of heavier, higher-boiling hydrocarbons to the gasoline if one seeks to restore T50 to its original value, as was the case in the EPAct study. The EPAct study also attempted to independently vary RVP/DVPE, aromatic content, and T90. Table 1 presents the correlation matrix for the EPAct test fuels. Values closer to 1 or -1 indicate greater positive or negative correlations between fuel properties, while values close to zero indicate no correlation. As shown in Table 1, fuels with higher ethanol content were correlated with T50 and DVPE. This is important because it means that statistical analysis of ethanol impacts on emissions using the EPAct data cannot be completely isolated from impacts actually associated with T50 or the changes to the base gasoline that were made in the attempt to hold T50 and DVPE as constant as possible. These correlations between variables can confound the analysis of data from emissions testing programs that seek to examine fuel-related effects, and this confounding is not necessarily eliminated by the type of statistical analysis performed to develop the EPAct statistical models. This is shown, for example, in the analysis presented by Darlington et al., where substitution of one distillation variable for another in a re-analysis of the EPAct data leads to the conclusion that E15—made by slash-blending ethanol and thus without other base gasoline adjustments to increase T50—will result in *reductions* in PM emissions, rather than the increase in PM emissions predicted by the EPAct models.

Table 1
Correlation Matrix for EPAct Test Fuel Design Variables

	EtOH	DVPE	T50	T90	Aromatics
EtOH	1.00	-0.10	-0.56	0.02	-0.04
DVPE		1.00	-0.30	0.13	0.05
T50			1.00	-0.04	-0.07
T90				1.00	-0.01
Aromatics					1.00

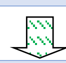
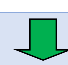
Given the above, there is reason to believe, as is discussed in detail by Anderson et al., that the EPAct study design caused emissions impacts due to changes in the base gasoline made in the attempt to hold other fuel properties, in particular T50, constant, and not due to the addition of ethanol itself to an otherwise unaltered blendstock. As noted by Clark et al., in normal practice it is not possible to add ethanol to a gasoline blendstock while keeping other properties, such as T50, constant. Finally, in the "real world," ethanol is splash-blended into gasoline blendstocks to make E15, and there is no reason to believe that refiners will seek to make adjustments to these blendstocks to hold distillation properties such as T50 constant. Accordingly, evaluating the effect of E15 while allowing properties such as T50 to vary is a more realistic representation of what will result in practice than the approach used to blend the fuels used in the EPAct study.

To put this in context, the primary effect of the proposed rule, at least in the near- to mid-term, will be that additional ethanol will be added to E10 fuels or to gasoline blendstocks designed for use with ethanol. As noted above, this "splash blending" will affect other fuel properties besides ethanol content and will have impacts on exhaust emissions. In the long-term, changes in blendstocks may be made to take advantage of, for example, the higher octane content of E15; those changes, however, will be made based on refinery economics, not as part of an effort to hold T50 and other fuel properties constant.

As noted above, the EPAct models are based on data from match-blended gasoline; however, EPA has used these models in an attempt to account for splash blending of E15 from E10 by estimating the RVP, T50, T90, aromatic, and ethanol content of resulting E15 fuels and found, as shown in Table II.E-1, that impacts on emissions will be small. However, given the issues raised above with the EPAct models, the agency should not ignore the results from studies other than EPAct, particularly those that have relied on splash blending to prepare test fuels as occurs in the real world.

As noted by Anderson et al., numerous studies based on splash blending have shown reductions in exhaust emissions of non-methane hydrocarbons (NMHC) and PM. In addition, the review and analysis of studies other than EPAct included in the California Multimedia Evaluation found no statistically significant impacts or statistically significant reductions in exhaust emissions of organics (e.g., NMOG), NOx, CO, PM, or potency-weighted emissions of air toxics (based on California risk factors) from E15 relative to either E10 or E0. Those findings are reported in Table 7 of that review and are reproduced below. Of particular note in that review is the wide range of vehicle model years and technologies spanned (MY 2001 to 2017 vehicles certified to California Air Resources Board [CARB] LEV I, LEV II, or LEV III, and/or EPA Tier 2 and Tier 3 standards using both PFI and gasoline direction injection [GDI] fuel systems) by the studies considered and the consistency of the assessment of the findings across those studies.

TAILPIPE EMISSIONS STUDIES ON E15 VERSUS EITHER E10 OR E0 AS BASE FUEL

Study Name	Test Cycle	No. of Vehicles	Vehicle Model Years	Base Fuel and Blending Strategy	NO_x	Organic Emissions	CO	PM mass emissions	Potency Weighted Toxics
DOE Intermediate Fuel Blends	LA-92	13	2001-2007	E10 splash blend	No significant difference	No significant difference	No significant difference	Not tested	Not tested
DOE Catalyst Study	FTP	24	2003-2009	E0 splash blend	No significant difference	No significant difference		Not tested	Not tested
UC Riverside -1	UC and FTP	7	2007-2012	E10 match blend	No significant difference	No significant difference	No significant difference	No significant difference	No significan difference
UC Riverside -3	LA-92	5	2016-2017	E10 low aromatics splash			No significant difference	No significant difference	
UC Riverside -3	LA-92	5	2016-2017	E10 low aromatics match blend	No significant difference	No significant difference	No significant difference	No significant difference	No significan difference
UC- Riverside-3	LA-92	5	2016-2017	E10 high aromatics match blend	No significant difference	No significant difference	No significant difference	No significant difference	No significan difference
All Data (no. of datapoints for each pollutant in parentheses)	Various		2001-2017	Various	No significant difference (66)	NMHC:No significant difference (42) THC:No significant difference (29) NMOG:No significant difference (24)	 (66)	No significant difference (24)	No significan difference (22)

Source: Table 7, California Multimedia Evaluation of Gasoline Ethanol Blends between E10 and E30, Tier 1 Report.

Clark et al. also highlight the issues associated with the analysis of emissions data from match blending studies like EPAct. In addition, they note the difficulties in assessing the impacts of changes in fuels, such as moving to E15 from E10, given that impacts vary from vehicle to vehicle based on the relatively small changes in emissions differences in vehicle technology and calibration strategies, the generally low emissions levels from vehicles, and the actual properties of fuels on which the vehicles would operate.

In addition to the EPAct models, EPA discusses the Coordinating Research Council (CRC) E-94-2 and E-94-3 studies with respect to the impact of the proposed rule on PM emissions. These studies investigated the impacts of ethanol at levels up to E10 and PM Index on exhaust emissions from MY 2010 to 2015 vehicles with GDI engines certified to EPA Tier 2 and/or CARB LEV II and LEV III standards, and found only statistically significant impacts of ethanol on PM emissions. EPA then assumes that the impacts on PM emissions observed from ethanol up to the E10 level can be linearly extrapolated to E15; based on this assumption, EPA concludes that PM emissions from GDI vehicles on E15 would increase by 10% relative to E10. Although EPA's focus on GDA vehicles is appropriate, given their increasing prevalence in the market, there are currently no data supporting EPA's hypothesis that the emissions observed from ethanol up to E10 can be linearly extrapolated from E10 to E15.

In fact, another study performed by "CE-CERT" on MY 2016 and 2017 vehicles certified to CARB LEV III and/or EPA Tier 3 standards that is briefly discussed by EPA found no statistically significant effects of E15 on exhaust emissions of NOx, NMHC, or PM emissions relative to E10. EPA appears to critique the validity of the results because T50, a variable found to be important in the EPAct Study, varied due to the addition of ethanol and there was no effort made to control it as in the EPAct study; however, T50 will in fact vary in the splash blending scenario expected for actual fuels in the real world. EPA provides no explanation for why refiners would seek to compensate by reformulating the base gasoline to counteract the effects of splash blending ethanol on T50, and real-world experience with E10 contradicts such an approach. In particular, given that this study actually investigated E15 impacts using fuel blending strategies representative of real-world fuels, EPA should focus on the results of this study on PM emissions, rather than speculation based on the CRC E-94-2 and E-94-3 studies, which did not include actual testing of E15. At the very least, EPA should acknowledge that the existence of PM emissions impacts due to E15 relative to E10 is uncertain and could depend on whether characteristics such as T50 change due to the addition of ethanol or whether refiners would compensate for the impact of adding ethanol on such characteristics by altering the base gasoline formulation.

Overall, although all of the available data, including the EPAct study and related models, reasonably establish that the exhaust emissions impacts will be at most slight, there is reason to suspect that there will not actually be any negative emissions impacts associated with the proposed rule. Given this, EPA should at least acknowledge that there is a question of whether there will be any adverse impacts on NOx or PM emissions resulting from the proposed rule.

Evaporative Emissions

In assessing the overall emissions impacts of its proposal, EPA also performs an analysis of the potential impact of the proposed rule on evaporative emissions. In its analysis, EPA assesses the impacts of E15 relative to E10 on the following six main "components" of evaporative emissions:

1. Diurnal emissions;
2. Refueling emissions;
3. Hot soak emissions;
4. Running loss emissions;
5. Permeation; and
6. Unintended leaks.[9]

EPA first concludes that E15 will not impact evaporative emissions arising from permeation, hot soak, or unintended leaks relative to E10. The agency then discusses impacts on diurnal, refueling, and running loss emissions in the context of potential E15 RVP levels in comparison to E10 RVP levels.

With respect to summertime E15 blends made from the same gasoline blendstocks as E10 that is currently subject to the 1 psi RVP tolerance, EPA concludes that the proposed rule will likely have no impact and may in fact slightly *decrease* diurnal, refueling, and running loss emissions. This conclusion is based on data showing that the actual RVP level of E15 at 10 psi is 0.1 psi lower than E10 at 10 psi.

In addition, EPA finds that evaporative emissions of the Mobile Source Air Toxic benzene may also be lower with E15 due to the additional dilution of the gasoline blendstock relative to E10. EPA similarly concludes that E15 at 9.0 psi RVP will not impact evaporative emissions relative to E10 at 9.0 psi RVP, since the volatility is the same. EPA's analysis and findings in these regards are appropriate as it is well-known that RVP is the key factor in determining the magnitude of evaporative emissions arising from these sources.

In addition to the above, EPA considers the impacts of E15 at 10.0 psi RVP relative to E15 and E10 at 9.0 psi RVP (even though E10 is subject to a 1 psi tolerance and is thus sold in the summer at 10 psi). For purposes of the sub sim analysis, the agency appropriately proposes to leave unchanged its historical approach to RVP in its current substantially similar interpretive rule and find that E15 is sub sim so long as its RVP is within the ASTM range. The agency notes in passing that "increasing fuel RVP from 9.0 psi to 10.0 psi increases fuel vapor generation significantly under summertime conditions, which can overwhelm a vehicle's evaporative control system and push it out of compliance." This is a significant over-generalization, and EPA should clarify in the final rule the narrow conditions under which such a difference in volatility can significantly affect evaporative emissions. Actual evaporative emissions from a given vehicle will depend on a number of factors and may be lower than expected based on certification test results, particularly for MY 2001 and later vehicles for which

[9] 84 Fed. Reg. 10,599 (Mar. 21, 2019).

E15 use has been approved. Factors affecting emissions from a particular vehicle include the following:

- Actual ambient temperatures experienced by a vehicle compared to those used in certification testing;
- The actual time between driving events that purge stored vapors from the evaporative emissions control system compared to the multi-day diurnals involved in certification testing; and
- The evaporative emissions control technology on the vehicle, including compliance margins that vehicle manufacturers have engineered into evaporative emission control systems.

First, to the extent that ambient temperatures are lower than those associated with certification testing, vapor generation and evaporative emissions will be reduced. In addition, it is well-known that vapor generation rates of ethanol blends are lower than those of gasoline not containing ethanol—where both are held to the same RVP—at temperatures below 100°F.[10] In other words, the "volatility increase" resulting from blending ethanol at 10-15% in terms of RVP is determined at 100°F and the amount of the increase in volatility is lower at temperatures below 100°F. Furthermore, more frequent driving reduces the amount of vapor stored in evaporative emission control systems relative to that during certification testing, again leading to lower emissions, as do manufacturer compliance margins. Therefore, although higher RVP levels generally lead to higher evaporative emissions, it is far from given that operation of a specific vehicle on a 10 psi RVP ethanol blend under summer conditions will either overwhelm its evaporative emission control system or push it out of compliance with applicable emission standards. EPA should acknowledge that such conditions are limited.

Air Toxics Impacts

EPA's analysis focuses on evaporative emissions of benzene. However, the proposed rule does have the potential to impact emissions of other exhaust emission toxic species such as benzene; 1,3 butadiene; formaldehyde; and acetaldehyde. The overall impact of the proposed rule when assessed using appropriate weightings based on risk factors such as those available from EPA's Integrated Risk Information System (IRIS)[11] is expected to be slight. The reason for this is that increases in emissions of one compound, such as acetaldehyde (a relatively less potent air toxic), will be offset by decreases in others, such as benzene and 1,3 butadiene (which are more potent air toxics).

[10] Reddy, S.R., "Prediction of Fuel Vapor Generation form a Vehicle Fuel Tank as a Function of Fuel RVP and Temperature," Society of Automotive Engineers Technical Paper Series, Paper No. 892089, 1989.
[11] https://www.epa.gov/iris. The mid-point of the IRIS range for inhalation risk for benzene was used in this analysis.

Materials Compatibility and Driveability

EPA's sub sim analysis also addresses materials compatibility and driveability of E15 as compared to E10 certification fuel. EPA refers back to its analysis in the 2010 and 2011 E15 waiver decisions that thoroughly explained the agency's findings that E15 would have no issues with respect to materials compatibility and driveability.[12] With respect to materials compatibility, EPA also notes that vehicle manufacturers have been using E15 as part of the new-vehicle certification process since at least MY 2014 to demonstrate the durability of emission control systems to conclude that impacts on newer vehicles are even less likely to be an issue.[13] EPA similarly finds that manufacturers are designing vehicles for operation on E15 and that fuel producers are ensuring that E15 complies with ASTM D4814–18c fuel specifications.[14] Accordingly, EPA appropriately finds that "E15 would have similar driveability characteristics to Tier 3 E10 certification fuel."[15] These conclusions apply equally to MY 2001 and later light-duty vehicles, including Tier 3 vehicles, as EPA documented in its earlier decisions providing partial waivers for E15 use in MY 2001 and later vehicles.

EPA's findings and analysis are supported by the fact that E15 has been in commercial use for a considerable period of time without any reports of issues with respect to either materials compatibility or driveability. In addition, the California Multimedia Evaluation includes a review of issues that could arise from use of gasoline ethanol blends above E10 and concludes that no materials compatibility impacts are expected to arise.

Comments Regarding Scope of "Sub Sim" Determinations for E15

As demonstrated above, the available data indicate that E15 will result in at most small, if any, increases in some exhaust pollutants and lower evaporative emissions than E10 blends at the same RVP standard across a wide spectrum of vehicle vintages (from MY 2001 forward), technologies, and certification standard levels. Indeed, EPA already approved E15 for use in *all* MY 2001 and later vehicles based on a thorough analysis of the emissions, materials compatibility and driveability impacts of the fuel in its partial waiver decisions, which compared E15 (with 15% ethanol) to E0 (with no ethanol). As shown in the DOE Catalyst Study[16] on which EPA relied heavily for the partial waiver decisions, the impacts of E10 and E15 on exhaust emissions were essentially the same.

As such, and given the historical approach EPA has consistently taken to require that a sub sim fuel meet the general fuel volatility specifications in the ASTM standard, there is no basis for EPA to limit its sub sim finding to constrain use of E15 to Tier 3 vehicles. EPA can reasonably find that E15 is sub sim to E10 (or E0) in all MY 2001 and later light-duty vehicles.

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[12] 84 Fed. Reg. 10,600 – 10,601 (Mar. 21, 2019).
[13] *Id.* at 10,600.
[14] *Id.* at 10,601.
[15] *Id.*
[16] https://info.ornl.gov/sites/publications/Files/Pub31271.pdf.

Appendix A

California Multimedia Evaluation of Gasoline Ethanol Blends between E10 and E30, Tier 1 Report

Section 4, "Use of Gasoline-Ethanol Blends in Vehicles"

California Multimedia Evaluation of Gasoline-Ethanol Blends between E10 and E30
Tier I Report

Submitted to the Multimedia Working Group

February 14, 2019

4 Use of Gasoline-Ethanol Blends in Vehicles

As discussed in Section 1.2, since 2010, virtually all fuel sold in the United States, and all California RFG, has been E10 and few if any ill effects have been observed in the existing vehicle fleet. Given this, E10 is the appropriate basis for comparison with gasoline-ethanol blends in the E11 – E30 range. Since only

2001 and later model-year light-duty vehicles are approved to use gasoline-ethanol blends above E10 by U.S. EPA, older vehicles and non-vehicular engines, motorcycles, heavy-duty vehicles, as well as off-road vehicles such as boats and snowmobiles, which are prohibited by U.S. EPA from using higher ethanol content fuels are not considered here. Some portion of the flexible fuel vehicles (FFVs), which comprise between 5% and 10% of the on-road fleet (more than 20 million on the road in the United States[62]) that operate primarily on E10, may begin to operate on E15 and so may impact overall fleet emissions.

As is shown below, emissions and compatibility data related to the use of gasoline-ethanol blends above E20 in existing vehicles is limited. In addition, federal waivers allowing the use of blends above E15 would have to be granted by U.S. EPA in order to use blends above E15 in existing vehicles.

4.1 Vehicle Compatibility

4.1.1 Vehicle design

Virtually all new U.S. vehicles are warrantied for use with E15 (see Section 4.2) by the Original Equipment Manufacturers (OEMs) which ensures material compatibility of the fuel system and that all emissions requirements are met when new and at full useful life. However, to ensure that older vehicles are also compatible with higher gasoline-ethanol blends, two programs have tested relatively large numbers of older vehicles for extended times on E15 and E20. (There has been no significant published data on the use of E30 in recent-model or older vehicles.)

A study undertaken in 2006 at the University of Minnesota[63] included 40 pairs of vehicles, model years 2000-2006, with matched usage patterns. One of each pair used commercially available E0, while the second was fueled with E20, made from commercially available E10 splash blended with additional ethanol. During the test period, only two vehicles in the program had maintenance issues, with only one being fuel related, and that was in an E0-fueled vehicle. Thus, the data from this program suggest that these older vehicles would not have increased maintenance issues associated with the use of gasoline-ethanol blends above E10 and up to E20.

A far more intensive program[64], overseen by the Oak Ridge National Laboratory included 82 MY 2000-2009 vehicles. Eighteen vehicle models (each represented by three matched vehicles) were aged with E0, E15 and E20; five vehicle models (each represented by four matched vehicles) were aged with E0, E10, E15 and E20; and four vehicle pairs were aged with E0 and E15. The E0 was TOP-TIER™[65] retail E0 fuel, into which ethanol was splash blended to produce the other test fuels. Each vehicle was aged the equivalent of 50,000 to more than 100,000 miles on each test fuel. The testing was conducted at three different facilities, the Southwest Research Institute (SwRI), the Transportation Research Center (TRC) and Environmental Testing Corporation (ETC). ETC is located in the Denver area and was included to assess the potential for altitude related effects.

Unscheduled maintenance was recorded, and the affected equipment was removed and analyzed for potential fuel effects. Failures of certain components, including the transmission, spark plug and radiator which had no contact with the fuel, are not included here. Fuel system repairs that were required over the course of the testing included an evaporative emissions hose, believed to be made of nitrile rubber, which split on a 2002 Dodge Durango. No differences could be detected between the inside and the outside of

[62] https://www.afdc.energy.gov/vehicles/flexible_fuel.html, accessed August 23, 2018.
[63] Kittleson, D., A. Tan, D. Zarling, B. Evans, C. Jewitt, Demonstration and Driveability Project to Determine the Feasibility of Using E20 as a Motor Fuel, November 2008.
[64] West, B., Sluder, C.S., Knoll, K., Orban, J., Feng, J., Intermediate Ethanol Blends Catalyst Durability Program, ORNL/TM-2011/234, February 2012.
[65] TOP-TIER™ is a fuel quality specification created and enforced by automakers. It is primarily intended to ensure that the fuel includes adequate level of detergents to avoid deposits on critical engine parts. More information can be found on the program website: www.toptiergas.com.

the hose, so the failure was attributed to general aging, rather than fuel effects. Two fuel pumps in 2006 MY vehicles (plus a fuel pump and a fuel level sender in a 2000 MY vehicle) were replaced when they failed, although the researchers determined that the failures were unrelated to fuel. In addition, all three (E0, E15 and E20) 2006 Chevrolet Impalas experienced canister vent solenoid failures.

Finally, a tear-down study[66] of the engines in eighteen of the vehicles (six makes and models from the model years 2006 to 2008, each run on E0, E15 and E20) showed an increase in intake valve deposits (IVD) in the E15 vehicles, relative to the E0 vehicles. The vehicles aged with E20 also showed an increase relative to both E15 and E0, although the results were not as consistent.
The authors hypothesize that the increase was due to the dilution of the normal detergent additives which are present in TOP TIER™ gasoline. However, these deposits were not found to result in either operational problems or increases in emissions.

Evaporative emission canister working capacities showed a slight decreasing trend with higher concentration ethanol blends for one-third of the six different models. The emissions systems of the eighteen aged vehicles were pressure checked, and all were found to have maintained their integrity. No fuel related differences were found in valve seat width, valve surface contours, fuel tanks, fuel lines and evaporative emissions lines. Fuel injector flow rates were equivalent to within +/- 3%. There were no statistically significant differences in oil consumption attributed to the ethanol level in the fuel.[67]

Emissions were measured using EPA certification E0 fuel on all vehicles at the start of the project, at one or two points, and at the end of scheduled aging. No discernible difference in aging effects from the different fuels could be found except that on those vehicles tested by ETC which showed slightly less catalyst deterioration with higher ethanol blends. One hypothesis suggested by the researchers was that the sulfur content of the fuel was lowered as the result of dilution by ethanol as the ethanol level increased, although this impact was not seen in other vehicle sets. Largely based on these test results, which showed no degradation in emissions at gasoline-ethanol blend levels up to E20, EPA has permitted the use of gasoline-ethanol blends of up to E15 in all 2001+ MY vehicles.

The CRC has conducted studies focused on finding and testing vehicles and components suspected of being most susceptible to damage from E15 and E20. One pump, identified only as Pump N, was shown to have a greater failure rate with E15 in comparison to standard E10.[68] However, confidentiality rules which limit CRC's ability to divulge the make and model of the pump, as well as the materials of which it is made, limit the usefulness of this information to the general scientific community.

In addition, the Minnesota Center for Automotive Research conducted a 30-day static soak test[69] followed by 4000-hour endurance tests[70] for eight different models of fuel pumps and three different models of sending units[71] using E20, E10 and E0 (a total of 24 pumps and 9 sending units). No fuel effects were identified during the soak test, but during the 4000 -hour endurance testing, four pumps out of the twenty-four failed – two using E10 and two using E0. The commutators[72] of several of the pumps tested in E0 wore substantially more than those tested in either E10 or E20. No evidence of negative effects of use of E20 on fuel pumps was found. All of the sending units failed during the 4000-hour endurance testing,

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[66] Shoffner, B., Johnson, R., Heimrich, M., Lochte, M., Powertrain Component Inspection from Mid-Level Blends Vehicle Aging Study, ORNL/TM-2011/65, November 2010.
[67] West, B., Sluder, C.S. "Lubricating Oil Consumption on the Standard Road Cycle", SAE Technical Paper No. 2012-01-0884.
[68] CRC, Durability of Fuel Pumps and Fuel Level Senders in Neat and Aggressive E15, CRC Contract No AVFL-15a, January 2013.
[69] Mead, G., B. Jones, P. Steevens, N. Hanson, T. Devens, C. Rohde, A. Larson, The Effects of E20 on Automotive fuel Pumps and Sending Units, Minnesota Center for Automotive Research, February 21, 2008.
[70] Mead, G., B. Jones, P. Steevens, N. Hanson, J. Harrenstein, An Examination of Fuel Pumps and Sending Units During a 4000 Hour Endurance Test in E20, Minnesota Center for Automotive Research, March 25, 2009.
[71] The fuel sending unit is installed inside of the fuel tank. Its purpose is to measure the fuel level and send that information to the fuel gauge.
[72] A commutator is a moving part in certain types of electric motors or generators that can convert alternating current into direct current.

regardless of fuel. The authors reported no significant differences in performance or failure between the sending units as a function of test fuel.

One engine durability study was considered in this review[73] although its results were disregarded because of significant problems with its methodological and statistical approach. This study, and what we view as its methodological problems, is extensively discussed elsewhere.[74]

4.2 Manufacturer Warranty Limitations

FFVs are warrantied for the use of all levels of ethanol in fuel. Warranty information for use of gasoline-ethanol blends of up to E15 in non-FFVs is summarized in Figure 2 below. Other than the BMW Mini (warrantied for gasoline-ethanol blends up to E25), no past or current production vehicles have warranties allowing the use of fuels above E15.

[73] CRC, Intermediate-Level Ethanol Blends Engine Durability Study, CRC Project CM-136-09-1B, April 2012.
[74] McCormick, R.L, j. Yanowitz, M. Ratcliff, B. Zigler, Review and Evaluation of Studies on the Use of E15 in Light-Duty Vehicles, https://ethanolrfa.3cdn.net/b378858ac325c6e165_sgm6bknd4.pdf, accessed September 18, 2018.

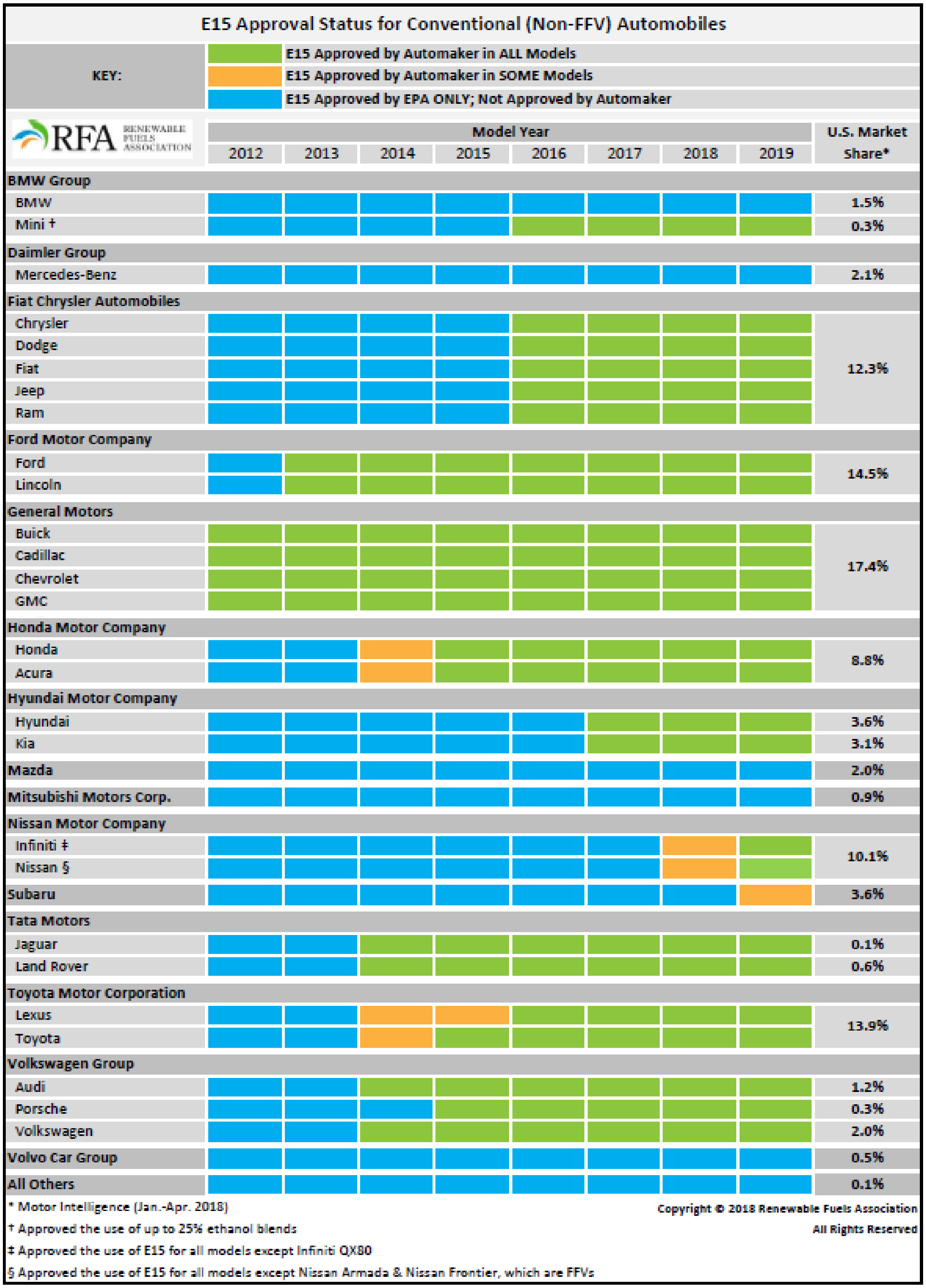

FIGURE 2. WARRANTY INFORMATION FOR USE OF E15 IN U.S. VEHICLES

4.3 Detailed Properties of Gasoline-Ethanol Blends Relevant to Use in Vehicles

The addition of ethanol to hydrocarbon gasoline changes the properties of the fuel, including its energy density, vapor pressure, octane, distillation properties and its impact on materials. Material compatibility of gasoline-ethanol blends with metals, elastomers and plastics that are used in vehicles and fuel infrastructure has been discussed in Section 3 above.

As noted in Section 1, ASTM Standard D4814-18d, specifies the properties of spark-ignition fuel and used by the Division of Measurement Standards (part of the California Department of Food and Agriculture) to set requirements for such fuels.[75] As present, this specification addresses blends up to E15 fuels so no changes would be required for CARB to approve fuels specifications covering those fuels. However, modifications would be needed for approval of blends above E15 up to E30.

The analysis of vapor pressure and octane below is based on results of a study in which the American Petroleum Institute (API) has tested a variety of fuel properties on 71 different gasolines with widely variant properties. Each gasoline was then blended with 10%, 12.5%, 15%, 20% and 30% ethanol and retested. Some of the gasolines were petroleum blendstocks intended to be used to make gasoline-ethanol blends (blendstocks for oxygenate blending or BOBs), others were intended for use without the addition of ethanol. These fuels were not selected to be representative of typical or average fuels, but rather to show the expected range of changes in properties that could occur due to the addition of ethanol to hydrocarbon fuels.

4.3.1 Energy Density

Ethanol has about 67% of the energy of gasoline on a volumetric basis.[76] Because the energy density of ethanol is lower than gasoline, fuel economy tends to decrease as the ethanol content in blends increases. Modern engines can take advantage of higher octane fuels to be slightly more efficient. Table 3 below shows the relative energy density of E15, E20 and E30, relative to E10.

TABLE 4. ENERGY DENSITY OF GASOLINE-ETHANOL BLENDS RELATIVE TO E10.

E15	97% of the energy of E10/gallon
E20	93% of the energy of E10/gallon
E30	90% of the energy of E10/gallon

4.3.2 Vapor Pressure

As noted in Section 3.5.1, at E10, the Reid Vapor Pressure (RVP) of the blended fuel is about 1 psi higher than that of the blendstock but is expected to decrease as the ethanol content increases as is shown in Figure 2, above.

As shown in Figures 5 and 6, the measured RVP at E15 and E20 was indistinguishable from that of an E10 using the same base gasoline blendstock using ASTM methods. Figure 7 shows that at E30, RVP is about one-half pound per square inch lower than that of an E10 made using the same gasoline blendstock.

[75] https://www.cdfa.ca.gov/dms/

[76] California Air Resources Board, Low Carbon Fuel Standard and Alternative Diesel Fuels Regulation 2018, Final Regulation Order, posted September 17, 2018, https://www.arb.ca.gov/regact/2018/lcfs18/fro.pdf accessed November 13, 2018.

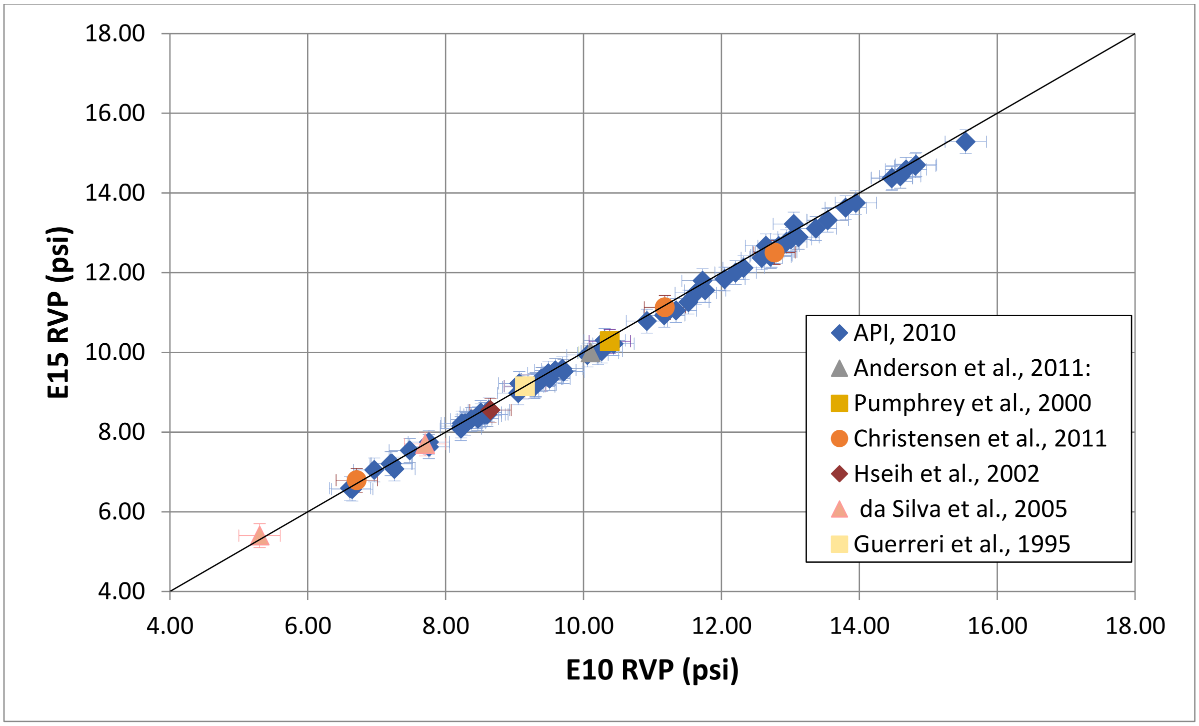

FIGURE 3. THE VAPOR PRESSURES OF E15 AND E10 BLENDS MADE USING THE SAME BASE GASOLINE BLENDSTOCK. THE ERROR BARS SHOW THE REPEATABILITY OF THE ASTM METHOD D5191 USED TO MEASURE REID VAPOR PRESSURE.

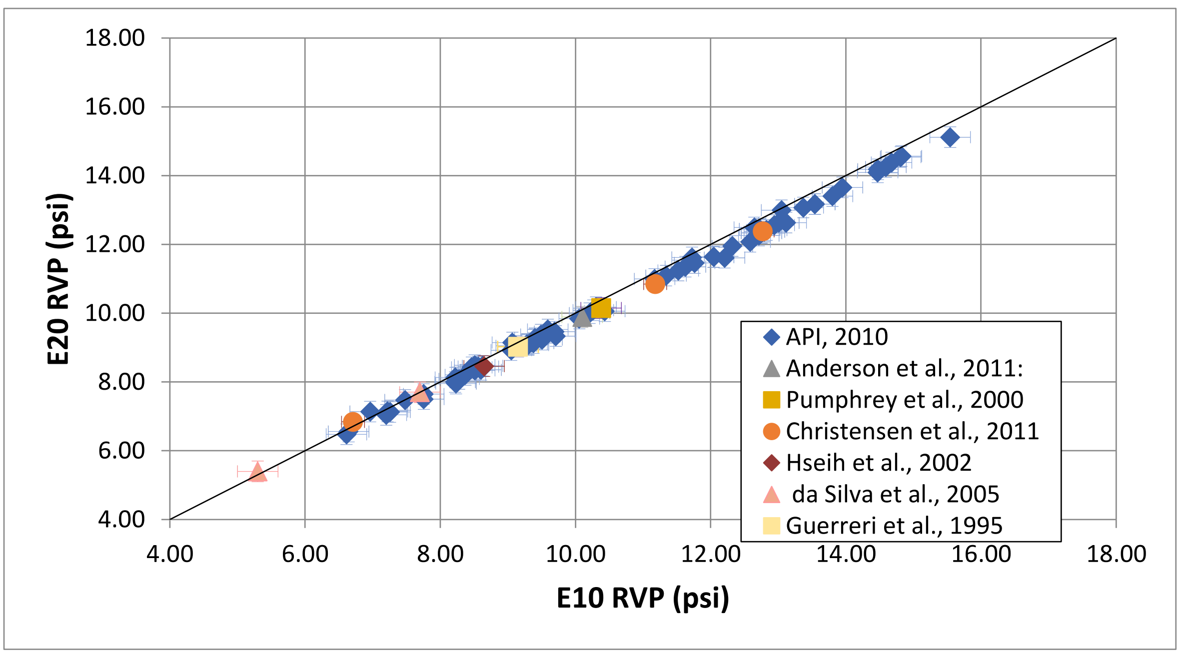

FIGURE 4. THE VAPOR PRESSURES OF E20 AND E10 BLENDS MADE USING THE SAME BASE GASOLINE BLENDSTOCK. THE ERROR BARS SHOW THE REPEATABILITY OF THE ASTM METHOD D5191 USED TO MEASURE REID VAPOR PRESSURE.

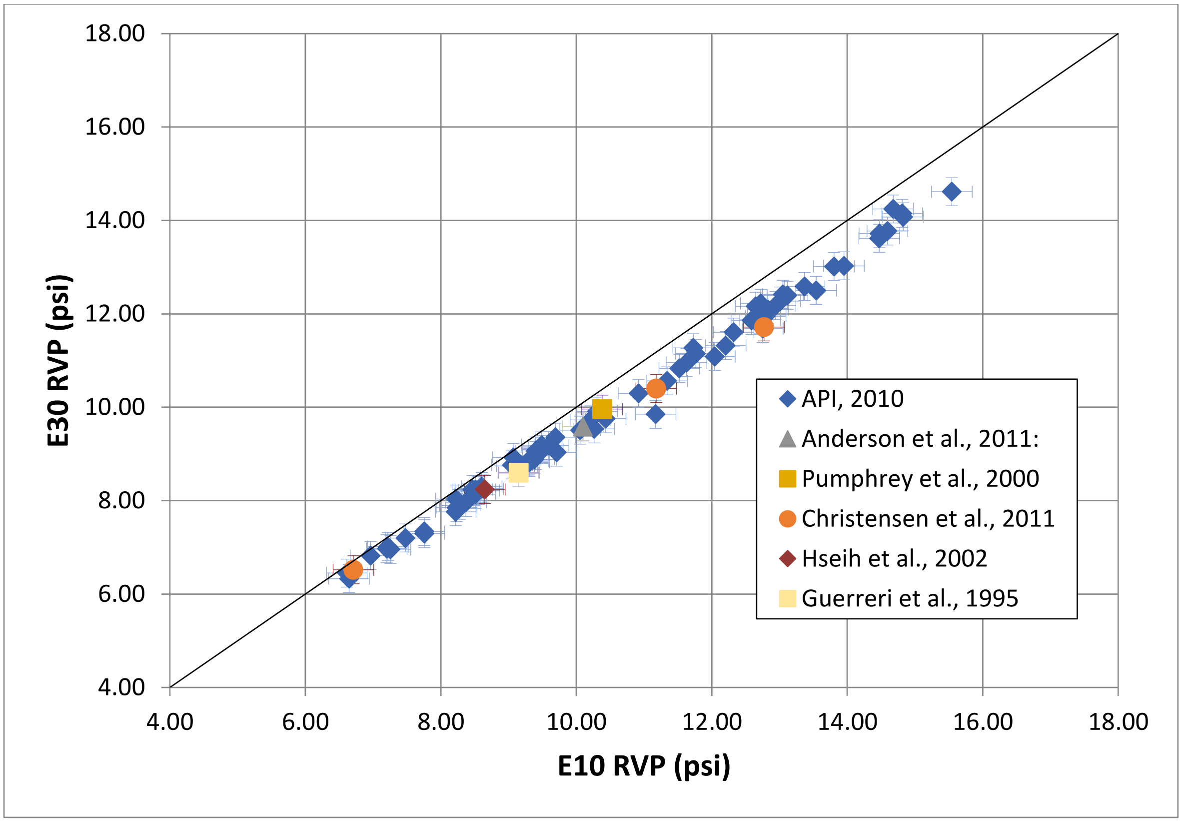

FIGURE 5. THE VAPOR PRESSURES OF E30 AND E10 BLENDS MADE USING THE SAME BASE GASOLINE BLENDSTOCK. THE ERROR BARS SHOW THE REPEATABILITY OF THE ASTM METHOD D5191 USED TO MEASURE REID VAPOR PRESSURE.

4.3.3 Octane

Inside the cylinder of an internal combustion engine the air/fuel mixture should ignite at a precise time in the piston's stroke. Engine knock occurs when pockets of the air/fuel mixture ignite earlier than they should. A minimum octane in fuel is required to prevent engine knocking. In comparison to retail gasoline, ethanol has a high octane number. Its AKI[77] (antiknock index) is 114 while gasoline is typically sold with an octane number of between 85 and 91. Adding additional ethanol to gasoline increases the octane number, as shown in Figure 6. As mentioned above, higher octane levels of ethanol blend fuels can also reduce fuel consumption in those vehicles which optimize fuel economy by advancing ignition timing to just below the knock limit offsetting to some degree the impacts of the lower energy content of those blends.

[77] AKI is equal to the average of the research octane number and the motor octane number, which are two different ways of measuring octane. The octane number posted at the retail fuel station is the AKI.

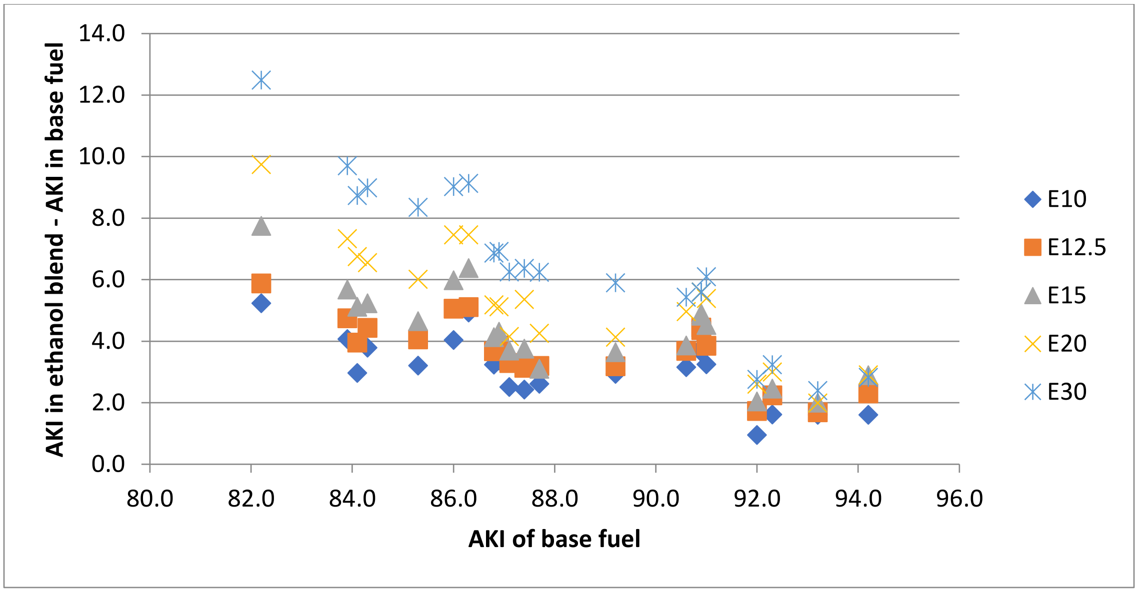

FIGURE 6. IMPACT OF INCREASING ETHANOL CONTENT ON 71 DIFFERENT BASE FUELS.[78]

4.3.4 Distillation Curve

Gasoline and oxygenate blendstocks are complex mixtures of hydrocarbon compounds with a range of boiling points. As a result, the distillation curves of these fuels typically rise steadily upward as temperature increases and individual compounds volatilize. As shown in Figure 7, the distillation curves of ethanol-containing blends start in the same way as pure hydrocarbon gasoline, but then plateau, at a relatively constant temperature as the azeotropes[79] that form between ethanol and various hydrocarbons distill. When the ethanol is gone, the curve shoots upward to rejoin the distillation curve of the base hydrocarbon fuel, thus T10 and T90 are largely unchanged by the addition of ethanol below 30 percent by volume. At higher ethanol concentrations, the length of the plateau increases, and typically impacts T50. Thus, one should expect the T50 of virtually all E15, E20 and E30 fuels to be 5 to 10 °C less than that of E10 blended with the same base fuel.

ASTM D4814-18d allows for the expected lower T50 with E15. Higher ethanol content (i.e., above E15) fuels will not result in significantly lower T50s.

[78] American Petroleum Institute, Determination of the Potential Property Ranges of Mid-Level Ethanol Blends, Final Report, April 23, 2010 https://www.api.org/~/media/Files/Policy/Fuels-and-Renewables/2016-Oct-RFS/The-Truth-About-E15/E10-Blending-Study-Final-Report.pdf
[79] An azeotrope is a mixture of two or more liquids that have the same concentration in the liquid and vapor phase and so cannot be separated by distillation.

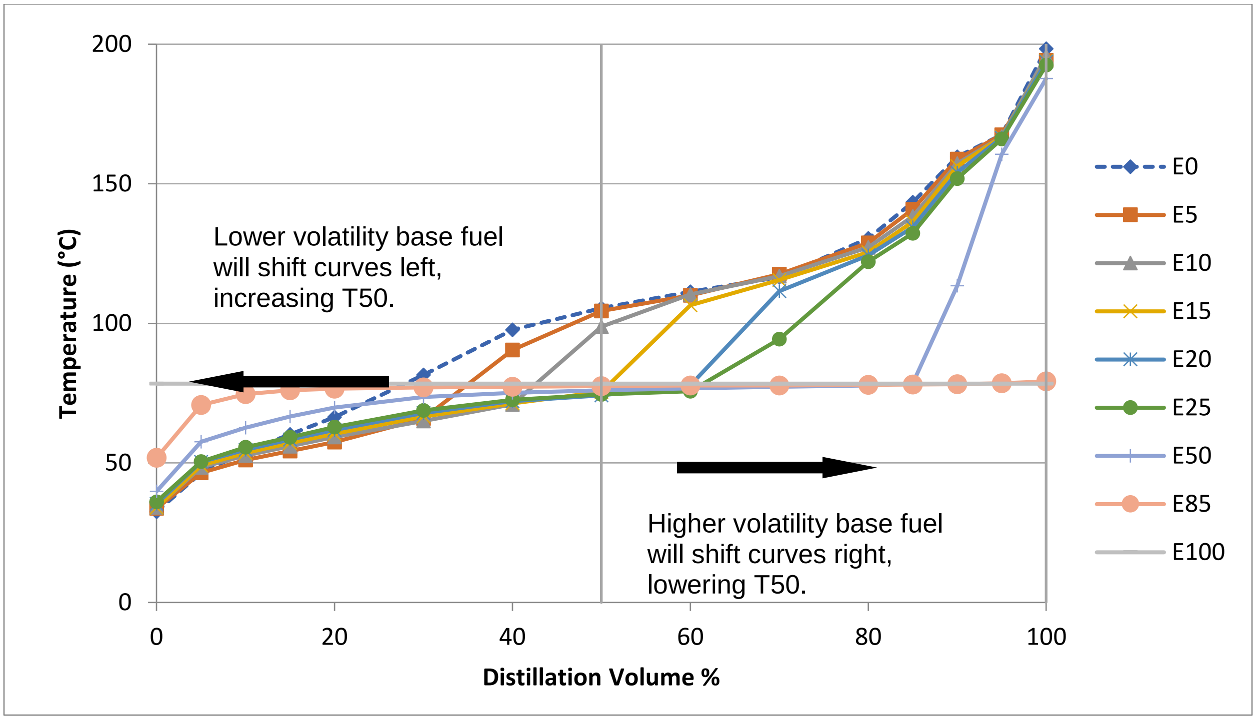

FIGURE 7. DISTILLATION CURVES OF ETHANOL IN CERTIFICATION GASOLINE FROM ANDERSON (2010)[80]

[80] V. F. Andersen, J. E. Anderson, T. J. Wallington, S. A. Mueller And O. J. Nielsen, Distillation Curves For Alcohol−Gasoline Blends, Energy Fuels, 2010, 24 (4), Pp 2683–2691.

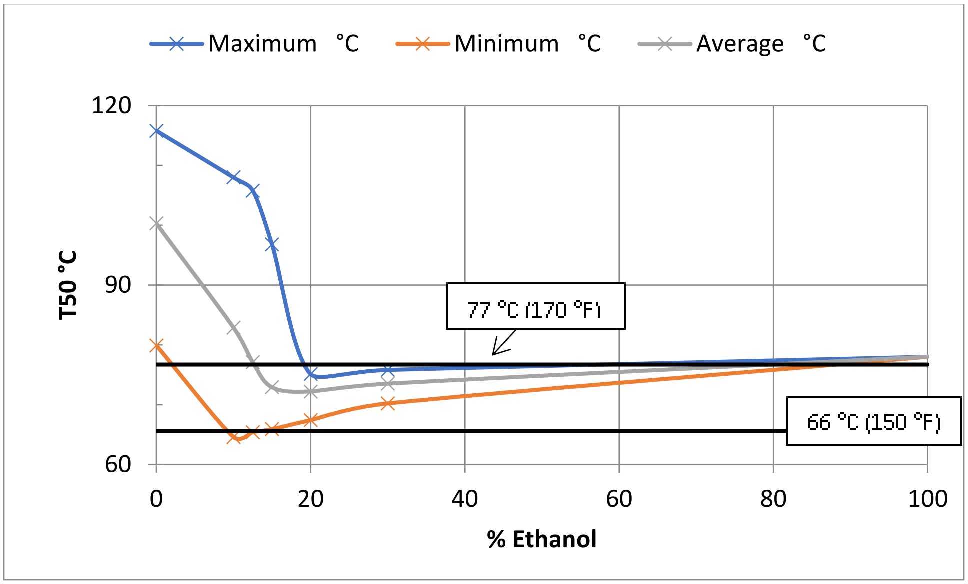

FIGURE 8. T50 RANGE FOR A VARIETY OF GASOLINES AT VARIOUS ETHANOL CONCENTRATIONS[81]

TABLE 5. T50 FOR A VARIETY OF GASOLINES, INCLUDING SOME BOBS, BLENDED WITH BETWEEN 10% AND 30% ETHANOL, AND EXTRAPOLATED TO BOILING POINT OF ETHANOL.[81]

T50 °C (°F)	E0 (straight gasoline)	E10	E12.5	E15	E20	E30	E100 (straight ethanol)
Average °C	100.3	82.9	77.1	72.9	72.2	73.5	78
°F	(212.6)	(181.2)	(170.8)	(163.2)	(161.9)	(164.3)	(173)
Std. Dev. °C	7.6	14.7	11.2	5.4	1.6	1.0	0
°F	(13.6)	(26.4)	(20.2)	(9.8)	(2.8)	(1.8)	(0)
Minimum °C	79.9	64.6	65.4	65.9	67.4	70.2	78
°F	(175.9)	(148.2)	(149.8)	(150.7)	(153.4)	(158.4)	(173)
Maximum °C	115.8	108.0	105.8	96.8	75.1	75.8	78
°F	(240.5)	(226.4)	(222.5)	(206.3)	(167.1)	(168.5)	(173)

4.4 Additive Requirements for Gasoline-Ethanol Blends

The U.S. EPA and CARB (California Title 13, Chapter 5, Article 1 section 2257) require detergent additives to be added to gasoline to control deposit formation at a minimum dosing rate. The detergents are tested using ASTM D5598 and ASTM D5500 to ensure that they perform adequately. Detergent is generally considered necessary for the purposes of reducing fuel injector deposits from the hydrocarbon portion of the fuel. In approving blends up to E15, U.S. EPA concluded that no changes were required relative to levels required for use with E10.[82] Given this, and the available data described above, use of additive levels consistent with those that apply in California for E10 would also be appropriate for blends

[81]From data in American Petroleum Institute, Determination of the Potential Property Ranges of Mid-Level Ethanol Blends, Final Report, April 23, 2010 https://www.api.org/~/media/Files/Policy/Fuels-and-Renewables/2016-Oct-RFS/The-Truth-About-E15/E10-Blending-Study-Final-Report.pdf

[82] US Government Accountability Office, BIOFUELS Challenges to the Transportation, Sale, and Use of Intermediate Ethanol Blends, June 2011.

of up to at least E15. Testing would be required to determine the appropriate detergent treat rate for E20 and E30 fuels.

4.5 Vehicle Emissions

This section evaluates the available emissions test data to assess the impacts of ethanol blends in the E11 – E30 range on air quality. Impacts on greenhouse gas emissions (GHGs) are addressed in Section 8. Since only vehicles that have been built since model year (MY) 2001 are permitted to use E15 under EPA regulations (in addition to specially designed FFVs which are permitted to use any ethanol concentrations of up to 85%) only data from testing of these vehicles are considered here and impacts are assessed relative to E10.

4.5.1 Test Fuels

All blends of ethanol and gasoline up to E10 sold in California must comply with CARB's California Reformulated Gasoline (CaRFG) regulations. This requirement imposes limits on the allowable properties of petroleum blendstocks for oxygenate blending (CARBOBs) used in preparing these compliant blends. The analysis presented below is focused on assessing the emission impacts associated with use of gasoline-ethanol blends above E10 that are created via splash blending of ethanol into a CARBOB that complies with CARB regulations for E10. Because of the limited number of studies done comparing nominal E15 and E20 blends to E10, this review will also describe testing performed to compare E15 and E20 to E0. Inclusion of these studies is conservative given that any observed differences in emission between E15 and E20 relative to E0 should be larger than those expected to exist between E15 and E20 relative to E10.

Further, the analysis also uses data from some studies involving what is known as "match blending" instead of splash blending. In match blending, the properties of the CARBOB or other blendstock are intentionally altered such that the properties of the blends being compared, E10 and E15, for example, are as close as possible except for the difference in ethanol content. The match characteristics vary but frequently include vapor pressure, and/or aromatic content and/or T50. Splash blending, by contrast, employs the same base hydrocarbon fuel for each blend regardless of ethanol content. Studies which employ splash blending are more representative than match blending studies of the changes that would occur should E11-E30 fuels be blended with the same CARBOBs that are used for E10, as is proposed for these new fuels.

There are many issues that need to be considered when using data from match blending studies to evaluate impacts of splash blending. These include:

- match blending for multiple fuel properties is difficult and rarely perfectly successful, because it is impossible to change one property without changing many of the other properties;
- despite extensive study it is not clear which fuel properties are most important with respect to emissions because the effects of correlated properties cannot be easily separated from each other by statistical analysis; and
- there are numerous properties that could conceivably have an impact on emissions[83] such that no match blending study could control for changes in all properties that could impacts emissions.

Given the differences in match and splash blending, it is not surprising that there are differences in the results from studies using the two approaches to evaluate the impact of ethanol content on emissions.

[83] See for example, "Analysis of EPAct Emission Data Using T70 as an Additional Predictor of PM emissions from Tier 2 Gasoline Vehicles," (Darlington, T. et al. SAE 2016-01-0996).

Of the studies considered only one,[84] by Karavalakis and colleagues at UC Riverside, used a base or test fuel that was specifically described as “CARB” fuel. In that case, the base CARB fuel included 6.6% ethanol by volume and was diluted to create E10 and E20 blends while maintaining constant RVP, and the fuel was tested on only one 2001+ vehicle. In other work conducted at UC Riverside [85] the fuel was described as follows:

> “The ethanol fuels were blended …………to represent ethanol fuels that would be utilized in California, in terms of properties such as aromatic content, Reid vapor pressure (RVP), and other properties.”

RVP and other fuel volatility parameters were matched within certain limits. A third study, also conducted by Karavalakis and his colleagues at the UC Riverside, did not employ
fuel that was selected based on compliance with CARB regulations and included both splash blended and match blended fuels.

4.5.2 Criteria Pollutants

The criteria pollutants considered include nitrogen oxides, (NOx), carbon monoxide (CO), particulate matter (PM) and organic compounds. Organic compounds result from both combustion as well as fuel evaporation and can be characterized in a number of ways: total hydrocarbons (THC – which includes all hydrocarbons), non-methane hydrocarbons (NMHC - which includes all hydrocarbons except methane which is relatively non-reactive and thus not a significant predictor of ozone) or non-methane organic gases (NMOG – which include NMHC plus gases that may have an oxygen molecule, like ethanol, acetaldehyde or formaldehyde). In this document we report the organic emissions, in whatever form they were published in the relevant studies. The emissions data considered in this analysis are compiled in Appendix 2.

Emissions of organic compounds and NOx react in the atmosphere to form ozone, the primary component of smog in the presence of sunlight. Different organic molecules differ in their reactivity in the production of ozone. The total amount and composition of organic compounds emitted can be analyzed to provide a rough gauge of their ozone-forming potential. Thus studies which speciated or otherwise considered the reactivity of the specific organic compounds emitted during testing form a more reliable basis for assessing changes in the ozone- forming potential of changes in the ethanol content of blends.

4.5.3 Toxic Air Contaminants

In assessing emissions of toxic air contaminants (TACs) from spark-ignition vehicles, U.S. EPA and CARB have long focused on emissions of formaldehyde, acetaldehyde,1,3-butadiene and benzene. Based on extensive research, the state of California has developed risk factors for exposure to these and other compounds.[86] These risk factors have been used by CARB to evaluate the relative toxic “potency” of the four compounds listed above for the purpose of assessing the relative risk in changes in fuel composition on overall exposure to air toxics. CARB’s Predictive Model has assigned the weighting factors listed in Table 6 to these pollutants, based on their relative toxicity. The potency-weighted toxicity is calculated as the sum of the concentration of each of these pollutants times the weighting factor.

TABLE 6. CARB TOXIC AIR CONTAMINANT POTENCY-WEIGHTING FACTORS

Pollutant	Weighting Factor
Benzene	0.170
1,3-butadiene	1.000
formaldehyde	0.035
acetaldehyde	0.016

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[84] Karavalakis, G., T. Durbin, M. Shrivasastava, Z. Zheng, M. Villela, H. Jung. “Impacts of ethanol fuel level on emissions of regulated and unregulated pollutants from a fleet of gasoline light-duty vehicles,” *Fuel* 93 (2012) 549-558.
[85] Karavalakis, G., D. Short, D. Vu, R. Russell, A. Asa-Awuku, T. Durbin, “A Complete Assessment of the Emissions Performance of ethanol blends and Iso-Butanol blends from a fleet of Nine PFI and GDI Vehicles,” SAE 2015-01-0957, (2015).
[86] CARB, California Procedures for Evaluating Alternative Specifications for Phase 3 Reformulated Gasoline Using the California Predictive Model, Last Amended August 24, 2012.

4.5.4 Statistical Analysis

Because test procedures were different, each dataset was analyzed independently. All emissions are presented on a weight/mile basis and were transformed logarithmically prior to the statistical analysis to equalize the impact of high and low emitting vehicles in determining the statistical significance of changes. Logarithmic transform of data is common with emissions data. Results were considered to be statistically significant for $p<=0.05$ and marginally significant if p fell between 0.05 and 0.1.

Extensive statistical analyses were also performed by the researchers and reported in these studies. In many cases the original researchers analyzed overall impacts between E0 and the highest ethanol blend considered, assuming linear effects. Where possible the statistical analysis performed here was limited to consider only emission differences between E10 and the higher gasoline-ethanol blends, given E10 as the reference point for this evaluation. Ethanol impacts on other fuel properties that are often thought to impact emissions (T50 and RVP) are clearly non-linear between E0, E10 and higher ethanol blends.

In addition, in the UC Riverside-3 study, the scientists apply the Tukey-Kramer correction to their analyses of the statistical significance of pairwise t test comparison of the eight different fuels they consider. This correction is intended to account for the increased probability of a Type 1 error (false positive showing statistically significant difference where none exists) when conducting multiple pairwise comparisons. For eight different fuels, and the resultant 28 different pairwise comparisons, this correction is quite large, resulting in p-values almost ten times the uncorrected value. However, this correction was not made in this statistical evaluation, since only four pairwise comparisons were made, with markedly less potential for false positives. Thus, in contrast to the original study report, the statistical analysis presented here found a marginally significant decrease in NOx emissions, and significant decrease in NMHC, as well as some significant changes in toxic emissions that were not identified in the original report. This type of finding also applies to differences in results presented here versus those presented in other original studies. Where statistical results differ, this is not due to errors in either analysis, but to differences in analytical approaches.

4.5.5 Tailpipe Emissions

The total dataset considered here includes tailpipe emissions from a total of 61 vehicles, including one FFV. Twenty-five vehicles were tested on E10 and E15; twenty-four were tested on E0 and E15; twenty-three were tested on E10 and E20; twenty-four were tested on E0 and E20 (there were a number of vehicles that fell into multiple categories). There are no published data on the impact of blends above E20 on tailpipe emissions. A summary of the results is included in Table 7 and Table 8 and a more detailed summary of the average emissions from each vehicle/test cycle/fuel are included in Appendix 2.

FFVs are vehicles designed and permitted to use any ethanol fuel level up to E85, but many may fill up with conventional fuel and so may be impacted by a change in the availability of E15 in place of E10. According to IHS Automotive[87] there are nearly 20 million FFVs on US roads today, or somewhere around one-tenth of the total number of vehicles on the road. Only one has been tested on E15 and E10, and the results of that test are included in this analysis.

Table 7 (E15) and Table 8 (E20) summarize the results of our analyses of the individual studies which directly compared the air emissions impacts of higher and lower ethanol concentrations in hydrocarbon fuel. None of the E15 studies, whether done on California fuels or other US fuels found a statistically significant increase in any criteria pollutant. NOx, CO, PM mass emissions, or organic emissions (NMOG, THC, or NMHC depending on the study) were measured. Statistically significant decreases were found for NMHC, CO and potency weighted toxics, and a marginally significant decrease in NO_x emissions due to changes in ethanol content in the fuel.

[87] Cited by the US DOE, https://www.afdc.energy.gov/vehicles/flexible_fuel.html, accessed March 2, 2018.

For E20, organic emissions are reduced in several studies by a significant or marginally significant amount. A statistically significant reduction in CO is also found in one study and a marginally significant reduction in another study. A significant increase in NOx for E20 was found in a single study.

The results of the EPAct[88] study, a large EPA study of 15 vehicles and 27 fuels, is not explicitly included in this analysis because it does not provide emissions data for a set of lower and higher ethanol content fuels that are either match blended or splash blended, that could be analyzed in the manner we used for the other studies. The experimental design of the EPAct study included 27 different fuels, by blending for 5 specific properties in such a way that the full reasonable range of each property was explored, but not all the possible different combinations (which would have required 240 different fuels). EPA's analysis of the results of their emissions data suggest that the emissions of total hydrocarbon (THC), NMOG, NMHC, CH4, NOx, PM would increase, and CO would decrease with increasing ethanol content (between E0 and E20) should aromatic content, T50, T90 and vapor pressure be held constant. However, Section 4.3.4, shows that T50 is inversely correlated with ethanol content, as is aromatic content by simple dilution. Increasing aromatic content and T50 are also correlated with increasing THC, NMOG, NMHC, NOx, PM emissions, potentially confounding any increase in emissions due to ethanol alone.

4.5.6 Description of Studies

4.5.6.1 Coordinating Research Council Study E74-B

The Coordinating Research Council (a consortium of car and petroleum companies) conducted a study[89] in 2009 which included 15 vehicles, model years 1994 to 2006, tested over the Federal Test Procedure (FTP) cycle. The study was intended to separate the effects of vapor pressure, ethanol content and test temperature on CO exhaust emissions, but THC and NO_x emissions were also reported. Seven match blended[90] E0, E10 and E20 fuels were tested at several different vapor pressures. Because their study included vehicles older than the 2001 MY cutoff, and E0 fuels, the CRC statistical analysis is not considered directly applicable. Instead, for this analysis, the dataset has been limited to tests conducted on post 2001 MY vehicles, the E20 fuel and the only E10 fuel with the same vapor pressure.

The results showed that for vehicles using both E20 and E10, the higher ethanol content fuel yielded an increase in NO_x in 6 out of the 11 vehicles at 75 °F, and for 7 out of 11 vehicles at 50 °F. The 2006 Ford Taurus seemed to show an especially large sensitivity to ethanol content in both tests. However, when the wide variability between vehicles is taken into account, the change in NO_x is not statistically significant ($p=0.38$) and could be due to chance alone. Similarly, there was a decrease in THC emissions for E20 in 8 out of 11, and 6 out of 11 vehicles in the 75 °F and 50 °F tests respectively. For the 75 °F test, the difference between THC emissions using the two different fuels is statistically significant at the 95% level ($p \leq 0.05$), but not for the 50 °F test. When the datasets at the two temperatures are combined, the reduction in THC is marginally significant ($p=.051$). Finally, for CO, 6 of the 11 vehicles saw a decrease at 75 °F, 7 out of 11 saw a decrease at 50 °F, but, statistically, this difference was not significant at either temperature.

Overall, there is little apparent difference in emissions between E10 and E20 from later model vehicles (2001+) for these criteria pollutants; given that differences between E10 and E15 should be smaller, the impact of changing from E10 to E15 would likely not cause any increase in emissions in these vehicles.

4.5.6.2 The Department of Energy (DOE) Study of Intermediate Blends on Legacy Vehicles

This study[91] included a number of vehicles older than 2001 and therefore the statistical analysis which accompanied the study is not applicable. Instead the data from the 2001+ MY vehicles were extracted

[88] EPA, Assessing the Effect of Five Gasoline properties on Exhaust Emissions from Light-Duty Vehicles Certified to Tier 2 Standards: Analysis of Data from EPAct Phase 3 (EPAct/V2/E-89), Final Report, April 26, 2013. https://www.epa.gov/moves/epactv2e-89-tier-2-gasoline-fuel-effects-study, accessed September 23, 2018.

[89] CRC E74-B, Effects of Vapor Pressure, Oxygen Content and Temperature on CO Exhaust emissions, May 2009.

[90] The fuels were blended to match four distillation points, octane values, and aromatic, benzene, olefin and sulfur content as close as practicable. For the E20 fuel, especially, a tight match was not possible.

[91] Knoll,K., B. West, W. Clark, R. Graves, J.Orban, S. Przesmitzki, T. Theiss , Effects of Intermediate Ethanol Blends on Legacy Vehicles and Small Non-Road Engines, Report 1 – Updated February 2009, NREL/TP-540-43543.

and analyzed. The base hydrocarbon fuel used was certification gasoline, and ethanol was fuel-grade per ASTM D4806. In this case we were able to compare splash-blended E15 with E10 and found NO_x increased in 7 out of 13 of 2001+ MY vehicles, and NMHC and CO decreased in 7 out of 13 vehicles, and 8 out of 13 vehicles, respectively. In comparison to the variability between the vehicles, the paired t-test conducted for each of these pollutants finds that the difference between the E15 results and the E10 results is not significant.

The same vehicles were tested on splash-blended E20. These showed a large (30%) and statistically significant increase in NOx (11 out of 13 vehicles), a marginally significant decrease of -5% in NMHC (9 out of 13 vehicles) and no statistically significant impact on CO emissions.

4.5.6.3 DOE Catalyst Study

The purpose of this study[92] was to determine if the use of higher ethanol content fuels for the full useful life of a vehicle (as defined in the EPA emissions standards) would adversely affect the emissions control systems and result in emissions which exceeded the EPA emissions standards. Retail top-tier E0 fuel was splash blended with ASTM D4806 ethanol to produce E10, E15 and E20 blends. This was the largest study and included 24 matched (make, model and approximate starting mileage) sets of vehicles which accumulated mileage on E0, E10, E15 or E20 and then were tested on different ethanol fuels. The vehicles aged on E15 were tested on E15 and E0, and the vehicles aged on E20 were tested on E0 and E20. No vehicle sets were tested on both E10 and E15, or E10 and E20 in this program.

Average emissions in the DOE Catalyst study show significant reductions in CO between E15 and E0 (-13%), and changes which are not statistically significant in NMOG and NO_x. The same make and model vehicles tested on E20 versus E0 showed no statistically significant change in NOx, and large significant reductions in NMOG (-16%) and CO (-22%). It is not clear how much of the difference between E0 and E15 occurs between E0 and E10 and what is due to the change between E10 and E15, or E10 and E20. However, the implication of this study is that changes in NOx emissions are likely to be non-detectable in these vehicles, and there is an apparent reduction in CO and NMOG.

4.5.6.4 UC Riverside-1 and UC Riverside-2

A total of 7 standard vehicles and one FFV MY 2001+, were tested by Karavalakis and his colleagues at UC Riverside using E10, E15 and E20 fuels that would likely be permissible in California should the higher ethanol fuels be legalized. Those results were reported in three different papers[93], and an extensive statistical analysis of the results from seven of those vehicles was made in a 2015 SAE paper. In addition, a single FFV, a 2007 Chevrolet Silverado, will be considered independently of the other vehicles because it is a different type of vehicle and also because it was not tested on E15 but was tested on E20 and E10. The data was provided in graphical form in the published papers, but this analysis of the 7 standard vehicles was based on the data in Excel form provided to us courtesy of Dr. Karavalakis. The graphic presentation of the Chevrolet Silverado results was on such a small scale that magnitude could not be accurately gauged and only the direction of change can be reported.

Considering only both E20, E15 and E10 emissions from the seven vehicles, Karavalakis and his colleagues found there were no significant differences in the weighted (cold start and running) emissions for PM, THC, NMHC, CO and NO_x emissions, although the cold start emissions were slightly higher for both THC and NMHC for E15, and the difference was statistically significant. They did not report any significant changes in PM mass and total particle number, between E15 and E10. Our analysis, in Table 7 generally supports these conclusions, although we found a marginally significant decrease in CO between E20 and E10. In addition, we calculated potency-weighted toxicity for the 7 vehicles and found

[92] West, B.H., C. S. Sluder, K.E. Knoll, J.E. Orban, J. Feng, Intermediate Ethanol Blends Catalyst Durability Program, February 2012, ORNL/TM-2011/234.

[93] Karavalakis, G., D. Short, D. Vu, R. Russell, A. Asa-Awuku, T. Durbin, " Evaluating the regulated emissions, air toxics, ultrafine particles, and black carbon from SI-PFI and si-di vehicles operating on different ethanol and iso-butanol blends," *Fuel* 128 (2014), 410-421.

no significant difference between these pollutants at either E15 or E20 and E10. The study also reported extensively on other pollutants including methane, carbon dioxide and a number of individual VOCs.

The single FFV (MY 2007) showed small reductions in all pollutants including CO, THC, NMHC and NO_x for E20 in comparison to E10, although none appear statistically significant in comparison to the standard deviations of the measurements as shown on the graph. Tests on higher ethanol concentrations suggest the trend is for reductions in CO, THC and NMHC at E20 and higher ethanol concentrations for this FFV. Taken together these CARB fuel studies show no evidence for any increase in emissions for potency-weighted toxicity, PM, CO, THC, NMHC or NO_x if E15 or E20 replaces E10 fuel in California.
The UC Riverside team performed this analysis for emissions from two 2012 model year vehicles and found that the ozone reactivity for emissions from E15 was less than those for E10 as shown in the figure below.

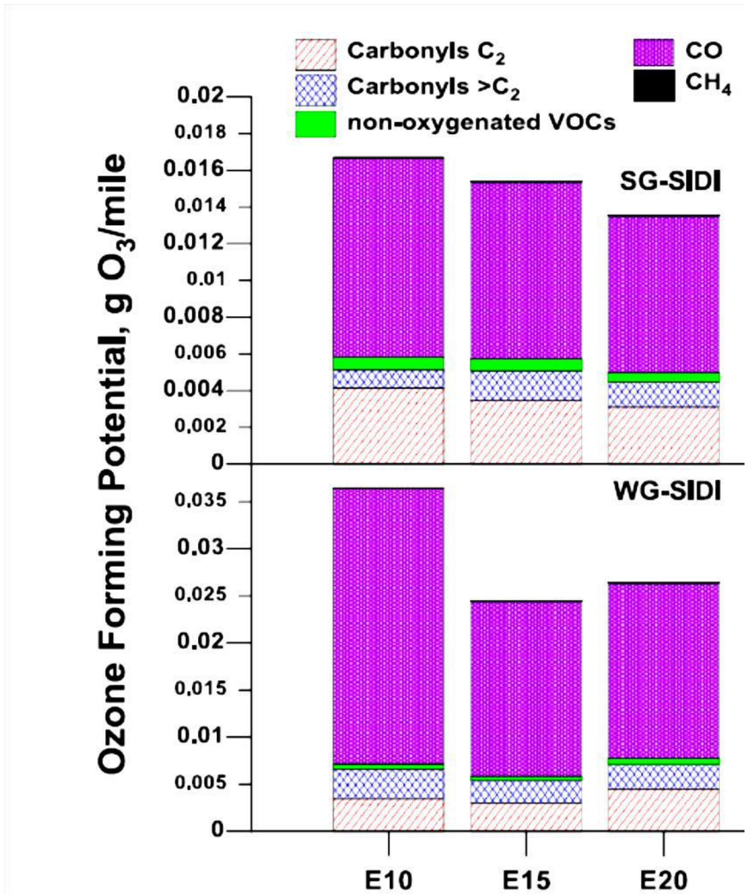


FIGURE 9. OZONE-FORMING POTENTIAL OF TAILPIPE EMISSIONS FROM VEHICLES USING E10, E15 AND E20.[94]

Because of the extremely limited data on the ozone-forming potential of E15 versus E10 the impact of both higher and lower ethanol contents on ozone-forming potential will be briefly mentioned, although this may not be representative of the change between E15 and E10. In their extensive study of FFV vehicle emissions from E6, E32, E59 and E85 fuels the CRC[95] found that the average ozone-forming potential

[94] Karavalakis, G., D. Short, D. Vu, R. Russell, A. Asa-Awuku, H. Jung, K.C. Johnson, T. Durbin, "The impact of ethanol and iso-butanol blends on gaseous and particulate emissions from two passenger cars equipped with spray-guided and wall-guided direct injection SI (spark ignition) engines," *Energy* 82 (2015) 168-179.
[95] CRC E-80, Exhaust and Evaporative Emissions Testing of Flexible-Fuel Vehicles, Final Report, August 2011.

decreased with increasing ethanol content of the fuels on the cold start FTP. There were mixed results on the US06 and Unified Cycle tests. Wang and colleagues[96] in China found a slight improvement in ozone-forming potential calculated from MIR values when E10 was compared to E0 in a Euro 4 vehicle. Taken together, these results suggest that there will be no increase in ozone-forming potential with higher ethanol content fuel.

4.5.6.5 UC Riverside-3

In another study conducted by UC Riverside[97] five 2016 and 2017 MY vehicles were tested on match-blended (E0, E10 and E15, at both high and low aromatic content) and splash-blended (E10, E15 and E20) fuels. The results of the study found that the splash blended E15 caused significant reduction in NMHC, THC and potency weighted-toxics, and marginally significant reductions in NOx. However, these reductions were not found in the splash blended E20 when compared to E10. The vehicles tested with match blended E10 and E15 showed no statistically significant differences at either low or high aromatic content.

In addition, the tailpipe emissions from one vehicle tested on the eight different fuels was injected into an atmospheric chamber to determine the potential for these emissions to form secondary aerosols in the environment. Secondary aerosol formation showed a weak negative correlation with increased ethanol content from E0 to E20, suggesting that higher concentrations of ethanol in fuel will lead to less secondary aerosols.

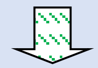
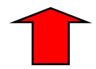
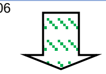
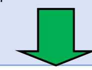
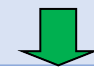
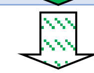
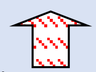
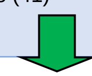
[96] Wang, X, Y. ge, C. Zhang, J. Liu, Z. Peng, H. Gong., Estimating Ozone Potential of Pipe-out Emissions from euro-3 to euro-5 Passenger cars Fueled with gasoline, Alcohol-Gasoline, Methanol and Compressed Natural Gas, SAE 2010-01-1009.
[97] Karavalakis, G, T.D. Durbin, J. Yang, P. Roth, Impacts of Aromatics and Ethanol Content on Exhaust Emissions from Gasoline Direct Injection (GDI) Vehicles, April 2018.

TABLE 7. TAILPIPE EMISSIONS STUDIES ON E15 VERSUS EITHER E10 OR E0 AS BASE FUEL[98]

Study Name	Test Cycle	No. of Vehicles	Vehicle Model Years	Base Fuel and Blending Strategy	NO_x	Organic Emissions	CO	PM mass emissions	Potency Weighted Toxics[99]
DOE Intermediate Fuel Blends	LA-92	13	2001-2007	E10 splash blend	No significant difference	No significant difference[100]	No significant difference	Not tested	Not tested
DOE Catalyst Study	FTP	24	2003-2009	E0 splash blend	No significant difference	No significant difference[101]	↓	Not tested	Not tested
UC Riverside -1	UC and FTP	7	2007-2012	E10 match blend	No significant difference	No significant difference[102]	No significant difference	No significant difference	No significant difference
UC Riverside -3	LA-92	5	2016-2017	E10 low aromatics splash	↓ (textured)	[100] ↓	No significant difference	No significant difference	↓
UC Riverside -3	LA-92	5	2016-2017	E10 low aromatics match blend	No significant difference	No significant difference[100]	No significant difference	No significant difference	No significant difference
UC- Riverside-3	LA-92	5	2016-2017	E10 high aromatics match blend	No significant difference	No significant difference[100]	No significant difference	No significant difference	No significant difference
All Data (no. of datapoints for each pollutant in parentheses)	Various		2001-2017	Various	No significant difference (66)	NMHC:No significant difference (42) THC:No significant difference (29) NMOG:No significant difference (24)	↓ (66)	No significant difference (24)	No significant difference (22)

[98] Solid arrows represent p values <.05, textured arrows represent p values between 0.05 and 0.1, for paired, two-tailed t-test.
[99] Calculated using CARB factors in California Procedures for Evaluating Alternative Specification for Phase 3 Reformulated Gasoline Using the California Predictive Model, Last Amended August 24, 2012
[100] Non-methane hydrocarbons, NMHC
[101] Non-methane organic gases, NMOG
[102] Total hydrocarbon and non-methane organic gases, THC and NMHC both measured with same statistical conclusion

TABLE 8. TAILPIPE EMISSION STUDIES ON E20 EITHER E10 OR E0 AS BASE FUEL[103]

Study Name	Test Cycle	No. of Vehicles	Vehicle Model Years	Fuels	NO_x	Organic Emissions	CO	PM mass emissions	Potency Weighted Toxics[104]
CRC E74B	FTP	11 (at two different temps)	2001-2006	E10 match blend	No significant difference	[105] 	No significant difference	Not tested	Not tested
DOE Intermediate Fuel Blends	LA-92	13	2001-2007	E10 splash blend		[106] 	No significant difference	Not tested	Not tested
DOE Catalyst Study	FTP	24	2003-2009	E0 splash blend	No significant difference	[107] 		Not tested	Not tested
UC Riverside-1	UC and FTP	7	2007-2012	E10 match blend	No significant difference	No significant difference[108]		No significant difference	No significant difference
UC Riverside-2	FTP	1 FFV	2007	E10 match blend	E20 emissions less than E10	E20 emissions less than E10[106]	E20 emissions less than E10	Not tested	Reported on graph, E20 is slightly less than E10
UC Riverside -3	LA-92	5	2016-2017	E10 low aromatics splash	No significant difference	No significant difference[106]	No significant difference	No significant difference	No significant difference
All Data (no. of datapoints for each pollutant in parentheses)	Various		2001-2017	Various	 (77)	NMHC: No significant difference (32) THC: No significant difference (41) NMOG: (24) 	 (78)	No significant difference (15)	No significant difference (12)

[103] Solid arrows represent p values <.05, textured arrows represent p values between 0.05 and 0.1, for paired, two-tailed t-test.
[104] Calculated using CARB factors in California Procedures for Evaluating Alternative Specification for Phase 3 Reformulated Gasoline Using the California Predictive Model, Last Amended August 24, 2012
[105] Total hydrocarbon, THC
[106] Non-methane hydrocarbons, NMHC
[107] Non-methane organic gases, NMOG
[108] Total hydrocarbon and non-methane organic gases, THC and NMHC both measured with same statistical conclusion

4.5.7 Evaporative Emissions

Evaporative emissions are volatile organic compounds which escape from the fuel system of the vehicle. Fuel systems are designed to be sealed off from the atmosphere, although emissions can occur due to system liquid leaks, vapor leaks through the air emissions control system and permeation of vapors through the materials that make up the fuel lines and other components of the fuel system.

Liquid leaks are rare but can result in large quantities of emissions. They are due to poorly maintained vehicles, or carelessness when fueling. The composition of the fuel is not believed to have any impact on the amount of liquid leaks.

Because this study is intended to evaluate E11-E30 generated from the blending of fuels into the same CARBOBs used for E10, California E10, E15 and E20 fuels would be expected to have roughly identical vapor pressures. (In many areas of the country E10 is permitted to have a vapor pressure that is 1 psi higher than either E0 or E15 fuel, but it is not expected to be permitted in California). E30 would slightly reduce the vapor pressure.

The quantity of evaporative emissions vented to the emissions control system, and the amount which escapes would be expected to be roughly the same for fuels with the same vapor pressure, thus we do not expect any differences due to splash blended E15 or E20 versus E10. E30 fuels would likely decrease these emissions by a small amount proportional to the reduction in vapor pressure. However, permeation emissions, in which fuels move through the fuel system materials are chemical specific and could be different for fuels with different chemical compositions. Two Coordinating Research Council studies were conducted to determine if higher ethanol content would affect permeation emissions.

Evaporative emissions of benzene are also of concern, but it should be noted that the other TACs of concern besides benzene are only of concern with respect to exhaust emissions. Unfortunately, no measurement of benzene emissions were reported in either of these two studies of E20 evaporative emissions. It seems likely that since benzene comes from the hydrocarbon portion of the ethanol-gasoline blend, diluting the hydrocarbon portion with additional ethanol would likely decrease the amount of benzene emissions by a roughly proportional amount.

TABLE 9. EVAPORATIVE EMISSION STUDIES ON E20

Study Name	Test Cycle	No. of Vehicles	Vehicle Model Years	Fuels	Organic Emissions	Ozone forming potential
CRC E-65-3	Diurnal	4	2001-2005	E10 match blend	No significant difference	No significant difference
CRC E-65-3	Steady-state	4	2001-2005	E10 match blend	No significant difference	No significant difference
CRC E-77-2	Static	6	2001-2006	E10 match blend	No significant difference	Not tested
CRC E-77-2	Running Loss	6	2001-2006	E10 match blend	No significant difference	Not tested
CRC E-77-2	Hot Soak	6	2001-2006	E10 match blend	No significant difference	Not tested
CRC E-77-2	Diurnal (3-day)	6	2001-2006	E10 match blend	No significant difference	Not tested

4.5.7.1 Description of Studies

4.5.7.1.1 Coordinating Research Council Study E-65-3

CRC E-65-3[109] was conducted using a number of fuels (E0, E6, E6 high aromatics, E10, E20 and E85), and five vehicles, but only the results of E10 and E20 (matched aromatic content) conducted on the four post 2001 MY vehicles are considered here. Neither E15 nor E30 were tested. The fuel systems were removed from the vehicles and the fuel rigs were tested over the 24-hour diurnal test in a Variable Temperature Sealed Housing Evaporative Determination (VT-SHED) using the California Enhanced Evaporative Testing rules. The fuel tanks and the canisters were vented to the outside of the SHED to limit measured emissions to permeation emissions alone. Test results in mg/day for the four vehicles are shown in Table 3 of the study. Two of the vehicles showed increases comparing E20 to E10, and two showed decreases, and the net change is not considered statistically significant. The specific reactivity of the emissions was measured and the ozone-forming potential was calculated. The result, in Table A- 8 of the study, shows that the ozone-forming potential of the permeation emissions from the two fuels were not statistically distinguishable.

4.5.7.1.2 Coordinating Research Council Study E-77-2

Similar permeation testing was conducted by Coordinating Research Council[110] in 2010 on six vehicles that were 2001+ MY. Again, the testing was conducted in a SHED to capture permeation emissions, with all of the emissions from the vehicle's activated carbon canister vented to the outside. The vehicles were tested on two E10 fuels, with vapor pressures of 7 psi and 10 psi, and a single match-blended E20 fuel (aromatic content held constant between the fuels) with a nominal vapor pressure of 9 psi, but which actually had a vapor pressure of 8.5 psi. The 10 psi E10 fuel was created from the 7 psi E10 fuel by adding butane. In order to equalize any impact of vapor pressure, the emissions results of the two E10 fuels were averaged to roughly estimate the emissions of an 8.5 psi fuel.

Measurements were made for the following tests:

- Static permeation: fuel system pressurized and monitored for vapor and fuel leaks at 86 °F
- Running loss: two cycles of the LA-92 test at 86 °F

[109] CRC E65-3 Fuel Permeation from Automotive Systems: E0, E6, E10, E20 AND E85, Final Report, December 2006.
[110] CRC E77-2 Enhanced Evaporative Emission Vehicles, March 2010.

- Hot soak: one hour immediately following LA-92 test
- Diurnal test: California 3-day test, in which temperature is varied between 65 °F and 105 °F.

None of the tests resulted in a statistically significant difference between the average of the E10 7 and 10 psi fuel results and the E20 8.5 psi fuel. Two of the tests showed an average increase in the higher ethanol content fuel, one showed almost no change, and one found a decrease.

Taken together, these results suggest that there is no trend in permeation emissions between E10 and E20 in these studies. There is no data specific to permeation emissions from E15 fuel, but these results suggest that they will not be significantly different than E10 emissions. There is no information on the impact of E30 on permeation emissions. A 2007 study[111] showed that permeation was strongly linked to aromatic content, with a 35% increase in permeation with every 10% increase in fuel aromatic content. Adding ethanol to the E10 in current use in California, as is proposed in this multimedia analysis, would decrease the aromatic concentration a small amount, and thus also potentially decrease the permeation emissions to a small extent.

4.5.8 Combined Analysis of All Emissions Data

Taken independently, these studies show no consistent, measurable difference between E10 and E15 or E10 and E20 tailpipe emissions of NO_x, organics, PM or toxic weighted potency, although a number of studies showed a tendency of lowered CO and organic emissions with both E15 and E20, and one study showed a statistically significant increase in NOx emissions with E20. Combining the data from all of the studies (Table 6 in Appendix 2) shows a statistically significant decrease in CO with both E15 (-7%, p value = 0.0009), and E20 (-9%, p value =0.0002), and a marginally significant increase (+11%, p value = 0.07) in NOx with E20. There is limited evidence that the organics emitted from the tailpipe will have a lower ozone forming potential with E15 in comparison to E10 for both California-specific fuels and other test fuels in the US and China.

The total mass of permeation emissions and the ozone-forming potential of those emissions from E20 and E10 are statistically indistinguishable, suggesting that the use of E15 or E20 in place of E10 will have no impact on permeation emissions. There has been no reported testing on benzene evaporative emissions. It seems likely that benzene emissions would decrease at higher ethanol content, since benzene is only present in the hydrocarbon portion of ethanol-gasoline blends.

These results are supported by tailpipe emissions data from 61 vehicles and permeation emissions data from 10 vehicles. There have been no emissions testing of 2001+ MY vehicles with E30.

4.6 Summary of Findings

The extensive existing emissions data shows that use of gasoline blends up to E15 as allowed by U.S. EPA in existing 2001 and later model-year vehicles and FFVs will not result in any increase in vehicle exhaust emissions of organic compounds or their ozone-forming potential, oxides of nitrogen, carbon monoxide, particulate matter, or potency-weighted toxic air contaminants relative to E10.

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[111] Reddy, S. Understanding Fuel Effects on Hydrocarbon Permeation through Vehicle Fuel System Materials, SAE 2007-01-4089.