Ethanol's Emissions Effects in MOVES2014

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Urban Air Initiative's Interest in the MOVES2014 Model

- **Urban Air Initiative** (UAI) is a non-profit organization dedicated to improving air quality and protecting public health by reducing vehicle emissions. UAI is focused on reducing the threat to public health posed by the use of aromatics in petroleum-based fuels, especially in urban areas where citizens are exposed to mobile source emissions at especially dangerous levels.

- UAI wants EPA to correct MOVES2014a's erroneous emissions estimates that will delay NAAQS attainment and harm public health, particularly in urban areas.

MOVES 2014 is Inaccurate when Estimating Ethanol's Emissions Effects

ABSTRACT: MOVES2014a yields fundamentally inaccurate estimates of ethanol's emissions effects because:

(1) Tailpipe Fuel Effects. The MOVES2014a model's tailpipe fuel effects are based on a study of match-blended test fuels that was biased against ethanol, was inconsistent with market fuels, and ignored confounding variables to conclude that ethanol raises tailpipe emissions. Simply including key terms (such as T70) disproves MOVES2014a's asserted ethanol effects.

(2) Evaporative Fuel Effects. The model's "fuel adjustment" for ethanol's effect on permeation emissions is based on CRC studies that were systemically biased against ethanol. The model says that adding any amount of ethanol to gasoline doubles permeation emissions, but it fails to account for the confounding effect of aromatics and other hydrocarbons in the test fuels.

(3) Default Fuel Parameters. MOVES2014 requires states to use inaccurate default fuel parameter inputs that contradict real-world market survey data.

Tailpipe Fuel Effects:

EPAct/V2/E-89 Tier 2 Gasoline Fuel Effects Study

The EPAct Study

The MOVES model's tailpipe fuel effects for light-duty vehicles vehicles are based on the EPAct study. The EPAct Study was an effort to predict the emission effects of five fuel "factors" in 15 Tier 2 PFI vehicles by match-blending 27 test fuels to predetermined levels of these factors.

Factor	No. Levels	Levels		
		Low	Middle	High
Ethanol (%)	4	0	10, 15	20
Aromatics	2	15		35
RVP (psi)	2	7		10
T50 (°F)	5	150	165, 190, 220	240
T90 (°F)	3	300	325	340

The EPAct Study's Erroneous Conclusion about Ethanol

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The EPAct Study erroneously concluded that "[o]ther factors being equal, increasing ethanol is associated with an increase in emissions."

Fuel Property	THC	NMOG	NMHC	CH_4	NO_x	PM	CO
Ethanol	↑	↑	---	↑	↑	↑	---
Aromatics	↓	↑	↑	↓	↑	↑	↑
RVP	↓	↓	↓	↓	---	---	↑
T50	↑	↑	↑	↑	---	---	↑
T90	↑	↑	↑	↑	---	↑	↑

The EPAct Study's Design Defects

The MOVES2014 tailpipe emissions factors result from fundamental defects in the EPAct Study's design:

- Did not control for confounding variables.
- Test fuels failed to "span the ranges of in-use fuel properties" as intended.
- The design efficiency fell below the acceptable range.

The EPAct Study Did Not Control For Confounding Variables

The EPAct Study failed to adequately control for the confounding effect of several factors, including the following:

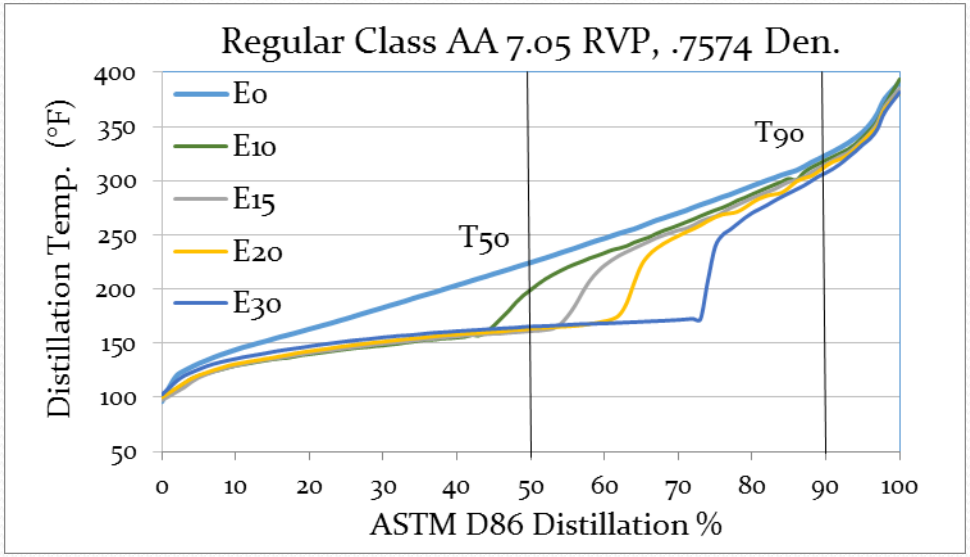
- Distillation temperature other than T50 and T90
- Differences in aromatic species
- Density
- The degenerative effect of using detergent-free test fuels

Ethanol Blending and T50/T90 Temperatures

T50 – Temperature at which 50% of the fuel mixture evaporates.

T90 – Temperature at which 90% of the fuel mixture evaporates.

Ethanol Affects T50 & T90 – Adding ethanol to gasoline "reduces T50 due to near-azeotropic behavior and reduces T90 and aromatics content by dilution." Anderson et al., (SAE 2014-01-9080).

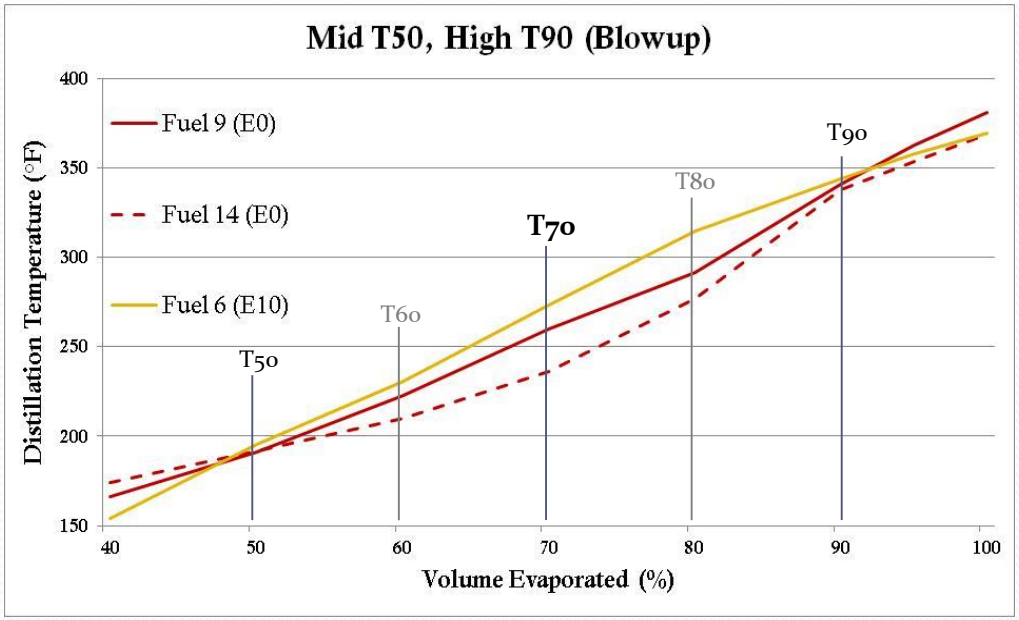


Ethanol Blending and T50/T90 Temperatures

- "[M]atching T50 and T90 for ethanol-gasoline blends does not ensure that the region in between will also be matched." Anderson et al., (SAE 2014-01-9080).
- "Higher T60, T70, and T80 values will likely have an adverse impact in tailpipe emissions (similar in magnitude as the T50 and T90 impacts)." *Id.*
- "[M]aintaining T50 and T90 while ethanol content is increased requires the addition of higher-boiling-point hydrocarbons. The addition of these hydrocarbons . . . can reasonably be concluded to be the underlying cause of the increased emissions, including PM." *Id.*

The EPAct Study Did Not Control for Distillation Temperatures Other than T50 and T90

Within every set of EPAct test fuels with matched T50 and T90, and varying ethanol concentrations, the boiling points of one or more higher-ethanol fuels exceeded those of one or more lower-ethanol fuels for the entire T60-T80 range.



The EPAct Study Failed to Control T 70

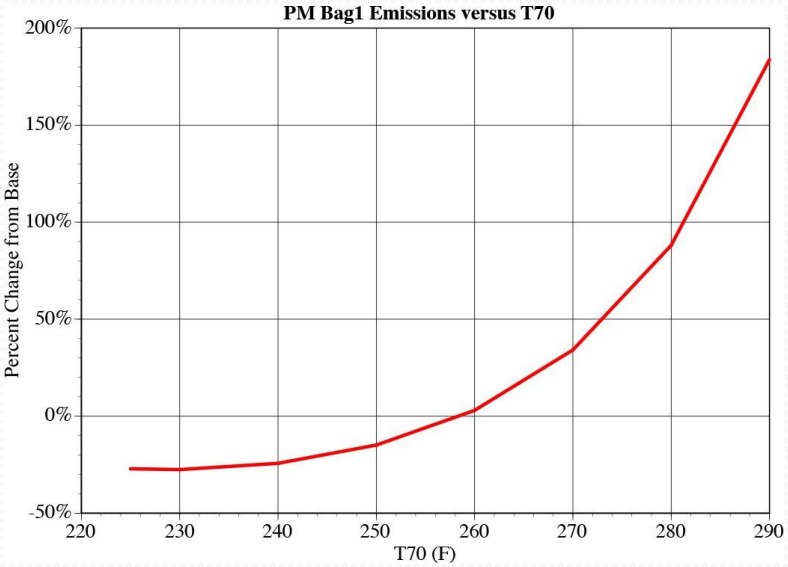
Test Fuel	ETOH (%)	T70 (°F)
10	10	290.4
12	10	275.1
23	20	270.9
25	20	281.6
26	15	277.0
27	15	274.9
31	20	271.6

Two E10 test fuels exceeded the highest T70 levels reported by the Auto Alliance in 2006 (270°F).

Since 2006, average T70 has steadily declined as the US transitioned to an E10 market fuel.

Two E15 test fuels and three E20 test fuels also have T70 values above that level.

The EPAct Study Did Not Recognize T70 as a Key Fuel Modeling Parameter



T70 is a key indicator for modeling PM emissions.

"Increasing T70 10 degrees above 260°F increases Bag 1 PM emissions by about 35%. Increasing T70 by another 10 degrees causes almost a doubling of Bag 1 PM from 260°F." Darlington et al., (SAE 2016-01-0996).

The EPAct Study Did Not Recognize T70 as a Key Fuel Modeling Parameter

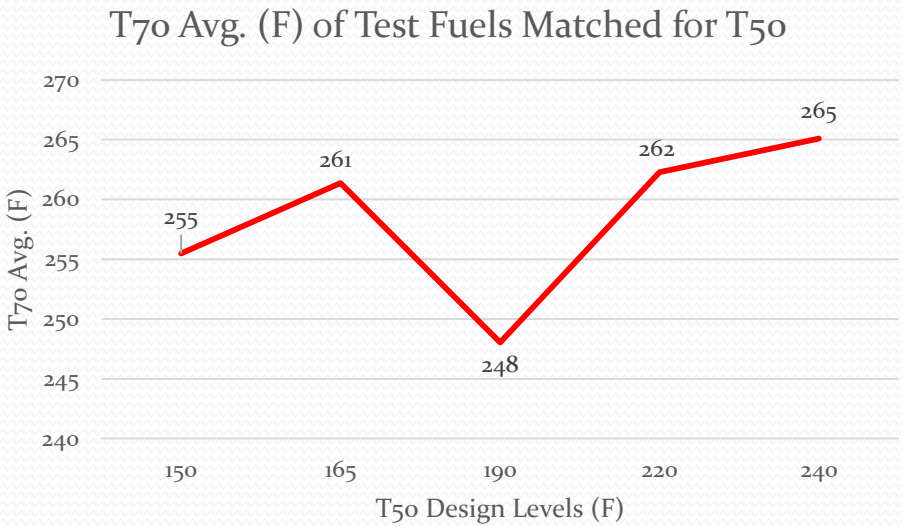
Darlington et al. (SAE 2016-01-0996), concluded that:

> "[I]f T70 is added to the Bag 1 [cold-start] EPAct model and used in EPA's MOVES2014 emission inventory model, increased ethanol levels beyond E10 are predicted to reduce PM from on-road motor vehicles in the U.S."

The EPAct Study reaches the opposite conclusion, because it ignores T70.

Late Changes to Fuel Blending in EPAct Study Impairs Accuracy of Modeling Emissions

T50 is likely being confounded with T70, which is inexplicably much higher on average for test fuels with a T50 of 150 or 165 degrees than for test fuels with a T50 of 190 degrees, contrary to market trends.



The EPAct Study Did Not Control For Differences in Aromatics Species

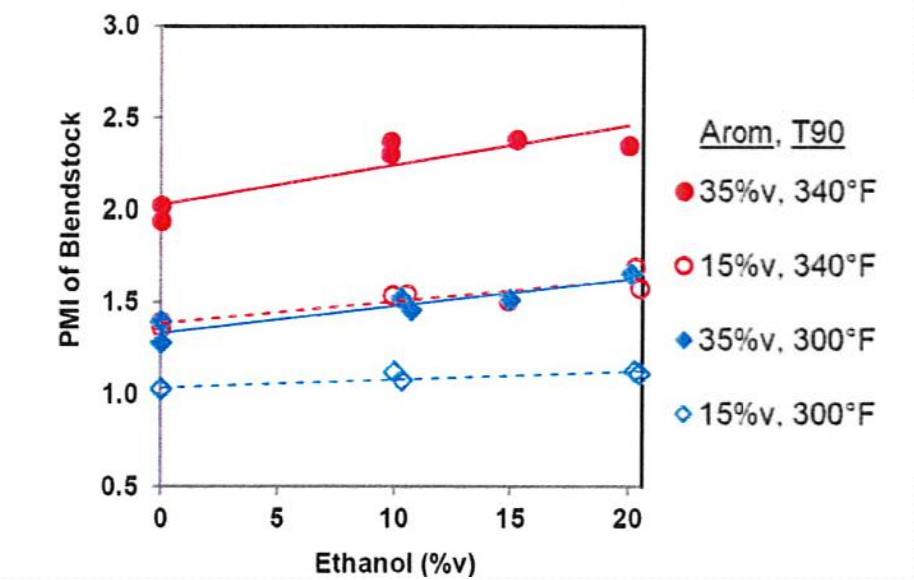
The EPAct Study could not control the test fuels' aromatic speciation while matching T50 and T90:

> "As a practical matter of meeting the distillation targets, the proportions [of aromatics] had to be adjusted to include more C7 and C8 aromatics for fuels with a combination of low T90 and high aromatics." Final Report on Program Design 14 (2013).

But higher-boiling-point aromatic hydrocarbons (C9+) have a greater influence on PM emissions than C6 to C8 aromatics.

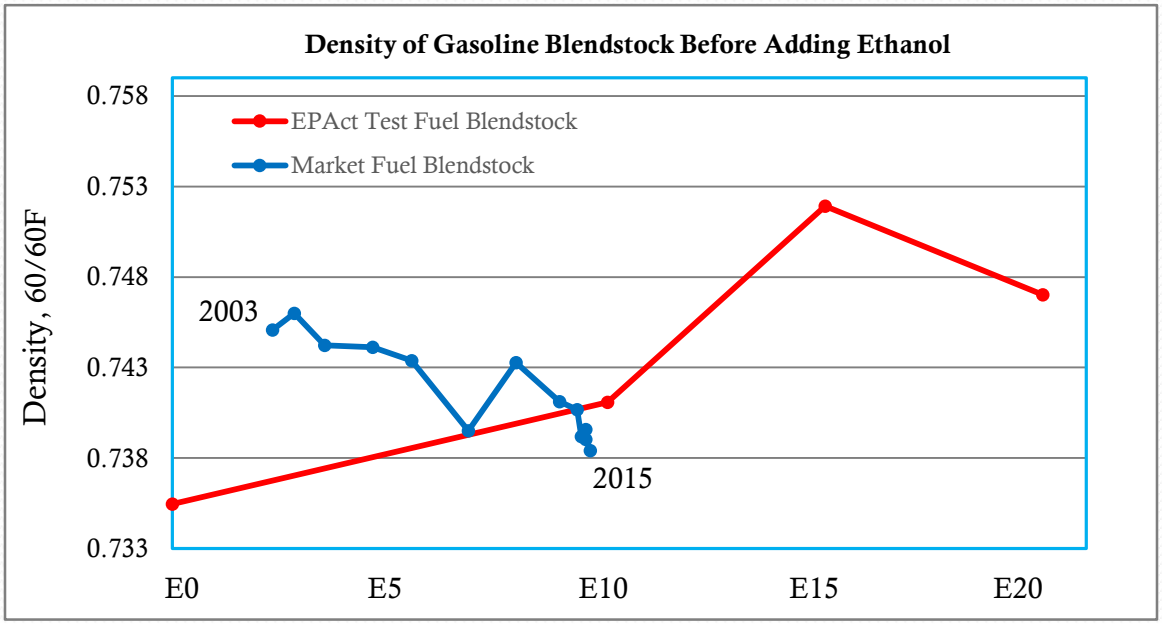
The EPAct Study Did Not Control For Differences in Aromatics Species

Anderson et al. (SAE 2014-01-9080) found that when the EPAct Study's ethanol test fuels are compared to the Eo test fuels with the same aromatic and T90 parameters, "the PMI values of the gasoline blendstocks increase significantly with increasing ethanol content in the finished fuels . . . . This trend is expected to lead to significantly increased PM emissions."



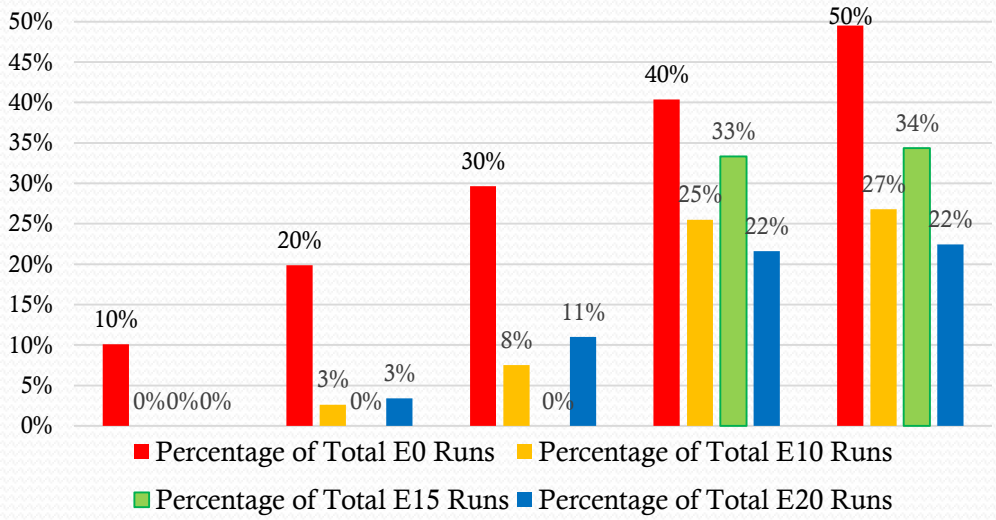
The EPAct Study Failed to Control for Density

According to data from the Auto Alliance's annual fuel surveys, in the real world, refiners reduce the density of gasoline blendstocks intended for ethanol blending. The EPAct Study inverts that relationship, increasing density with increasing ethanol levels.



The EPAct Study Did Not Account for the Degenerative Effect of Detergent-Free Test Fuels

The EPAct test fuels had no detergents. This resulted in a gradual build-up of carbon deposits in the combustion chamber, increasing emissions. Because, on average, ethanol test fuels were tested later in the testing schedule, ethanol's effects were confounded with the gradual build-up of carbon deposits.



The Test Fuels Did Not "Span the Ranges of In-Use Fuel Properties"

According to the EPAct Study:

- "A critical feature of the study design is that the properties of the test fuels are assigned to span the ranges of in-use fuel properties[.]"

But the EPAct test fuel properties were inconsistent with the range of test fuel properties found in the market:

- Octane levels
- Driveability index values
- Aromatics levels

The Test Fuels' Octane Levels Were Skewed High

Ethanol has a higher octane blending value than that of aromatics.

EPA's desire to match-blend aromatics and ethanol made it impossible to control the test fuels' octane ranges. Octane levels increased as ethanol increased.

As a result, the octane levels found in the EPAct test fuels exceeded the octane levels found in the market according to the Auto Alliance's 2014 fuel survey.

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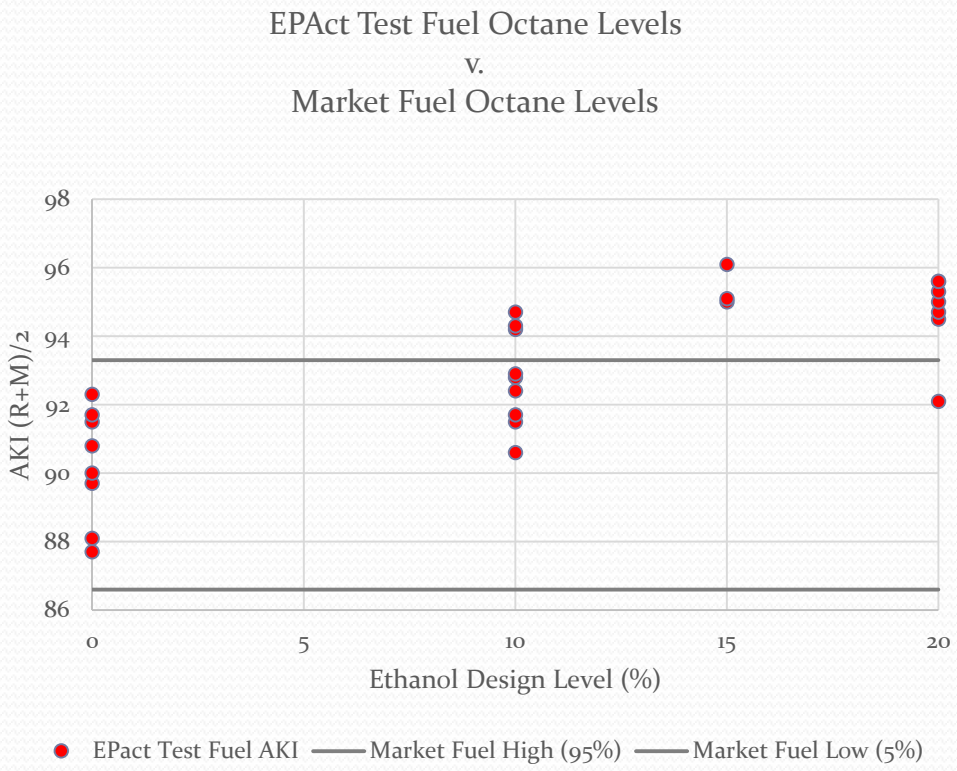


The E15 Test Fuels With High T50 Exceeded ASTM's Driveability Index

Two out of three E15 test fuels had a high T50 value: 220°F.

As a result, test fuel 27 exceeded ASTM's driveability index (DI) maximum of 1250, using the DI formula in effect at the time of the EPAct Study.

ASTM D4814-10b Method

D4814-10b VARIABLES	UNIT	FUELS	
		27	28
T10 * 1.5	°F	213	216
T50 * 3	°F	665	650
T90 * 1	°F	340	299
Ethanol % *2.4	°F	37	37
Driveability Index (D4814-10b)	°F	**1255**	**1202**

The E15 Test Fuels With High T50 Exceeded ASTM's Driveability Index

Test fuels 27 and 28 exceeded ASTM's DI maximum of 1250, using the updated DI formula.

Many states enforce ASTM D4814 standards.

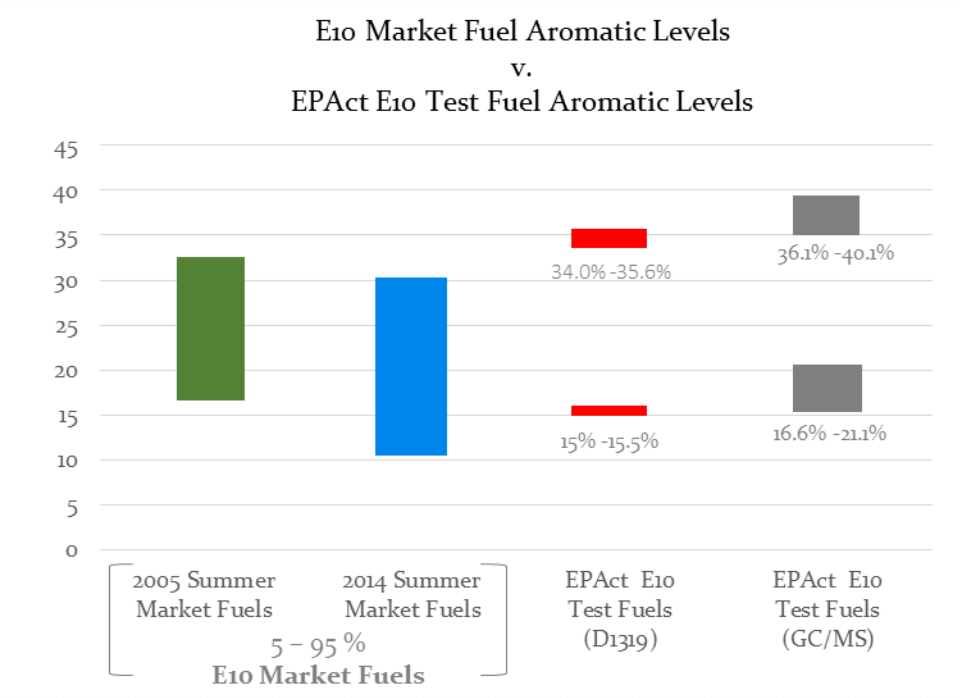
Sierra Research, Report No. SR2010-08-01, at 15-16.

ASTM D4814-16e Method

D4814-16e VARIABLES	UNIT	FUELS	
		27	28
T10 * 1.5	°F	213	216
T50 * 3	°F	665	650
T90 * 1	°F	340	299
Ethanol % * 9.49	°F	141	142
Driveability Index (D4814-16e)	°F	**1360**	**1307**

The E10 Test Fuels' Aromatics Levels Were Skewed High

The E10 EPAct test fuels ranged from 15% to 35.6% aromatics. In the market, E10 blends have a lower range of aromatics, ranging from 17% to 33% in 2005 and from 11% to 30.4% in 2014, according to Auto Alliance Survey data (5 to 95% percentile range). Thus, the aromatics levels in the EPAct study's E10 test fuels exceeded those found in market E10 blends.



Statistical Quality of Fuel Blending in EPAct Study

- A "partial" fuel matrix inevitably leads to confounding. To minimize confounding, EPA sought to optimize the fuel matrix based on a "G-optimality criterion."
- This was significantly below the minimum level that EPA initially "considered satisfactory": 60%.
- But after several revisions of the fuel matrix, the G-efficiency of the final matrix was extremely low: 51.6%.

Evaporative Fuel Effects:

CRC Studies E-65, E65-3, E77-2, and E-77-2b

MOVES2014's Fuel Adjustment for Ethanol's Permeation Emissions

MOVES2014 includes a "fuel adjustment" factor for ethanol's permeation emissions. This "fuel adjustment" factor predicts that the addition of any amount of ethanol to ethanol-free gasoline more than doubles permeation emissions in today's vehicles.

Model Year	Fuel Adjustment (%)
1995 and older	65.9
1996	75.5
1997-2000	107.3
2001 and later	113.8

The CRC Studies EPA Relied On Were Biased Against Ethanol

MOVES2014's "fuel adjustment" factor is based on 4 CRC Studies: E-65, E65-3, E77-2, and E-77-2b. Each of these CRC studies suffers from one or more of the following design defects:

- **Aromatics.** The ethanol test fuels contained artificially high levels of aromatics. The studies' failure to model the effect of aromatic is significant, because aromatics are known to permeate at high rates (Reddy, SAE 2007-01-4089).

- **Confounding Variables.** The studies ignored other confounding variables known to affect permeation emissions, including aromatic and paraffin speciation.

The MOVES2014 Fuel Adjustment Is Not Supported by the CRC Studies

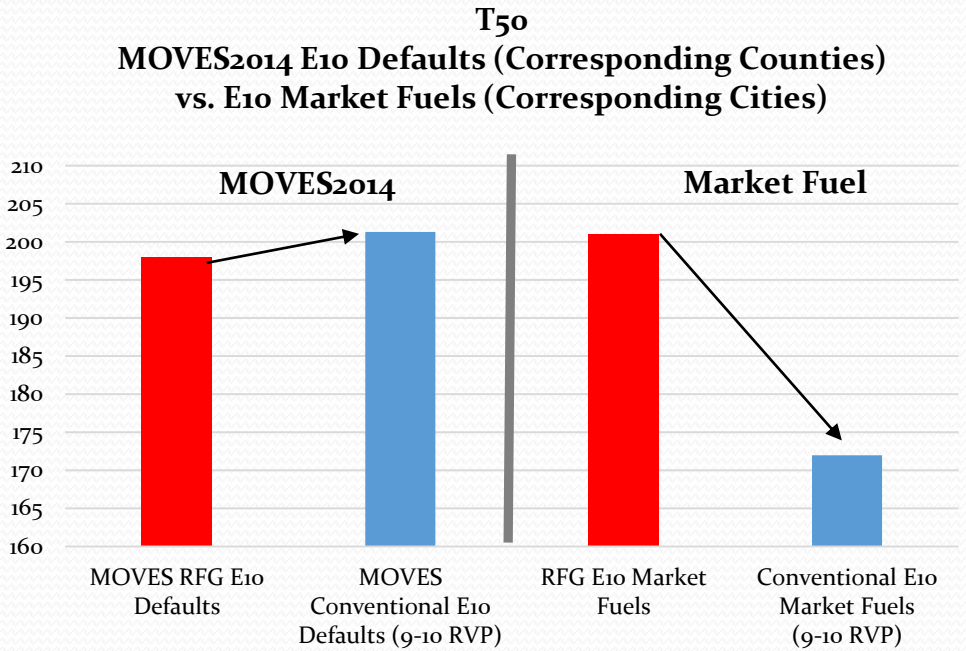
The CRC studies do not support a fuel adjustment for E85 blends. The only E85 fuel tested in the studies reduced permeation emissions, but MOVES2014 still assumes that E85 doubles emissions.

The CRC studies do not support the MOVES2014 model's prediction that permeation emissions increase or remain constant in new model years. MOVES2014 counterfactually predicts that newer vehicles (model years 2001 to 2015) produce more evaporative emissions than older vehicles (model year 1999 and 2000). That is because MOVES2014 arbitrarily assigns the same base permeation rate for model year 1999 to 2015 vehicles, but a greater permeation adjustment for ethanol's effects in 2001 and later vehicles.

Default Fuel Parameters

MOVES2014 Default Fuel Parameters Do Not Correspond to Market Fuel

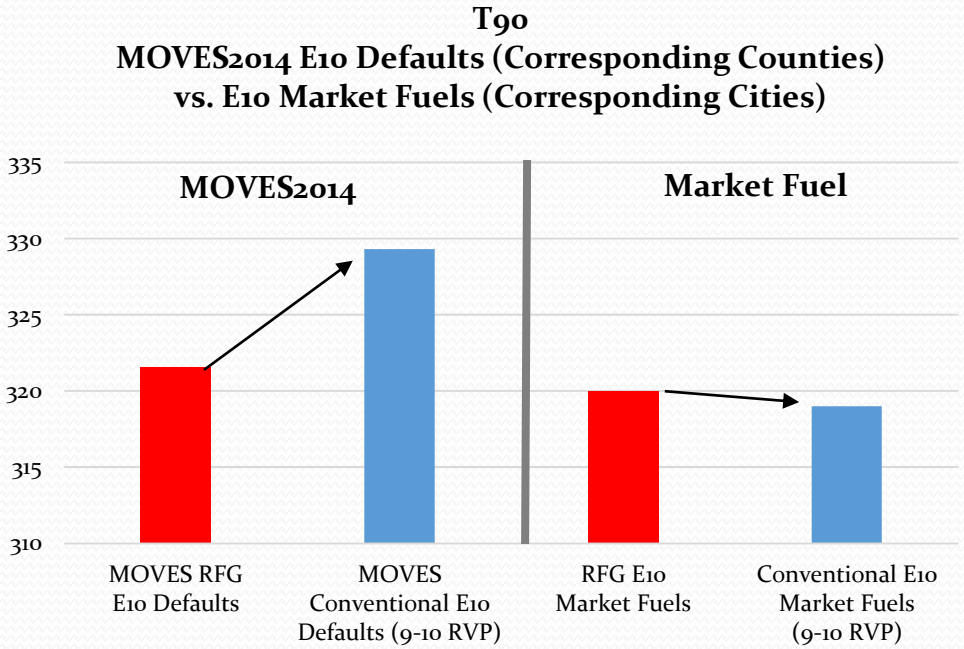
In the real world, reformulated gasoline (RFG) tends to have a *higher* T50 than conventional gasoline, because high-boiling-point hydrocarbons are added to lower RVP. The MOVES2014 defaults reverse this relationship without explanation.



Market Data Source: 2014 Auto Alliance Fuel Survey

MOVES2014 Default Fuel Parameters Do Not Correspond to Market Fuel

The average MOVES2014 default T90 (327.34°F) is much higher than the corresponding market averages for both RFG (314.87°F) and conventional gasoline (317.71°F).



Market Data Source: 2014 Auto Alliance Fuel Survey

Solutions

Short-term solutions:

- Temporarily lock the MOVES2014 model's ethanol fuel effects at 10% to prevent spurious comparisons between fuels with different levels of ethanol content.

- Fix default fuel parameters by replacing them with real world market fuel properties.

Long-term solutions:

- Develop a new model based on data that includes GDI/Tier 3 vehicles and realistic test fuels that are not biased against ethanol.

- Promulgate the model through notice-and-comment after review by the Science Advisory Board.

Thank you.

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For additional detail and references, please see:

Request for Correction of Information Submitted on Behalf of the State of Kansas, the State of Nebraska, the Energy Future Coalition, and Urban Air Initiative, Concerning EPA's EPAct/V2/E-89 Fuel Effects Study and Motor Vehicle Emissions Simulator Model (MOVES2014) (filed Jan. 19, 2017) available at: http://bit.ly/2m9cw3u

MOVES 2014 is Inaccurate when Estimating Ethanol's Emissions Effects

ABSTRACT: MOVES2014a yields fundamentally inaccurate estimates of ethanol's emissions effects because:

(1) Tailpipe Fuel Effects

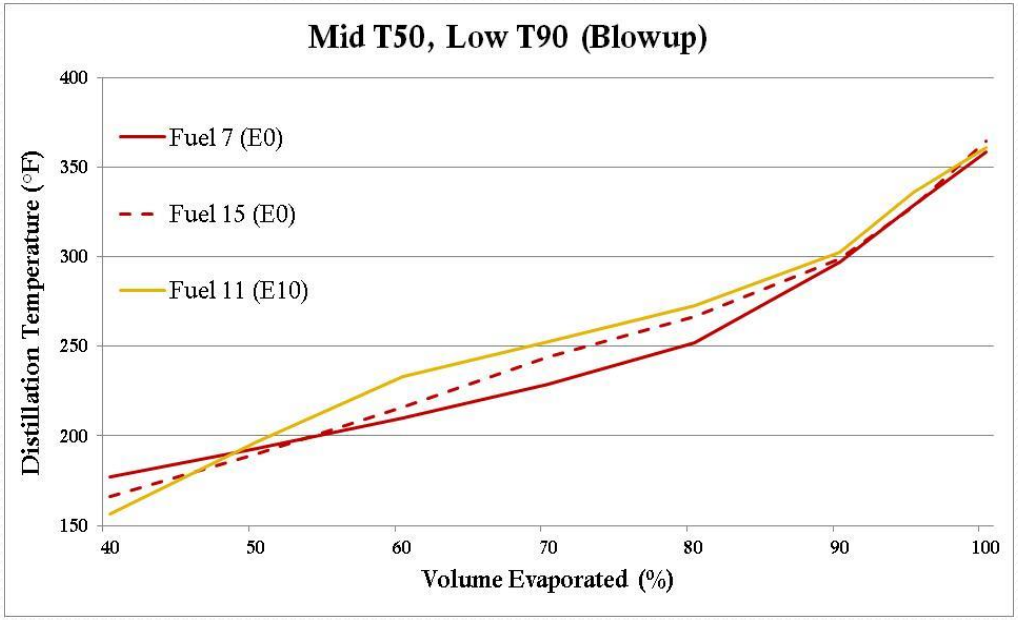
(2) Evaporative Fuel Effects

(3) Default Fuel Parameters

Additional Slides

The EPAct Study Did Not Control for Distillation Temperatures Other than T50 and T90

Within every set of EPAct test fuels with matched T50 and T90, and varying ethanol concentrations, the boiling points of one or more higher-ethanol fuels exceeded those of one or more lower-ethanol fuels for the entire T60-T80 range.



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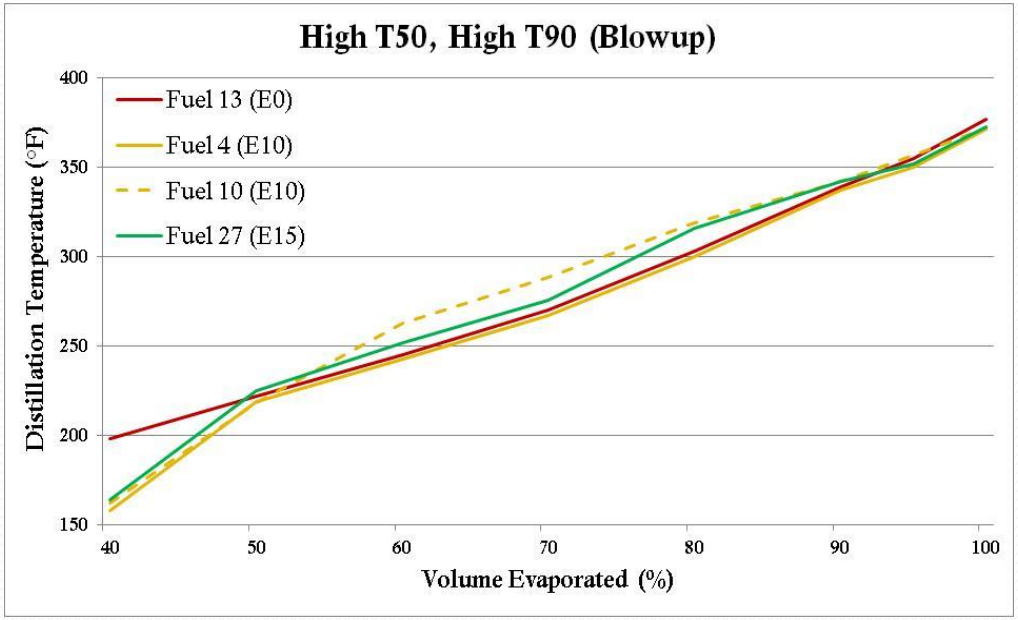
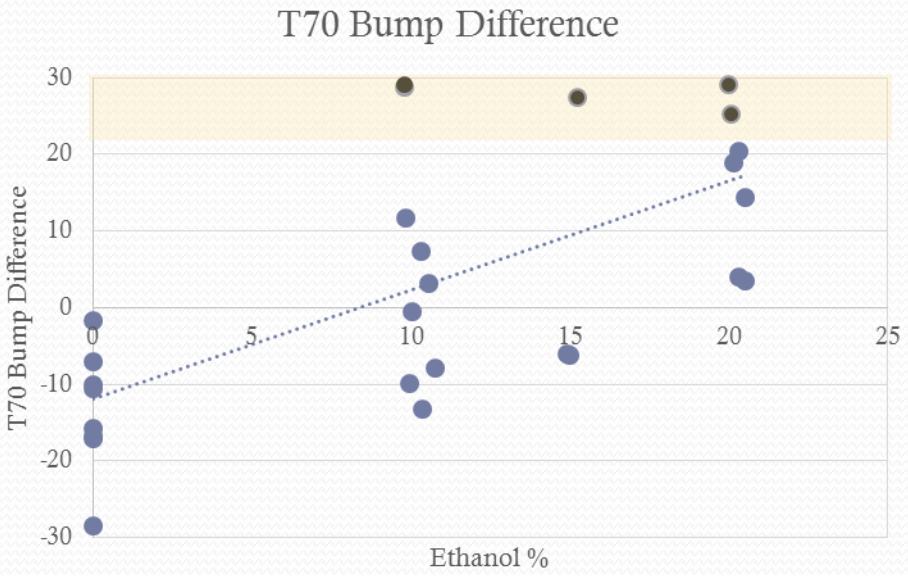


The EPAct Study Did Not Control for Distillation Temperatures Other than T50 and T90

As ethanol content increases in the test fuels, the "T70 bump" also increases.

"[A] fuel's deviation from a normal distillation slope can be quantified by determining the difference between" T70 and the arithmetic average of T50 and T90. D4814-16e, at 16.

T70 – (T50 +T90)/ 2



The EPAct Study Did Not Control for Distillation Temperatures Other than T50 and T90

The EPAct study also produces erroneous results for T50. The EPAct study counterintuitively suggests that Bag 1 PM emissions increase when T50 falls below 190°F. Anderson et al., (SAE 2014-01-9080).

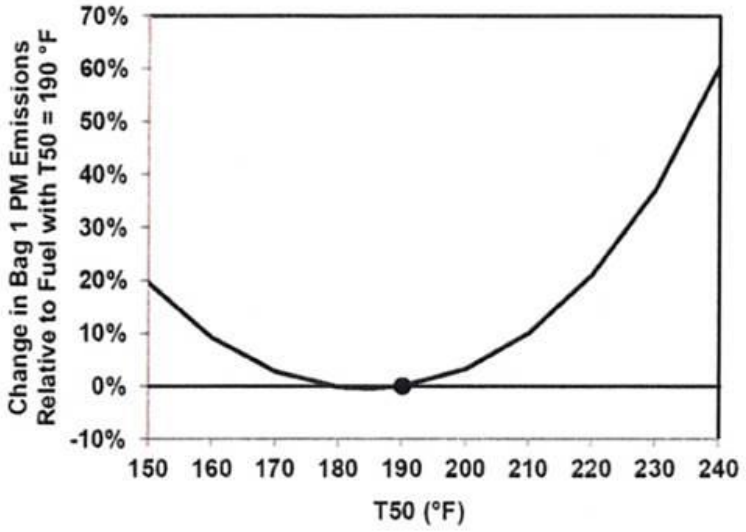


Figure 9. Change in Bag 1 PM emissions vs. fuel T50, relative to a reference fuel with T50 = 190 °F, according to the EPAct model [23].

The Test Fuels Selected for Speciation Were Biased Against Ethanol

The EPAct Study also models emission effects for selected air toxics, including acetaldehyde, formaldehyde, acrolein, ethanol, ethane, benzene, and 1-3 butadiene. Ethanol has positive Bag 1 coefficients for all air toxics except benzene and butadiene.

Fuel Property	Acet.	Form.	Acro.	Ethanol	Benz.	1,3-buta.
Ethanol	↑	↑	↑	↑	↓	↓
Aromatics	↑	↑	↑	---	↑	↑
RVP	↓	↓	↓	↓		
T50	↑	↑	↑	↑	↑	↑
T90	↑	↑	↑	↓	↑	↑

The Test Fuels Selected for Speciation Were Biased Against Ethanol

The EPAct Study relies on a limited subset of 12 fuels to measure 1,3-butadiene emissions and benzene emissions, as well as running emissions for ethane, ethanol, and formaldehyde.

These fuels are biased against ethanol because:

- Out of the three E20, two E15, and four E10 test fuels selected for speciation, none combines low T50, low T90, and low aromatics (factors associated with low emissions). By contrast, one E0 (fuel 7) has all of these characteristics.
- One of the four E10 test fuels selected for speciation (fuel 10) had the highest T70 value (290°F) of all of the Study's test fuels.

Test Fuel	ETOH (%)	T50 (°F)	T90 (°F)	RVP (psi)	Aromatics (%)
3	10.4	218	296	6.9	15
4	9.9	222	338	10	15.5
6	10.6	189	340	7.2	15
7	<0.10	193	298	7.2	17
10	9.8	217	340	7.1	34
13	<0.10	223	338	6.9	34.1
14	<0.10	193	339	7.1	16.9
21	20.1	168	305	7.1	35.5
23	20.3	163	338	6.8	15.9
27	14.9	222	340	7	14.9
28	15	217	299	6.9	34.5
31	20.1	167	325	7	35.5