Survey of Flex Fuel in 2014: CRC Project E-85-3

Teresa L. Alleman

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Technical Report
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Prepared under Task No. VTP2.9530

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List of Abbreviations

ASTM	ASTM International
CCR	California Code of Regulations
CRC	Coordinating Research Council
DVPE	dry vapor pressure equivalent
Exx	ethanol-gasoline blend where XX is the volume percent ethanol in the blend
mass%	percent by mass
max	maximum
min	minimum
MLEB	mid-level ethanol blend
PADD	Petroleum Area Defense District
psi	pounds per square inch
vol%	percent by volume

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Executive Summary

ASTM International (ASTM) Specification D5798 sets the specifications for Ethanol Flex Fuel, which currently permits between 51 volume percent (vol%) and 83 vol% ethanol. The vapor pressure varies seasonally and geographically and is divided into four distinct classes to ensure year-round driveability. This project is the first survey of Ethanol Flex Fuel since these changes were made to Specification D5798. Ninety-one Ethanol Flex Fuel samples were collected in this project, across all four classes and throughout the United States. Four samples were collected in California, which has quality requirements different from the rest of the country. Samples from more than one class were collected from most stations visited. All samples were analyzed for vapor pressure, ethanol content, and water content.

In this study, 60% of the samples met the relevant vapor pressure specifications, while 98% met the ethanol content specifications. Over 80% of the samples contained less water than the specification limit. Classes 2 and 3 had the most samples off specification for vapor pressure, with only 58% and 30% of the samples meeting the requirements, respectively. The class 1 data contained several on-specification samples with high ethanol content and high vapor pressure, indicating they may be been blended with a higher vapor pressure blendstock relative to the other samples in the class. Compared to previous surveys, the water content in these samples was notably higher and more often exceeded the specification.

Table ES-1. Summary data from for Ethanol Flex Fuel samples collected in E-85-3 project

	Vapor Pressure	Ethanol Content	Water Content
All data (91 samples)	60% on spec (55 samples)	98% on spec (89 samples)	84% on spec (76 samples)
Class 1 (26 samples)	65% on spec (17 samples)	100% on spec (26 samples)	88% on spec (23 samples)
Class 2 (24 samples)	58% on spec (14 samples)	96% on spec (23 samples)	83% on spec (20 samples)
Class 3 (10 samples)	30% on spec (3 samples)	100% on spec (10samples)	80% on spec (8 samples)
Class 4 (31 samples)	68% on spec (21 samples)	97% on spec (30 samples)	81% on spec (25 samples)

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Introduction

Utilization of ethanol in the United States has increased dramatically in the last several decades. The primary use of ethanol is in a 10 percent by volume (vol%) blend in gasoline (referred to as E10 and considered conventional gasoline). A much smaller volume of ethanol is being used in mid-level ethanol blends (MLEBs, defined as E11 to E50) and as Ethanol Flex Fuel (E51 to E83). With the increases in vehicle efficiency, the reduction in gasoline consumption, and the increase in ethanol production, the E10 market has hit the "blend wall".[1] The "blend wall" refers to the situation where no additional ethanol can be blended into E10 under current scenarios.

By increasing volumes of MLEBs and Ethanol Flex Fuel, additional ethanol could be blended in the near term further increasing ethanol use. While E10 has been extremely successful and almost all gasoline in the United States contains 10 vol% ethanol, MLEBs and Flex Fuel have been far less successful. Recently, a partial waiver was granted by the U.S. Environmental Protection Agency that paved the way for introduction of E15. Conventional gasoline is sold at over 150,000 stations in the United States, while there are fewer than 100 E15 stations[2] and between 2,500 and 3,500 Ethanol Flex Fuel stations.[3] Ethanol Flex Fuel can only be used in special vehicles, called flex-fuel vehicles, that have specific components and engine calibration that allow them to run on Ethanol Flex Fuel. The Alternative Fuels Data Center[4] estimates there are 17 million flex-fuel vehicles on the road.

The state of California sets its own fuel quality guidelines through the California Air Resources Board.[5] Most other states adopt the ASTM International (ASTM) specifications or NIST Handbook 130 specifications. The ASTM specification for Ethanol Flex Fuel is ASTM D5798.[6] The specification is a "living" document and is updated as needed. Specification D5798 includes classes that specify ethanol content and minimum and maximum vapor pressure limits to ensure adequate driveability and cold starting for vehicles operating on the fuel, as well as other critical properties to ensure the fuel is fit for purpose. The classes change geographically throughout the year based on ambient temperature conditions.

The Coordinating Research Council (CRC) and the National Renewable Energy Laboratory have undertaken surveys of Ethanol Flex Fuel quality in the United States. This study is the third effort in recent years and the first survey since major modifications to the specification in 2011. These changes added a fourth class and reduced the minimum ethanol content to 51 vol% for all classes. The changes were made in an effort to provide more flexibility to blenders and to increase compliance with the specification.

In the first E-85 survey, in 2009, 123 Ethanol Flex Fuel samples were collected.[7] Only 26% were on-specification for vapor pressure and 56% for ethanol content. In 2011, a second Ethanol Flex Fuel survey was conducted in which 116 samples were collected.[8] This survey showed an improvement in quality, with 46% of the samples meeting the vapor pressure requirements and 91% meeting the ethanol requirements.

This study, E-85-3, is a follow-on to the previous work and examines the quality of Ethanol Flex Fuel in the United States across various classes. The samples were tested for vapor pressure, ethanol content, and water content and the results were compared to the appropriate class from Specification D5798-13a, the standard when the samples were collected.

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Methodology

To ensure the most representative samples possible, stations were selected from each Petroleum Area Defense District (PADD). Figure 1 illustrates the location where the samples were collected. The largest number of stations came from the Midwest, where Ethanol Flex Fuel stations are most common. Stations were identified in states with at least 20 Ethanol Flex Fuel stations, and where possible, from larger cities within each state.[9]

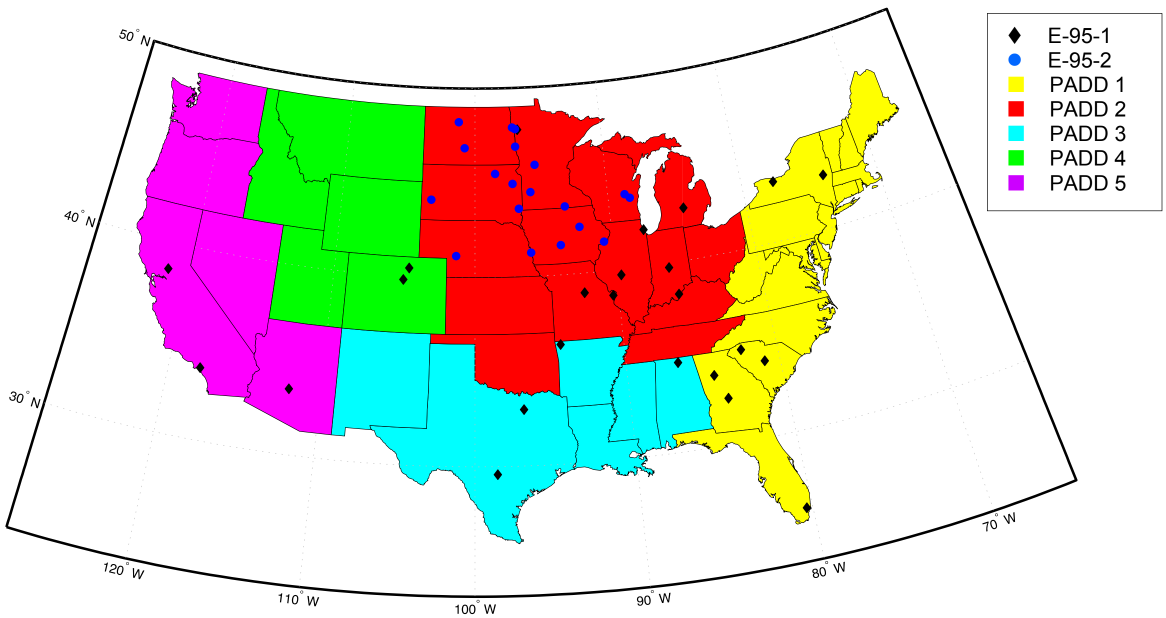

Figure 1. Location of Ethanol Flex Fuel samples collected for this study (black diamonds). Samples collected in the E-95-2 study are shown as blue dots.

Specification D5798 defines classes based on ambient temperatures in each geographic area. Most states have unique requirements for classes, and some states are further divided into regions; for example, California is divided into North Coast, South Coast, Interior, and Southeast. The study collected similar numbers of samples from Classes 1, 2, and 4. Only ten samples were collected in Class 3 due to the relative rarity of this class in the states sampled in the project.

To allow transition from one fuel class to another, Specification D5798 includes shoulder seasons that allow more than one class of fuel to be sold at the same time. Sampling dates were set at the latter half of the month in an effort to ensure the fuel sample was from the correct class and any fuel from the previous class had been fully depleted, although there was no way to guarantee this had occurred.

The project budget limited collection to 72 samples, significantly fewer than in previous projects. In an effort to obtain as many samples as possible, the E-95-2 samples were included in this project and analysis. The E-95-2 survey sampled Ethanol Flex Fuel and MLEBs from blender pumps in the Midwestern United States in the winter of 2013. The goal of the E-95-2 project was to collect the range of blends available at each station and compare the measured ethanol content to the ethanol content listed on the pump (additional information on the other samples collected

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in E-95-2 can be found in the report).[10] The 19 supplemental samples came from PADD 2 class 4 and allowed additional samples to be collected from other classes and regions of the country.

All samples were tested by ASTM test methods for vapor pressure, water content, and ethanol content. Sample results were compared to Specification D5798-13a, the applicable version of the specification when the samples were collected, to determine if they met the specification for the appropriate class. The exceptions are the four samples collected from California, which must meet the requirements in Title 13 of the California Code of Regulations (CCR), § 2292.4. The limits for samples collected outside California are listed in Table 1. The contract laboratory does not perform either E203 or E1064, and D6304 was used for water content analysis.

Table 2 lists the applicable specification limits and test methods for Ethanol Flex Fuel samples collected in California in this project. This list is not complete and only covers the requirements for the months and locations in this study. The vapor pressure limits in California are taken from the volatility classes in ASTM Specification D4814-91b. A list of the full requirements can be found in Reference 5. All samples in this project were tested by the same ASTM methods as listed in Table 1.

Table 1. List of Test Methods and ASTM Specification D-5798-13a Specification Limits for Ethanol Flex Fuel for Samples Not Collected in California

Property	ASTM Test Method	Property Limit			
		Class 1	Class 2	Class 3	Class 4
Vapor pressure, psi	D5191-12	5.5-9.0	7.0–9.5	8.5–12.0	9.5–15.0
Ethanol content, vol%	D5501-12ε1	51–83	51–83	51–83	51–83
Water content, mass%	D6304-07	1.0, max	1.0, max	1.0, max	1.0, max

Table 2. California Requirements for Ethanol Flex Fuel for March and May for South Coast and Interior

Property	ASTM Test Method	March Class (from D4814)	March Limit	May Class (from D4814)	May Limit
South Coast vapor pressure, psi	D323-58	D/C	7.3–9.4	C/B	7.3–9.4
Interior vapor pressure, psi	D323-58	D	8.7–10.2	C/B	7.3–9.4
Ethanol content, vol%	D3545-90	NA	79, min	NA	79, min
Water, mass%	E203-75	NA	1.25, max	NA	1.25, max

NA = not applicable

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Results and Discussion

Due to the small number of stations visited in this study compared to the total number of Ethanol Flex Fuel pumps in the United States, the samples collected are not meant to be representative of national Ethanol Flex Fuel quality.

The data are shown with error bars based on the method reproducibility to illustrate the expected variability in measurement for each property. For the discussion, the absolute value is used to determine how many samples met the specification. Results from all tests are listed in Tables A-1 through A-4 in the appendix.

Vapor Pressure

The minimum dry vapor pressure equivalent (DVPE) limit of Ethanol Flex Fuel is an important property for cold startability in the winter, and the maximum limit prevents hot weather driveability issues in warmer months. In Specification D5798, class 1 has the lowest vapor pressure limits and is typically available in the warm summertime months. Figure 2 shows the scatter plot for class 1 vapor pressure for all states sampled.

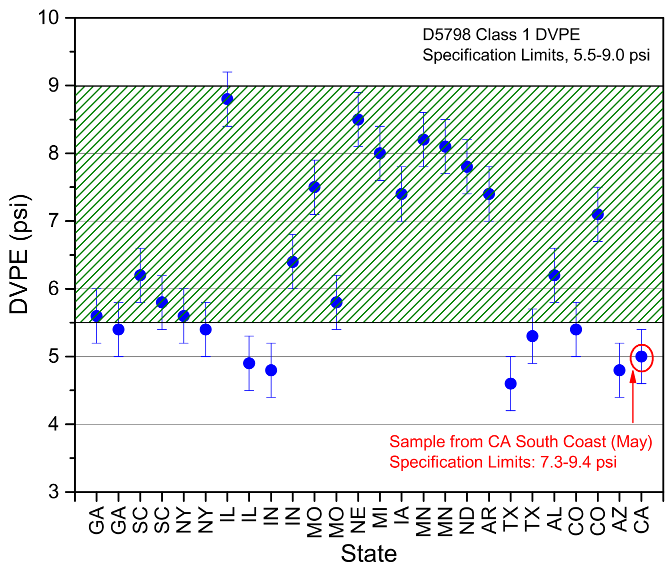

Figure 2. Scatter plot of class 1 DVPE data.
Note the Ethanol Flex Fuel sample from California should meet the California requirements of 7.3–9.4 psi, not the Specification D5798-13a requirements of 5.5–9.0 psi.

The California Ethanol Flex Fuel sample was collected from the South Coast in May. Per the California requirements, this sample is required to meet the D/C class specification, which requires the vapor pressure to be between 7.3 pounds per square inch (psi) and 9.4 psi, which is slightly higher than the D5798-13a requirements for Class 1 (5.5–9.0 psi).

All samples are considered on or off specification based on their absolute value. The average vapor pressure was 6.4 psi for all samples, well within the range allowed by the specification, and 17 of 26 samples were within the specification limits (65%, including the sample from California).

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The California sample illustrates the impact of ethanol's vapor pressure on the finished fuel vapor pressure. The Reddy model uses the vapor pressure of the blendstock and ethanol to predict finished fuel vapor pressure at various ethanol contents.[11] By applying the Reddy model and assuming that the Ethanol Flex Fuel is only composed of a blendstock and ethanol, the vapor pressure of the blendstock can be estimated. For a California-compliant Ethanol Flex Fuel with a vapor pressure of 7.3 psi and 79 vol% ethanol, the blendstock needs to be 11.6 psi. With a 5.0 psi finished fuel vapor pressure, it is hypothesized that the blendstock used had a vapor pressure well below 11.6 psi.

Twenty-two Ethanol Flex Fuel samples were collected in class 2 outside of California (Figure 3). These samples must have a vapor pressure between 7.0 and 9.5 psi. Two Ethanol Flex Fuel samples were collected in California's Interior region in March (first California data point) and May (second California data point). These California samples must meet 8.7–10.2 psi in March and 7.3–9.4 psi in May. Similar to the sample in Figure 2, these California samples fell well below the specification limits, likely due to the use of a low vapor pressure blendstock. To make an Ethanol Flex Fuel with a minimum of 8.7 psi and 79 vol% ethanol, the blendstock needs to have a vapor pressure over 14 psi, based on the Reddy model.

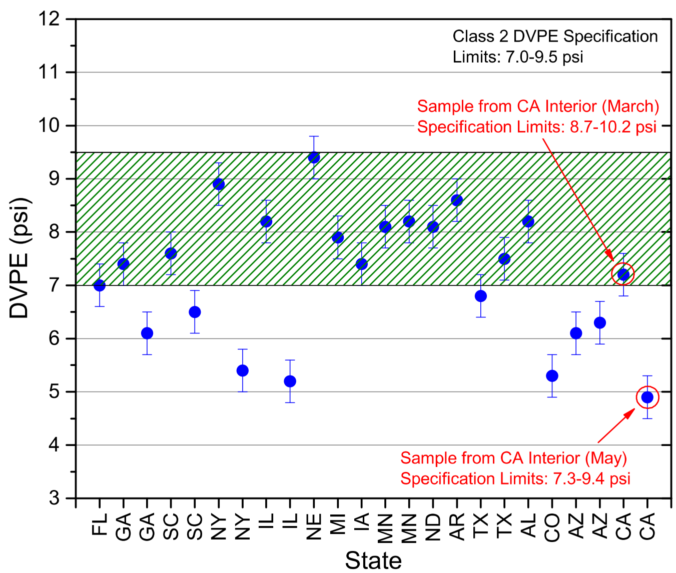

Figure 3. Scatter plot of Ethanol Flex Fuel samples for vapor pressure in class 2.
Note the California samples must meet 8.7–10.2 psi and 7.3–9.4 psi in March and May, respectively.

Including the California samples, only 14 of the 24 samples (58%) met the vapor pressure requirements. The off-specification samples were below the minimum allowable limit in all cases. The average vapor pressure for all Ethanol Flex Fuel samples was 7.3 psi, just above the specification minimum. Note that both samples from California were below the requirements in that state, though the second sample would have met Specification D5798 limits.

The fewest number of Ethanol Flex Fuel samples were collected in class 3. Only ten samples were collected in this class. Seven of the ten failed to meet the vapor pressure minimum, including the sample from California (Figure 4) (30% on specification for the class). This sample was collected from California's South Coast region in March (class D/C) and should have had a

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vapor pressure between 7.3 and 9.4 psi, requiring a blendstock with a vapor pressure of 11.6 psi, based on the estimation from the Reddy model.

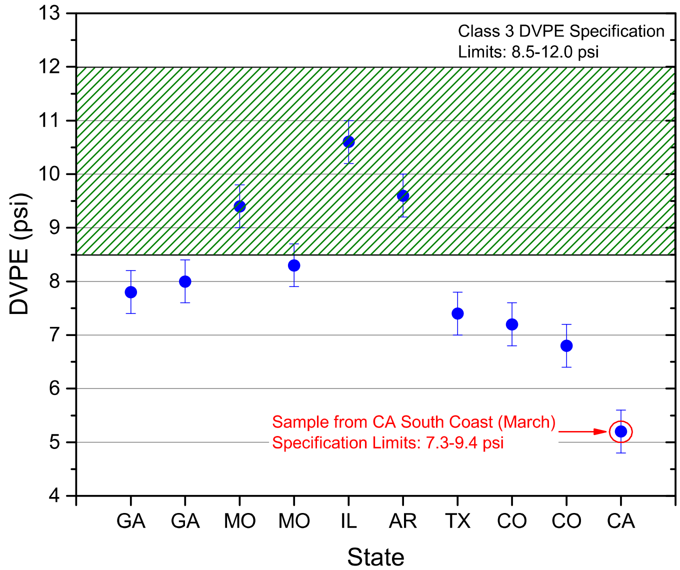

Figure 4. Vapor pressure results of Ethanol Flex Fuel from class 3.
Note the California regulations require the sample to have a vapor pressure between 7.3 and 9.4 psi.

Figure 5 shows that 68% of the samples (21 of 31 samples collected) in class 4 met the vapor pressure limits in Specification D5798 (9.5–15.0 psi). No samples were collected from California. The average vapor pressure of all samples was 9.7 psi, slightly above the specification minimum. Similar to other classes, several samples were below the specification minimum. The sample from Nebraska with vapor pressure below 5 psi was a sample with over 90 vol% ethanol content, collected in the E-95-2 survey, and was clearly misblended.

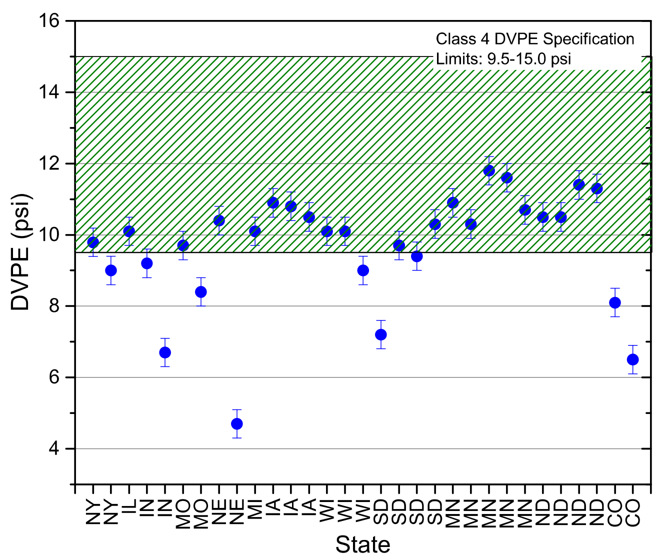

Figure 5. Class 4 DVPE results showing 67% of the samples meeting the specification

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Ethanol Content

In 2010, the ethanol content in Specification D5798 was harmonized between classes, with 68 vol%–83 vol% allowed. In 2011, the lower limit for all classes was changed to 51 vol%. The reduction in minimum ethanol content allowed for larger quantities of high-volatility hydrocarbons to be blended in Ethanol Flex Fuel to meet the higher wintertime vapor pressure limits. The exception to these limits is Ethanol Flex Fuel sold in California, which must have 79 vol% ethanol content year-round.

As shown in Figure 6, all the class 1 Ethanol Flex Fuel samples met the limits for ethanol content. The Ethanol Flex Fuel sample from California met the much more stringent requirements under CCR Title 13 of 79 vol% minimum.

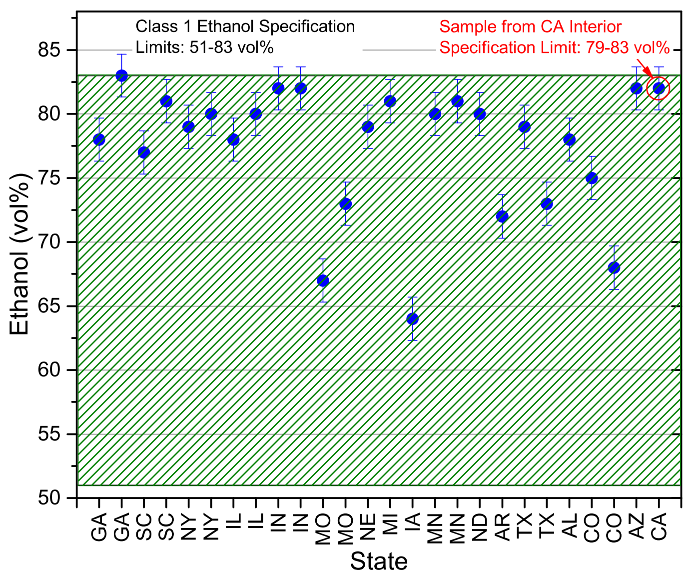

Figure 6. Class 1 ethanol content of samples

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Figure 7 shows that 23 of 24 samples collected in class 2 were on specification (96% of samples collected). The second sample from California had ethanol content in excess of the 83 vol% maximum required and also had vapor pressure below the minimum requirement (see Figure 3).

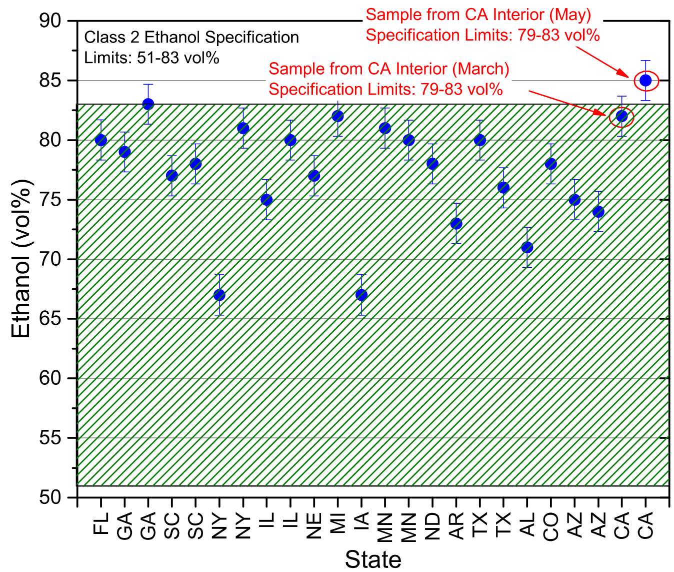

Figure 7. Scatter plot of ethanol content for Ethanol Flex Fuel samples from class 2

All 10 Ethanol Flex Fuel samples collected in class 3 samples met the ethanol content specifications for 100% compliance. Figure 8 shows the ethanol content for the class 3 Ethanol Flex Fuel samples collected. The average ethanol content dropped slightly from class 1 and class 2 to 74 vol% in class 3.

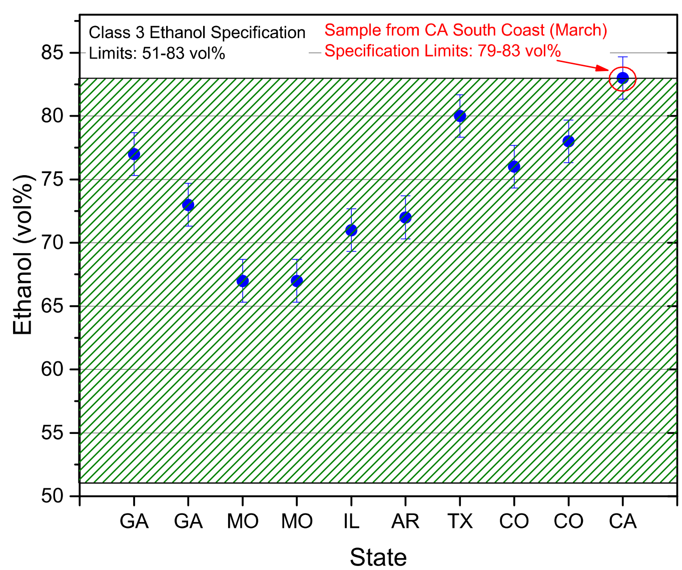

Figure 8. Ethanol content by state for class 3 Ethanol Flex Fuel samples

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The class 4 samples are notable for the very high ethanol content sample from Nebraska (Figure 9). This sample corresponds to the very low vapor pressure sample from Figure 5. This sample came from the E-95-2 survey, from a blender pump, and shows that some problem occurred at the pump in blending this sample. For this class, 30 out of 31 Ethanol Flex Fuel samples met the ethanol content specification limits (97%), and had an average ethanol content of 71 vol%.

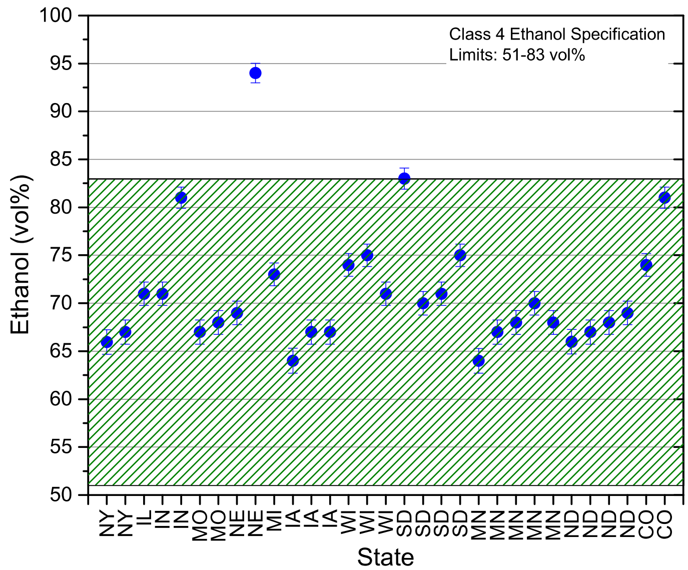

Figure 9. Ethanol Flex Fuel class 4 ethanol content

The ethanol content and DVPE for all classes have been plotted in Figures 10 a–d. With the exception of one sample in class 2, every sample that fails to meet the vapor pressure fails because it is below the minimum specified for the class in Specification D5798-13a.

Figure 10a shows an interesting trend not observed in the other figures. In classes 2–4 (Figures 10b, 10c, and 10d), the increasing ethanol content decreases the vapor pressure. It is well known that the low vapor pressure of ethanol has a strong effect on the finished blend. However, the group of samples in class 1 with about 80 vol% ethanol and between 8 psi and 9 psi vapor pressure do not appear to follow this trend. Previous E-85 studies have shown that vapor pressure is often below the specification minimum. Using the Reddy model and making the assumption that these blends are only composed of ethanol and blendstock, these samples required a blendstock with 14 psi to make a finished blend with 8–9 psi vapor pressure and 80 vol% ethanol content.

All of the Ethanol Flex Fuel samples collected that do not meet the vapor pressure requirements fall below the required minimum specification limit. In addition, these samples all have ethanol content above 65 vol%, illustrating that the blenders did not take advantage of the broader range of blendstock content allowed under Specification D5798. As discussed previously, the allowable range of ethanol in Ethanol Flex Fuel was expanded to 51 vol% to 83 vol% in 2011 to give blenders maximum flexibility in the final blends to meet the vapor pressure requirements.

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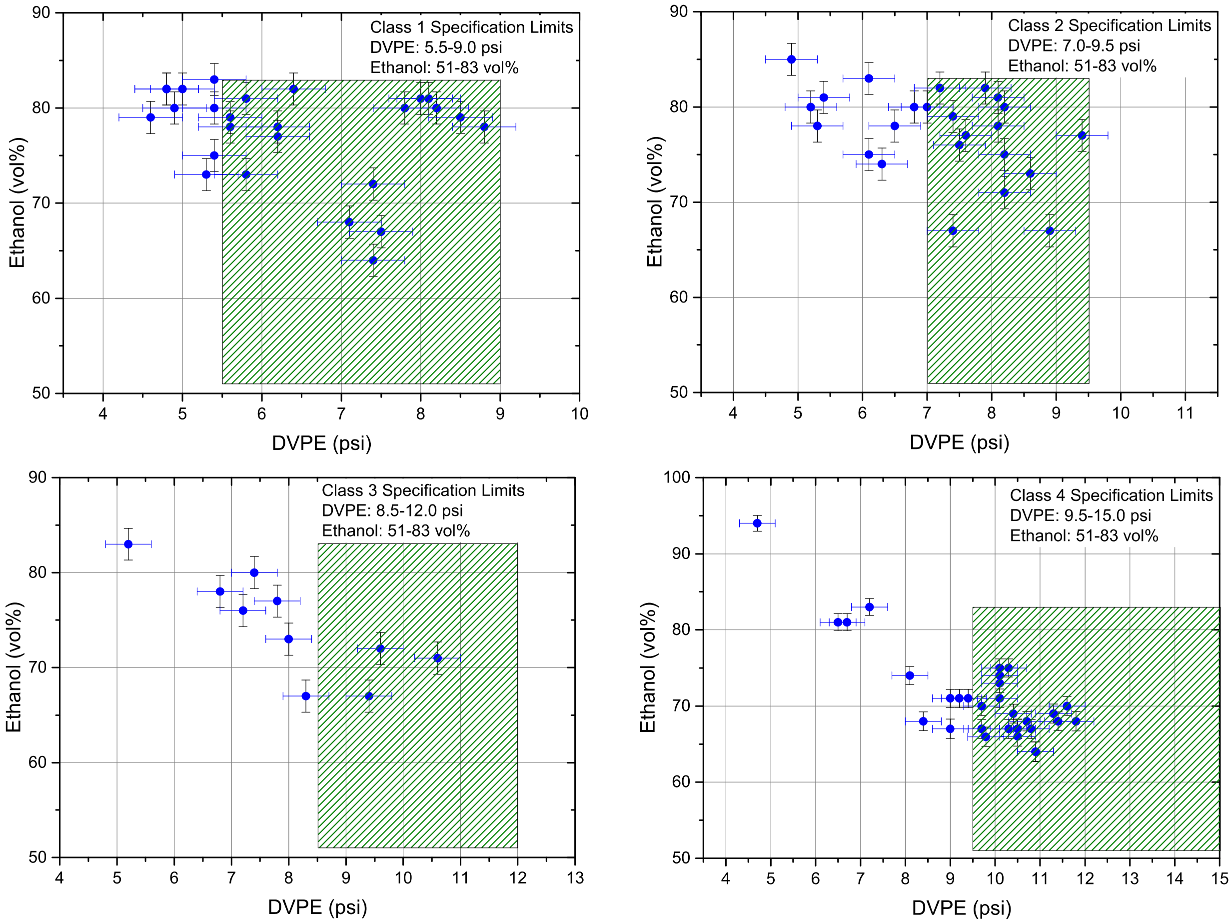

Figures 10a–d. Ethanol content and vapor pressure for Ethanol Flex Fuel in each class.
Clockwise from upper left: class 1, class 2, class 4, and class 3.

Water Content

Figures 11a–d illustrate the water content for the Ethanol Flex Fuel samples. Similar to vapor pressure and ethanol content, the state of California has different requirements from Specification D5798. California allows higher water content in Ethanol Flex Fuels, with a specification maximum of 1.25 percent by mass (mass%) water, compared to 1.0 mass% water in Specification D5798.

In class 1 (Figure 11a), the average water content is 0.9 mass%, with three samples above the ASTM specification limit. Class 2, Figure 11b, has four samples above the ASTM specification limit and two samples at twice the limit for Ethanol Flex Fuel, nearly 2 mass%. The average water content for samples in class 2 was 1.0 mass%. Figure 11c shows the class 3 samples, with an average water content of 1.0 mass%, mainly due to two samples with over 1.5 mass% water. The highest water content in any individual sample was observed in class 4, with a sample at 3.9 mass% water. The average water content of the samples in class 4 was 1.0 mass%, again, right at the specification limit. At the ASTM specification limit of 1.0 mass%, the test method measurement error is 0.42 mass%. Most of the samples in this study are well within the measurement error at the ASTM specification limit. Overall, 15 of 91 samples exceeded the specification limit for water.

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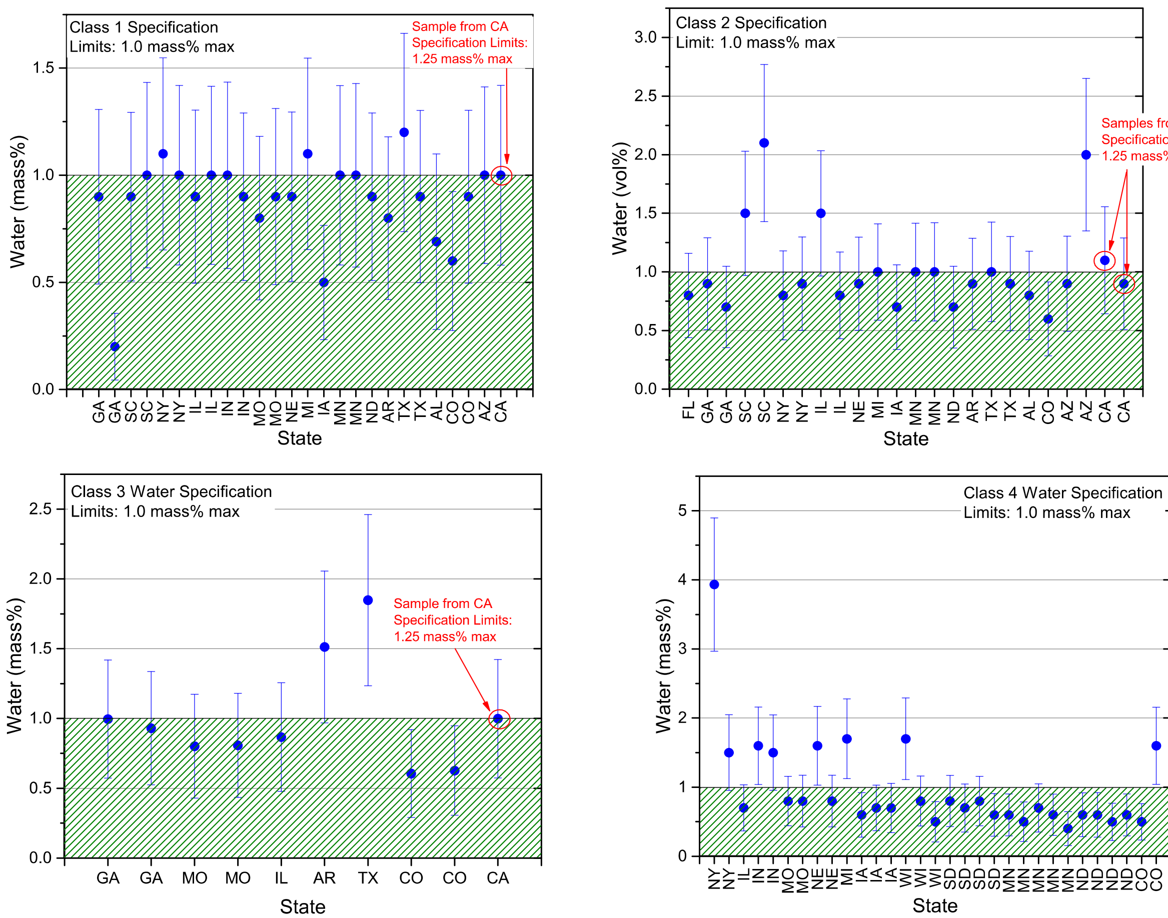

Figures 11a–d. Water content of Ethanol Flex Fuel samples for all classes.
Clockwise from upper left: class 1, class 2, class 4, and class 3.

Although high water content in a sample on any given day can be a function of housekeeping at the station, several locations produced samples with high water content at multiple times. The two samples from a site in South Carolina were at or slightly over the 1.0 mass% limit for Ethanol Flex Fuel in both classes 1 and 2. Likewise, the samples collected in Dallas, Texas (first TX point in classes 1 and 2 and only TX point in class 3) were typically at or above the specification limit, implying a potentially long-term problem with water contamination at the site or from the supplier. The number of samples off specification for water content is notable, as previous E-85 surveys had very few samples with elevated water content.[7,8]

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Conclusions

Ninety-one Ethanol Flex Fuel samples were collected from the continental United States in all Specification D5798-13a classes. Four of the 91 samples were collected in California, where Ethanol Flex Fuel must meet the requirements of CCR Title 13 §2292.4. Twenty-six samples were collected in class 1, 24 in class 2, 10 in class 3, and 31 in class 4. The class 4 samples included 19 previously collected in the E-95-2 survey of blender pumps.

Recent changes in the D5798 specification were made to give blenders maximum flexibility to meet the DVPE requirements year-round. These changes were the addition of a fourth class in the winter and reducing the minimum ethanol content to 51 vol%.

This study showed that lowering the minimum allowable ethanol content to 51 vol% (the allowable range in Ethanol Flex Fuel is from 51 vol% to 83 vol%) increased compliance over previous surveys. Two samples exceeded the ethanol content requirements: a sample from the E-95-2 blender pump survey that had almost 95 vol% ethanol and a class 2 sample from California with 85 vol% ethanol (requirements are 79 vol%–83 vol% ethanol). The average ethanol content in classes 1–3 was 77 vol%, dropping slightly to 71 vol% in class 4.

Compliance with Specification D5798-13a vapor pressure specifications was poor. In class 1, eight samples out of 25 failed to meet the ASTM vapor pressure minimum of 5.5 psi. The sample from California also fell below the prescribed vapor pressure limit of 7.3 psi. Only 58% of the Ethanol Flex Fuel samples in class 2 met the minimum vapor pressure limits. Both California samples were below the specification minimum set by the California Air Resources Board. Thirty percent of the class 3 samples and 67% of the class 4 samples met the minimum ASTM DVPE requirements. While this is an improvement over previous surveys, the results show problems may still be expected in the market due to low vapor pressure in Ethanol Flex Fuel.

A subset of class 1 samples showed high vapor pressure and high ethanol content. This is different than the trend observed in the other classes in this survey. Generally, as ethanol content increases, vapor pressure decreases. In this subset of samples, the ethanol content was high and the vapor pressure was also high, not showing the reduction observed in other samples. Using the Reddy model and assuming the blends were composed only of ethanol and blendstock, these samples required a blendstock with a minimum vapor pressure of 14 psi.

An interesting trend was observed with water content in this study compared to previous work. In previous surveys,[7,8] very few samples, if any, failed to meet the water limit of 1.0 mass%. In this survey, 15 out of 91 samples exceeded the 1.0 mass% limit. This is notable due to the number of samples with high water content and the difference from previous work, where samples almost never failed the specification.

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Appendix

Table A-1. Class 1 Data

City/State	Date	D5191		D5501		D6304	
		DVPE, psi	Error	Ethanol, vol%	Error	Water, mass%	Error
Atlanta, GA	5/15/14	5.59	0.40	77.5	1.2	0.94	0.41
Perry, GA	5/15/14	5.44	0.40	82.8	1.1	0.19	0.16
Greenville, SC	5/17/14	6.21	0.40	77.3	1.2	0.88	0.39
Columbia, SC	5/19/14	5.83	0.40	81.5	1.1	1.03	0.43
Schenectady, NY	7/25/14	5.6	0.40	78.7	1.1	1.10	0.45
Rochester, NY	7/27/14	5.39	0.40	79.7	1.1	0.98	0.42
Springfield, IL	6/25/14	8.8	0.40	78.3	1.1	0.92	0.40
Chicago, IL	7/22/14	4.86	0.40	79.5	1.1	0.97	0.42
New Albany, IN	6/22/14	4.76	0.40	81.6	1.1	1.04	0.44
Indianapolis, IN	6/21/14	6.42	0.40	81.7	1.1	0.87	0.39
Columbia, MO	6/22/14	7.49	0.40	66.8	1.3	0.84	0.38
St Louis, MO	6/25/14	5.83	0.40	73.2	1.2	0.95	0.41
Omaha, NE	7/23/14	8.5	0.40	79.0	1.1	0.89	0.40
Lansing, MI	7/23/14	7.99	0.40	81.4	1.1	1.09	0.45
West Des Moines, IA	7/22/14	7.4	0.40	63.9	1.3	0.46	0.27
Marshall, MN	7/23/14	8.16	0.40	80.3	1.1	0.98	0.42
Crookston, MN	7/23/14	8.09	0.40	81.0	1.1	1.02	0.43
Fargo, ND	7/23/14	7.82	0.40	80.4	1.1	0.87	0.39
Bentonville, AR	5/17/14	7.38	0.40	71.7	1.2	0.83	0.38
Dallas, TX	6/21/14	4.64	0.40	78.9	1.1	1.16	0.46
San Antonio, TX	8/21/14	5.31	0.40	73.4	1.2	0.91	0.40
Huntsville, AL	6/22/14	6.15	0.40	77.6	1.2	0.94	0.41
Arvada, CO	7/25/14	5.39	0.40	75.1	1.2	0.64	0.32
Greeley, CO	6/25/14	7.13	0.40	67.6	1.3	0.92	0.40
Phoenix, AZ	5/18/14	4.82	0.40	81.6	1.1	0.95	0.41
Anaheim, CA	5/18/14	4.99	0.40	81.8	1.1	0.98	0.42

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Table A-2. Class 2 Data

City/State	Date	D5191		D5501		D6304	
		DVPE, psi	Error	Ethanol, vol%	Error	Water, mass%	Error
Hialeah Gardens, FL	1/17/14	7.40	0.40	79.5	1.1	0.76	0.36
Atlanta, GA	3/20/14	7.38	0.40	78.9	1.1	0.87	0.39
Perry, GA	3/24/14	6.13	0.40	83.2	1.1	0.72	0.35
Greenville, SC	2/9/14	7.62	0.40	76.6	1.2	1.45	0.53
Columbia, SC	2/9/14	6.53	0.40	77.7	1.2	2.15	0.67
Schenectady, NY	5/18/14	8.87	0.40	67.4	1.3	0.83	0.38
Rochester, NY	5/21/14	5.44	0.40	81.2	1.1	0.90	0.40
Chicago, IL	2/9/14	8.24	0.40	75.1	1.2	1.47	0.53
Chicago, IL	5/14/14	5.17	0.40	79.8	1.1	0.79	0.37
Omaha, NE	5/22/14	9.36	0.40	76.5	1.2	0.90	0.40
Lansing, MI	5/19/14	7.92	0.40	82.0	1.1	0.95	0.41
W Des Moines, IA	5/21/14	7.37	0.40	66.6	1.3	0.76	0.36
Marshall, MN	9/18/14	8.08	0.40	81.1	1.1	0.97	0.42
Crookston, MN	9/15/14	8.21	0.40	80.1	1.1	0.98	0.42
Fargo, ND	9/15/14	8.05	0.40	78.5	1.1	0.72	0.35
Bentonville, AR	10/24/13	8.58	0.40	72.6	1.2	0.86	0.39
Dallas, TX	10/25/13	6.76	0.40	80.3	1.1	1.00	0.42
San Antonio, TX	11/13/13	7.49	0.40	76.0	1.2	0.91	0.40
Huntsville, AL	11/13/13	8.16	0.40	70.5	1.2	0.82	0.38
Arvada, CO	5/21/14	5.28	0.40	78.5	1.1	0.61	0.31
Phoenix, AZ	11/16/13	6.10	0.40	74.8	1.2	0.93	0.41
Phoenix, AZ	2/12/14	6.31	0.40	74.4	1.2	2.03	0.65
Sacramento, CA	3/7/14	7.15	0.40	81.7	1.1	1.13	0.46
Sacramento, CA	5/15/14	4.87	0.40	84.6	1.1	0.87	0.39

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Table A-3. Class 3 Data

City/State	Date	D5191		D5501		D6304	
		DVPE, psi	Error	Ethanol, vol%	Error	Water, mass%	Error
Atlanta, GA	1/25/14	7.73	0.40	77.4	1.2	1.00	0.42
Perry, GA	1/25/14	8.00	0.40	73.1	1.2	0.93	0.41
Columbia, MO	3/21/14	9.40	0.40	66.8	1.3	0.80	0.37
St Louis, MO	3/24/14	8.34	0.40	66.7	1.3	0.81	0.37
Bentonville, AR	2/7/14	9.59	0.40	71.7	1.2	1.51	0.54
Springfield, IL	3/23/14	10.55	0.40	70.7	1.2	0.87	0.39
Dallas, TX	2/8/14	7.44	0.40	80.1	1.1	1.85	0.61
Arvada, CO	11/17/13	7.24	0.40	75.8	1.2	0.61	0.31
Greeley, CO	4/15/14	6.81	0.40	77.9	1.2	0.63	0.32
Anaheim, CA	3/9/14	5.20	0.40	83.3	1.1	1.00	0.42

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Table A-4. Class 4 Data

City/State	Date	D5191		D5501		D6304	
		DVPE, psi	Error	Ethanol, vol%	Error	Water, mass%	Error
Schenectady, NY	2/11/14	9.79	0.40	66.0	1.3	3.93	0.96
Rochester, NY	2/9/14	9.02	0.40	66.7	1.3	1.53	0.55
Springfield, IL	1/17/14	10.12	0.40	70.6	1.2	0.67	0.33
New Albany, IN	2/13/14	9.22	0.40	71.4	1.2	1.58	0.56
Indianapolis, IN	2/19/14	6.72	0.40	81.3	1.1	1.52	0.54
Columbia, MO	1/18/14	9.69	0.40	67.3	1.3	0.75	0.36
St Louis, MO	1/22/14	8.41	0.40	68.1	1.2	0.80	0.37
Omaha, NE	2/8/14	10.34	0.40	69.2	1.2	1.63	0.57
Paxton, NE	2/1/13	4.73	0.40	93.9	1.0	0.81	0.37
Lansing, MI	2/8/14	10.12	0.40	73.0	1.2	1.67	0.58
Des Moines, IA	2/1/13	10.93	0.40	63.9	1.3	0.63	0.32
Waterloo, IA	2/12/14	10.8	0.40	67.0	1.3	0.66	0.33
Davenport, IA	2/1/13	10.5	0.40	67.4	1.3	0.75	0.36
Pickett, WI	2/12/14	10.08	0.40	73.8	1.2	1.73	0.59
Pickett, WI	2/1/13	10.13	0.40	74.7	1.2	0.76	0.36
Eden, WI	2/1/13	8.98	0.40	71.4	1.2	0.53	0.29
Rapid City, SD	2/1/13	7.24	0.40	82.7	1.1	0.80	0.37
Sioux Falls, SD	2/1/13	9.68	0.40	69.9	1.2	0.72	0.35
Watertown, SD	2/1/13	9.35	0.40	71.3	1.2	0.76	0.36
Aberdeen, SD	2/1/13	10.28	0.40	74.5	1.2	0.58	0.31
Glenville, MN	2/1/13	10.87	0.40	64.2	1.3	0.57	0.30
Fischer, MN	2/1/13	10.26	0.40	67.1	1.3	0.52	0.29
Marshall, MN	2/1/13	11.76	0.40	67.6	1.3	0.72	0.35
Alexandria, MN	2/1/13	11.56	0.40	69.6	1.2	0.56	0.30
Moorhead, MN	2/1/13	10.67	0.40	67.6	1.3	0.40	0.25
Fargo, ND	2/1/13	10.51	0.40	65.8	1.3	0.62	0.32
Grand Forks, ND	2/1/13	10.48	0.40	66.6	1.3	0.63	0.32
Minot, ND	2/1/13	11.42	0.40	68.0	1.2	0.47	0.27
Bismarck, ND	2/1/13	11.32	0.40	68.6	1.2	0.57	0.30
Arvada, CO	1/19/14	8.14	0.40	74.0	1.2	0.45	0.26
Greeley, CO	2/13/14	6.50	0.40	81.0	1.1	1.57	0.56

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