National 2010-2011 Survey of E85: CRC Project E-85-2

Teresa L. Alleman

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

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NATIONAL RENEWABLE ENERGY LABORATORY

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Teresa L. Alleman

Prepared under Task No. FC08.0075

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Executive Summary

Domestic ethanol usage has continued to increase in recent years, and over 90% of the gasoline in the United States contains 10 volume percent (vol%) ethanol. Another market that has seen dramatic increases in fuel ethanol use is "E85." "E85" is a common term to describe ethanol fuel meeting the ASTM D5798 fuel specification; however, it is a misnomer, as an on-specification fuel should never contain 85 vol% ethanol. The fuel should contain between 68 vol% and 83 vol% ethanol. Due to the common usage of this name to describe the fuel, it will be used throughout this report.

The goal of this study, a collaboration between the National Renewable Energy Laboratory and the Coordinating Research Council, was to examine the quality of "E85" fuel around the country in each of the three classes defined in ASTM D5798. The vapor pressure, measured as dry vapor pressure equivalent varies among classes due to driveability requirements as ambient temperature changes, but all other properties are the same in each class. A significant change to the 2010 version of the specification is the reduction of minimum ethanol content to 68 vol% for all classes. Previous versions of the specification required different minimum ethanol content depending on the allowable vapor pressure.

Samples were collected in 21 states between July 2010 and May 2011, with almost 40 samples collected in each class. Samples were tested for key properties in D5798-10 to assess fuel quality. The parameters tested were vapor pressure, ethanol content, water content, acidity, pHe (acid strength of high-ethanol content fuels), inorganic chloride and sulfate, and total sulfate.

Class 1 (summer) samples more often met the volatility specification than samples from other classes, with 67% of the samples collected in this study meeting the specification. Samples in Classes 2 (fall/spring) and 3 (winter) met the applicable volatility specifications 43% and 30% of the time, respectively. Compliance with the ethanol content specification was almost 90% in all three volatility classes (see Table ES-1). This is a significant improvement over previous surveys, where very few samples met the specification. Several samples that would be off-specification for ethanol content under previous versions of the specification now met the specification with the reduction in ethanol content for all classes. For the other properties tested, a few samples were off-specification for pHe, acidity, water, and inorganic chloride. Few samples were off-specification for more than one property.

Forthcoming changes to D5798-11 include a minimum ethanol content of 51 vol% for all classes. Coupled with this change in ethanol content, a fourth volatility class was added. A future study is recommended to assess how fuel properties may change with these changes in the specification.

Table ES-1. Summary of vapor pressure and ethanol content results

Class	Comments	# Samples	DVPE			Ethanol		
			Below Specification	Above Specification	On Specification	Below Specification	Above Specification	On Specification
1	All Data	42	31.0%	2.4%	66.6%	7.1%	4.8%	88.1%
2	All Data	37	56.8%	0%	43.2%	5.4%	2.7%	91.9%
3	All Data	37	70.3%	0%	29.7%	2.7%	2.7%	94.6%

Abbreviations

ASTM	ASTM International
CRC	Coordinating Research Council
DVPE	dry equivalent vapor pressure
“E85”	fuel meeting ASTM D5798-10 specifications
FFV	flex fuel vehicle
mass%	percent by mass
mg/100mL	milligrams per 100 milliliters
NREL	National Renewable Energy Laboratory
PADD	Petroleum Area Defense District
pHe	acidity of high ethanol content liquids
ppm	parts per million
ppmw	parts per million by weight
psi	pounds per square inch
RFG	reformulated gasoline
vol%	volume percent

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Introduction

The Renewable Fuels Association estimates 13 billion gallons of fuel-grade ethanol was produced in 2010.[1] Most of this ethanol is blended at 10 volume percent (vol%) with conventional gasoline. This 10 vol% blend of ethanol and gasoline is commonly referred to as E10. With what amounts to effectively a need for 12.6 billion gallons of corn-based ethanol to fulfill the total renewable fuel requirements of the 2011 Renewable Fuel Standard, the E10 market is at or near saturation. With the growth in fuel-grade ethanol production, some ethanol is exported, while other domestic markets must either expand or be developed to continue to utilize ethanol.

One potential area for increased ethanol penetration is the "E85" market. The term "E85" is colloquial, meaning a fuel that meets ASTM D5798-10 ("Standard Specification for Fuel Ethanol (Ed70-Ed85) for Automotive Spark-Ignition Engines") and has been historically described as a fuel containing nominally 85 vol% ethanol in a balance of hydrocarbons, typically gasoline. The use of the term "E85" is not rigorously correct, as D5798–compliant fuel should never contain 85 vol% ethanol and is limited in the specification to 68 to 83 vol% ethanol. The title of D5798 was changed in the 2011 (–11) version to better describe the fuel ("Standard Specification for Ethanol Fuel Blends for Flexible-Fuel Automotive Spark Ignition Engines"). However, for clarity throughout this report, the fuel will still be referred to as "E85".

"E85" is a fuel marketed specifically for flex fuel vehicles, or FFVs. Due to the higher ethanol concentration in "E85," conventional engine systems may face compatibility issues, so FFVs are designed with different materials and components to handle this high ethanol content fuel.

Over the past year, there has been an 11% growth in the number of stations around the United States that have "E85" available, with 2,433 stations reported in July 2011.[2] In 2009, a study by the National Renewable Energy Laboratory (NREL) and the Coordinating Research Council (CRC) found that many "E85" samples did not meet the required quality specifications.[3] Almost 75% of the samples had vapor pressure below the required minimum, and nearly 50% had ethanol content outside the specified range for the volatility class.

In the 2010 survey, the ethanol content was typically above the specification limit, although Class 3 samples more often met the specification. The version of D5798 published in 2010, which is applicable to the current study, included major changes in the allowable minimum ethanol content. In previous versions, the minimum ethanol content changed with volatility class, with Class 1 having a lower limit of 79 vol% ethanol, Class 2 allowing a minimum of 74 vol% ethanol, and Class 3 allowing a minimum of 70 vol% ethanol. The D5798-10 specification now allows a minimum of 68 vol% ethanol for all volatility classes.

Another potential market for fuel grade ethanol is as a blendstock for creating blends at levels between conventional gasoline and "E85." Currently, these fuels may be referred to as Exx blends, where xx is the vol% of ethanol in the fuel. The Exx fuels are dispensed out of so-called blender pumps, where at-station blending of fuels to obtain Exx blends is conducted. Although little data exist, two scenarios are possible with ethanol blender pumps. In the first case, gasoline or E10 and "E85" are blended to produce Exx fuels. In the second case, fuel-grade ethanol is blended with gasoline to produce Exx and "E85" fuels. Little data exist on the typical configuration of these blender pumps, although the quality of fuels from the blender pumps has recently been examined.[4]

The goal of this study, a collaboration between the National Renewable Energy Laboratory (NREL) and the Coordinating Research Council (CRC), was to collect "E85" samples from around the country and compare the quality to the D5798-10 specification. The work is a follow-on to the previous NREL/CRC "E85" survey.[3] A second facet to this study was to compare fuels dispensed from so-called ethanol blender pumps to fuels dispensed from conventional pumps.

Test Methodology

Samples were collected from around the United States between July 2010 and May 2011, covering a range of geographic locations. Sampling locations were based heavily on the information available in Table 2 of ASTM D5798-10, with only the 48 contiguous states considered for sampling. States with no "E85" stations were eliminated from consideration.

The highest numbers of samples were collected in the Midwest, from Petroleum Area Defense District (PADD) 2 (see Table 1 for PADD definitions). PADD 2 has the highest concentration of "E85" stations in the United States. With the exception of PADD 3 and part of PADD 5, states were only considered if all three volatility classes were represented. In PADD 3 and PADD 5, "E85" market penetration, as evidenced by number of stations, is low.[5] To collect samples in these regions, the requirement for three volatility classes was waived. Only Class 1 and 2 samples were collected from South Carolina, Florida, Arizona, and part of California.

To ease the transition from one volatility class to another, D5798-10 allows the use of "shoulder seasons." In the specification, an example shoulder season would be designated 2/1, meaning that either Class 2 "E85" or Class 1 "E85" can legally be sold during this month. In an effort to ensure the samples collected were from the appropriate volatility class, no samples were collected during shoulder seasons. When possible, samples were collected during the second full month of a season and during the last two weeks of the month.

Table 1. PADD Definitions

PADD	Included States
1 (East Coast)	CT, ME, MA, NH, RI, VT, DE, DC, NJ, NY, PA, FL, GA, NC, SC, VA, WV
2 (Midwest)	IL, IN, IA, KS, KY, MI, MN, MO, NE, ND, SD, OH, OK, TN, WI
3 (Gulf Coast)	AL, AR, LA, MS, NM, TX
4 (Rocky Mountain)	CO, ID, MT, UT, WY
5 (West Coast)	AK, AZ, CA, HI, NV, OR, WA

Approximately 40 samples were collected in each volatility class. Fifteen of 24 samples collected in PADD 2 came from so-called blender pumps. All other samples were taken from conventional pumps. Figure 1 shows the locations of the sample collected. Each station was sampled in all applicable classes. Samples were collected in the latter half of the month in an effort to ensure that no carryover fuel was present from the previous month. Appendix A-1 contains details of station location, sample collection month, and applicable volatility class.

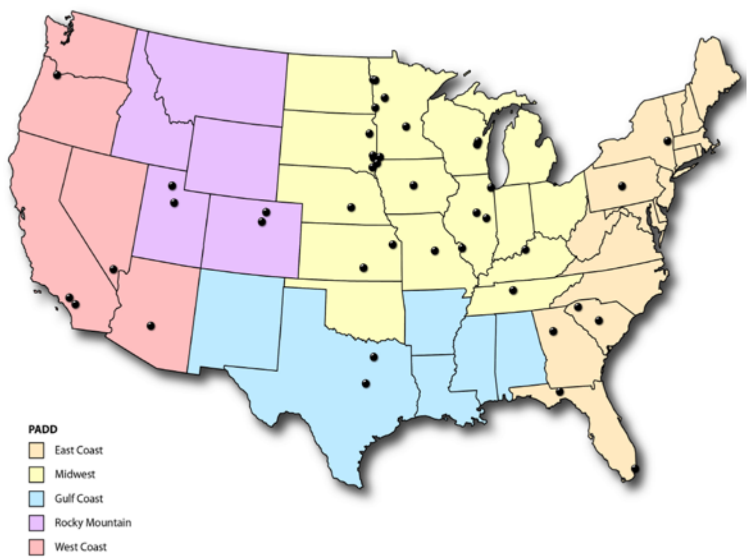

Figure 1. Sampling locations for CRC E-85-2 survey in 2011

Samples were collected and analyzed by Southwest Research Institute of San Antonio, Texas. All testing was performed per ASTM test methods for the properties listed in Table 2. The specification limits from D5798-10 are also listed in Table 2.

Table 2. Properties Tested and D5798-10 Specification Limits

Property	ASTM Method	D5798-10 Limit		
		Class 1	Class 2	Class 3
Ethanol content, vol%	D5501	68-83	68-83	68-83
Vapor Pressure, psi	D5191	5.5-8.5	7.0-9.5	9.5-12.0
All Classes				
Methanol, vol%	D5501	0.5, maximum		
Higher Alcohols, vol%	D5501	2, maximum		
Sulfur, ppmw	D5453	80, maximum		
Acidity, mass%	D1613	0.005, maximum		
Washed gum, mg/100mL	D381	5, maximum		
Unwashed gum, mg/100mL	D381	20, maximum		
pHe	D6423	6.5-9.0		
Inorganic Chloride, ppmw	D7328	1, maximum		
Water, mass%	E203	1.0, maximum		
Inorganic Sulfate, ppmw	D7328	No Limit		
Potential Sulfate, ppmw	D7328	No Limit		

Results and Discussion

Error Bars

Although the results presented in this report are typically for a single measurement on each fuel, results are presented with error bars. The error bars are taken from the ASTM test method reproducibility for all tests. Not all the test methods used in this study have a measured precision for high ethanol content fuels. The methods used in this study are listed in the specification and are commonly used to test “E85” fuels. The test methods for dry equivalent vapor pressure (DVPE) (D5191), water (E203), pHe (acidity of high ethanol content liquids) (D6423), and sulfur (D5453) have a scope and precision that cover “E85” fuels. The test methods for ethanol content (D5501), gum content (D381), acidity (D1613), and chloride and sulfate (D7328) do not cover “E85” fuels in the scope, and the precision may differ from the values used here. Thus, for lack of a better estimate of method precision, the reproducibility from the method has been used to generate the error bars. For assessing pass/fail criteria, where applicable, samples are deemed to be on-specification if either the result is within the limit or if the error bar is within the limit.

Results Summary

Samples in this survey were collected randomly from around the country. The small number of samples is not meant to be representative of “E85” in the United States. Thus, results presented are not meant to imply, either implicitly or explicitly, that the overall fuel quality of the “E85” market in would be similar to the results presented.

Table 3 summarizes the ethanol content and vapor pressure results for these samples. Samples have been divided by volatility class, then divided into three subcategories. The first subcategory is for samples, regardless of state, that are from areas that have either reformulated gasoline (RFG) areas, are ozone non-attainment areas, or have state restrictions on vapor pressure of gasolines during the summer months. The second subcategory is for samples from states with conventional gasoline and with conventional “E85” dispensers, where the fuel is blended at the terminal and delivered to the station. The third category is for samples collected from states with conventional gasoline, but dispensed by blender pumps, where the “E85” may have been blended at the terminal or at the station from denatured ethanol and gasoline.

Table 3. Summary of Vapor Pressure and Ethanol Content Compliance by Volatility Class

Class	Comments	# Samples	DVPE			Ethanol Content		
			Below Specification	**Above** Specification	**On** Specification	**Below** Specification	**Above** Specification	**On** Specification
1	All Data	42	31.0%	2.4%	66.6%	7.1%	4.8%	88.1%
	RFG/Ozone Areas and Vapor Pressure Restriction Areas	13	76.9%	0%	23.1%	7.7%	7.7%	84.6%
	Conventional Areas, Conventional Pumps	14	14.3%	7.1%	78.6%	14.3%	7.1%	78.6%
	Conventional Areas, Blender Pumps	15	6.7%	0%	93.3%	0%	0%	100%
2	All Data	37	56.8%	0%	43.2%	5.4%	2.7%	91.9%
	RFG/Ozone Areas and Vapor Pressure Restriction Areas	14	78.6%	0%	21.4%	7.1%	0%	92.9%
	Conventional Areas, Conventional Pumps	13	46.2%	0%	53.8%	7.7%	0%	92.3%
	Conventional Areas, Blender Pumps	10	40%	0%	60%	0%	10%	90%
3	All Data	37	70.3%	0%	29.7%	2.7%	2.7%	94.6%
	RFG/Ozone Areas and Vapor Pressure Restriction Areas	11	100%	0%	0%	0%	0%	100%
	Conventional Areas, Conventional Pumps	11	45.5%	0%	54.5%	0%	0%	100%
	Conventional Areas, Blender Pumps	15	66.7%	0%	33.3%	0%	6.7%	93.3%

Vapor Pressure

To ensure driveability and adequate cold start, the D5798-10 specification requires an increase in DVPE as ambient temperature decreases. The 2009 survey of "E85" noted significant vapor pressure failures across all volatility classes.[4] Overall, two-thirds of the samples in this study met the vapor pressure requirement (Figure 2). "E85" is typically blended from conventional gasoline and denatured fuel ethanol. The specification for gasoline, D4814-10, includes various requirements for gasoline properties depending on geography and time of year, and also to meet air quality requirements. Several of the samples in this project were collected from areas with additional gasoline requirements (typically lower vapor pressure), such as for ozone control, areas with RFG, or with summer vapor pressure restrictions. These areas were subcategorized to determine if the quality of "E85" differed in these areas from the quality in the rest of the country. Compared to the other two groups, this group was less likely to meet the DVPE requirements in Class 1 for the samples collected.

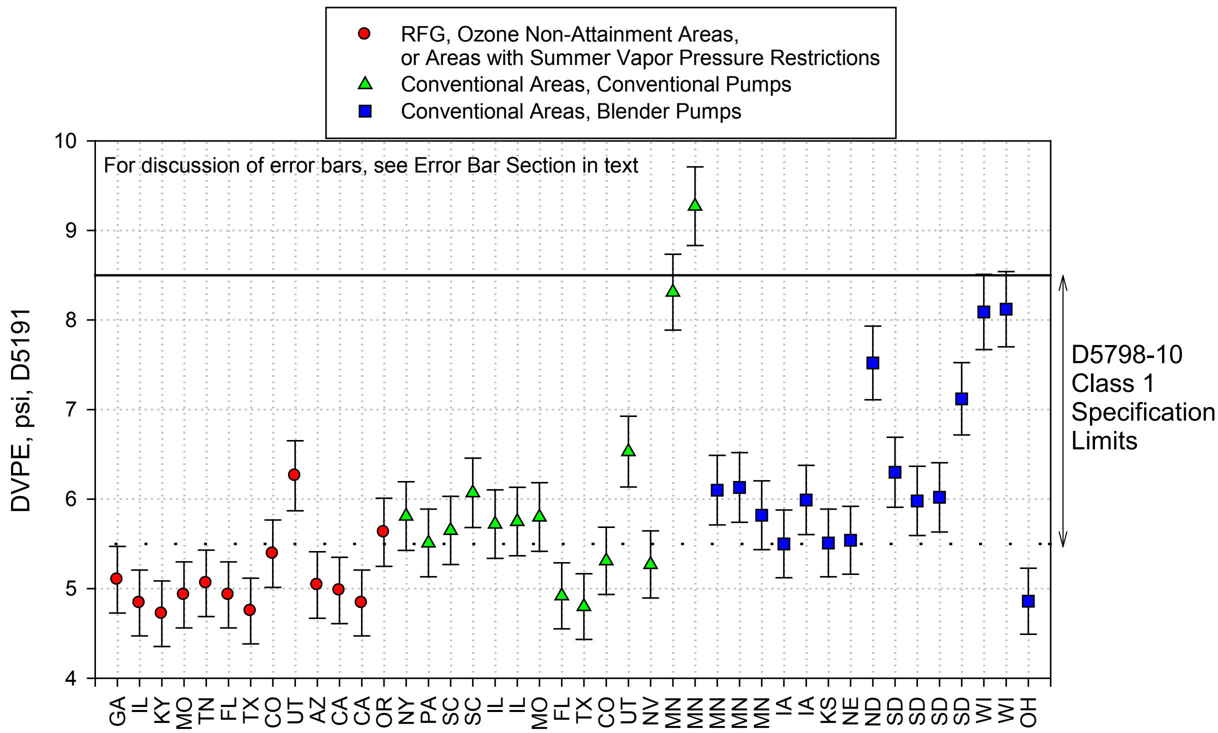

Figure 2. Class 1 DVPE results for "E85" samples.
Error bars were determined from the ASTM method reproducibility.

Only 43% of the samples in Class 2 met the vapor pressure requirements only, with little difference between sample groups (Figure 3). All the off-specification samples for this class were below the minimum required vapor pressure of 7.0 psi.

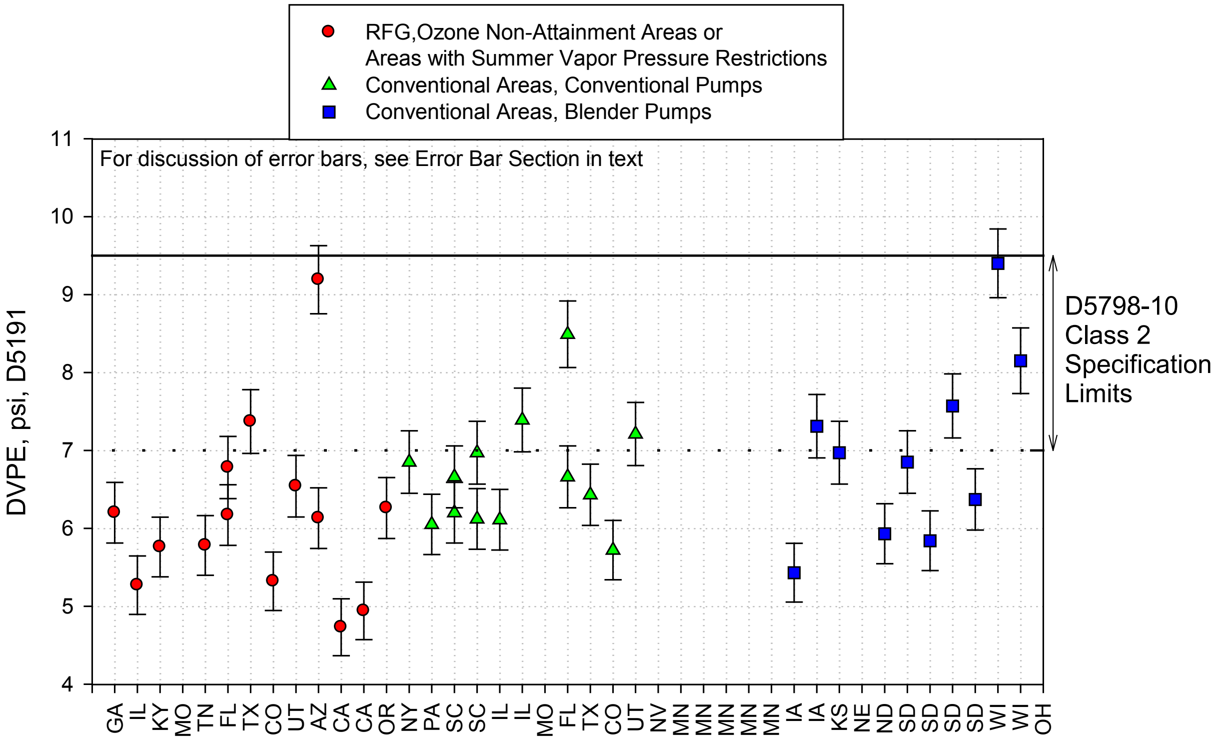

Figure 3. Class 2 DVPE results for “E85” samples.
Error bars were determined from the ASTM method reproducibility.

Similar to Class 2, the Class 3 samples were typically below the specification limit. Overall, only 30% of the samples met the specification limits (Figure 4). No samples from RFG/Ozone/State Vapor Pressure Restriction Areas met the specification minimum of 9.5 psi in this study. An increasing number of samples from the conventional areas met the vapor pressure specifications, but still less than 50% of the samples in this study did. This result appears to be counterintuitive, as gasoline during these months should have the highest vapor pressure, resulting in an "E85" blend with higher vapor pressure. As expected, no differences between the areas were noted in the Class 3 samples, in part because RFG, ozone and/or vapor pressure restrictions are strictly required between May and September only.

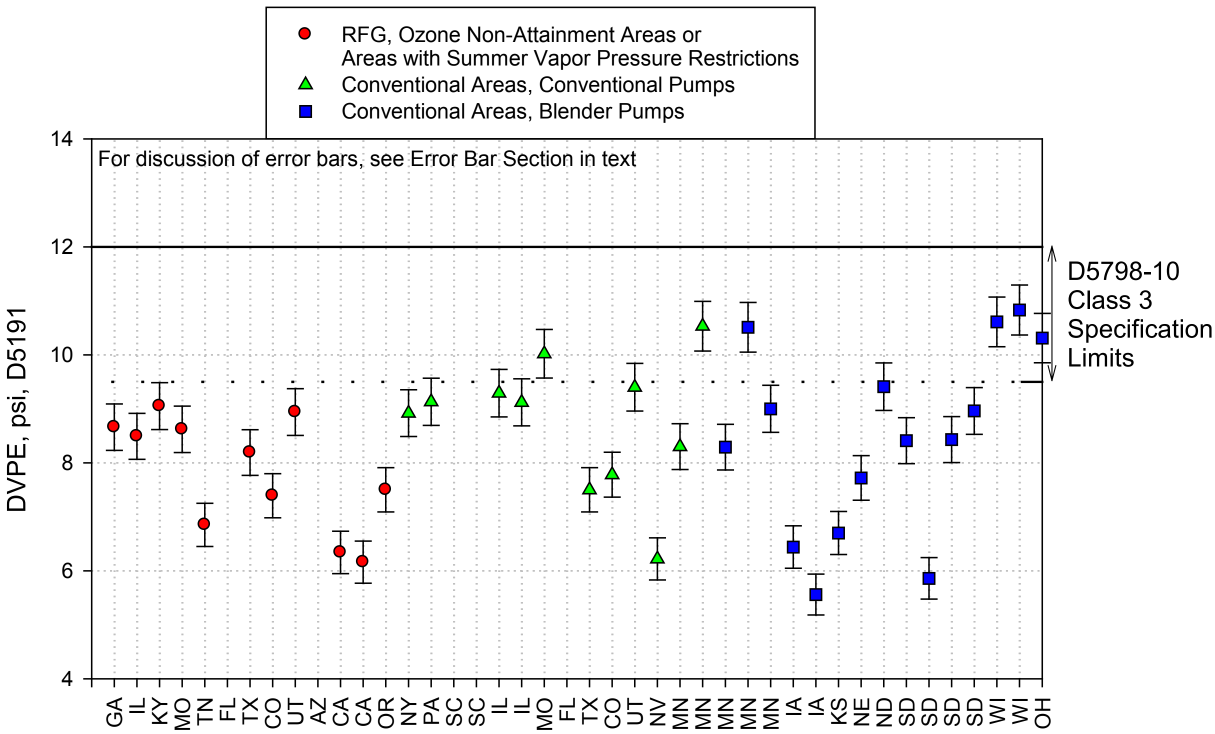

Figure 4. Class 3 vapor pressure for "E85" samples.
Error bars were determined from the ASTM method reproducibility.

Ethanol Content

The ethanol content of "E85" samples typically trends inversely to the vapor pressure, so samples with the highest vapor pressures have the lowest ethanol content. The reverse also holds true: samples with the lowest vapor pressures have the highest ethanol contents. Figure 5 shows the relationship between vapor pressure and ethanol content for all the data in this survey, separated by volatility class.

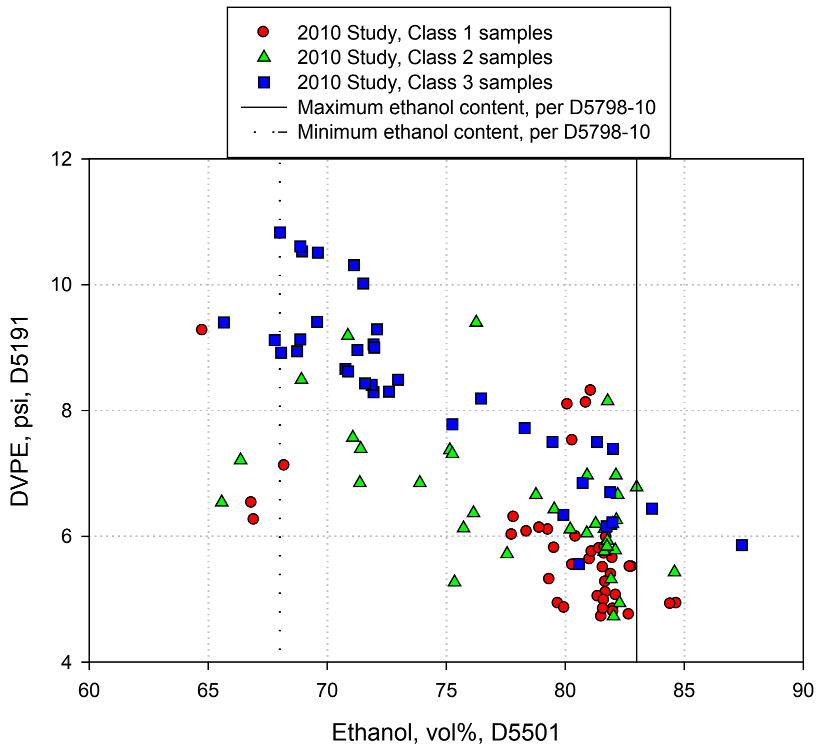

Figure 5. Ethanol content as a function of volatility for samples collected in this study

To further illustrate the ethanol content of the samples collected in this study, the data have been separated by volatility class. The ethanol content of the Class 1 samples was typically at the higher end of the specification limit, averaging 80 vol% across all samples. There was little difference between samples collected in the various regions around the country (Figure 6). Although the specification limits do not change with volatility class in the D5798-10 version of the specification, this was the first version published with the common specification limits. Three samples that meet the D5798-10 specification limit for ethanol content would not have met the requirements of previous versions (with a minimum ethanol content of 79 vol% for Class 1). Similar to the last study, a few samples are below the specification minimum.

In Class 2, the ethanol content of the samples begins to vary more within the allowable specification limits. Although the average is 78 vol%, the range extends from 66 vol% to 85 vol% (Figure 7). Four samples that would have failed previous versions of D5798 (minimum ethanol content of 74 vol% in previous versions) are now on specification. There are no significant differences among the samples based on region of collection.

Figure 8 shows the ethanol content for the samples collected in Class 3. The D5798-10 version reduced the minimum allowable ethanol content to 68 vol%, compared to previous versions of the specification that required 70 vol% minimum ethanol content. In this survey for Class 3, seven samples that would have previously failed are now on specification. This class showed the largest variability in ethanol content between samples. The average ethanol content was 74 vol%, and ranged from 66 vol% to 87 vol%.

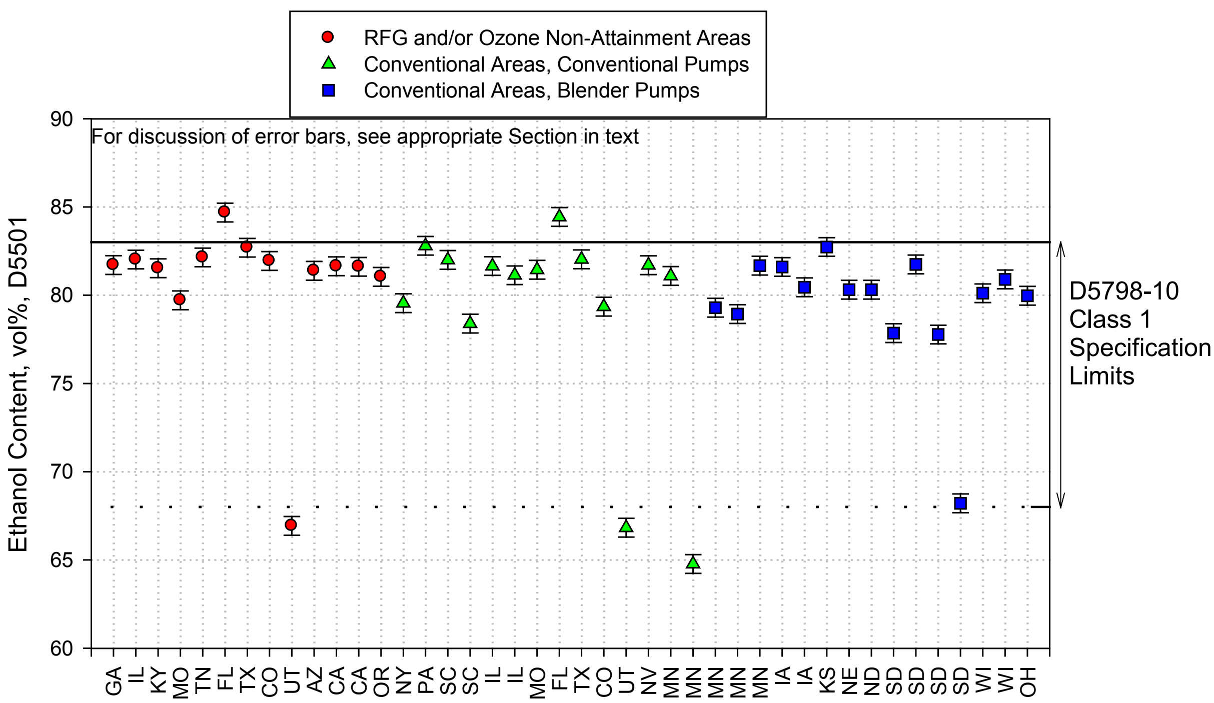

Figure 6. Ethanol content of Class 1 samples

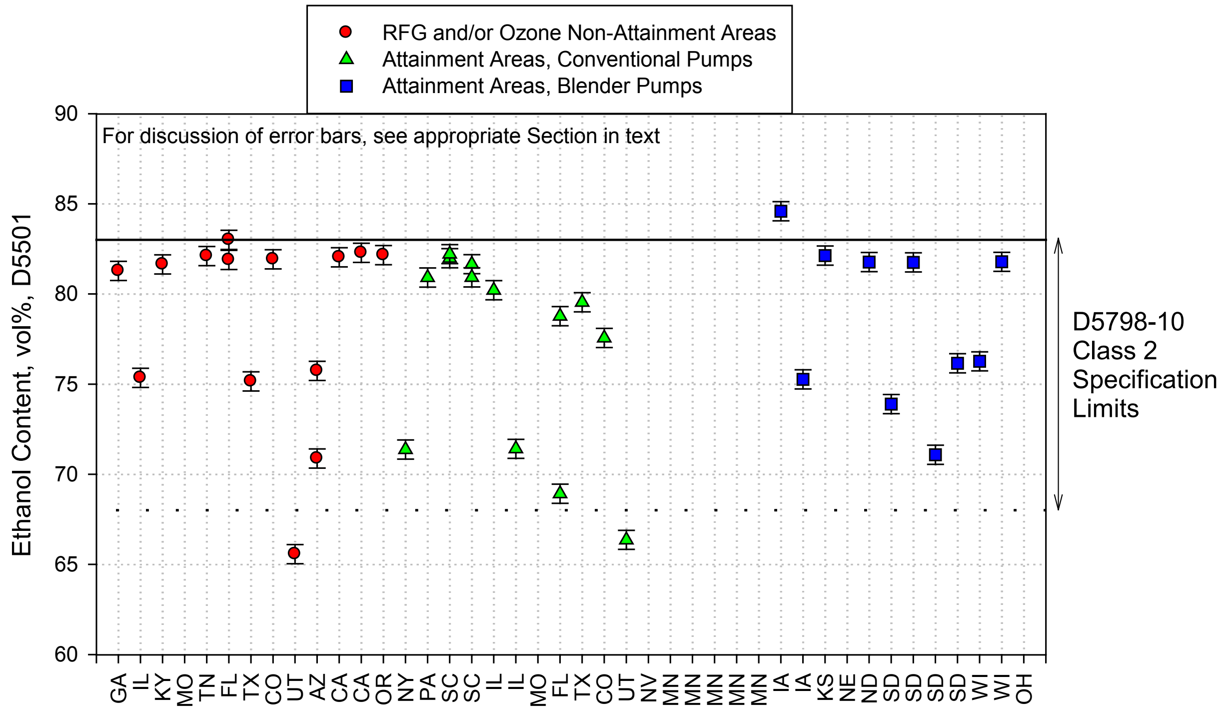

Figure 7. Ethanol content of Class 2 samples

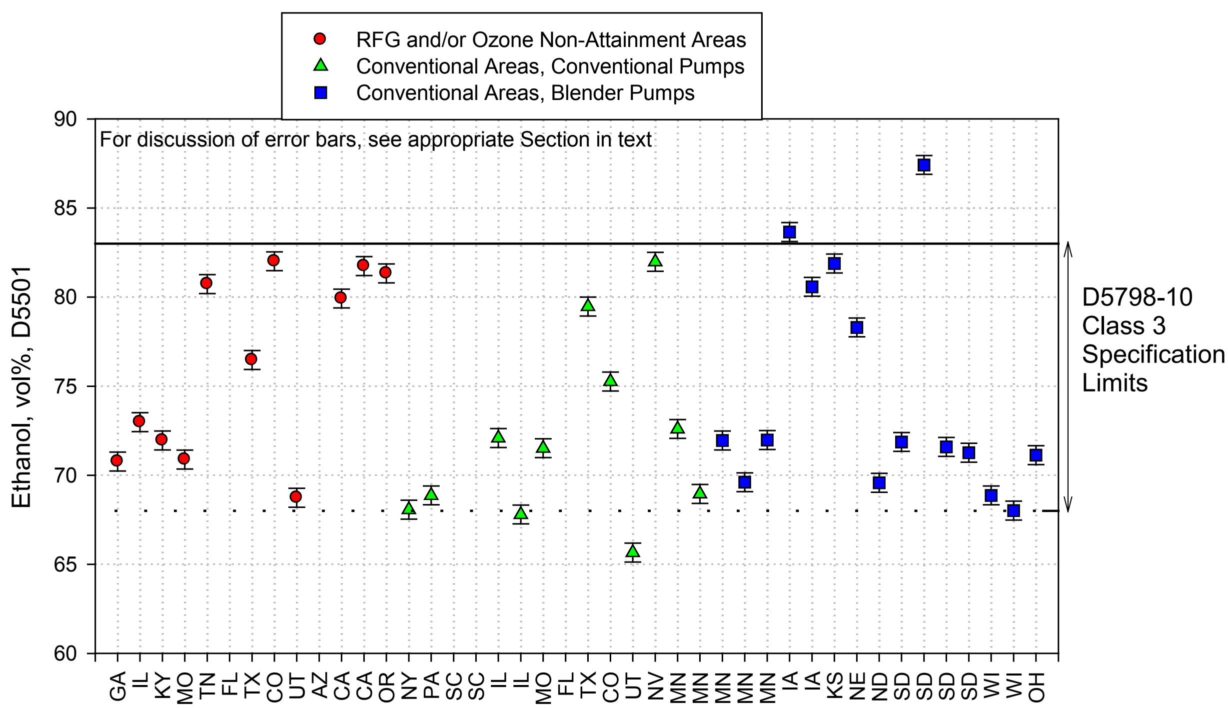

Figure 8. Ethanol content of Class 3 samples

Water Content

Ethanol-gasoline blends may have more dissolved water due to the highly polar nature of the ethanol in the blend. All samples in this project were tested for water content. The average water content for these samples was 0.7 mass% for Classes 1 and 3 and 0.8 mass% for Class 2. There is no apparent influence of ethanol content of the samples on the measured water content. Only two samples failed to meet the water content specification of D5798-10. One of the samples was from Class 2, from the state of Texas; the other out-of-specification sample was from Class 3, from the state of Illinois. The data are illustrated in Figures 9–11.

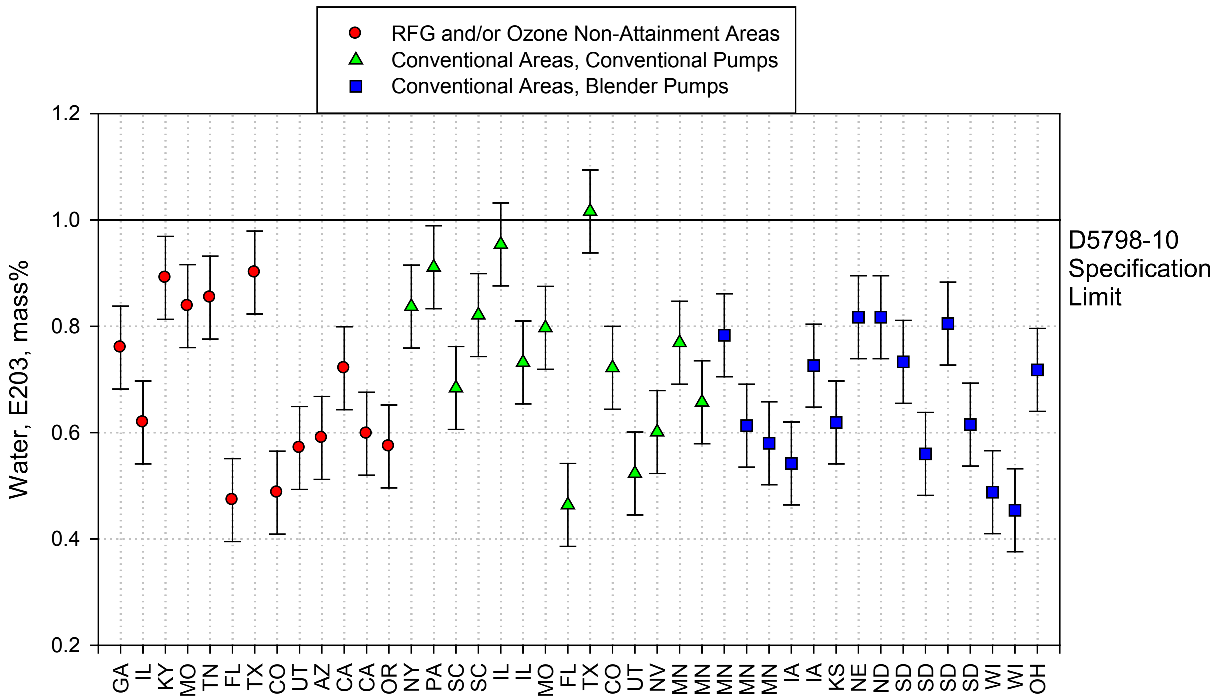

Figure 9. Water content in Class 1 samples

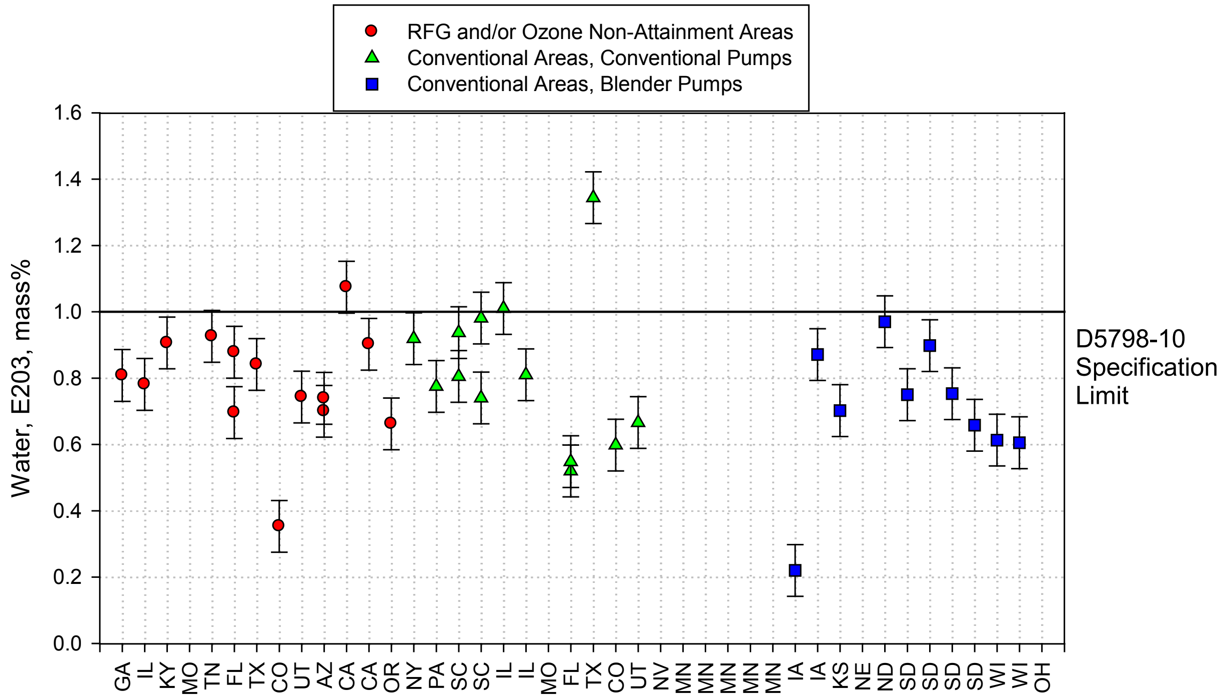

Figure 10. Water content in Class 2 samples

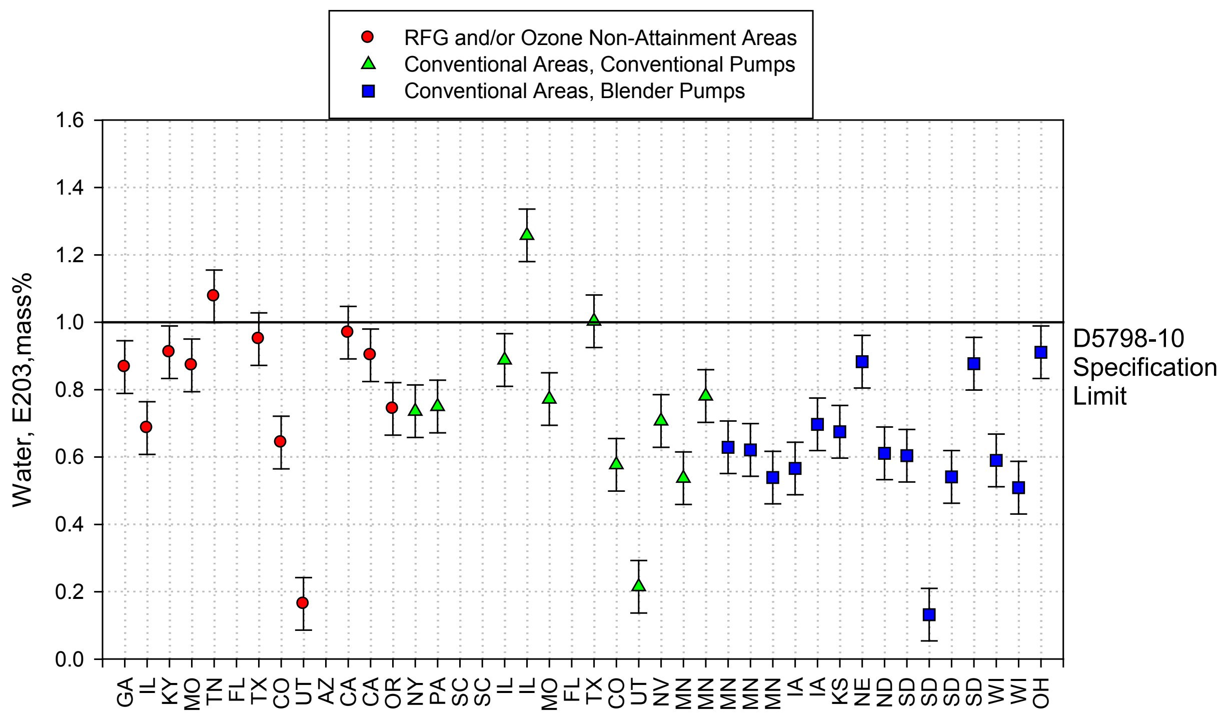

Figure 11. Water content in Class 3 samples

pHe

The pHe measures the acid strength of high-ethanol content fuels. High values may result in fuel corrosivity. All of the samples collected in this study readily met the pHe specification, with the average value being around 7.2. Figures 12–14 show the pHe results for the three volatility classes.

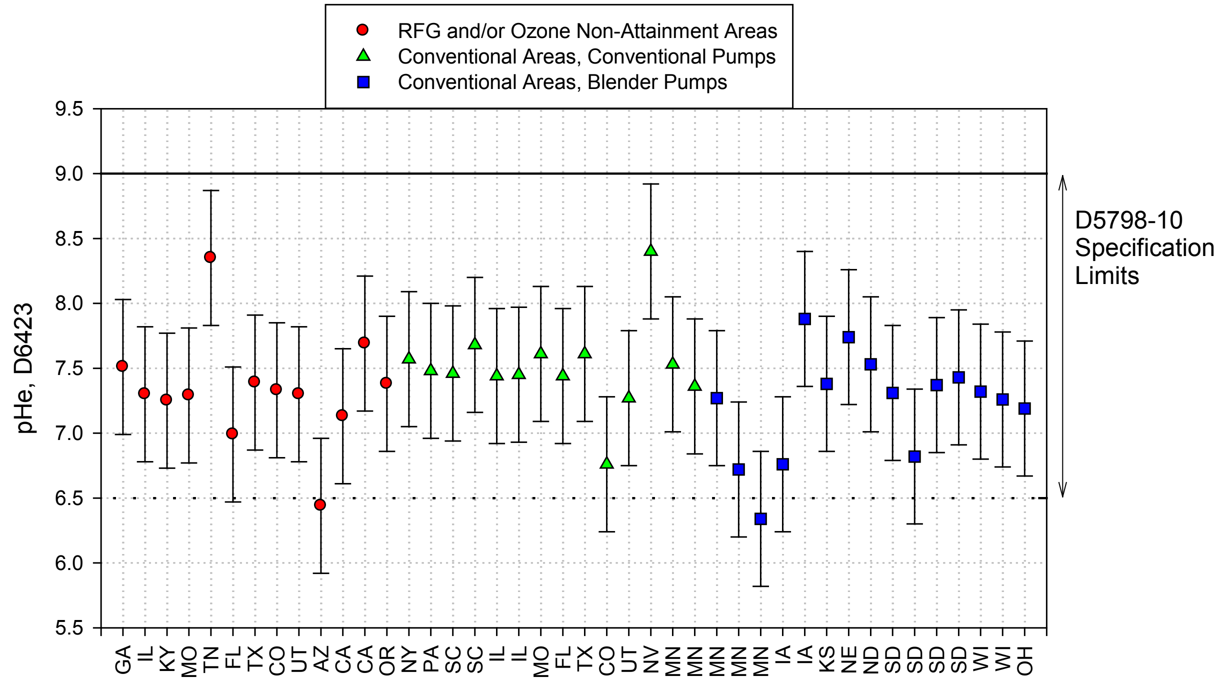

Figure 12. pHe of Class 1 samples

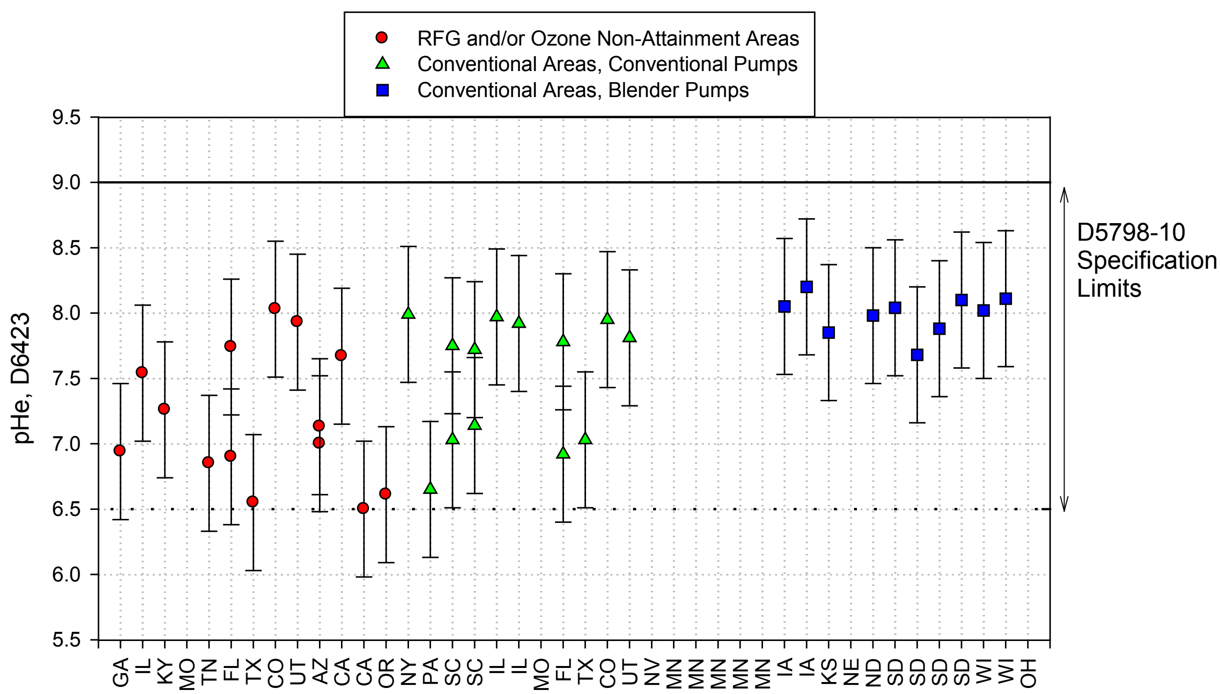

Figure 13. pHe of Class 2 samples

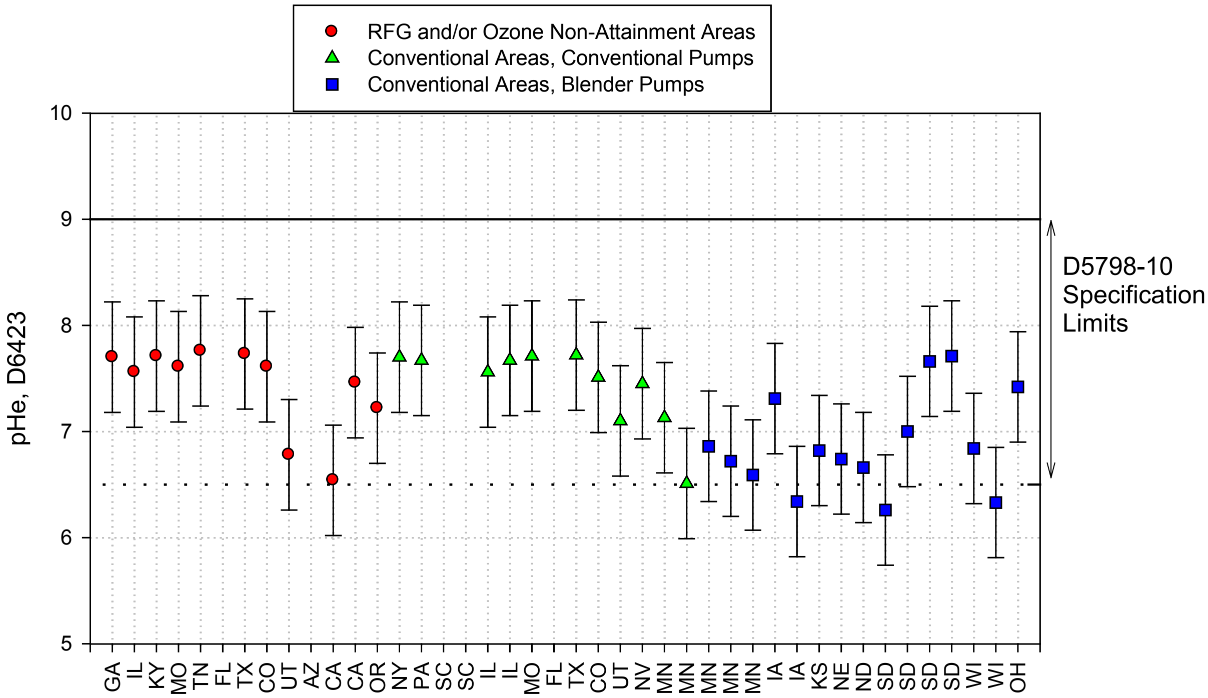

Figure 14. pHe of Class 3 samples

Acidity

Acids in fuels can be corrosive and lead to component failures. In past surveys, samples typically met the acidity specification, with a few exceptions. The same trend is observed in this work, where samples generally meet the specification maximum. The acidity results for Class 1 are shown in Figure 15. Four samples did not meet the specification; three values were only slightly above the limit and one was a gross failure. Only one sample in Class 2 failed to meet the specification (Figure 16). Three samples failed in Class 3, with two samples almost an order of magnitude greater than the acidity specification limit (Figure 17). The handful of samples from Class 1 and Class 3 that were significantly higher than the allowable specification were retested several times, with similar results each time.

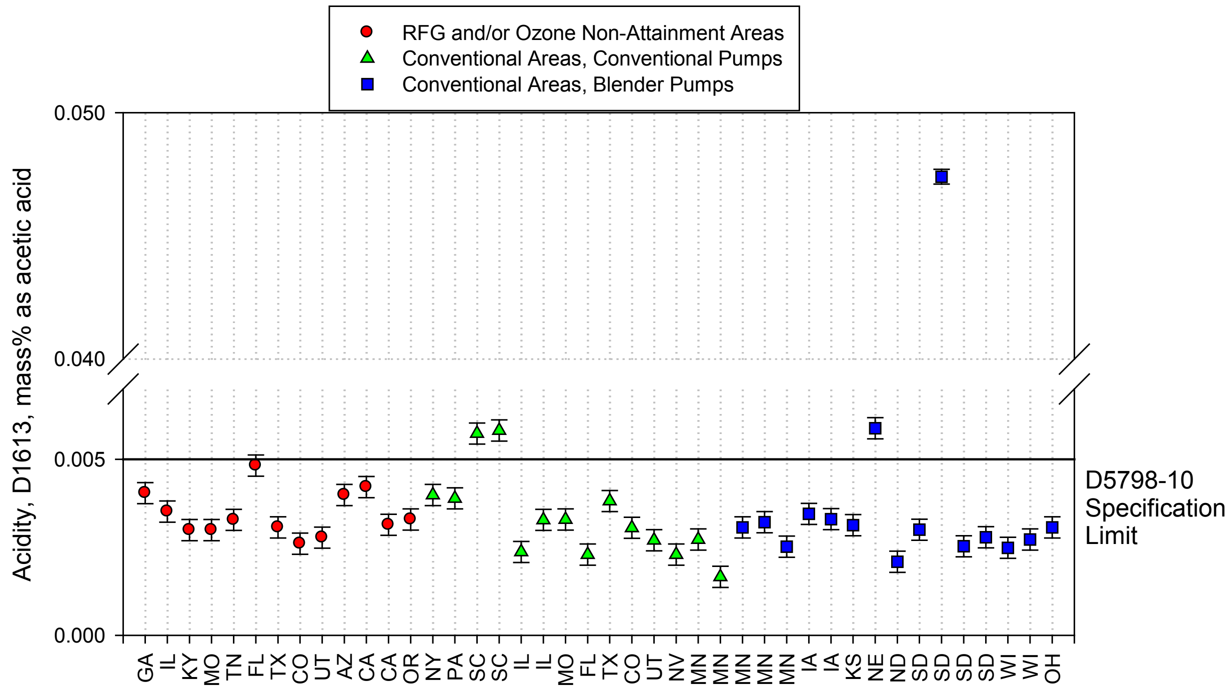

Figure 15. Acidity results for Class 1 samples

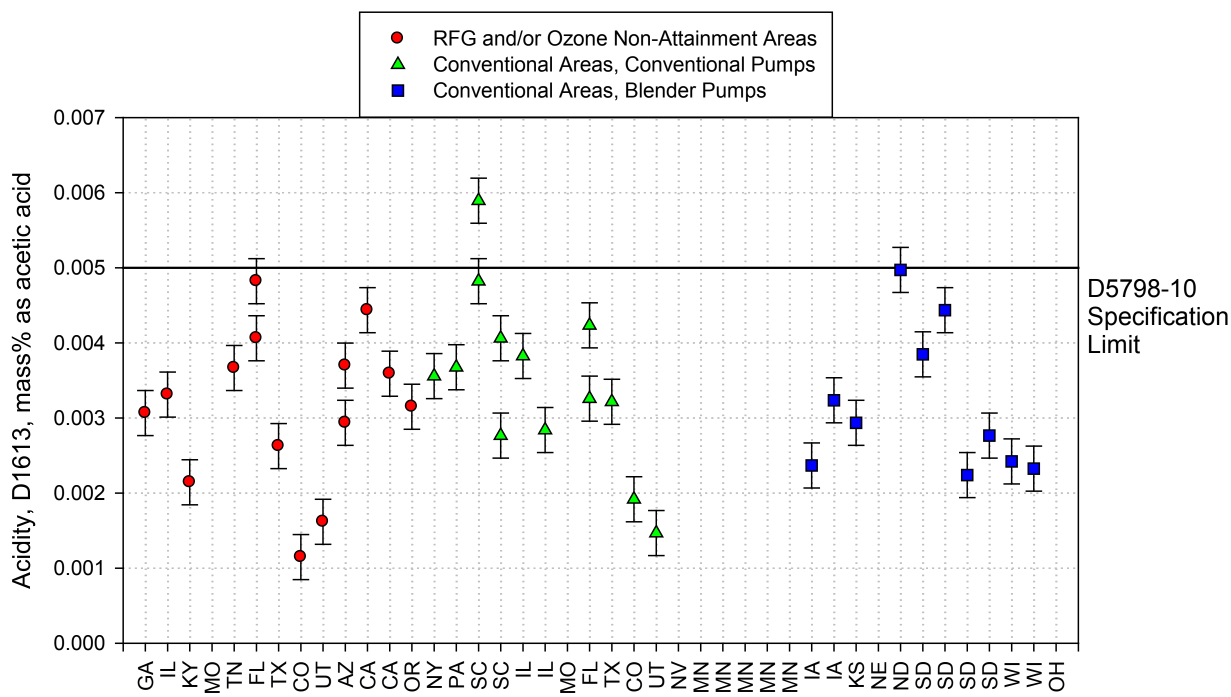

Figure 16. Acidity results for Class 2 samples

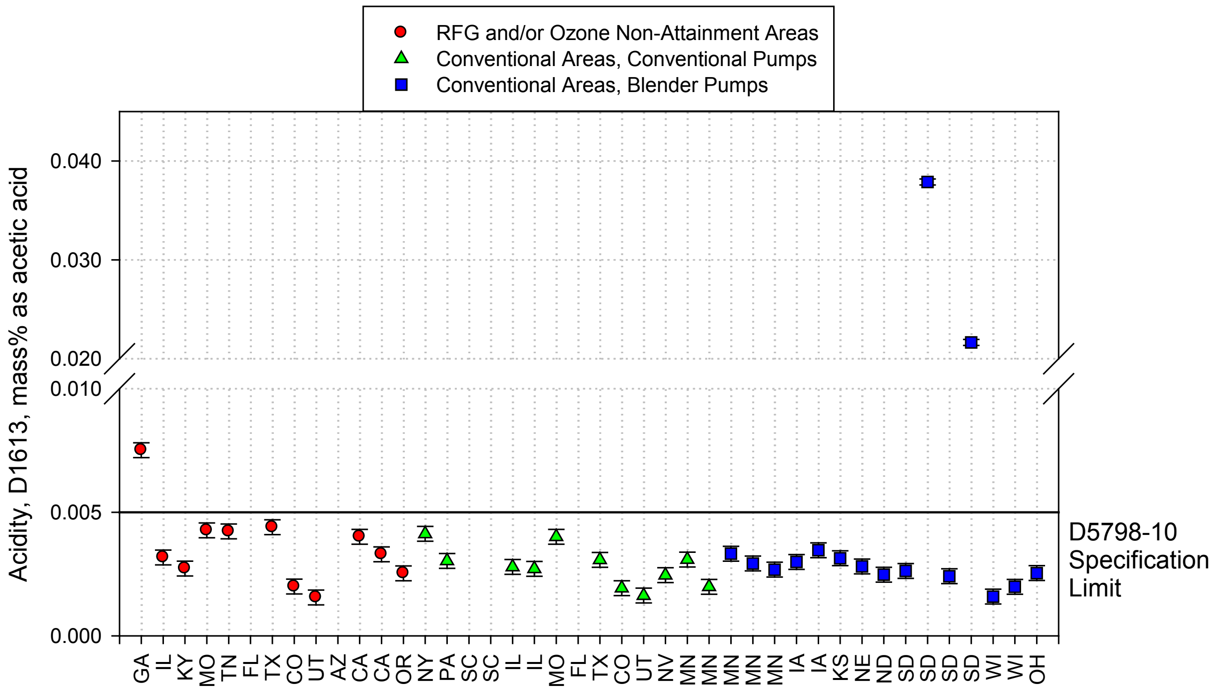

Figure 17. Acidity results for Class 3 samples

Sulfur Content

The maximum allowable sulfur content in "E85" is 80 ppm. Every sample in this study easily met this specification limit. The highest sulfur content measured was 39 ppm, half the specification limit.

Washed and Unwashed Gum Content

The unwashed gum content of these "E85" fuels was below the maximum specification of 20 mg/100mL for every sample in Class 1 and Class 2. Two samples in Class 3 greatly exceeded the unwashed gum specification maximum of 20 mg/100 mL, but did not fail for other properties, such as acidity; these samples had unwashed gum content of 80 mg/100mL and over 200 mg/100mL. Despite the high unwashed gum content, these samples had washed gum near the method detection limit of 0.5 mg/100 mL. All the samples in this study were at or near this detection limit.

Inorganic Chloride, Inorganic Sulfate, and Potential Sulfate

Only the inorganic chloride content of "E85" fuels is limited in the D5798-10 specification. Samples were also tested for inorganic sulfate and potential sulfate. One sample in Class 1 and two samples in Class 3 did not meet the 1-ppm maximum for chloride. One of the Class 3 samples was also an order of magnitude greater than the acidity specification. The inorganic and potential sulfate results are less than 5 ppm for all samples.

Conclusions

The goal of this project was to assess the quality of "E85" in the United States compared to the specifications in ASTM D5798-10. The term "E85" is the name given to fuels that meet ASTM D5798-10 and are used in flex fuel vehicles and contain 68 vol% to 83 vol% ethanol. Samples of "E85" were collected from public stations around the country between July 2010 and May 2011. Samples were collected either from conventional pumps, where the "E85" is blended at the terminal and delivered to the station, or from blender pumps, typically located in the Midwest. Samples taken from these blender pumps were leveraged to conduct a smaller study on the quality of fuels from these pumps. Results from that study are presented in Reference 4.

Samples were collected at each station in each of the three volatility classes, where possible, as defined in D5798-10. Overall, approximately 40 samples were collected in each class, with a total project sampling of 116 samples. The samples were analyzed for the following properties in D5798-10, including vapor pressure, ethanol content, gum content, acidity, pHe, water, inorganic chloride, sulfate and potential sulfate.

Although not a goal of this study, the samples were divided into categories to determine if there is any impact on properties due to region or type of pump. About one-quarter of the samples were collected from areas that have RFG, ozone non-attainment status, and/or have vapor pressure restrictions for air quality for the conventional gasoline. Another quarter of the samples were collected from stations with blender pumps. The remaining samples were collected from conventional "E85" pumps throughout the country.

Results for vapor pressure and ethanol content for the samples, across all regions and classes, are summarized in Table 3. For Class 1, meeting the DVPE for "E85" samples is more difficult in RFG regions, due to the lower DVPE required for summertime gasoline in these regions. Overall, two-thirds of the samples in this study met the DVPE requirements for Class 1. Samples collected in Classes 2 and 3 met the DVPE 43% and 30% of the time, respectively. On average, 90% of these samples met the ethanol content specifications. Some variability was observed in Class 1 between the RFG regions and conventional regions, though over 75% of the samples fell within the ethanol requirements.

Samples generally met the water specification, although a few samples were slightly above the specification maximum. There was no impact of sample collection location on the water content of the samples, thus samples from coastal regions did not differ from samples collected in land-locked states.

No failures were noted for pHe, and a majority of the samples met the acidity specification. It is notable that the samples that did not meet the acidity specification were gross failures, almost an order of magnitude greater than the specification limit. One of these samples also failed the chloride specification. Similar to the other properties, over 95% of the samples met the chloride specification requirements.

In 2011, significant changes to the D5798 specification were published as D5798-11. These changes include the addition of a fourth volatility class and the reduction of the minimum ethanol content in each class to 51 vol%. A follow-on study is highly recommended to examine how these significant changes to the specification have impacted "E85" quality.

References

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2. Ethanol Retailer. "New E85 and Flex Fuel Pump Stations." July 15, 2011 News Archive; http://www.ethanolretailer.com/templates/news-archive/2011/07/#top; Accessed July 28, 2011.
3. Alleman, T.L. "National Survey of E85 Quality." CRC Report No. E-85, November 2009. http://www.crcao.org/reports/recentstudies2009/E-85/E-85%20Final%20Report%20_120609_%20Revised.pdf
4. Alleman, T.L. "Blender Pump Fuel Survey: CRC Project E-95." NREL/TP-5400-51863. Golden, CO:National Renewable Energy Laboratory. July 2011. http://www.nrel.gov/docs/fy11osti/51863.pdf
5. Alternative Fuels and Advanced Vehicles Data Center. "E85 Fueling Station Locations." http://www.afdc.energy.gov/afdc/ethanol/ethanol_locations.html, Accessed May 15, 2010.

Appendices

Appendix A-1

Station Locations and Sampling Date

Location	Class 1 Date	Class 2 Date	Class 3 Date
Atlanta, GA	7/21/10	11/17/10	1/24/11
Chicago, IL	7/20/10	5/18/11	1/26/11
Louisville, KY	7/20/10	10/20/10	1/26/11
St Louis, MO	7/26/10	No Class 2 Season	2/18/11
Nashville, TN	7/16/10	10/20/10	2/17/11
Miami, FL	7/21/10	11/19/10 3/22/11	No Class 3 Season
Sachse, TX	7/19/10	10/14/10	2/15/11
Thornton, CO	7/22/10	5/19/11	1/25/11
Clearfield, UT	7/22/10	5/17/11	1/28/11
Scottsdale, AZ	7/20/10	11/18/10 3/16/10	No Class 3 Season
Pomona, CA	7/20/10	3/16/11	12/20/10
Perris, CA	7/22/10	10/21/10	1/28/11
Portland, OR	7/23/10	10/20/10	12/20/10
Glenmont, NY	7/20/10	5/18/11	2/23/11
State College, PA	7/20/10	10/19/10	1/27/11
W Columbia, SC	7/20/10	11/18/10 3/18/11	No Class 3 Season
Greenville, SC	7/16/10	11/16/10 3/18/11	No Class 3 Season
Champaign, IL	7/26/10	5/25/11	2/21/11
Bloomington, IL	7/26/10	5/25/11	2/21/11
Jefferson City, MO	7/21/10	No Class 2 Season	1/26/11
Tallahassee, FL	7/21/10	11/19/10 3/17/11	No Class 3 Season
Waco, TX	7/20/10	10/19/10	1/26/11
Greeley, CO	7/22/10	5/19/11	2/21/11
East Provo, UT	7/22/10	5/17/11	2/17/11
Las Vegas, NV	7/21/10	5/17/11	2/21/11
Windom, MN	7/21/10	No Data Collected	11/19/10

Location	Class 1 Date	Class 2 Date	Class 3 Date
Heron Lake, MN	7/21/10	No Data Collected	11/19/10
Inwood, IA	7/17/10	5/17/11	11/19/10
Gilbert, IA	7/18/10	5/16/11	11/23/10
Lawrence, KS	7/17/10	5/12/11	11/16/10
Luverne, MN	7/14/10	No Data Collected	11/19/10
Annandale, MN	7/15/10	No Data Collected	11/22/10
Crookston, MN	7/19/10	No Data Collected	11/19/10
Grand Island, NE	7/19/10	5/18/11	11/17/10
Wahpeton, ND	7/14/10	No Data Collected	11/19/10
Sioux Falls, SD	8/1/10	5/17/11	11/22/10
Baltic, SD	8/1/10	5/17/11	11/22/10
Watertown, SD	7/18/10	5/23/11	3/24/11
Beresford, SD	7/17/10	5/20/11	3/24/11
Grand Chute, WI	7/18/10	5/16/11	11/18/10
Oshkosh, WI	7/18/10	5/16/11	11/18/10
Columbiana, OH	8/1/10	No Class 2 Season	3/31/11

Appendix A-2

Class 1 Results

City/State	DVPE, psi, D5191	Acidity, mass% as acetic acid, D1613	Unwashed gum, mg/100mL, D381	Washed gum, mg/100mL, D381	Water, mass%, E203	Sulfur, ppm, D5453	Ethanol, vol%, D5501	pHe, D6423	Inorganic Chloride, ppm, D7328	Inorganic Sulfate, ppm, D7328	Potential Sulfate, ppm, D7328
Atlanta, GA	5.1	0.004	2	0.5	0.76	3.6	81.71	7.51	0.1	0.1	0.1
Chicago, IL	4.84	0.004	3.5	0.5	0.619	6.6	82.02	7.3	0.1	0.1	0.2
Louisville, KY	4.72	0.003	6	0.5	0.891	3.2	81.53	7.25	0.1	0.2	0.4
St Louis, MO	4.93	0.003	6.5	0.5	0.838	6.2	79.71	7.29	0.1	0.2	0.3
Nashville, TN	5.06	0.003	2	0.5	0.854	6.9	82.14	8.35	0.1	0.1	0.1
Miami, FL	4.93	0.005	2	0.5	0.473	3.5	84.68	6.99	1.6	0.1	0.1
Sachse, TX	4.75	0.003	3.5	0.5	0.901	5	82.69	7.39	0.1	1.1	1.2
Thornton, CO	5.39	0.003	5	0.5	0.487	20	81.94	7.33	0.1	0.4	0.4
Clearfield, UT	6.26	0.003	3	0.5	0.571	9.9	66.93	7.3	0.1	1.2	0.1
Scottsdale, AZ	5.04	0.004	6.5	0.5	0.59	6.2	81.38	6.44	0.1	1.3	1.3
Pomona, CA	4.98	0.004	3	0.5	0.721	2.7	81.64	7.13	0.1	0.2	0.2
Perris, CA	4.84	0.003	3	0.5	0.598	3.1	81.61	7.69	0.1	0.1	0.1
Portland, OR	5.63	0.003	3.5	0.5	0.574	6.5	81.04	7.38	0.1	0.8	0.8
Glenmont, NY	5.81	0.004	2	0.5	0.837	10.1	79.55	7.57	0.1	0.1	0.1
State College, PA	5.51	0.004	1.5	0.5	0.911	6.1	82.8	7.48	0.1	0.1	0.1
W Columbia, SC	5.65	0.006	2.5	0.5	0.684	7.6	82	7.46	0.1	0.8	0.9
Greenville, SC	6.07	0.006	3.5	0.5	0.821	9.1	78.39	7.68	0.1	0.6	0.6
Champaign, IL	5.72	0.002	3	0.5	0.954	7.1	81.65	7.44	0.1	0.5	0.7
Bloomington, IL	5.75	0.003	4	0.5	0.732	4.6	81.13	7.45	0.1	0.3	0.5
Jefferson City, MO	5.8	0.003	2	0.5	0.797	11	81.44	7.61	0.1	0.1	0.2
Tallahassee, FL	4.92	0.002	5	1	0.464	6.6	84.43	7.44	0.1	0.1	0.2
Waco, TX	4.8	0.004	3.5	0.5	1.016	9.2	82.03	7.61	0.1	0.9	1.2
Greeley, CO	5.31	0.003	3	0.5	0.722	10.9	79.35	6.76	0.1	2.7	2.7

City/State	DVPE, psi, D5191	Acidity, mass% as acetic acid, D1613	Unwashed gum, mg/100mL, D381	Washed gum, mg/100mL, D381	Water, mass%, E203	Sulfur, ppm, D5453	Ethanol, vol%, D5501	pHe, D6423	Inorganic Chloride, ppm, D7328	Inorganic Sulfate, ppm, D7328	Potential Sulfate, ppm, D7328
East Provo, UT	6.53	0.003	2	0.5	0.523	10.3	66.83	7.27	0.1	1	1.2
Las Vegas, NV	5.27	0.002	12	1	0.601	6.5	81.7	8.4	0.1	1.1	1.1
Windom, MN	8.31	0.003	1	0.5	0.769	10.6	81.09	7.53	0.1	0.2	0.3
Heron Lake, MN	9.27	0.002	1	0.5	0.657	25.6	64.77	7.36	0.1	0.2	0.2
Inwood, IA	5.5	0.003	2	0.5	0.542		81.6	6.76	0.1	0.2	0.3
Gilbert, IA	5.99	0.003	1.5	0.5	0.726		80.45	7.88	0.1	0.1	0.1
Lawrence, KS	5.51	0.003	1	0.5	0.619		82.73	7.38	0.1	0.2	0.2
Luverne, MN	6.1	0.003	3	0.5	0.783		79.29	7.27	0.1	0.3	0.3
Annandale, MN	6.13	0.003	1.5	0.5	0.613		78.93	6.72	0.1	0.2	0.2
Crookston, MN	5.82	0.003	3	0.5	0.58		81.67	6.34	0.1	2.3	2.3
Grand Island, NE	5.54	0.006	1	0.5	0.817		80.31	7.74	0.1	1.3	1.3
Wahpeton, ND	7.52	0.002	1	0.5	0.817		80.31	7.53	0.1	0.2	0.3
Sioux Falls, SD	6.3	0.003	2	0.5	0.733		77.85	7.31	1	0.3	1
Baltic, SD	5.98	0.047	1	0.5	0.56		81.74	6.82	1	0.2	1
Watertown, SD	6.02	0.003	2	0.5	0.805		77.77	7.37	0.1	0.2	0.3
Beresford, SD	7.12	0.003	3.5	0.5	0.615		68.21	7.43	0.1	0.3	0.4
Grand Chute, WI	8.09	0.002	3	1	0.488		80.11	7.32	0.1	1.1	1.1
Oshkosh, WI	8.12	0.003	2.5	0.5	0.454		80.89	7.26	0.1	1	1
Columbiana, OH	4.86	0.003	4	0.5	0.718		79.97	7.19	-0.1	0.7	0.8

Class 2 Results

City/State	DVPE, psi, D5191	Acidity, mass% as acetic acid, D1613	Unwashed gum, mg/100mL, D381	Washed gum, mg/100mL, D381	Water, mass%, E203	Sulfur, ppm, D5453	Ethanol, vol%, D5501	pHe, D6423	Inorganic Chloride, ppm, D7328	Inorganic Sulfate, ppm, D7328	Potential Sulfate, ppm, D7328
Atlanta, GA	6.2	0.003	1	<0.5	0.808	3.6	81.28	6.94	<0.1	0.4	0.4
Chicago, IL	5.27	0.003	3.5	0.5	0.781	12.1	75.35	7.54	<0.1	1.8	2
Louisville, KY	5.76	0.002	6.5	<0.5	0.906	3.2	81.64	7.26	<0.1	0.4	<1
Nashville, TN	5.78	0.004	2.5	0.5	0.926	6.1	82.1	6.85	<0.1	0.2	<1
Miami, FL	6.17 6.78	0.005 0.004	1.5 2	<0.5 0.5	0.696 0.878	2.3 3.6	81.89 83	6.90 7.74	0.5 0.1	<0.1 0	0.1 0.4
Sachse, TX	7.37	0.003	3	<0.5	0.841	8	75.15	6.55	<0.1	1.2	1.3
Thornton, CO	5.32	0.001	6	<0.5	0.353	8.8	81.92	8.03	<0.1	0.3	0.5
Clearfield, UT	6.54	0.002	2	<0.5	0.743	9.8	65.57	7.93	<0.1	<0.1	0.3
Scottsdale, AZ	9.19 6.13	0.003 0.004	3 5.5	<0.5 <0.5	0.7 0.739	18.6 4.4	70.87 75.73	7.00 7.13	<0.1 0	0.2 1.9	0.3 1.8
Pomona, CA	4.73	0.004	3	<0.5	1.074	3.2	82.03	7.67	0	0	0
Perris, CA	4.94	0.004	2.5	<0.5	0.902	2.5	82.28	6.5	<0.1	0.3	<1
Portland, OR	6.26	0.003	4	0.5	0.662	4.4	82.15	6.61	<0.1	0.4	<1
Glenmont, NY	6.85	0.004	3.5	<0.5	0.919	12.6	71.37	7.99	<0.1	0.4	0.5
State College, PA	6.05	0.004	4	0.5	0.775	5.9	80.91	6.65	<0.1	0.4	<1
West Columbia, SC	6.2 6.66	0.006 0.005	2.5 1	<0.5 <0.5	0.805 0.937	7 6.7	81.98 82.21	7.03 7.75	<0.1 0	0.2 0.8	0.40.7
Greenville, SC Greenville, SC	6.12 6.97	0.004 0.003	2 2.5	0.5 <0.5	0.74 0.981	6.6 7.8	81.65 80.92	7.14 7.72	<0.1 0.1	0.2 0.7	0.3 0.8
Champaign, IL	6.11	0.004	2	<0.5	1.01	10.2	80.21	7.97	<0.1	0.3	0.4
Bloomington, IL	7.39	0.003	1	<0.5	0.81	8	71.41	7.92	<0.1	0	0.3
Tallahassee, FL	6.66 8.49	0.004 0.003	1 3.5	<0.5 <0.5	0.52 0.548	8.2 11.8	78.77 68.92	6.92 7.78	<0.1 0	0.1 0	0.2 0.4

City/State	**DVPE, psi,** D5191	**Acidity, mass%** as acetic acid, D1613	**Unwashed gum,** mg/100mL, D381	**Washed gum,** mg/100mL, D381	**Water, mass%,** E203	**Sulfur, ppm,** D5453	**Ethanol, vol%,** D5501	**pHe,** D6423	**Inorganic Chloride,** ppm, D7328	**Inorganic Sulfate,** ppm, D7328	**Potential Sulfate,** ppm, D7328
Waco, TX	6.43	0.003	2	0.5	1.344	8.7	79.54	7.03	<0.1	0.7	<1
Greeley, CO	5.72	0.002	1.5	0.5	0.598	9.7	77.56	7.95	<0.1	0.6	0.9
Provo, UT	7.21	0.001	11.5	<0.5	0.666	11.6	66.36	7.81	<0.1	0.4	0.6
Inwood, IA	5.43	0.002	2	<0.5	0.22	6.4	84.59	8.05	<0.1	0.2	0.3
Gilbert, IA	7.31	0.003	2	<0.5	0.871	6.8	75.26	8.2	<0.1	0	0.3
Lawrence, KS	6.97	0.003	3	<0.5	0.702	6.7	82.13	7.85	<0.1	0	0.3
Grand Island, NE	5.93	0.005	1	0.5	0.97	5.1	81.77	7.98	<0.1	1.6	1.6
Sioux Falls, SD	6.85	0.004	2.5	<0.5	0.75	8.1	73.89	8.04	<0.1	0.3	0.4
Baltic, SD	5.84	0.004	2	0.5	0.898	6.2	81.75	7.68	<0.1	0.7	0.8
Watertown, SD	7.57	0.002	0.5	<0.5	0.753	9.6	71.08	7.88	<0.1	<0.1	0.3
Beresford, SD	6.37	0.003	0.5	<0.5	0.658	7.2	76.15	8.1	<0.1	<0.1	0.4
Appleton, WI	9.4	0.002	1.5	<0.5	0.613	3.4	76.26	8.02	<0.1	0.7	0.8
Oshkosh, WI	8.15	0.002	2	<0.5	0.605	2.3	81.78	8.11	<0.1	0.6	0.6

Class 3 Results

City/State	**DVPE, psi,** D5191	**Acidity, mass%** as acetic acid, D1613	**Unwashed gum,** mg/100mL, D381	**Washed gum,** mg/100mL, D381	**Water, mass%,** E203	**Sulfur, ppm,** D5453	**Ethanol, vol%,** D5501	**pHe,** D6423	**Inorganic Chloride,** ppm, D7328	**Inorganic Sulfate,** ppm, D7328	**Potential Sulfate,** ppm, D7328
Atlanta, GA	8.66	0.008	3	0.5	0.867	5.7	70.77	7.7	0.1	0.3	0.3
Chicago, IL	8.49	0.003	2.5	0.5	0.686	9.2	72.98	7.56	0.1	0.7	0.6
Louisville, KY	9.05	0.003	5.5	0.5	0.911	5.4	71.95	7.71	0.1	0.2	0.3
St. Louis, MO	8.62	0.004	7.5	0.5	0.872	11	70.88	7.61	0.1	1	1.3
Nashville, TN	6.85	0.004	2.5	0.5	1.077	5.6	80.73	7.76	0.1	0.1	0.1
Sachse, TX	8.19	0.004	2	0.5	0.95	11.5	76.47	7.73	0.1	0.1	0.3
Thornton, CO	7.39	0.002	4	0.5	0.643	8.7	82.01	7.61	0.1	0.6	0.6
Clearfield, UT	8.94	0.002	206.5	0.5	0.164	14.1	68.74	6.78	0.1	0.1	0.2
Pomona, CA	6.34	0.004	1.5	0.5	0.969	2.4	79.92	6.54	0.1	0.2	0.3
Perris, CA	6.16	0.003	1	0.5	0.902	4.1	81.74	7.46	0.1	0.4	0.6
Portland, OR	7.5	0.003	3.5	0.5	0.743	4.3	81.33	7.22	0.1	0.2	0.2
Glenmont, NY	8.92	0.004	3	0.5	0.736	12.8	68.07	7.7	0	0	0.4
Milroy, PA	9.13	0.003	3	0.5	0.75	12.9	68.87	7.67	0.1	0.4	0.4
Champaign, IL	9.29	0.003	4	0.5	0.888	12.1	72.09	7.56	0.1	0.8	0.7
Bloomington, IL	9.12	0.003	6	2	1.258	8.6	67.8	7.67	7	0	0.4
Jefferson City, MO	10.02	0.004	2	0.5	0.772	6.9	71.52	7.71	0.1	0.2	0.2
Waco, TX	7.5	0.003	2.5	0.5	1.003	7.6	79.47	7.72	0.1	0.1	0.4
Greeley, CO	7.78	0.002	2	0.5	0.577	16.2	75.26	7.51	0.1	0.9	1
Provo, UT	9.4	0.002	81.5	0.5	0.215	13.7	65.66	7.1	0.1	0.3	0.5
Las Vegas, NV	6.22	0.002	4.5	0.5	0.707	6	81.98	7.45	0.1	1	1.2
Fisher, MN	8.3	0.003	5.5	0.5	0.537	9.9	72.6	7.13	0.1	0.3	0.5
Detroit Lakes, MN	10.53	0.002	1.5	0.5	0.781	18.9	68.95	6.51	0.1	0.3	0.4
Luverne, MN	8.29	0.003	2	1	0.629	39	71.95	6.86	0.1	0.1	0.2
Annandale, MN	10.51	0.003	1.5	0.5	0.621	21.7	69.61	6.72	0.1	0	0.2

City/State	DVPE, psi, D5191	Acidity, mass% as acetic acid, D1613	Unwashed gum, mg/100mL, D381	Washed gum, mg/100mL, D381	Water, mass%, E203	Sulfur, ppm, D5453	Ethanol, vol%, D5501	pHe, D6423	Inorganic Chloride, ppm, D7328	Inorganic Sulfate, ppm, D7328	Potential Sulfate, ppm, D7328
Crookston, MN	9	0.003	2	0.5	0.539	9.6	71.98	6.59	0.1	1.4	1.4
Inwood, IA	6.44	0.003	3	0.5	0.566	12.7	83.65	7.31	0.1	0.1	0.2
Gilbert, IA	5.56	0.003	6	0.5	0.697	5.6	80.58	6.34	0.1	1.3	1.4
Lawrence, KS	6.7	0.003	2	0.5	0.675	4.2	81.89	6.82	0.1	0.2	0.3
Grand Island, NE	7.72	0.003	1	0.5	0.883	15.3	78.3	6.74	0.1	0.7	0.9
Wahpeton, ND	9.41	0.002	0.5	0.5	0.611	8.3	69.58	6.66	0.1	0.4	0.5
Sioux Falls, SD	8.41	0.003	3	0.5	0.604	25.7	71.87	6.26	0.1	0.2	0.3
Baltic, SD	5.86	0.038	1	0.5	0.132	17.1	87.42	7.00	0.1	0	0.1
Beresford,SD	8.43	0.002	2	<0.5	0.541	8.2	71.59	7.66	<0.1	<0.1	0.4
Watertown, SD	8.96	0.022	2	1.5	0.877	9	71.27	7.71	3.3	<0.1	<0.1
Appleton, WI	10.61	0.002	1.5	0.5	0.59	3.7	68.87	6.84	0.1	0.9	0.9
Oshkosh, WI	10.83	0.002	2.5	0.5	0.509	4.3	68.02	6.33	0.1	1.4	1.6
Columbiana, OH	10.31	0.003	0.5	<0.5	0.911	14.5	71.13	7.42	<0.1	<0.1	<0.1