Fuels Institute

DFQC DIESEL FUEL QUALITY COUNCIL

Diesel Fuel Sampling Study

AN EVALUATION OF DIESEL FUEL SOLD AND CONSUMED IN THE U.S. MARKET

NOVEMBER 2021

Fuels Institute

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Introduction

The Fuels Institute's Diesel Fuel Quality Council commissioned a fuel quality study to better understand the condition of diesel fuel being sold and consumed in the U.S. market. The primary goal was to evaluate diesel fuel for specific properties that may affect engine operations. The Council also sought to understand the quality of fuel sitting in storage tanks by evaluating properties[1] that contribute to corrosion and product contamination.

The Fuels Institute contracted with Tanknology to collect samples from nozzles and diesel fuel storage tanks from retail and non-retail facilities according to a specific geographic mix throughout the U.S. The Fuels Institute contracted with the Iowa Central Testing Laboratory to conduct 11 tests on every nozzle sample received, six tests on every middle tank sample, and five tests on every bottom tank sample (see "Methodology," next section, for further details). Decisions Innovations Solutions LLC (DIS) was contracted to conduct the initial statistical analyses of the laboratory results.

The test results and statistical analyses were then submitted to the Fuels Institute and evaluated to determine:

- **Sample results relative to applicable standards or other selected comparable benchmarks**
- **Potential variability in fuel properties between retail and non-retail fueling facilities**
- **Existence of correlation between any set of variables**
- **Influence of site-level characteristics (i.e., throughput, filter type, maintenance programs, etc.) on fuel properties**
- **Potential regional variability in fuel properties**

This report summarizes the results of this sampling and testing project as reviewed by the Fuels Institute and accepted by the Diesel Fuel Quality Council.

1 The use of the word "properties" in this report is a generic term being applied to the results of tests conducted on the diesel samples collected and to conditions observed in the field. It does not refer to any specific standard or term of art used to describe diesel fuel and is used to describe various conditions including contaminants and adulterants.

Methodology

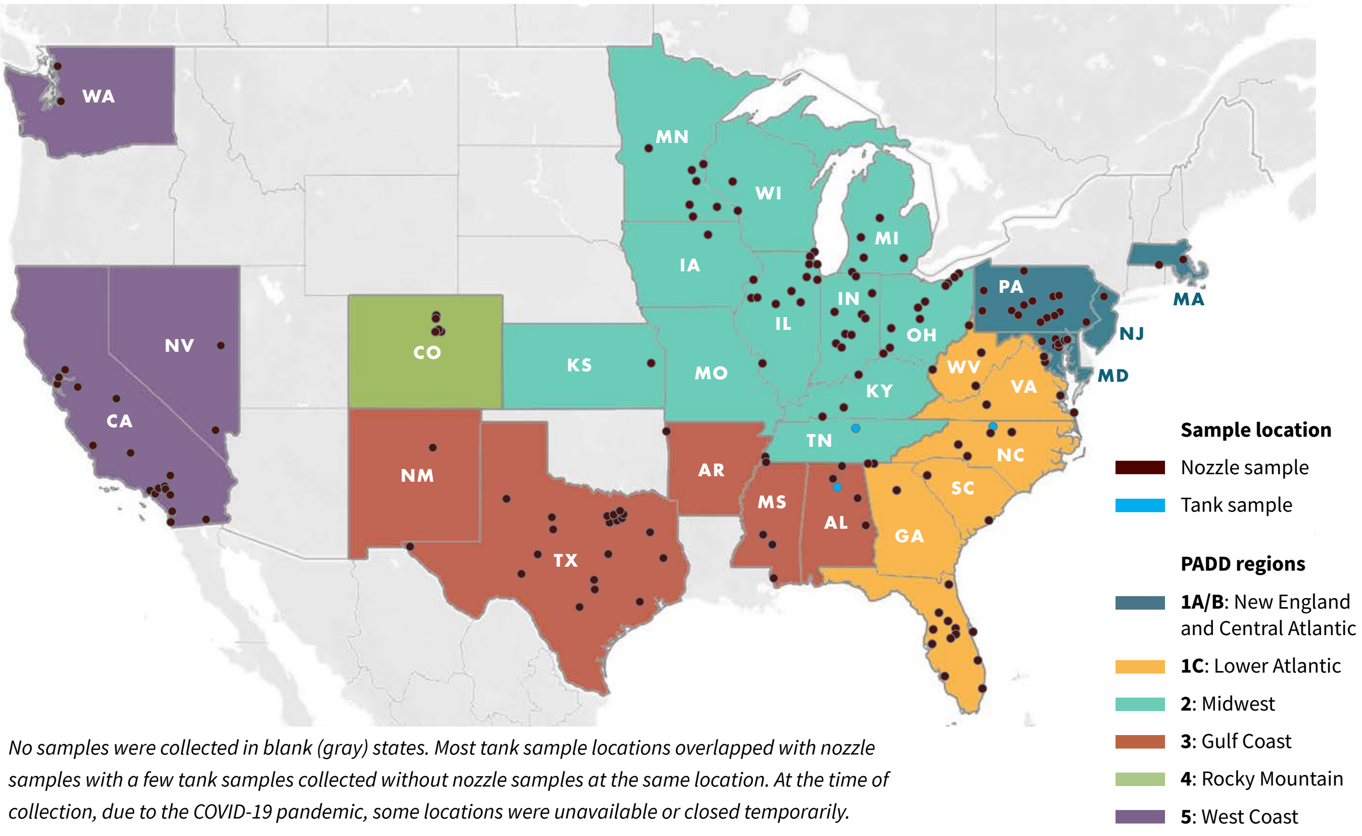
SAMPLE SET

Tanknology collected 190 nozzle samples and 134 tank samples from sites selected by a random sampling technique, following a regional distribution of samples by Petroleum Administration for Defense Districts (PADD), as shown below:

- **PADD 1A/B:** New England and Central Atlantic
- **PADD 1C:** Lower Atlantic
- **PADD 2:** Midwest
- **PADD 3:** Gulf Coast
- **PADD 4:** Rocky Mountain
- **PADD 5:** West Coast

Sample sites of nozzle and tank samples are shown in Figure 1.

FIGURE 1: NOZZLE AND TANK SAMPLED SITES BY PADD REGION



No samples were collected in blank (gray) states. Most tank sample locations overlapped with nozzle samples with a few tank samples collected without nozzle samples at the same location. At the time of collection, due to the COVID-19 pandemic, some locations were unavailable or closed temporarily.

TABLE 1: NOZZLE AND TANK SAMPLE DISTRIBUTION

PADD REGION	TARGET PERCENT	NOZZLE FREQUENCY	NOZZLE SAMPLED PERCENT	TANK FREQUENCY	TANK SAMPLED PERCENT
New England & Central Atlantic	15%	28	15%	17	13%
Lower Atlantic	18%	34	18%	21	16%
Midwest	30%	57	30%	49	37%
Gulf Coast	20%	38	20%	27	20%
Rocky Mountain	4%	8	4%	6	4%
West Coast	13%	25	13%	14	10%
Total	**100%**	**190**	**100%**	**134**	**100%**

The samples referred to in this report are of diesel fuel, collected from fuel dispenser nozzles and the inside of fuel storage tanks between April and September 2020. Distributions of nozzle and tank samples are shown in Table 1:

- **Target percent** represents the share of samples requested by the Fuels Institute, which was based upon an analysis of the regional distribution of diesel fuel retailing facilities
- **Nozzle frequency and tank frequency** both represent the number of nozzle or tank samples selected for a given region
- **Nozzle sampled percent and tank sampled percent** both represent the nozzle or tank sample percentage achieved from each region

Due to the COVID-19 pandemic, some locations were unavailable or temporarily closed. Alternative sites were identified according to Tanknology's work schedule. As a result, the tank sample percent varies slightly from the target percent.

SITE CHARACTERISTICS

Nozzle samples were collected from 163 retail fueling facilities, 10 of which were truck stops, and 27 non-retail facilities. Retail facilities represented 86% of all sites while non-retail facilities represented 14% of sample sites. Among non-retail facilities, there were six subcategories: casino, distribution center, fleet, medical, rental equipment, and trucking (Figure 2). Tank samples were collected from 119 retail facilities and 15 non-retail facilities, representing 89% and 11% respectively. The vast majority of samples were collected from automotive-diesel-dedicated dispenser and tank systems.

All but three of the tank samples were collected from underground storage tank systems. The aboveground storage tank samples were collected in the Gulf Coast and Lower Atlantic regions (Figure 3).

SAMPLE COLLECTION

Tanknology collected all samples for this study. The complete fuel sampling work instructions are included in Appendix A; below is a summary of how each sample was collected.

NOZZLE SAMPLES: The operator obtained a one liter from the diesel nozzle at the dispenser closest to the diesel storage tank. Data was recorded regarding the filter type, model, and date the filter was changed, if available. A stick test of the tank was performed using water-finding paste for diesel fuel, and a photograph of the stick was included in the report. In addition, the automatic tank gauge (ATG) report tape was included in the report.

FIGURE 2: SAMPLE DISTRIBUTION BY FUELING FACILITY TYPE AND PADD REGION

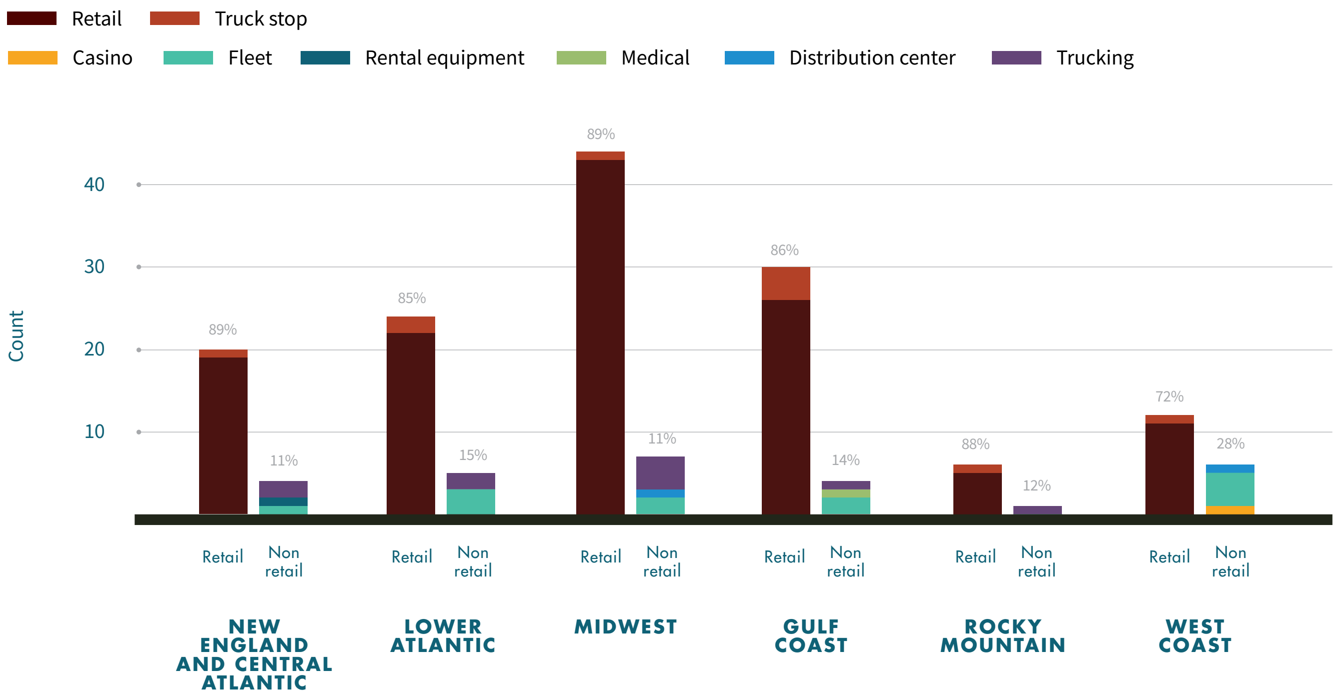
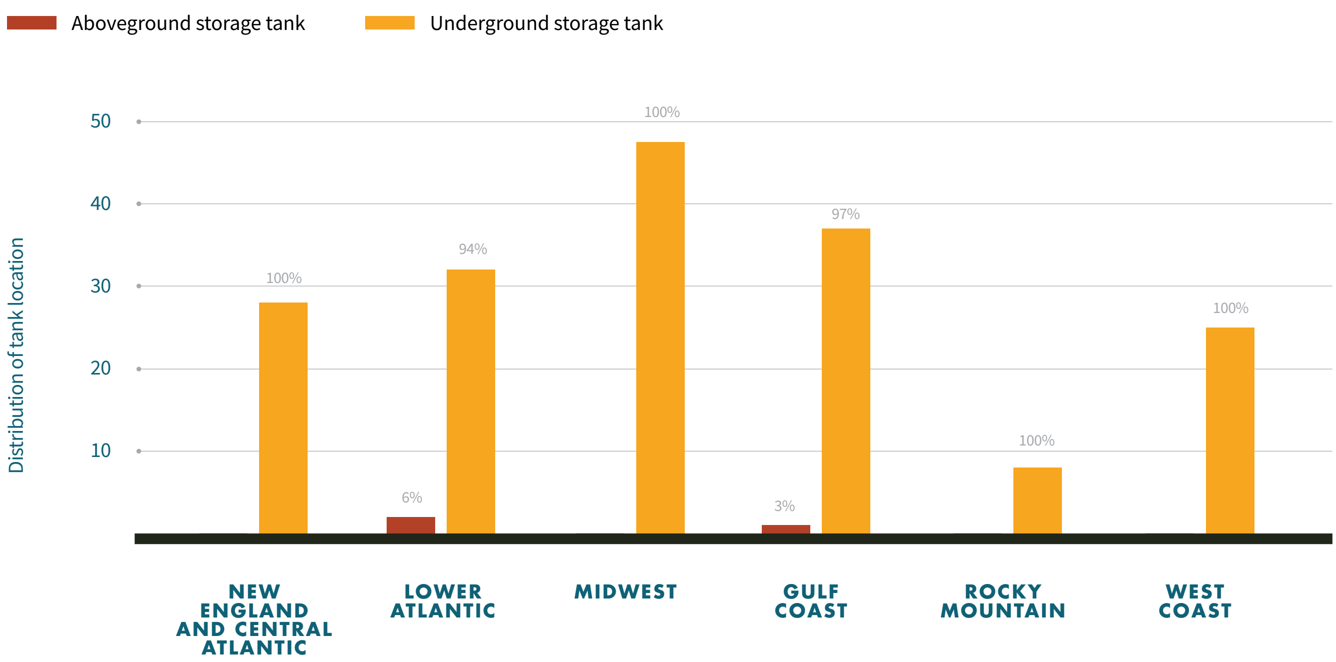


FIGURE 3: SAMPLE DISTRIBUTION BY FUELING FACILITY TYPE AND PADD REGION



TANK SAMPLES: Two tank samples were taken from each location — one from the bottom of the tank and one from the middle of the tank, as follows:

Bottom samples: When using a vacuum sampler, the operator lowered the tube into the tank until the brass pipe was just above the fuel level. The tubing was then swung back and forth until freely swinging lengthwise in the tank. Additional tubing was released to lower the brass pipe to the tank bottom. A vacuum was then created with the hand pump to collect the sample.

When using a bacon bomb, the operator lowered the device until it contacted the tank bottom, where the device was given enough time to completely fill.

A stick test of the tank was performed using water-finding paste for diesel fuel, and a photograph of the stick was included in the report.

Middle samples: Samples were obtained from the same tank as the bottom samples. Based on the number of inches of product in the tank, the operator lowered the sampling device to the mid-point of the fuel and retrieved a sample of the product. For example, if a tank had 60″ of product, the sampling device was lowered to the 30″ level in the fuel.

SAMPLE ANALYSIS

Each sample was collected and subjected to laboratory testing to evaluate specific fuel properties identified by the Council. The laboratory tests utilized to evaluate each fuel property were determined collectively by the Council at the beginning of the project. The Iowa Central Fuel Testing Laboratory analyzed all the samples. See Table 2 for the nozzle sample tests and Table 3 for the tank sample tests.

To provide context regarding tested fuel properties, where possible the testing results were compared to the prevailing standard in the U.S.: ASTM D975. For many of the test results evaluated in this project, ASTM D975 does not provide a required value. In these cases, alternative comparable benchmarks are provided as reference, primarily sourced from the Worldwide Fuel Charter (WWFC). This report, as well as Tables 2 and 3, notes the source of the benchmark against which a fuel property is compared throughout.

TESTING METHODS AND THE ANALYSIS

The members of the Diesel Fuel Quality Council selected the testing methods applied to the samples when the project was originally designed. During review of the results, some limitations of the selected tests were discovered and some terms identified that needed additional clarification:

- **Oxidation stability:** According to the scope of the method applied to evaluate oxidation stability (EN15751), the results are valid for fuels containing a minimum of 2% biodiesel (vol/vol). This limitation was not identified at the beginning of this project and, therefore, was not accommodated. Of the nozzle samples collected, 57% (109 samples) measured biodiesel content below 2%. Consequently, the oxidation stability results from this testing method are not accurate for these samples. The analysis of oxidation stability in this report has been applied only to those samples that contained at least 2% biodiesel.
- **Flash point:** ASTM D975 sets a flash point standard of 52°C but allows 38°C when fuel has been winterized with No.1 Diesel or S15 kerosene. Because all samples were collected between the months of April and September, the standard of 52°C has been applied.

TABLE 2: LAB TESTS WITH BENCHMARKS FOR NOZZLE SAMPLES

TEST	METHOD	UNIT	FUEL TYPE	ASTM	WWFC
Oxidation stability	EN15751	Hours	Diesel	NA	>35
Total acid number	D664	Mg KOH/g[1]	Diesel	NA	<0.08
Flash point (closed cup)	D93	°C	Diesel	>52	>55
Water (Karl Fischer)	D6304	mg/kg	Diesel	NA	<200
Water and sediment	D2709	mg/kg	Diesel	<500	NA
Potassium	EN14538	mg/kg	Diesel	NA	<1
Sodium	EN14538	mg/kg	Diesel	NA	<1
Calcium	EN14538	mg/kg	Diesel	NA	<1
Magnesium	EN14538	mg/kg	Diesel	NA	<1
Zinc	EN14538	mg/kg	Diesel	NA	<1
Appearance	D4176	--	Diesel	NA	Clear and bright

TABLE 3: LAB TESTS WITH BENCHMARKS FOR TANK SAMPLES

TEST	METHOD	UNIT	FUEL TYPE	ASTM	WWFC
Water (Karl Fischer)	D6304	mg/kg	Diesel	NA	<200
Water and sediment	D2709	mg/kg	Diesel	<500	NA
Ethanol (middle only)	D4815	%v/v	Diesel	NA	Non-detectable
Microbial count—bacterial	D6974	Count	Diesel	NA	Zero content
Microbial count—mycological	D6974	Count	Diesel	NA	Zero content
Appearance	D4176	--	Diesel	NA	Clear and bright

- **Water and sediment:** Results from D2709 return a percent volume value. However, the ASTM Standard D975 applies a limit of 500 parts per million (ppm), or milligrams per kilogram (mg/kg). For the analyses conducted for this report, the test results were converted from percent volume to mg/kg by multiplying the percent volume by 10,000. While this is considered to not be a perfect calculation, the Fuels Institute considers it suitable for the analysis contained in this report.[2]
- **Outlier samples:** Upon review of the testing results, it was clear that some samples represented clear outliers.[3] During analysis, we did not eliminate the outliers from the primary evaluation of fuel properties with the exception of one sample that was reported as "primarily aqueous" and was removed from the analysis.[4] The remaining outlier results were further segmented and analyzed among themselves and are presented in a separate section of this report.

2 The unit KOH/g refers to potassium hydroxide per gram.

3 An outlier is a result that is numerically distant from the rest of the data. Labeling a result as a statistical outlier does not infer any assumptions regarding accuracy of test results or sample collection. See Figure 5 below.

4 Removal of the "primarily aqueous" sample from the statistical analysis does not infer the sample was not representative of the conditions within the tank from which it was obtained. This result was removed to enable comparison of diesel fuel test results and to avoid comparing diesel fuel with a sample that was primarily water.

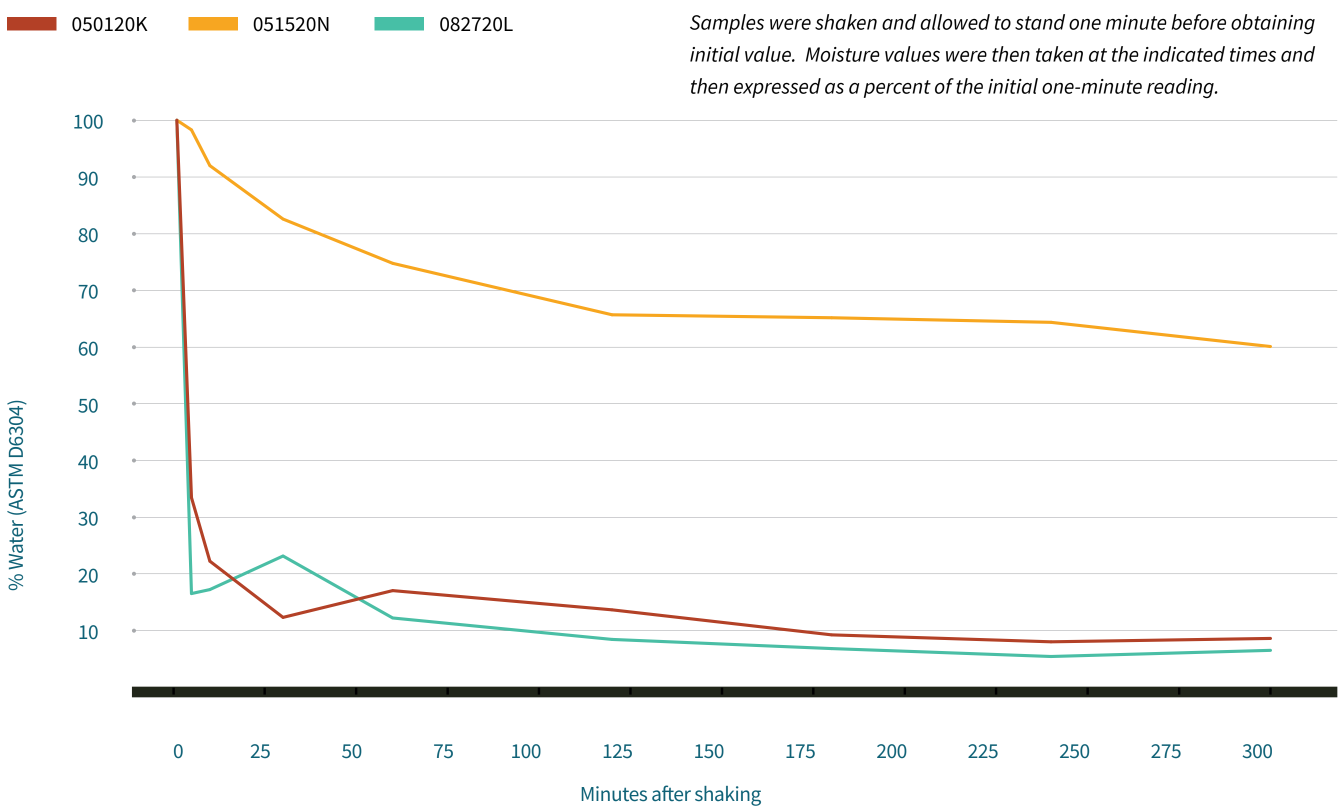
WATER AND SEDIMENT AND KARL FISCHER MOISTURE

The Fuels Institute performed two moisture-related tests on samples to provide greater perspective regarding water content in diesel fuel. To that end, staff reviewed the lab results closely and requested retesting of certain samples. These samples indicated a visually strong sediment and water content (haze or free phase), but original analysis did not fully reflect the gross contamination present. This raises questions regarding fuel sampling integrity in general and suggests that testing procedures need improvements. To fully understand the potential degree of water contamination in fuel, test methods must reflect the general state or level of gross water contamination in the diesel fuel storage tank upon physical inspection. At this moment, the best available options are reflected in the two tests conducted for this project, but it is important to understand their limitations.

Water contamination may be completely dissolved in fuel or it may be present at a high enough saturation level where the water falls out of the solution and collects on the bottom of the tank (free phase). Some fuel additives allow higher concentrations of water to remain in the dissolved phase. The chart below shows three different samples containing free-phase water. All three samples were shaken for one minute and the proceeding rate of water fallout was measured. It is important to note that whether water is present in a free phase or in a dissolved phase (water droplets from ullage migrating downward), microbial growth may be promoted (Figure 4).

It should be noted that the general ASTM standard for diesel fuel quality (D975) does not include Karl Fischer moisture analysis (D6304) but does include the water and sediment testing standard (D2709).

FIGURE 4: RATE OF WATER FALLOUT POST SHAKING



During testing, samples with free-phase water produced non-repeatable test results when using the Karl Fischer test method (D6304). Repeatability is the expected range of values if analyzing a sample multiple times in succession, i.e., the test was performed by the same person in the same laboratory using the same instrument on the same day. Testing results suggest that if a sample has free-phase water, then the Karl Fischer test method is less accurate and generally not repeatable or accurate. In the absence of free-phase water, the Karl Fischer test method is accurate and has lower detection limits, which allow for greater detection of dissolved phase water.

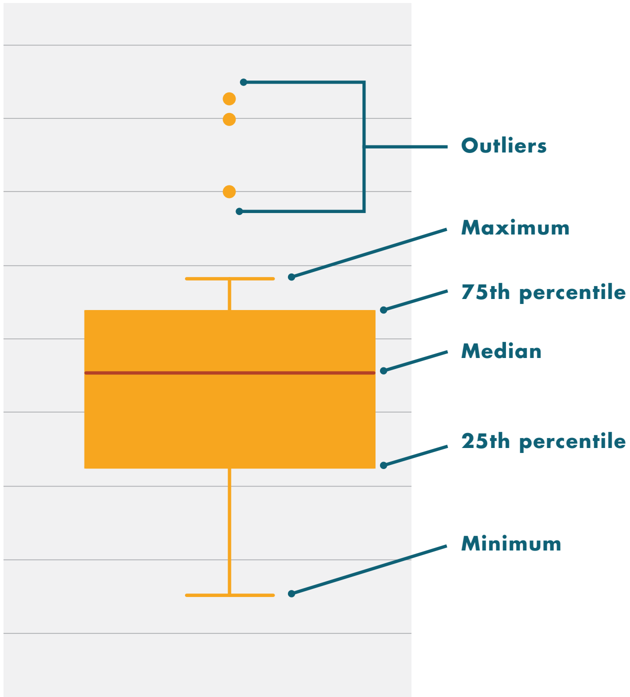
For samples containing obvious free-phase water, the water and sediment method in D2709 appears to be the more suitable approach. However, this test method determines the total volume of water and sediment as a percent of the sample and likely does not reflect water content alone. By contrast, the Karl Fischer moisture method only determines water content and, based upon this report's findings, water content in the dissolved phase accurately.

ANALYSIS OF LABORATORY TESTING RESULTS

The results of the laboratory testing were then evaluated in the following ways to determine what could be learned about the selected fuel properties:

- **Distribution of sample results by fuel property:** The results of each test across all samples were plotted in boxplots to provide a quick overview of test results and demonstrate the range of fuel properties found within the sample set (Figure 5).
- **Sample results compared with benchmarks:** Sample results were compared with the applicable benchmark to determine the percent of samples that met the benchmark and to measure the range of results for each fuel property.
- **Regional differences by PADD:** Sample results were grouped by the sample's PADD location, and the results from each PADD were analyzed to determine if fuel properties were influenced by geographic region.
- **Relationships between fuel properties:** Sample results for each fuel property were then subject to correlation analysis to determine to what extent fuel properties are related to other fuel properties. This analysis was conducted among nozzle fuel properties, among tank fuel properties, and between tank and nozzle fuel properties to calculate the correlation coefficient to show any linear relationships between fuel properties.

FIGURE 5: INTERPRETING A BOXPLOT



This coefficient, known as the R-value, returns results ranging from −1 to +1. An R-value of −1 or +1 indicates the variables being compared are perfectly statistically related to one another (either positively or negatively), whereas a value of 0 indicates no statistically relevant relationship exists. For this analysis, the Fuels Institute defined statistically significant relationships as those with R-values of greater than 0.5 or less than −0.5.

Distribution of Sample Results by Fuel Property

The laboratory analyzed each sample and measured it for selected fuel properties. The following boxplots provide a graphical overview of the results by fuel property (Figures 6-15). For some graphics, the range on the vertical axis was adjusted to improve visibility. This sometimes caused some sample results to not appear on the chart. When this occurs, the number of results that exceed the range of the adjusted axis is noted within the applicable chart.

NOZZLE SAMPLE FUEL PROPERTIES

The following box plot graphics present the range of fuel properties measured by the laboratory from the collected nozzle samples.

FIGURE 6: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: OXIDATION STABILITY

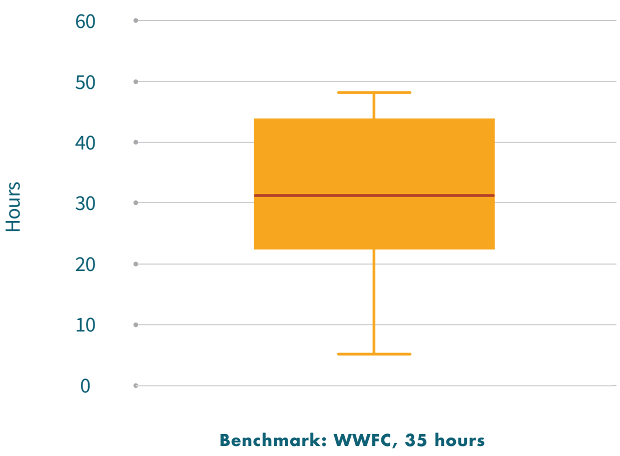


FIGURE 7: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: TOTAL ACID NUMBER

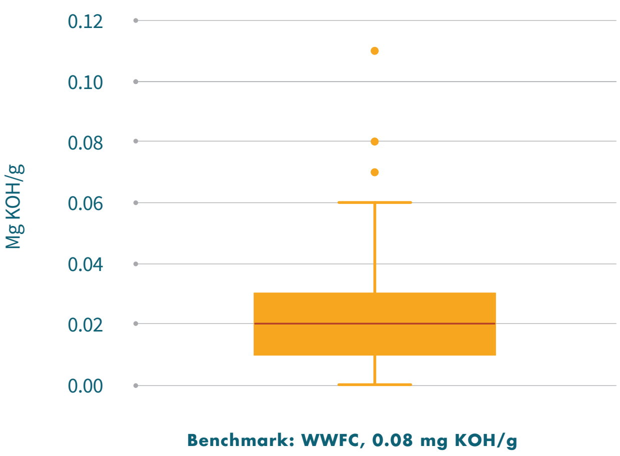


FIGURE 8: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: FLASH POINT

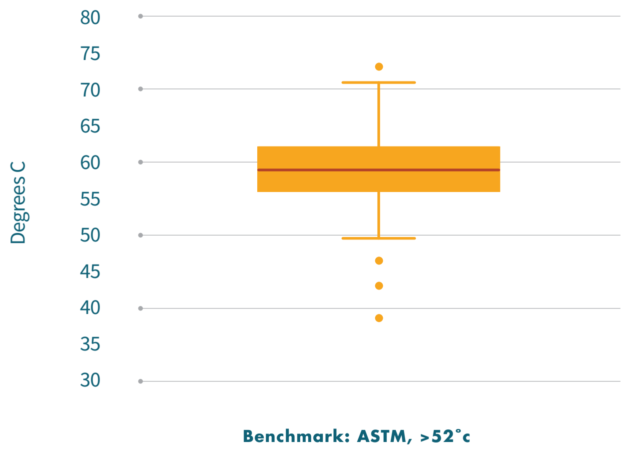


FIGURE 9: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: WATER (KARL FISCHER)

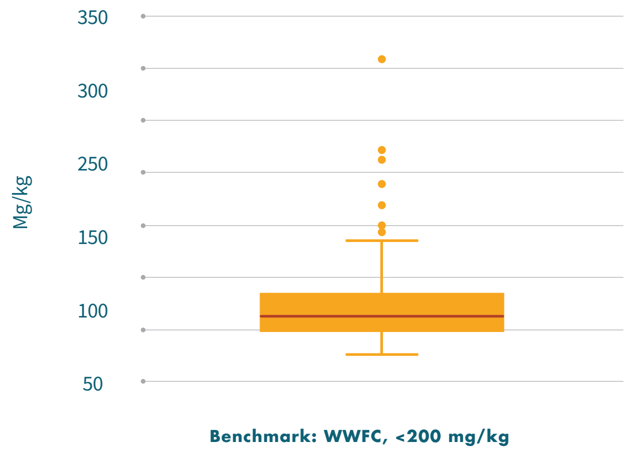


FIGURE 10: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: WATER AND SEDIMENT

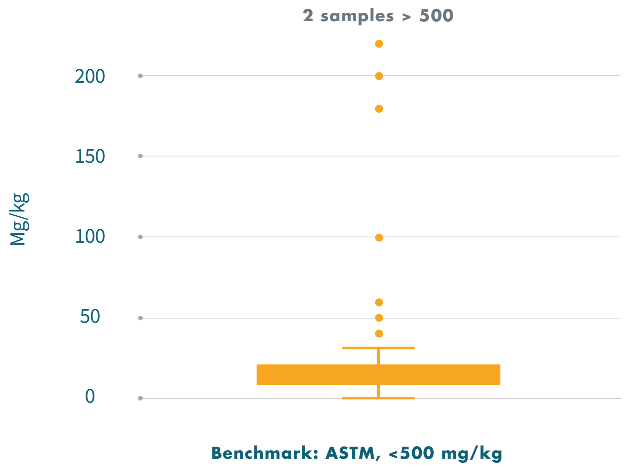


FIGURE 11: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: POTASSIUM

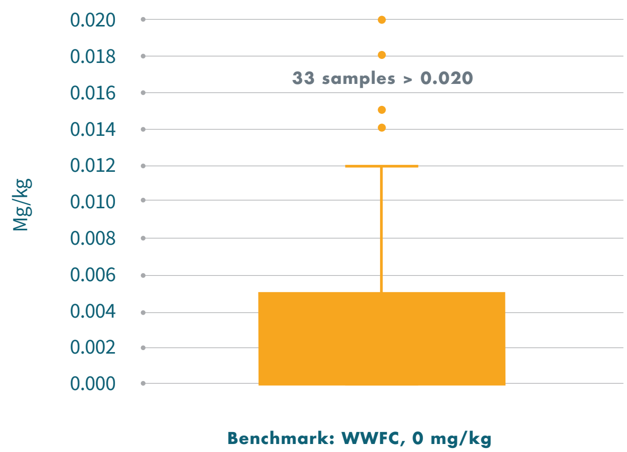


FIGURE 12: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: SODIUM

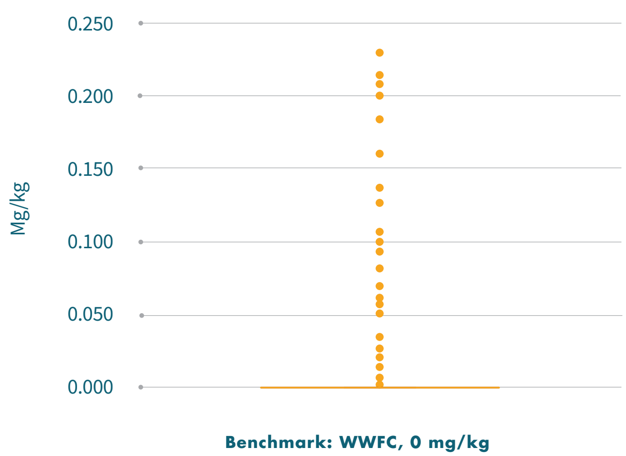


FIGURE 13: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: CALCIUM

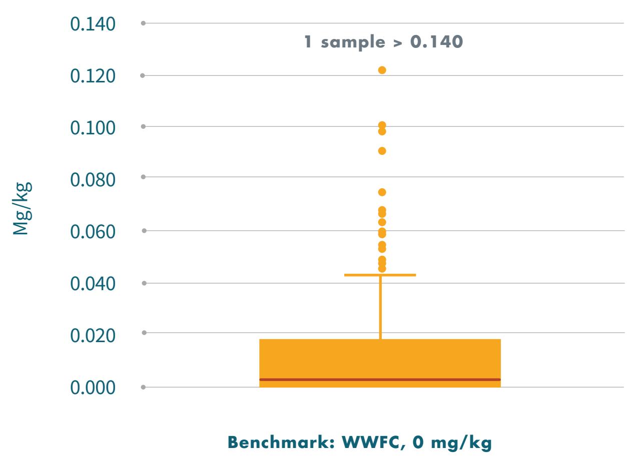


FIGURE 14: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: ZINC

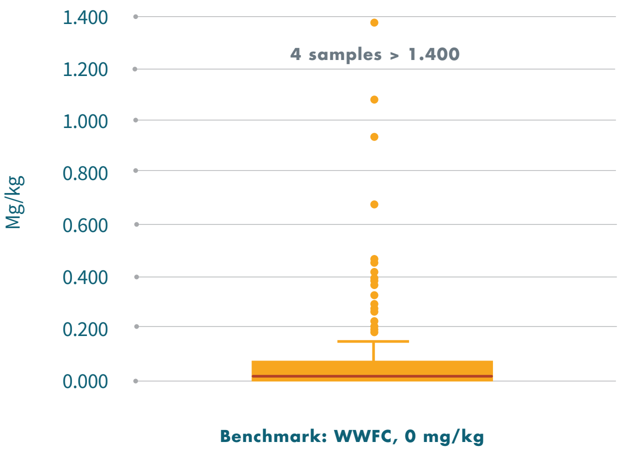
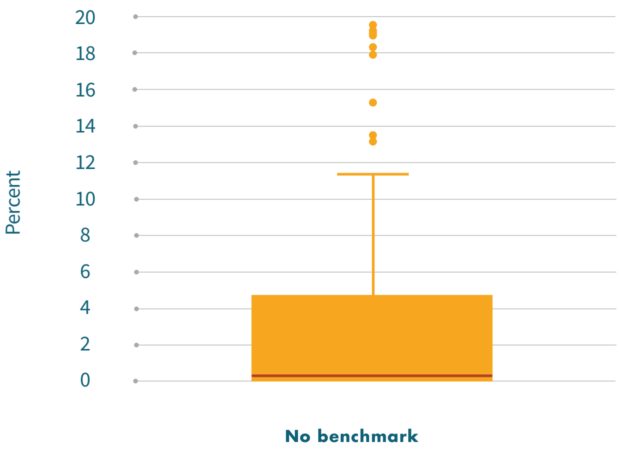


FIGURE 15: RANGE OF NOZZLE SAMPLE FUEL PROPERTIES: BIODIESEL



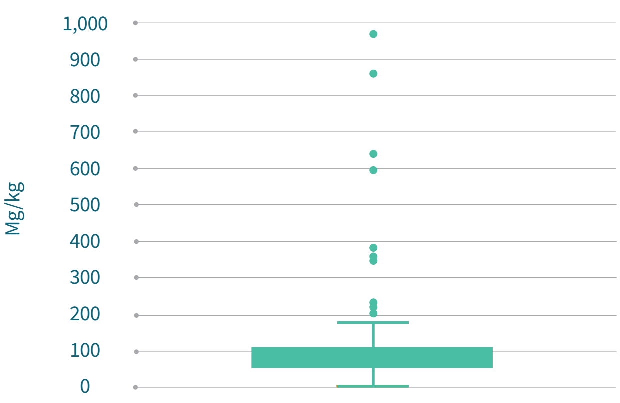
MIDDLE LAYER TANK SAMPLE FUEL PROPERTIES

The following box plot graphics present the range of fuel properties measured by the laboratory from the collected middle layer tank samples.

FIGURE 16: RANGE OF MIDDLE TANK SAMPLE FUEL PROPERTIES: MICROBIAL COUNT—BACTERIAL

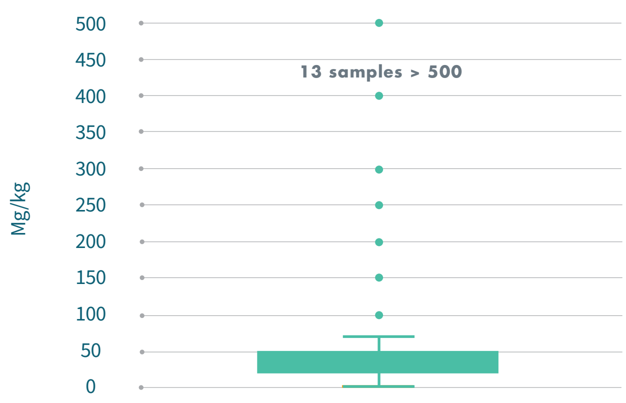
FIGURE 17: RANGE OF MIDDLE TANK SAMPLE FUEL PROPERTIES: MICROBIAL COUNT—MYCOLOGICAL

FIGURE 18: RANGE OF MIDDLE TANK SAMPLE FUEL PROPERTIES: WATER (KARL FISCHER)



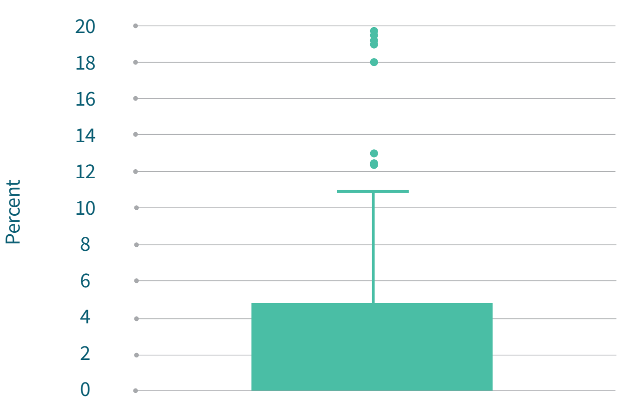
Benchmark: WWFC, <200 mg/kg

FIGURE 19: RANGE OF MIDDLE TANK SAMPLE FUEL PROPERTIES: WATER AND SEDIMENT



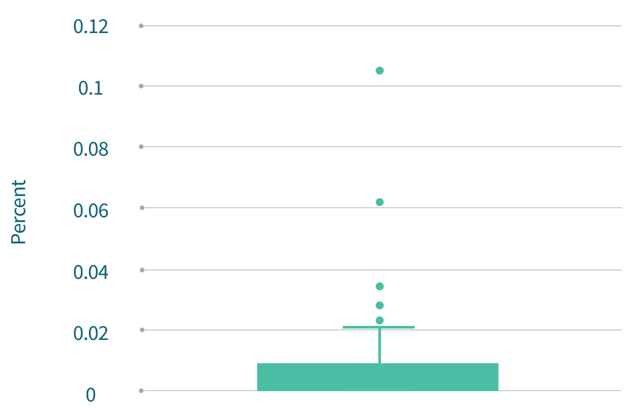
Benchmark: ASTM, <500 mg/kg

FIGURE 20: RANGE OF MIDDLE TANK SAMPLE FUEL PROPERTIES: BIODIESEL



No benchmark

FIGURE 21: RANGE OF MIDDLE TANK SAMPLE FUEL PROPERTIES: ETHANOL

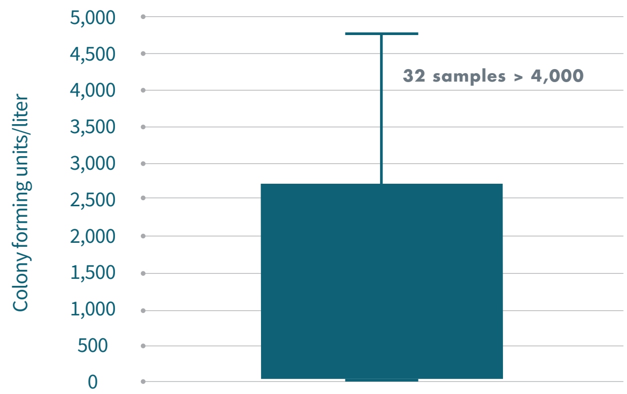


Benchmark: WWFC, Non-detectable

BOTTOM LAYER TANK SAMPLE FUEL PROPERTIES

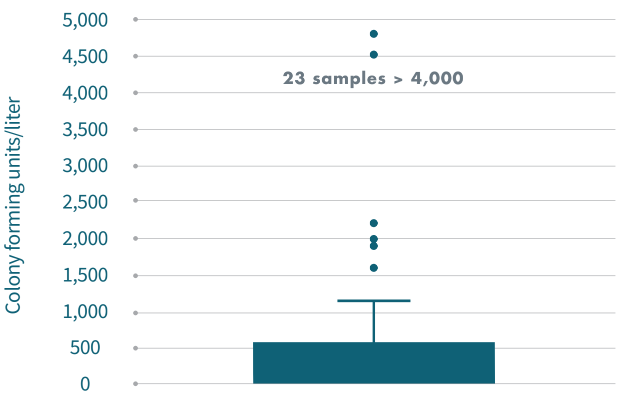
The following box plot graphics present the range of fuel properties measured by the laboratory from the collected bottom layer tank samples.

FIGURE 22: RANGE OF BOTTOM TANK SAMPLE FUEL PROPERTIES: MICROBIAL COUNT—BACTERIAL



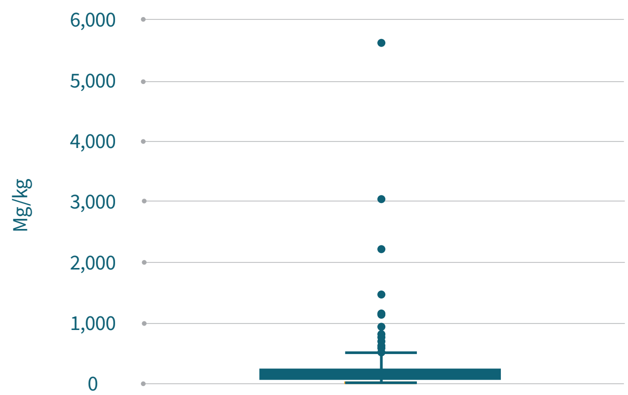
Benchmark: Industry experts, 4,000 CFU/L

FIGURE 23: RANGE OF BOTTOM TANK SAMPLE FUEL PROPERTIES: MICROBIAL COUNT—MYCOLOGICAL



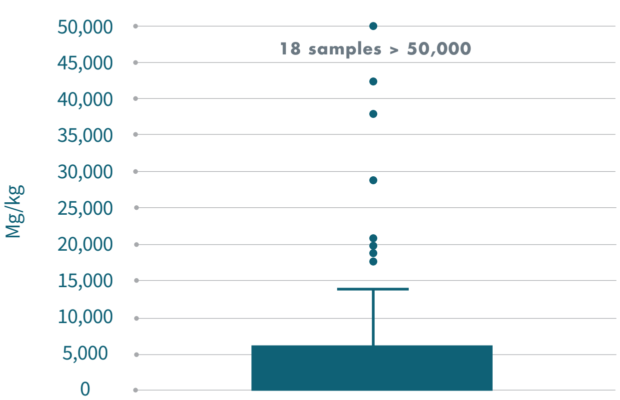
Benchmark: Industry experts, 4,000 CFU/L

FIGURE 24: RANGE OF BOTTOM TANK SAMPLE FUEL PROPERTIES: WATER (KARL FISCHER)



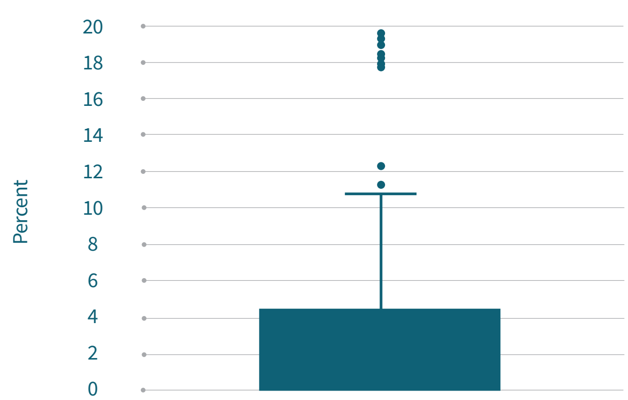
Benchmark: WWFC, <200 mg/kg

FIGURE 25: RANGE OF BOTTOM TANK SAMPLE FUEL PROPERTIES: WATER AND SEDIMENT



Benchmark: ASTM, <500 mg/kg

FIGURE 26: RANGE OF BOTTOM TANK SAMPLE FUEL PROPERTIES: BIODIESEL



No benchmark

Sample Results and Comparable Benchmarks

The nozzle and tank samples were individually analyzed using the methodology and against comparable benchmarks to evaluate fuel properties (Tables 2 and 3). Table 4 presents the percentage of samples that met the comparable benchmark for each test (Figures 27-29).

TABLE 4: PERCENT OF SAMPLES MEETING COMPARABLE BENCHMARK

SAMPLE LOCATION	TEST	COMPARABLE BENCHMARK	PERCENT SAMPLES MEETING BENCHMARK
Nozzle	Oxidation stability	>35 hours (WWFC)	37%
	Total acid number	<0.08 mg KOH/g (WWFC)	99%
	Flash point (closed cup)	>52°C (ASTM)	96%
	Water (Karl Fischer)	<200 mg/kg (WWFC)	98%
	Water and sediment	<500 mg/kg (ASTM)	99%
	Potassium	<1 mg/kg (WWFC)*	100%
	Sodium	<1 mg/kg (WWFC)*	100%
	Calcium	<1 mg/kg (WWFC)*	100%
	Magnesium	<1 mg/kg (WWFC)*	100%
	Zinc	<1 mg/kg (WWFC)*	97%
	Appearance test	Clear and bright (WWFC)	94%
Tank (middle layer)	Water (Karl Fischer)	<200 mg/kg (WWFC)	90%
	Water and sediment	<500 mg/kg (ASTM)	90%
	Ethanol	Non-detectable (WWFC)	33%
	Microbial count—bacterial	4,000 CFU/L (Industry Experts)[5]	92%
	Microbial count—mycological	4,000 CFU/L (Industry Experts)	96%
	Appearance test	Clear and bright (WWFC)	75%
Tank (bottom layer)	Water (Karl Fischer)	<200 mg/kg (WWFC)	69%
	Water and sediment	<500 mg/kg (ASTM)	53%
	Microbial count—bacterial	4,000 CFU/L (Industry Experts)	76%
	Microbial count—mycological	4,000 CFU/L (Industry Experts)	83%
	Appearance test	Clear and bright (WWFC)	33%

**WWFC Category 4 Diesel Fuel Specifications set a metals maximum level as "non-detectable." For this chart, a max of 1 mg/kg was used as a baseline.*

5 ASTM standards do not include a limit for microbial growth and there exists no other standard setting a limit. According to input from fuel quality testing professionals, they typically deem levels around 100 CFU/L as background levels common in fuel. However, levels at or exceeding 4,000 CFU/L are indicative of a microbial growth issue. While this level is not definitive in suggesting a likely operational issue should result, it does serve as a credible and acceptable benchmark against which to measure the microbial condition of the samples studied in this report.

FIGURE 27: NOZZLE SAMPLE RESULTS RELATIVE TO APPLIED BENCHMARK

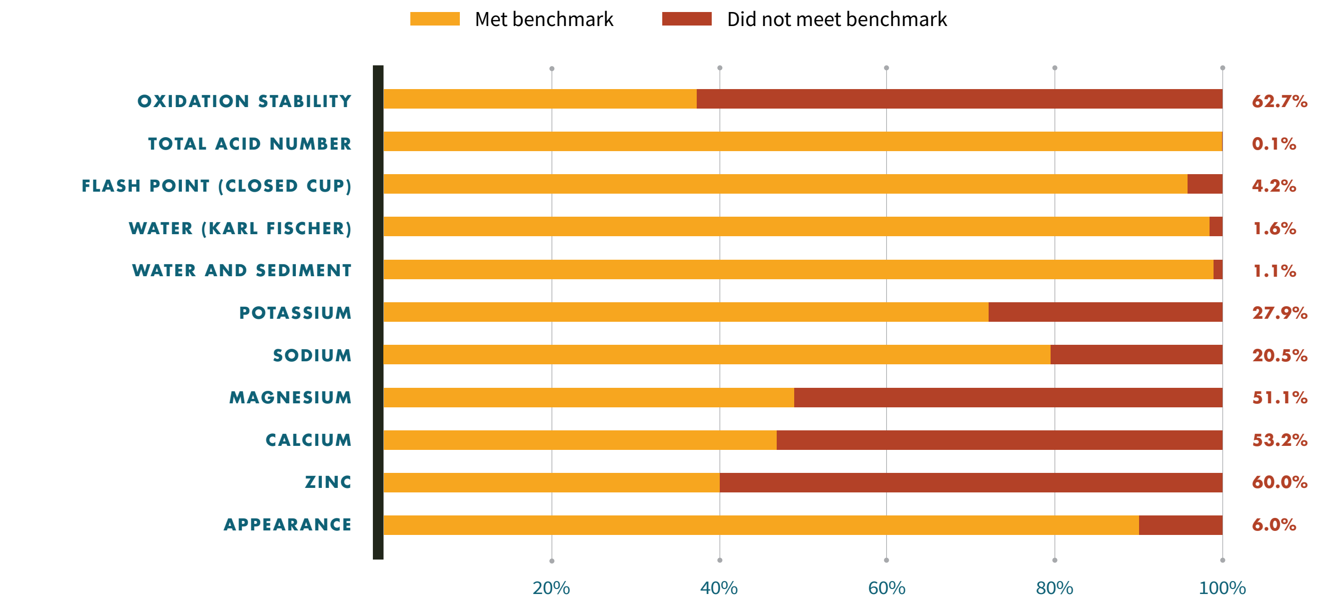


FIGURE 28: MIDDLE TANK SAMPLE RESULTS RELATIVE TO APPLIED BENCHMARK

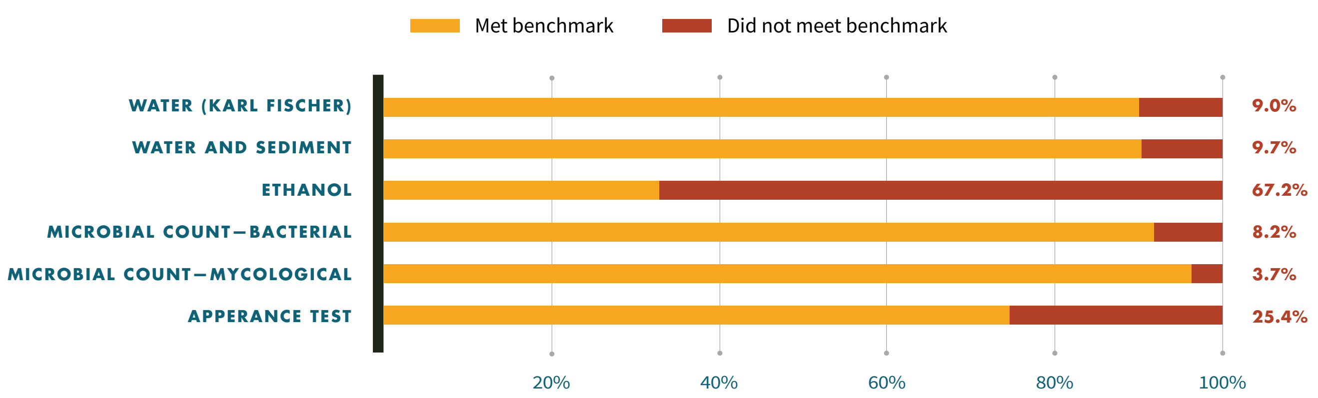
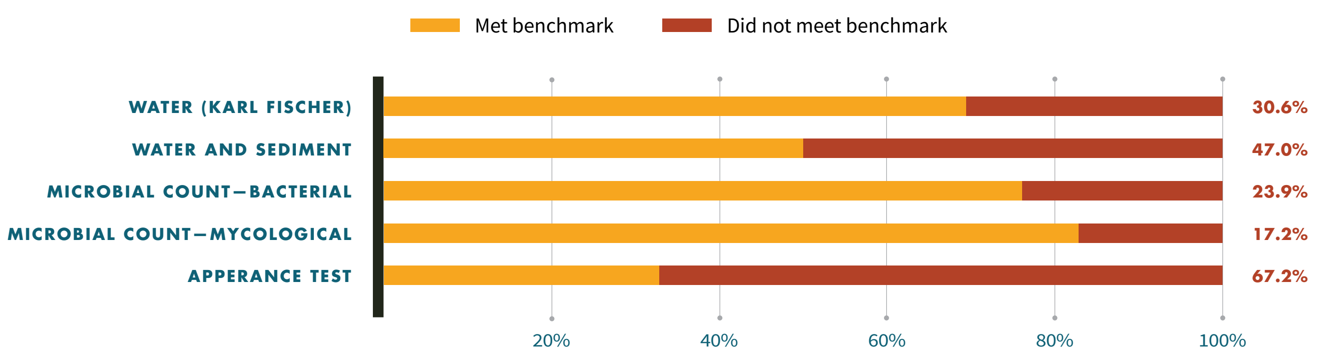


FIGURE 29: BOTTOM TANK SAMPLE RESULTS RELATIVE TO APPLIED BENCHMARK



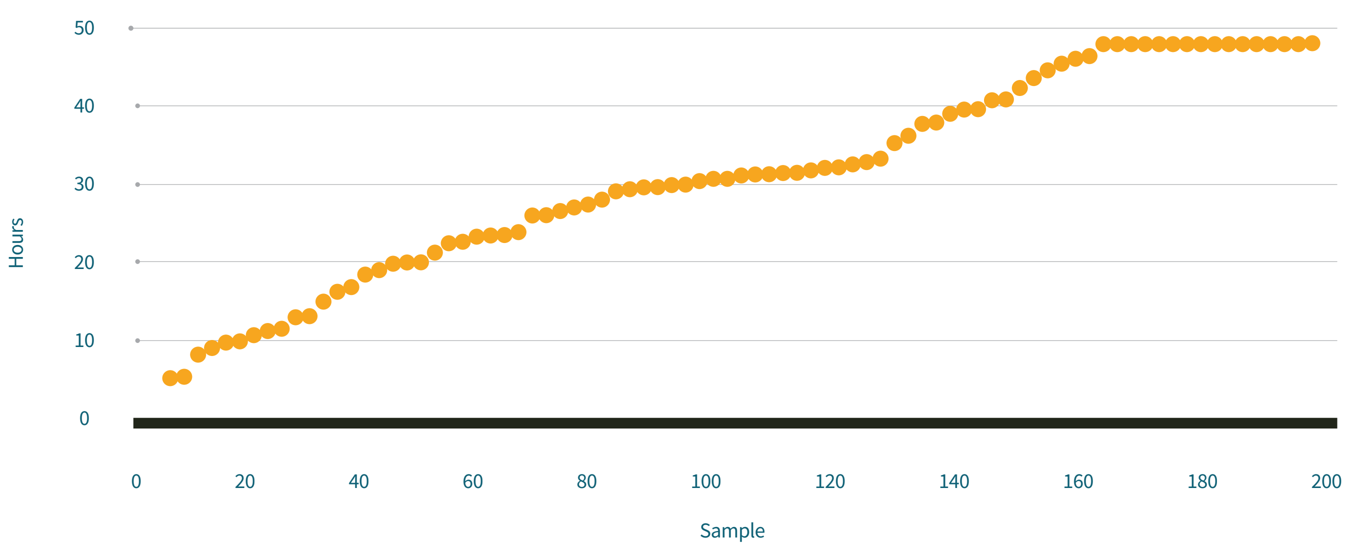
OBSERVATIONS FROM NOZZLE SAMPLE DATA

The following observations provide greater detail on the fuel properties relative to selected benchmarks and the range of fuel properties within each category.

OXIDATION STABILITY

Of the 190 samples collected, 83 samples (43.7%) contained a minimum of 2% biodiesel for which the EN15751 test is designed. Of these samples, 31 (37.3%) satisfied the WWFC minimum benchmark of 35 hours. When applying the less stringent minimum benchmark of 20 hours, the standard in Europe (EN 590), 66 samples (57.8%) would meet the benchmark. For those samples that satisfied WWFC, the average stability was 44.7 hours. For those samples that failed, the results ranged from 5.3 hours to 33.4 hours, with an average of 23.0 hours (Figure 30).

FIGURE 30: NOZZLE SAMPLE DATA: OXIDATION STABILITY



TOTAL ACID NUMBER

Only one sample exceeded the 0.08 mg KOH/g (potassium hydroxide per gram) benchmark from the WWFC; that sample measured 0.11. From conversations with stakeholders, the Fuels Institute discovered some concerns about total acid number (TAN) values at 0.05 mg KOH/g, and perhaps even lower. When a benchmark of 0.05 mg KOH/g was applied, 18 samples (9.5%) failed to meet the benchmark. The average of compliant samples (under 0.08 mg KOH/g) was 0.024 mg KOH/g, with a range between 0.00 and 0.08 (Figure 31).

FLASH POINT (CLOSED CUP)

Of the 190 samples analyzed, eight samples (4.2%) failed to meet the 52°C benchmark from ASTM. Of these, results ranged from 38.8°C to 51.5°C with an average flash point of 47.9°C. For the compliant samples, the flash point ranged from 52.0°C to 73.0°C with an average of 59.5°C (Figure 32).

FIGURE 31: NOZZLE SAMPLE DATA: TOTAL ACID NUMBER

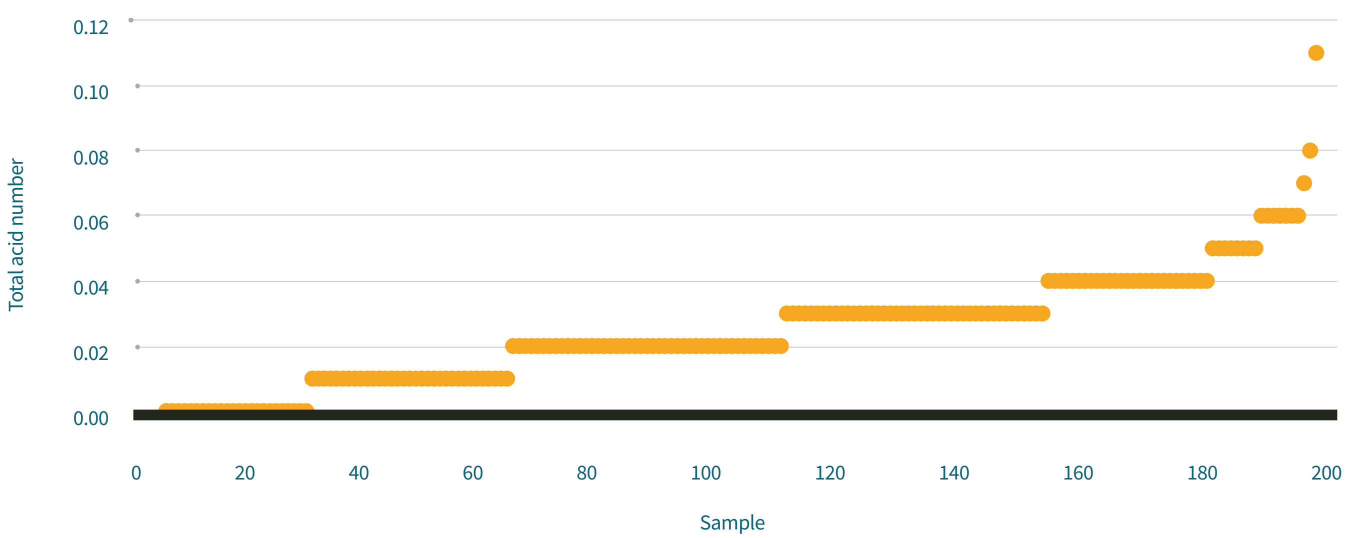
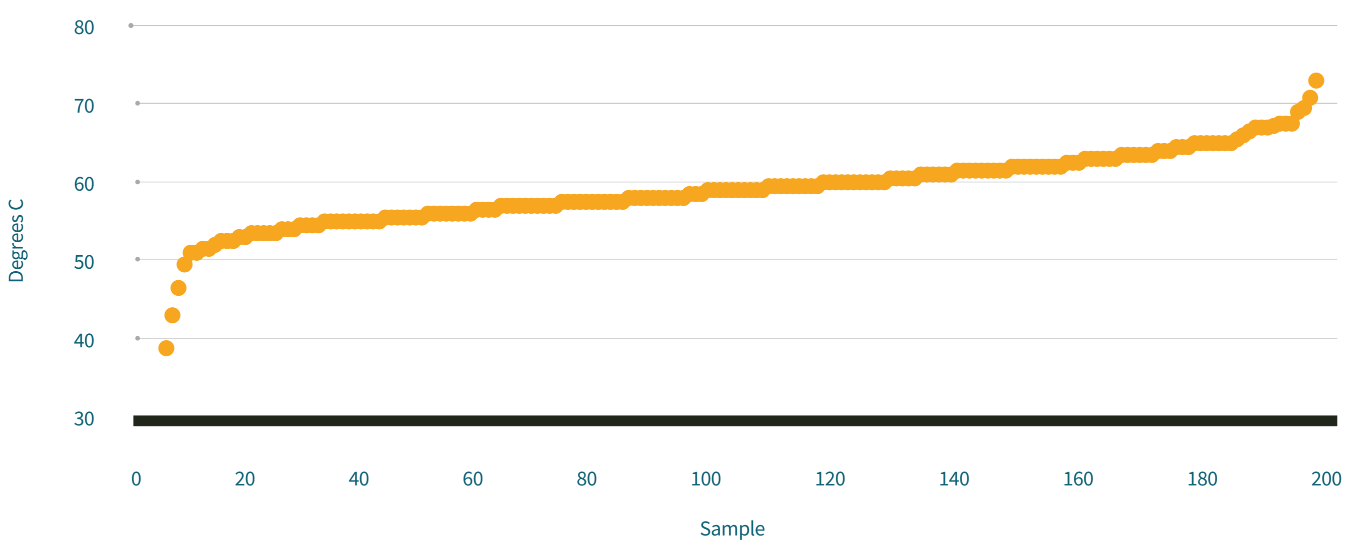


FIGURE 32: NOZZLE SAMPLE DATA: FLASH POINT



WATER (KARL FISCHER)

Only three samples (1.6%) failed to meet the WWFC benchmark of <200 mg/kg, and these ranged from 213 to 309. The compliant samples ranged from 26 mg/kg to 189 mg/kg, with an average of 69 mg/kg (Figure 33).

WATER AND SEDIMENT

Only two of the samples exceeded the ASTM standard of 500 mg/kg. The samples that did not meet the ASTM benchmark contained 700 and 2,000 mg/kg, respectively (Figure 34).

FIGURE 33: NOZZLE SAMPLE DATA: WATER (KARL FISCHER)

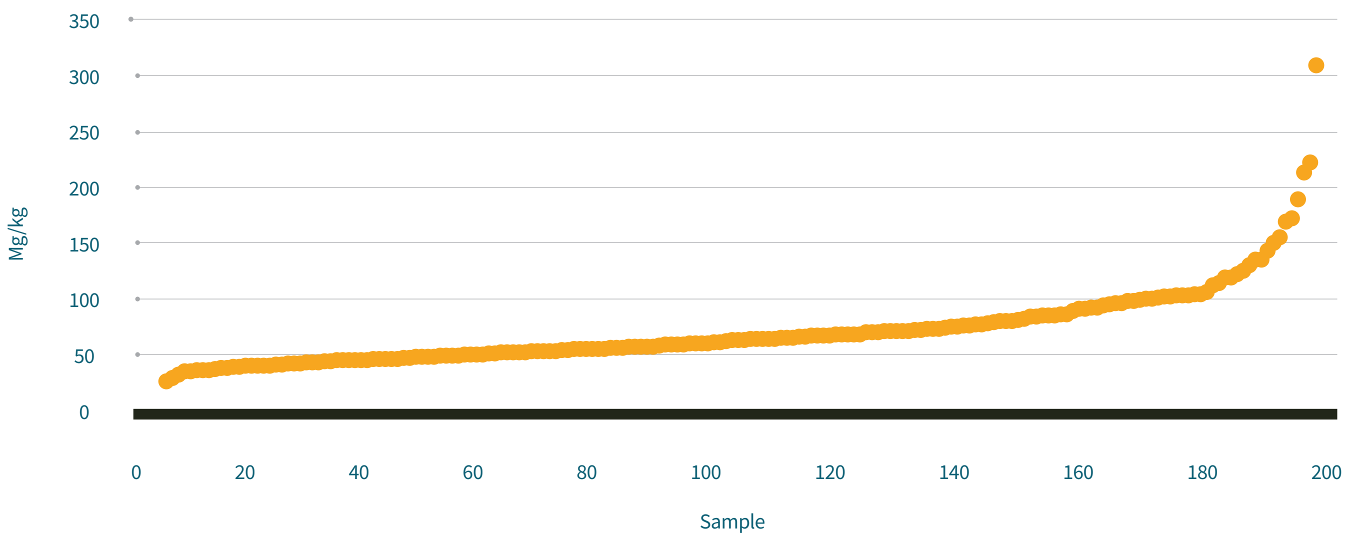
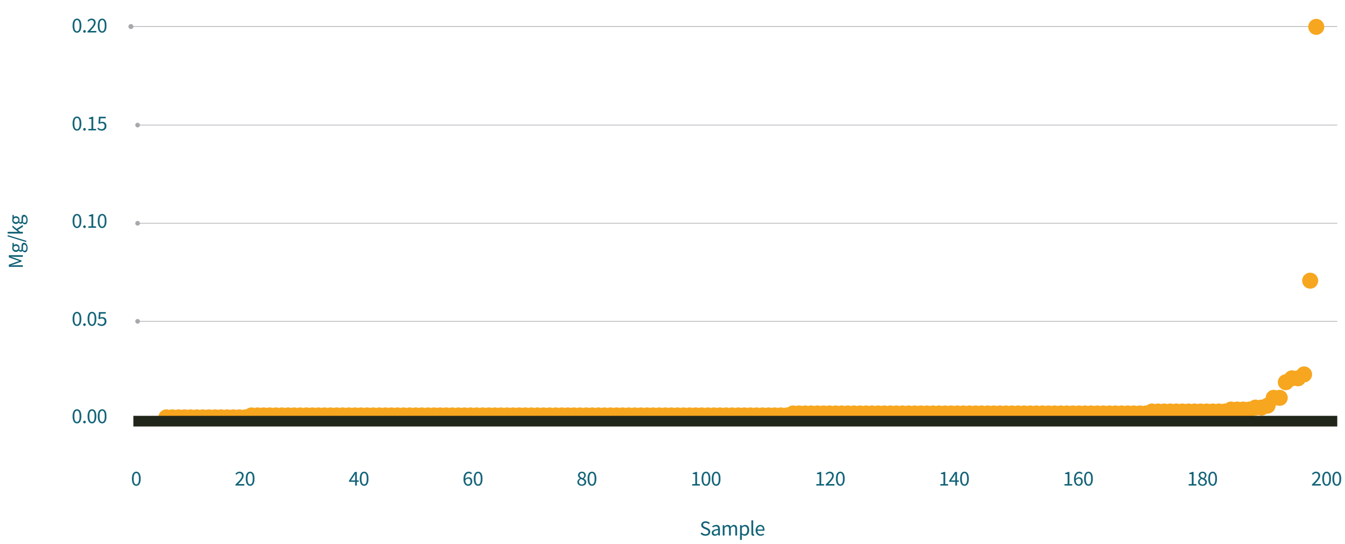


FIGURE 34: NOZZLE SAMPLE DATA: WATER AND SEDIMENT



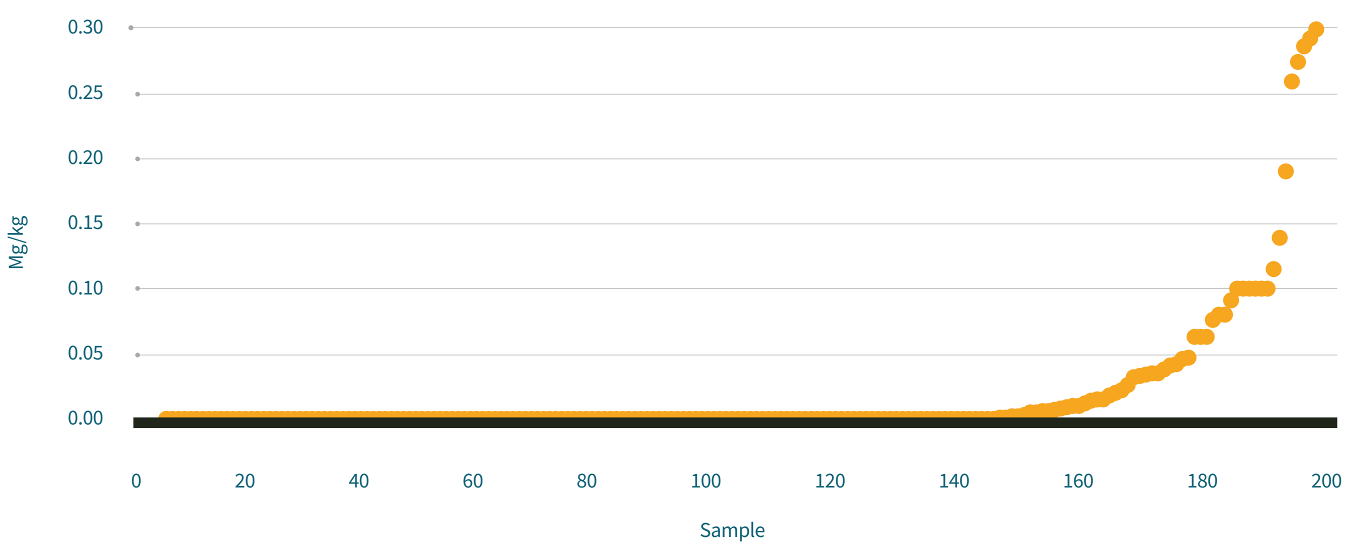
METALS

As previously noted, the WWFC Category 4 Diesel Fuel Specification sets a maximum level for metals as "non-detectable." The baseline used in the laboratory analysis was <1 mg/kg. Using the 1 mg/kg, all but six samples met the benchmark. However, the results were vastly different when the "non-detectable" benchmark was applied, which raised questions relative to what should be the appropriate benchmark. In discussions with industry stakeholders and the testing laboratory, the Fuels Institute learned it is possible to perform repeatable, reliable tests to detect metals at concentrations of 0.5 mg/kg. The discussion below considers the samples with respect to all three of these potential benchmarks:

Potassium

None of the samples measured potassium greater than 1 mg/kg or 0.5 mg/kg. However, potassium was detected in 53 samples (27.9%). Of these samples, the potassium content ranged from 0.001 mg/kg to 0.299 mg/kg, with an average of 0.067 mg/kg (Figure 35).

FIGURE 35: NOZZLE SAMPLE DATA: POTASSIUM



Sodium

None of the samples measured sodium greater than 1 mg/kg or 0.5 mg/kg. However, sodium was detected in 39 samples (20.5%). Of these samples, the sodium content ranged from 0.002 mg/kg to 0.299 mg/kg, with an average of 0.091 mg/kg (Figure 36).

Magnesium

None of the samples measured magnesium greater than 1 mg/kg or 0.5 mk/kg. However, magnesium was detected in 97 samples (51.1%). Of these samples, the magnesium content ranged from 0.001 mg/kg to 0.083 mg/kg, with an average of 0.014 mg/kg (Figure 37).

FIGURE 36: NOZZLE SAMPLE DATA: SODIUM

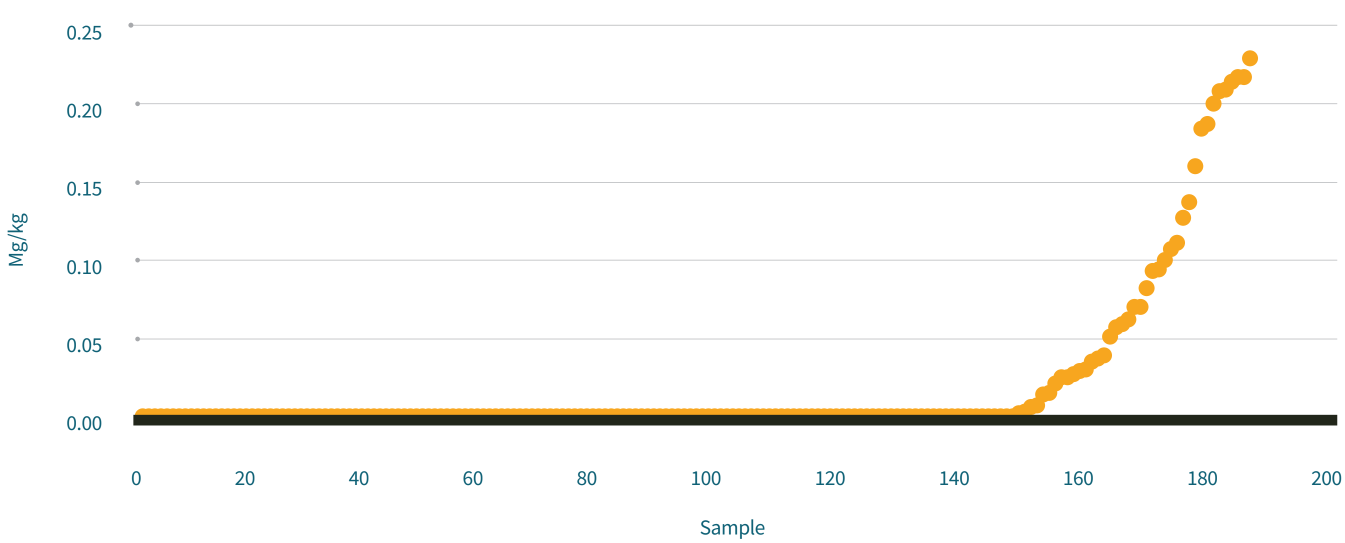
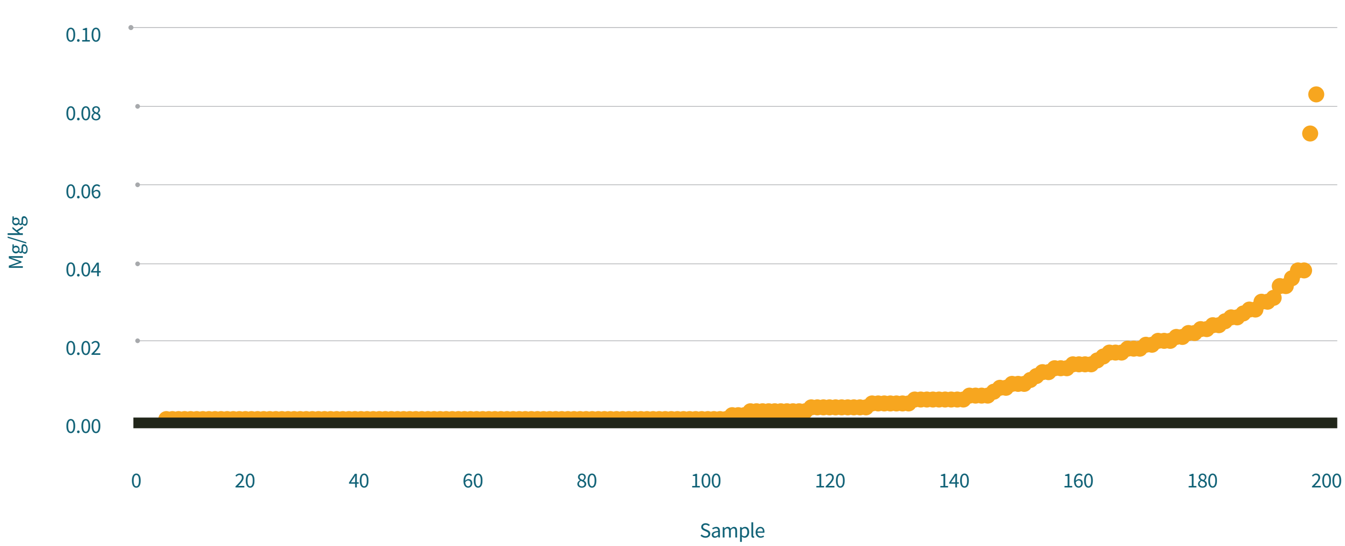


FIGURE 37: NOZZLE SAMPLE DATA: MAGNESIUM



Calcium

None of the samples measured calcium greater than 1 mg/kg or 0.5 mk/kg. However, calcium was detected in 101 samples (53.2%). Of these samples, the calcium content ranged from 0.001 mg/kg to 0.276 mg/kg, with an average of 0.028 mg/kg (Figure 38).

Zinc

Six (3%) of the samples measured zinc above 1 mg/kg, and eight measured above 0.5 mg/kg. These samples ranged from 0.676 mg/kg to 2.321 mg/kg, with an average of 1.605 mg/kg. Including these eight samples, zinc was detected in 114 samples (60.0%). Of these samples, the zinc content ranged from 0.001 mg/kg to 2.321 mg/kg, with an average of 0.204 mg/kg (Figure 39).

FIGURE 38: NOZZLE SAMPLE DATA: CALCIUM

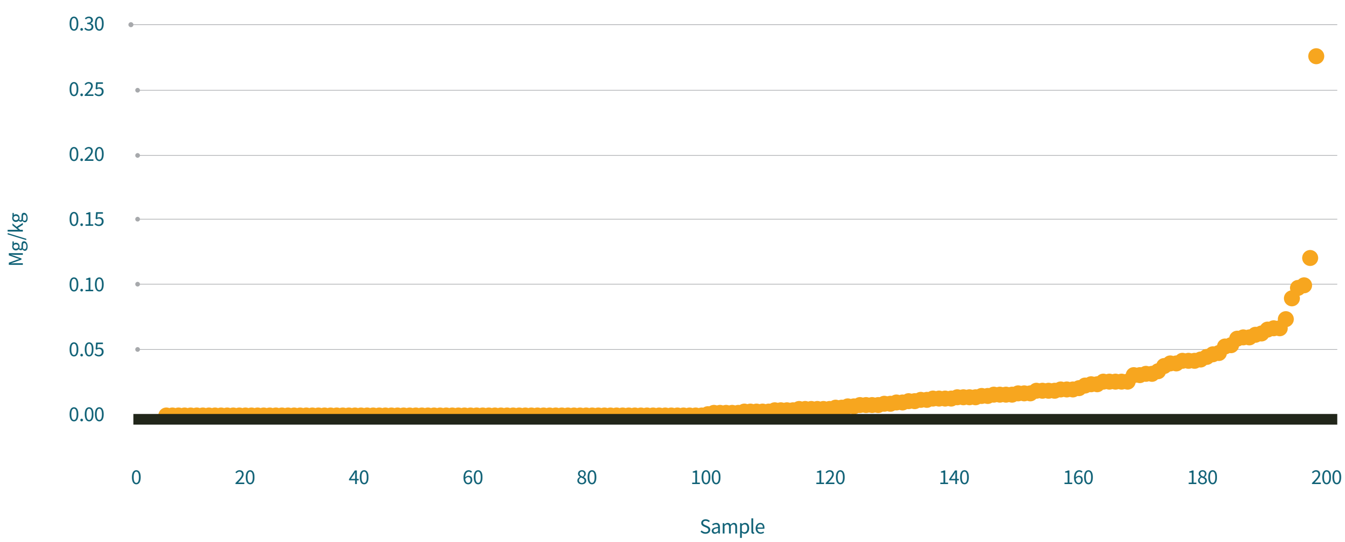
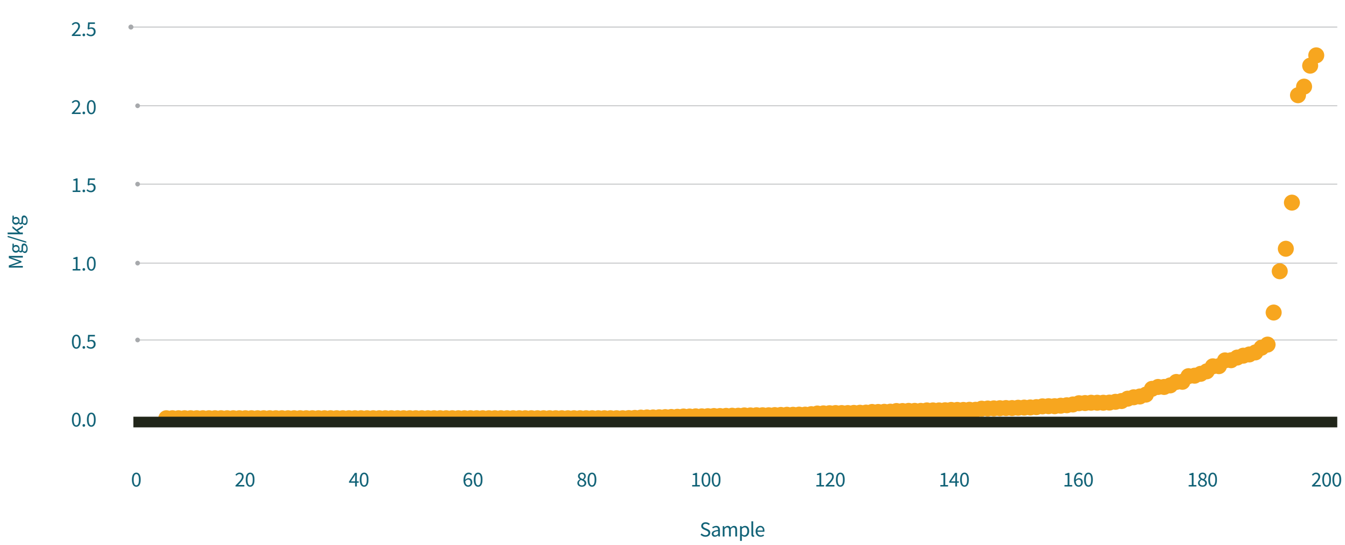


FIGURE 39: NOZZLE SAMPLE DATA: ZINC



Biodiesel

Each sample was tested for biodiesel content. Of the 190 samples collected, 80 samples (42.1%) contained no detectable biodiesel. Seventy-eight samples (41.1%) contained less than 5% biodiesel, ranging from 0.01% to 4.93%, with an average concentration of 2.72%. Thirty-two samples (16.8%) contained more than 5% biodiesel, ranging from 5.02% to 19.6%, with an average concentration of 12.5%.

Some stakeholders asked if there was any observable difference among samples containing different volumes of biodiesel and those satisfying any applicable benchmark. The Fuels Institute separated biodiesel blends into three categories (0%, <5%, and >5%) and evaluated the sample results for each category against applicable benchmarks. (For oxidation stability analysis, only samples containing a minimum of 2% biodiesel were included, and these samples were broken into only two categories - <5% and >5%.) The results are presented in Figure 40.

FIGURE 40: NOZZLE SAMPLE DATA: BIODIESEL CONTENT

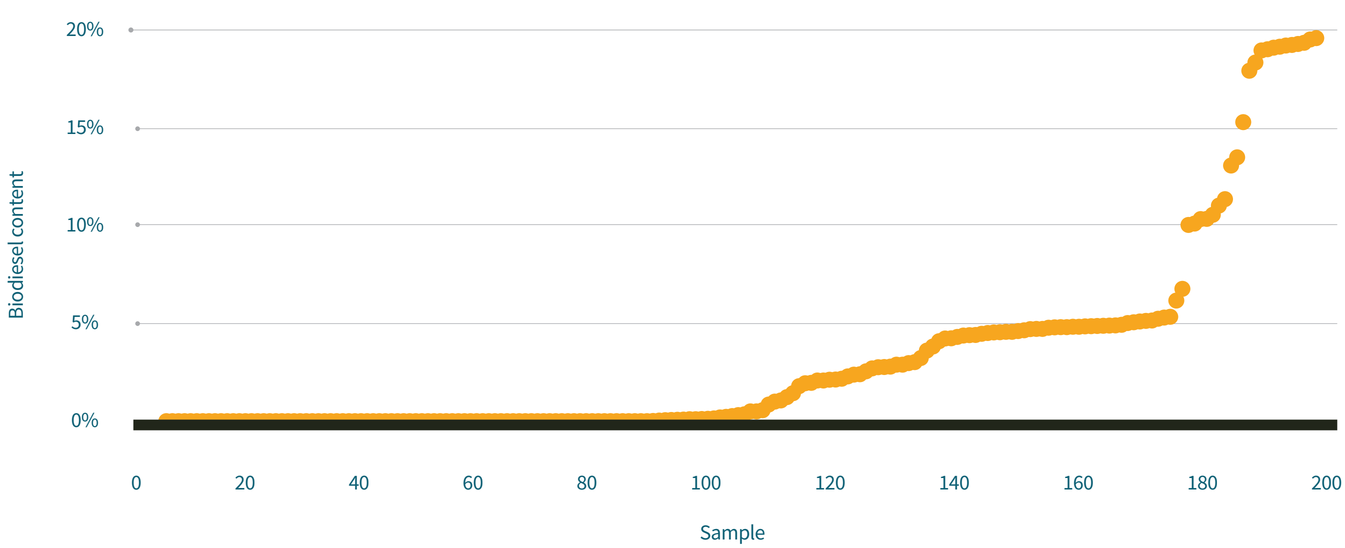
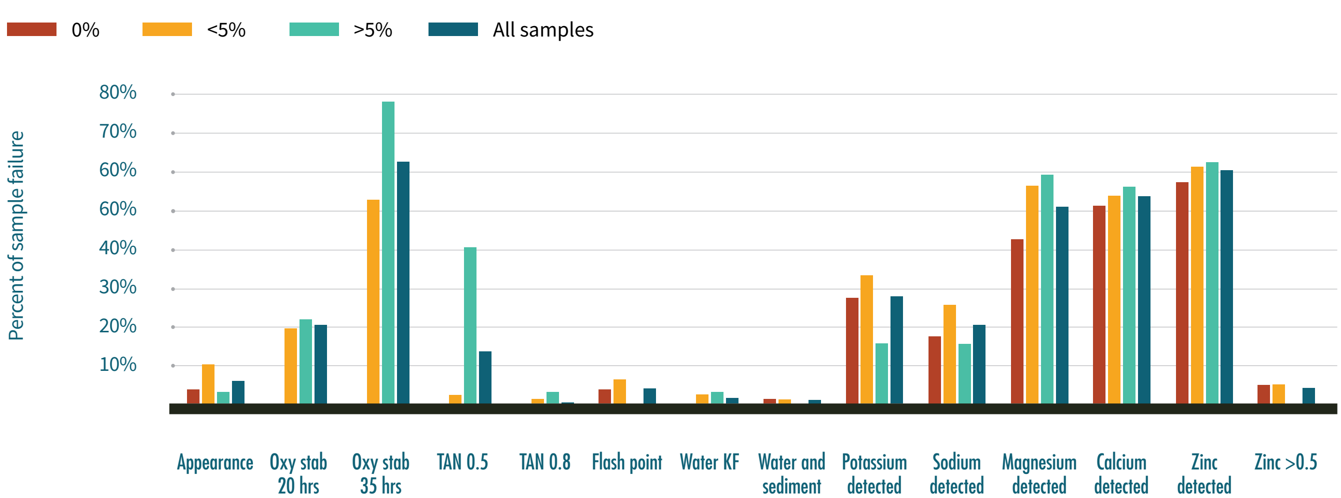


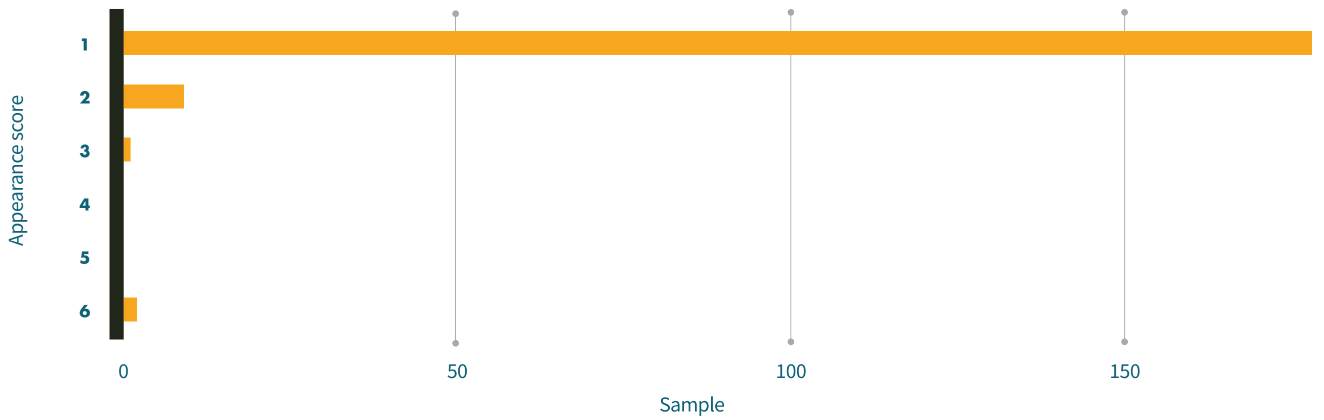
FIGURE 41: EFFECT OF BIODIESEL ON SAMPLE FAILURE PERCENT



APPEARANCE TEST

Whereas the benchmark for clear and bright is represented by an appearance score of 1, 12 samples (6%) failed to satisfy the benchmark. Of these, nine were rated 2, one rated 3, and two rated 6 (Figure 42).

FIGURE 42: NOZZLE SAMPLE APPEARANCE



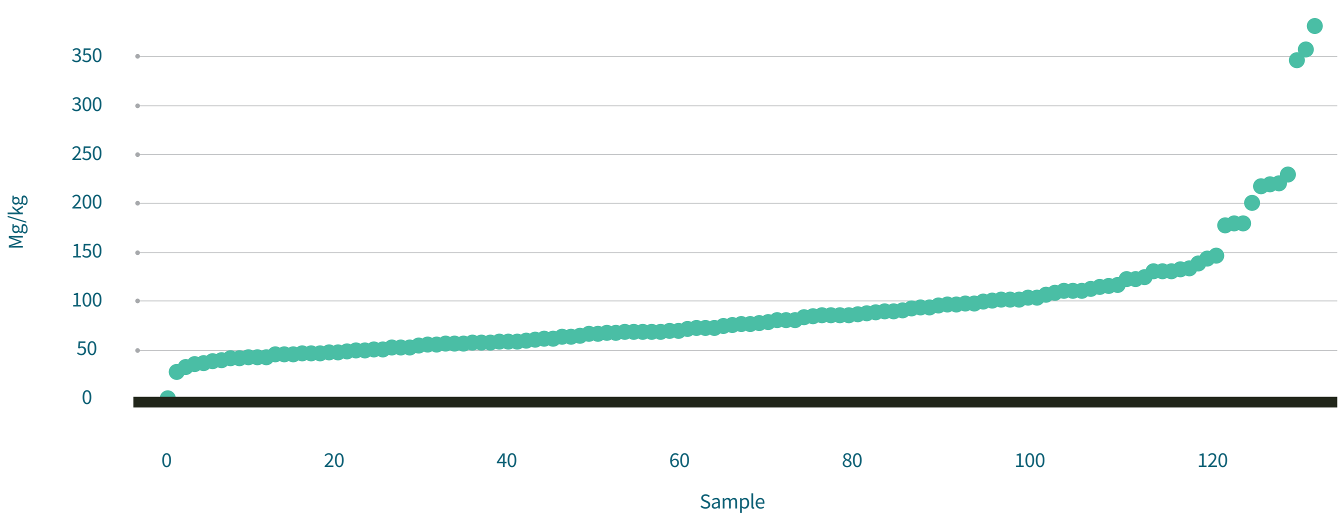
OBSERVATIONS FROM MIDDLE TANK SAMPLE DATA

The following observations provide greater detail on the fuel properties relative to selected benchmarks and the range of fuel properties within each category.

WATER (KARL FISCHER)

Of the 134 samples collected, 12 samples (9.0%) had water content above 200 mg/kg. These ranged from 217 mg/kg to 970 mg/kg, with one outlier that appeared to be primarily aqueous and was excluded from additional analysis. The compliant samples ranged from 0 mg/kg to 200 mg/kg, with an average water content of 80 mg/kg (Figure 43).

FIGURE 43: MIDDLE TANK SAMPLE DATA: WATER (KARL FISCHER)



WATER AND SEDIMENT

Of the 134 samples, 13 samples (9.7%) exceeded the ASTM standard of 500 mg/kg. These 13 samples ranged from 1,000 mg/kg to a sample that appeared to be fully aqueous and was excluded from additional analysis. If the benchmark were lowered to 200 mg/kg, another six samples would exceed the benchmark (Figure 44 and 44B).

FIGURE 44: MIDDLE TANK SAMPLE DATA: WATER AND SEDIMENT

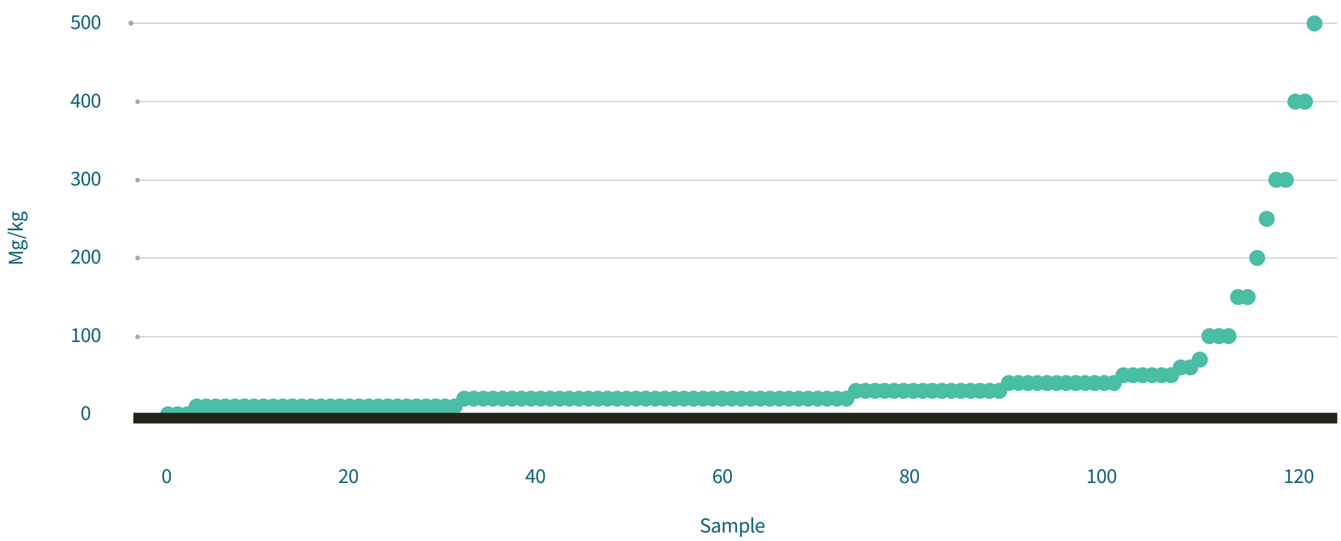
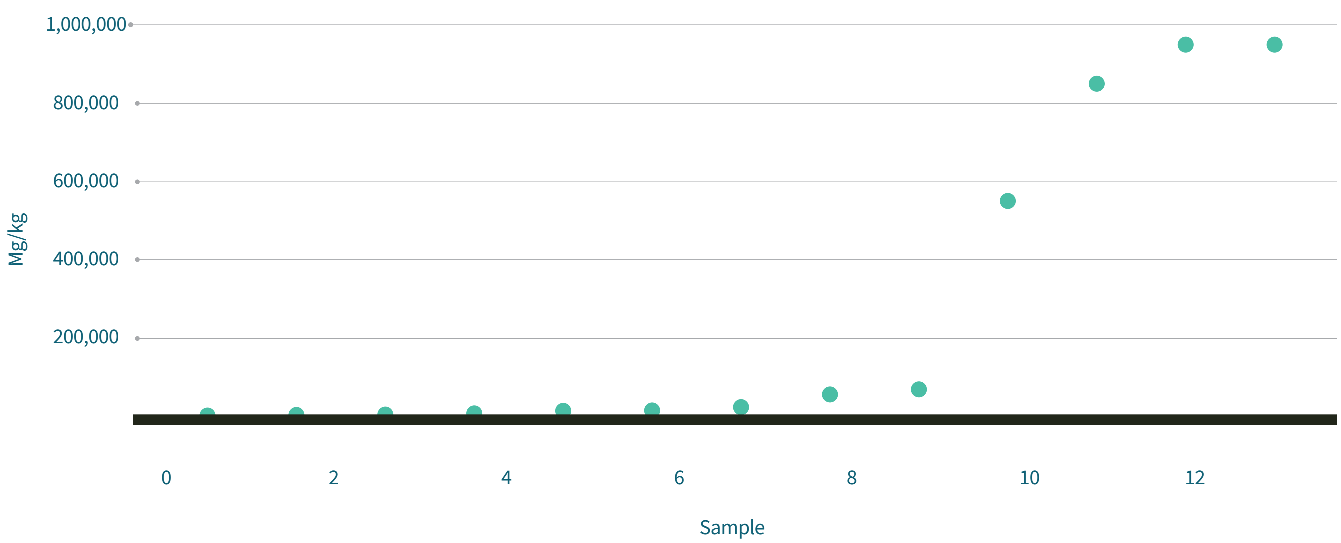


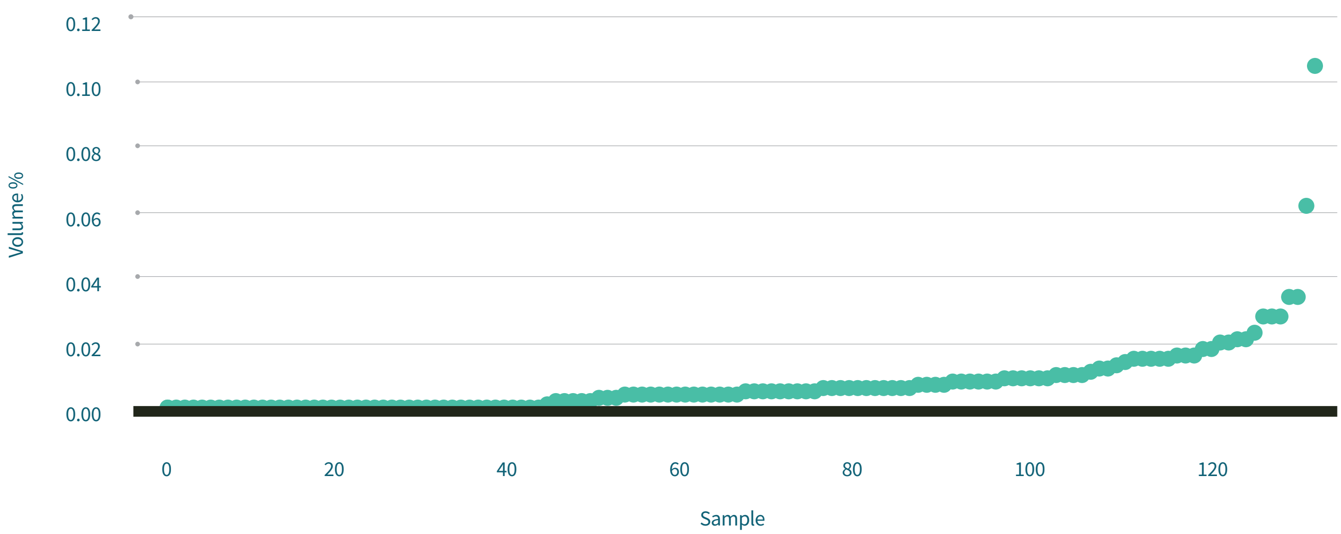
FIGURE 44B: MIDDLE TANK SAMPLE DATA: WATER AND SEDIMENT (ABOVE THE BENCHMARK)



ETHANOL

Of the 134 samples collected, 90 samples (67.2%) had detectable amounts of ethanol. This ranged from 0.001% to 0.105%, with an average of 0.011% (Figure 45).

FIGURE 45: MIDDLE TANK SAMPLE DATA: ETHANOL



MICROBIAL COUNT—BACTERIAL

Of the samples collected, 11 samples (8.2%) exceeded a measure of 4,000 CFU/L (colony forming units per liter).[6] Five of these samples were recorded simply as "overgrown." The remaining samples ranged from 0 CFU/L to 2,840 CFU/L, with an average of approximately 206 CFU/L (Figure 46 and 46B).

FIGURE 46: MIDDLE TANK SAMPLE DATA: MICROBIAL COUNT—BACTERIAL

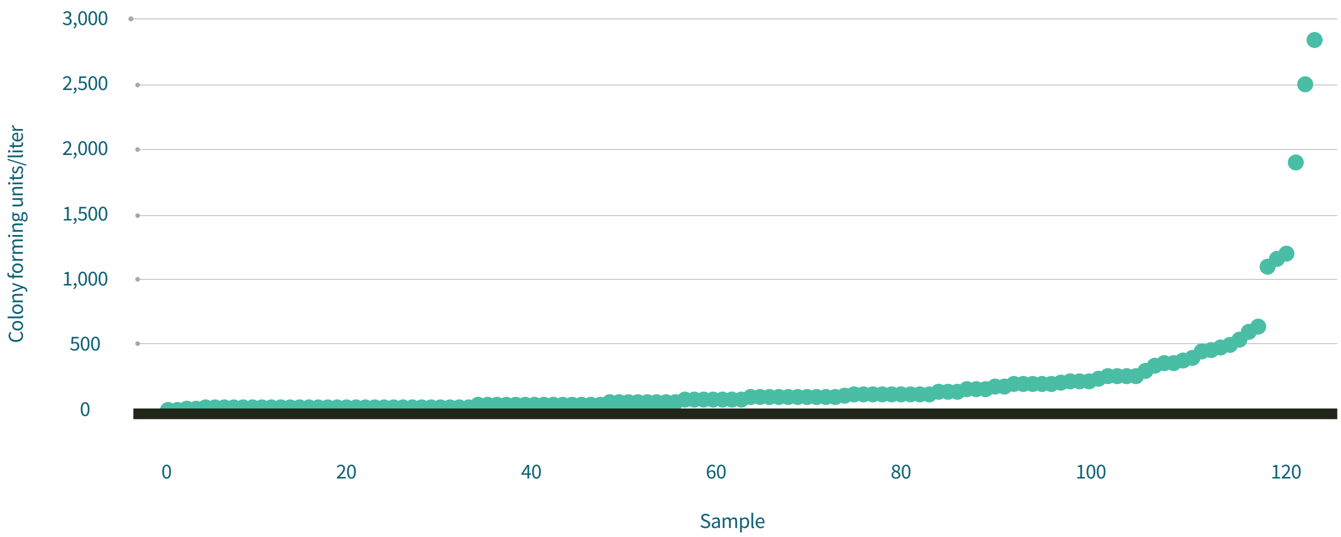
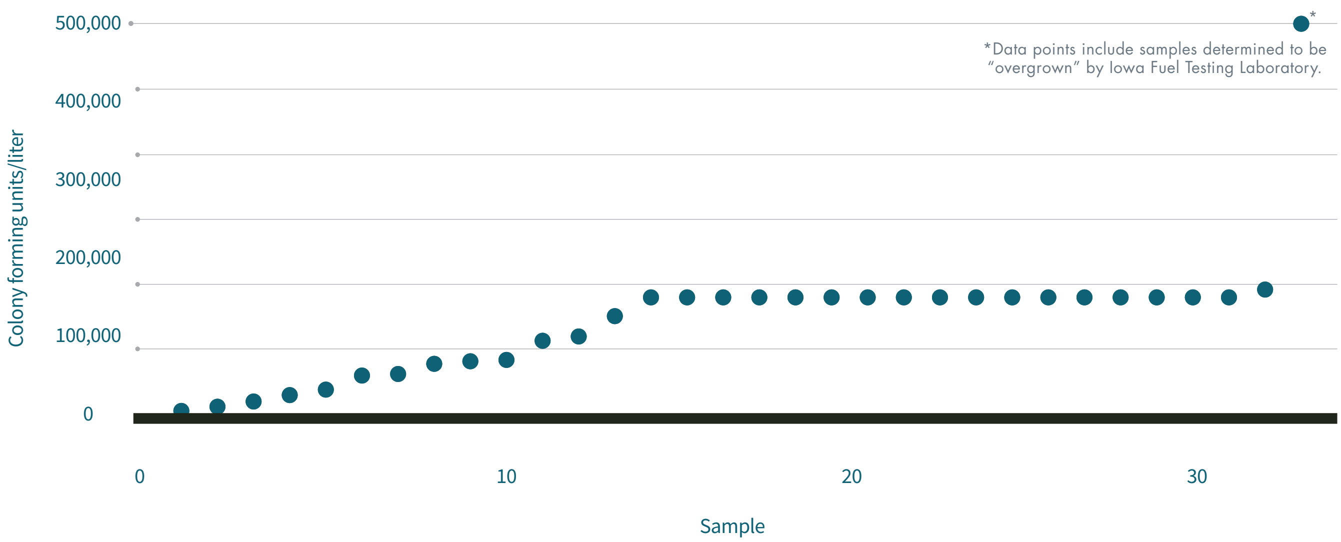


FIGURE 46B: MIDDLE TANK SAMPLE DATA: MICROBIAL COUNT—BACTERIAL (ABOVE THE BENCHMARK)



6 ASTM standards do not include a limit for microbial growth and there exists no other standard setting a limit. According to input from fuel quality testing professionals, they typically deem levels around 100 CFU/L as background levels common in fuel. However, levels at or exceeding 4,000 CFU/L are indicative of a microbial growth issue. While this level is not definitive in suggesting a likely operational issue should result, it does serve as a credible and acceptable benchmark against which to measure the microbial condition of the samples studied in this report.

MICROBIAL COUNT—MYCOLOGICAL

Of the samples collected, five samples (3.7%) were found to exceed 4,000 CFU/L. Three of these samples were recorded simply as "overgrown." The remaining samples ranged from 0 CFU/L to 3,500 CFU/L, with an average of approximately 233 CFU/L (Figure 47 and 47B).

FIGURE 47: MIDDLE TANK SAMPLE DATA: MICROBIAL COUNT—MYCOLOGICALIAL

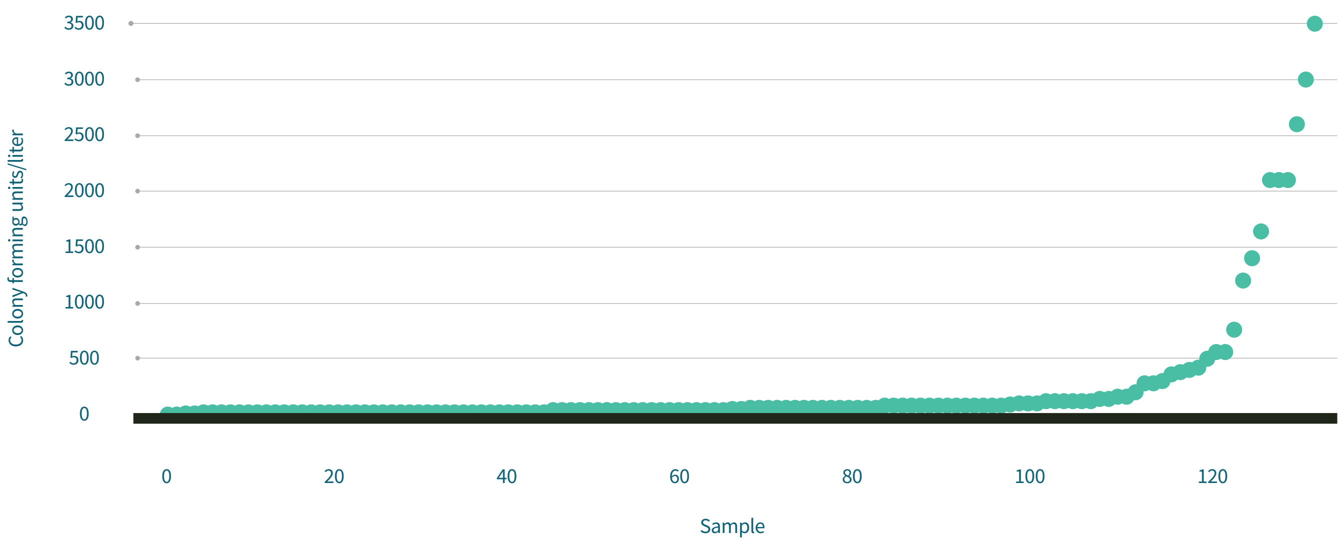


FIGURE 47B: MIDDLE TANK SAMPLE DATA: MICROBIAL COUNT—MYCOLOGICALIAL (ABOVE THE BENCHMARK)

APPEARANCE

Whereas the benchmark for clear and bright is represented by an appearance score of 1, 34 samples (25.4%) failed to satisfy the benchmark. Of these, fifteen were rated 2, three rated 3, three rated 4, and thirteen rated 6 (Figure 48).

FIGURE 48: MIDDLE TANK SAMPLE APPEARANCE

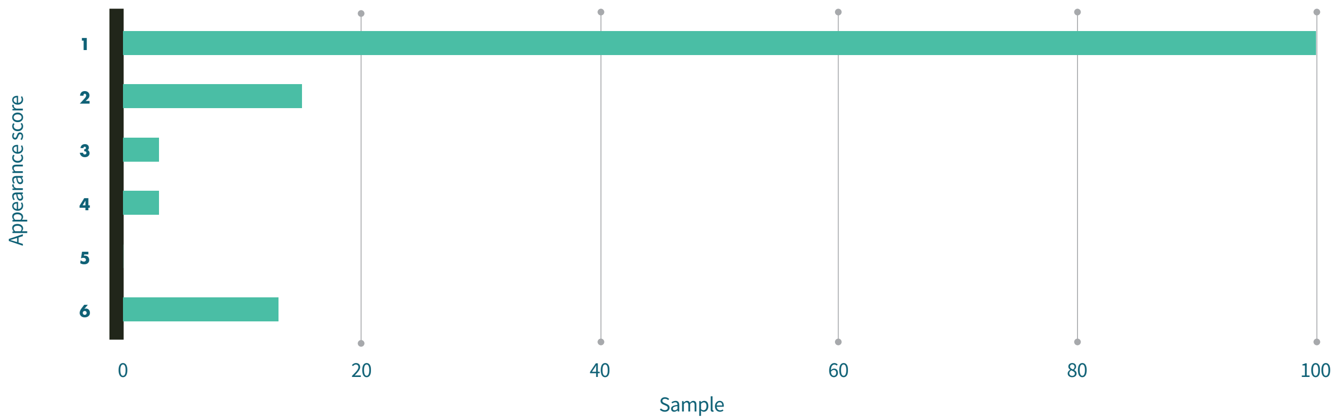


FIGURE 48B: ASTM D4176 STANDARD VISUALLY MEASURING HAZE

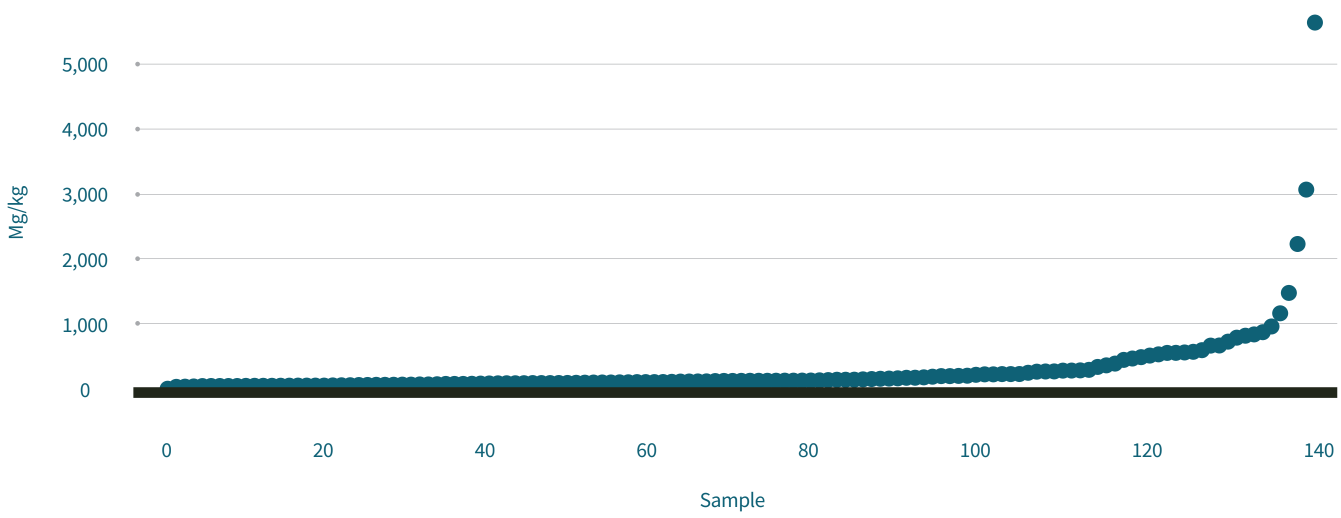
OBSERVATIONS FROM BOTTOM TANK SAMPLE DATA

The following observations provide greater detail on the fuel properties relative to selected benchmarks and the range of fuel properties within each category.

WATER (KARL FISCHER)

Of the 134 samples collected, 41 samples (30.6%) had water content above 200 mg/kg. These ranged from 214 mg/kg to 5,621 mg/kg, with one outlier that appeared to be primarily aqueous and was excluded from additional analysis. The compliant samples ranged from 0 mg/kg to 200 mg/kg, with an average water content of 95 mg/kg (Figure 49).

FIGURE 49: BOTTOM TANK SAMPLE DATA: WATER (KARL FISCHER)



WATER AND SEDIMENT

Of the 134 samples, 63 samples (47.0%) exceeded the ASTM standard of 500 mg/kg. These samples ranged from 650 mg/kg to one sample that appeared to be fully aqueous. If the benchmark were lowered to 200 mg/kg, another five samples would exceed the benchmark (Figure 50 and 50B).

FIGURE 50: BOTTOM TANK SAMPLE DATA: WATER AND SEDIMENT

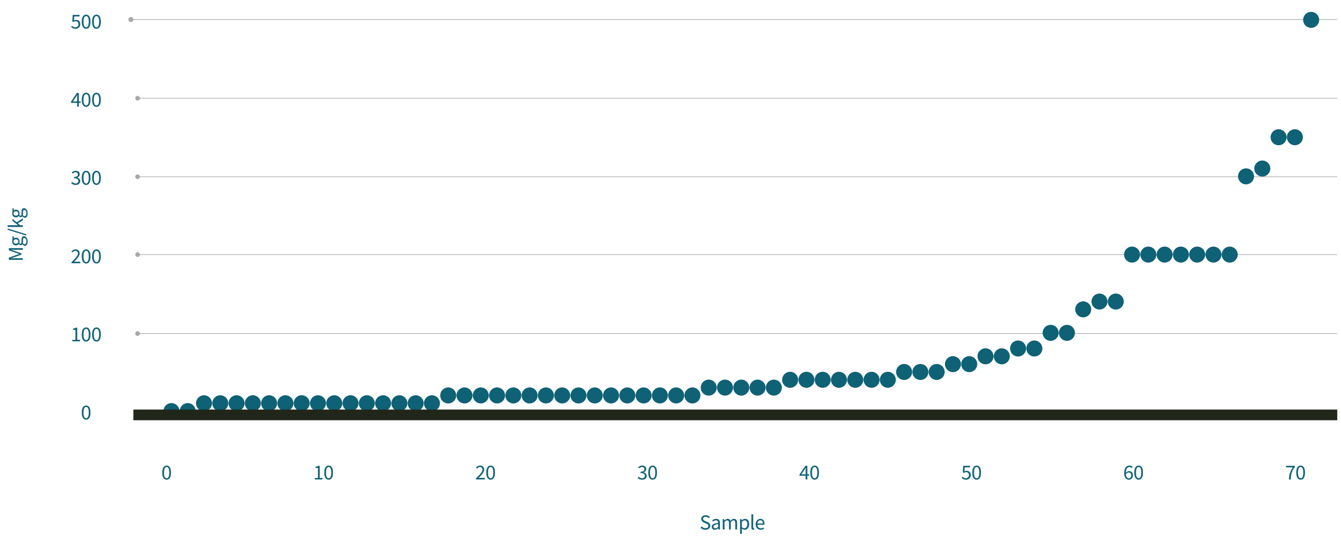
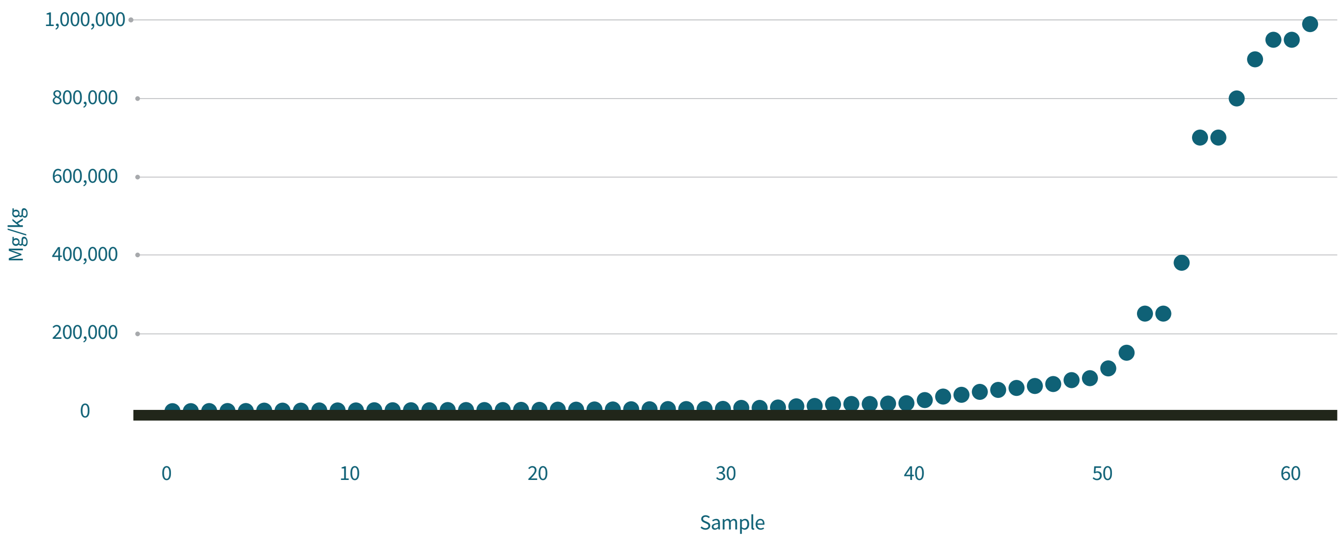


FIGURE 50B: BOTTOM TANK SAMPLE DATA: WATER AND SEDIMENT (ABOVE THE BENCHMARK)



MICROBIAL COUNT—BACTERIAL

Of the samples collected, 32 samples (23.9%) exceeded a measure of 4,000 CFU/L.[7] Twenty-one of these samples were recorded simply as "overgrown," and another 13 contained between 50,000 CFU/L and 500,000 CFU/L, with an average of 118,750 CFU/L. The remaining samples ranged from 0 CFU/L to 2,940 CFU/L, with an average of approximately 244 CFU/L (Figure 51 and 51B).

FIGURE 51: BOTTOM TANK SAMPLE DATA: MICROBIAL COUNT—BACTERIAL

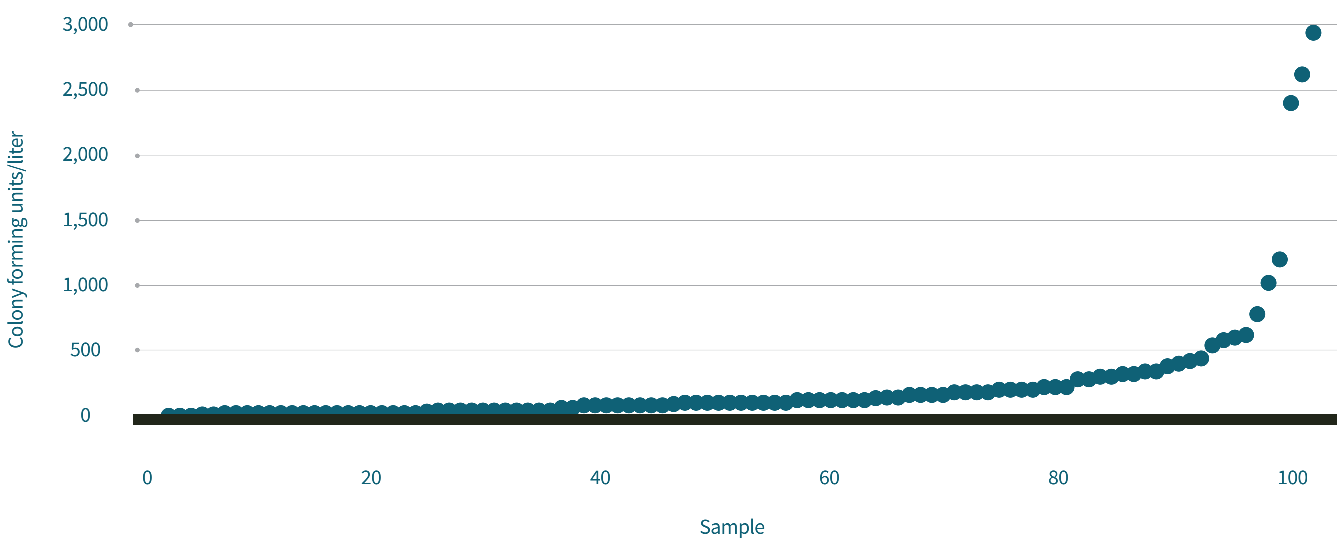
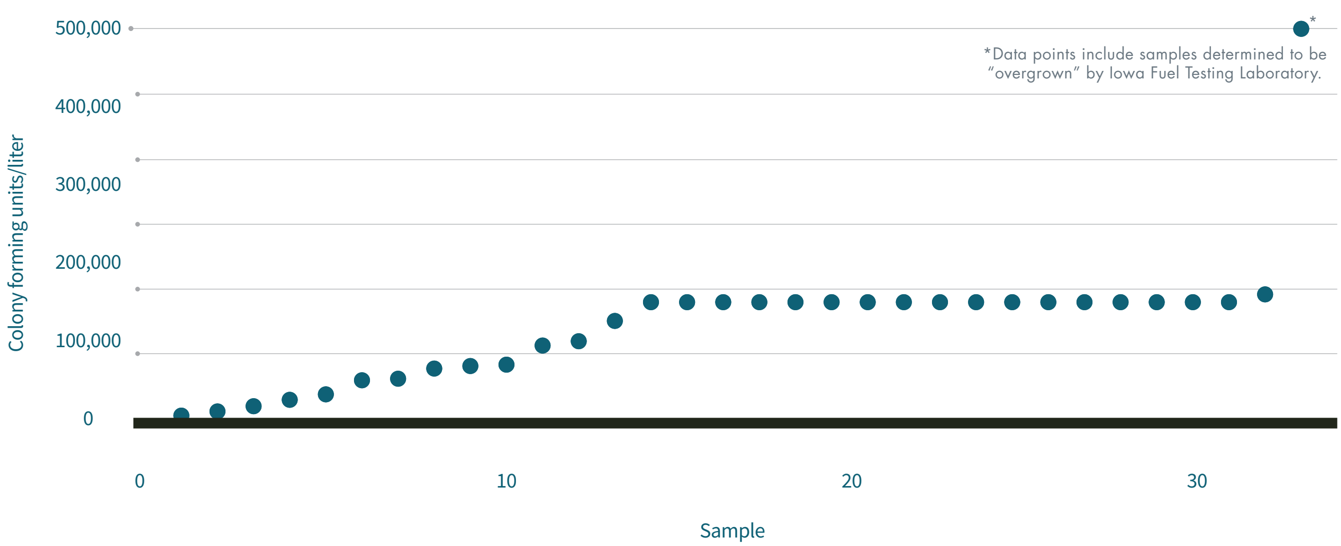


FIGURE 51B: BOTTOM TANK SAMPLE DATA: MICROBIAL COUNT—BACTERIAL (ABOVE THE BENCHMARK)



7 ASTM standards do not include a limit for microbial growth and there is exists no other standard setting a limit. According to input from fuel quality testing professionals, they typically deem levels around 100 CFU/L as background levels common in fuel. However, levels at or exceeding 4,000 CFU/L are indicative of a microbial growth issue. While this level is not definitive in suggesting a likely operational issue should result, it does serve as a credible and acceptable benchmark against which to measure the microbial condition of the samples studied in this report.

MICROBIAL COUNT—MYCOLOGICAL

Of the samples collected, 23 samples (17.2%) were found to exceed 4,000 CFU/L. Twenty of these samples were recorded simply as "Overgrown." The remaining samples ranged from 0 CFU/L to 2,200 CFU/L, with an average of approximately 193 CFU/L (Figure 52 and 52B).

FIGURE 52: BOTTOM TANK SAMPLE DATA: MICROBIAL COUNT—MYCOLOGICAL

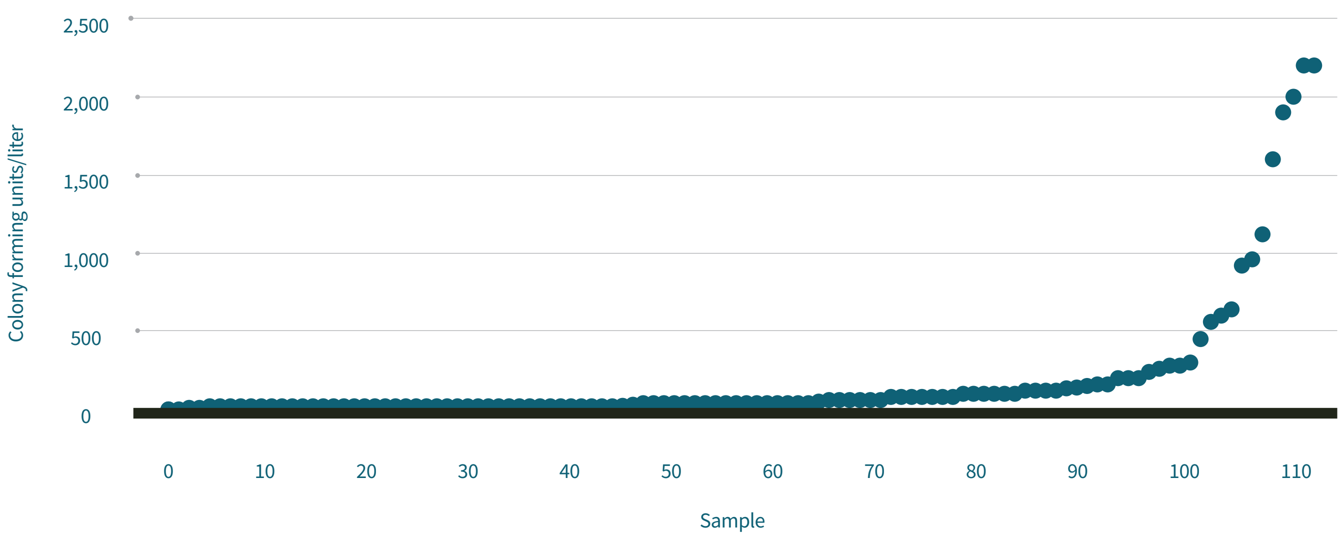
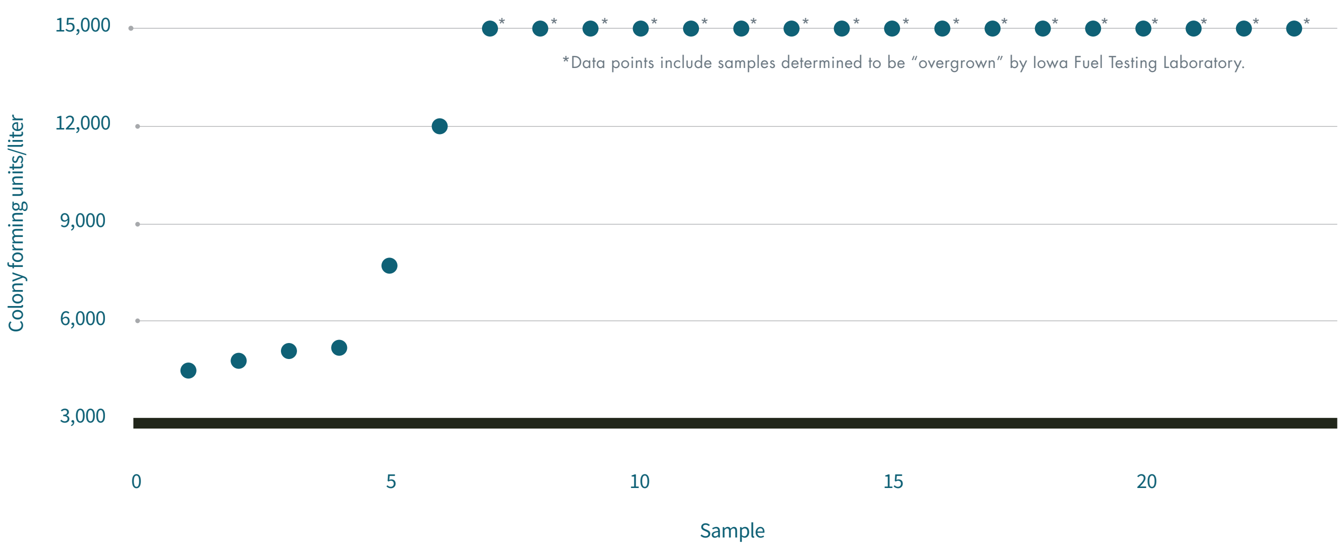


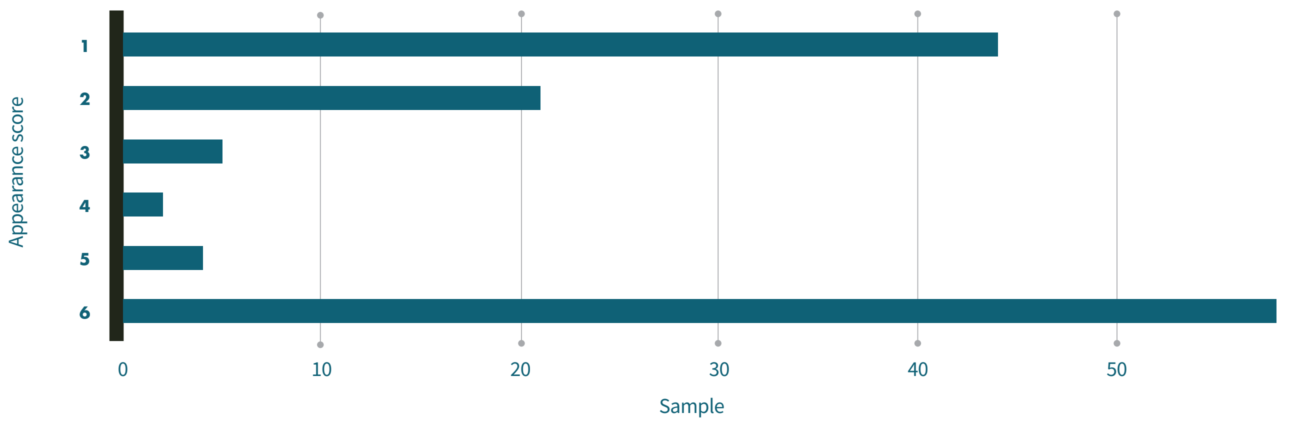
FIGURE 52B: BOTTOM TANK SAMPLE DATA: MICROBIAL COUNT—MYCOLOGICAL (ABOVE THE BENCHMARK)



APPEARANCE TEST

Whereas the standard for clear and bright is represented by an appearance score of 1, 90 samples (67.2%) failed to satisfy the standard. Of these, twenty-one were rated 2, five rated 3, two rated 4, four rated 5, and fifty-eight rated 6. (Figure 53)

FIGURE 53: BOTTOM SAMPLE APPEARANCE



DIFFERENCES BETWEEN RETAIL AND NON-RETAIL FACILITIES

Samples for this study were collected from retail and non-retail fueling facilities. Of the 190 nozzle samples collected, 86% were from retail facilities and 14% were from non-retail facilities. Of the 134 samples collected from storage tanks, 89% were collected from retail facilities and 11% from non-retail. The vast majority of samples were collected from automotive-diesel-dedicated dispenser and tank systems (low-flow systems). The results from the laboratory tests on the samples from retail and non-retail facilities were compared.

The following charts present the percent of samples from each facility format that failed to meet the applicable benchmark for the tests applied to the nozzle and tank samples. From this comparison, there appears to be no significant difference in the rates of compliance between retail and non-retail fueling facilities, except for the bottom samples in which non-retail tanks more frequently failed to meet all of the benchmarks (Figure 54, 55, 56).

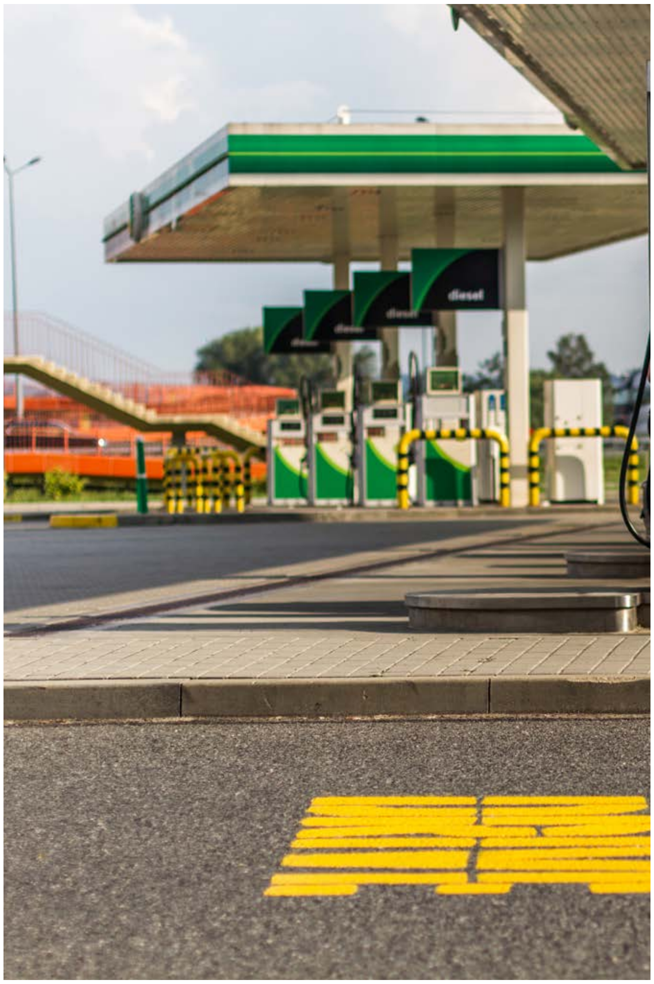


FIGURE 54: PERCENT OF NOZZLE SAMPLES NOT MEETING BENCHMARK (RETAIL VS. NON-RETAIL)

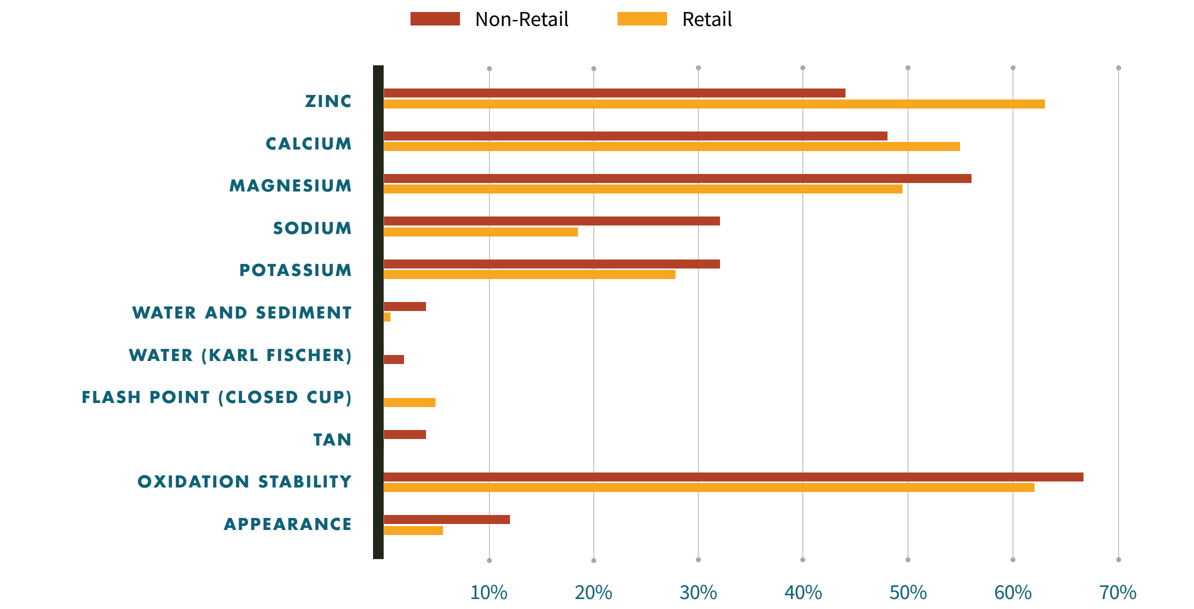


FIGURE 55: PERCENT OF MIDDLE TANK SAMPLES NOT MEETING BENCHMARK (RETAIL VS. NON-RETAIL)

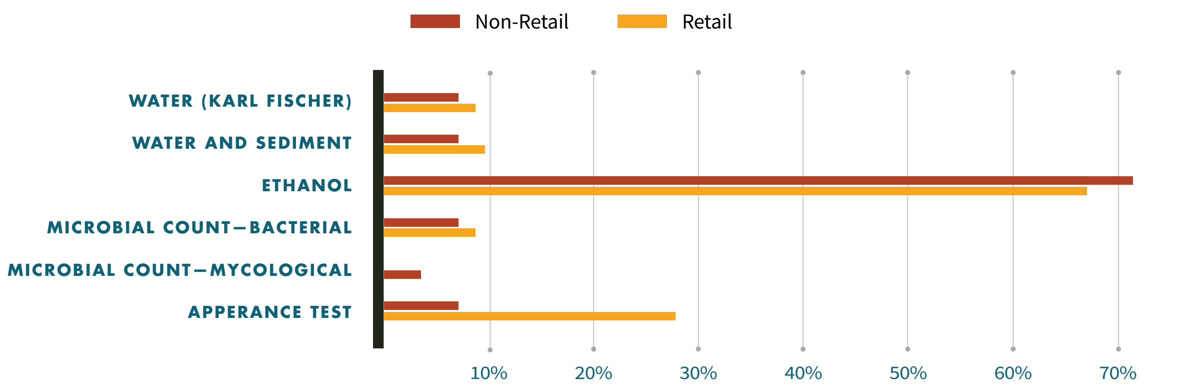
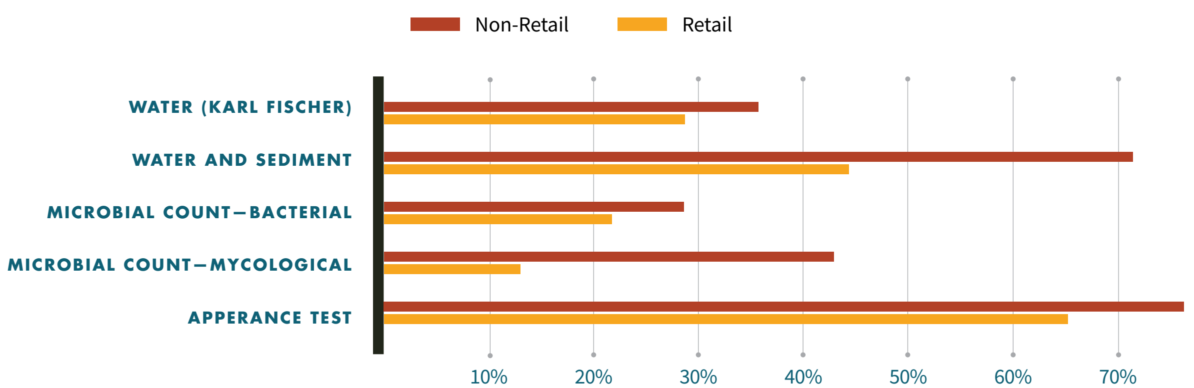


FIGURE 56: PERCENT OF BOTTOM TANK SAMPLES NOT MEETING BENCHMARK (RETAIL VS. NON-RETAIL)



Relationships Between Fuel Properties

The results of all laboratory tests were compared to determine if there was any statistically significant association. The correlation coefficient (R-value) calculates if two variables have a positive or negative effect on each other. A result of 1 or −1 indicates that the variables have perfectly linear correlation; values closer to 0 are less correlated. The comparisons presented in this section are based upon the actual values for each fuel property reported by the lab.

It is important to recognize that correlation does not equal causation. Correlation describes the size and direction of a relationship between two variables but does not mean that a change in one variable will automatically result in a change in the other.

NOZZLE SAMPLE ANALYSIS

The nozzle samples analyzed had very few indications of correlation. Table 5 presents all the correlation coefficients. The bolded data points indicate a significant association (a value greater than 0.50 or less than −0.50). From the data, it appears the following correlations exist:

- **Appearance with water and sediment (0.85)**
- **Appearance with water (Karl Fischer) (0.64)**
- **Magnesium with calcium (0.60)**
- **TAN with biodiesel (0.53)**

While these four relationships present a statistically significant correlation, there are five others that present a minor relationship with a correlation coefficient between 0.25 and 0.50. These are italicized in Table 5 and include:

- **Water (Karl Fischer) with TAN (0.34)**
- **Water and sediment with water (Karl Fischer) (0.40)**
- **Magnesium with potassium (0.31)**
- **Calcium with potassium (0.25)**
- **Biodiesel with water (Karl Fischer) (0.29)**

TABLE 5: CORRELATION COEFFICIENTS BETWEEN FUEL PROPERTIES MEASURED FROM NOZZLE SAMPLES

	APP	OXIDATION STABILITY	TAN	FLASH POINT (CLOSED CUP)	WATER (KARL FISCHER)	WATER/SED	POTASSIUM	SODIUM	MAGNESIUM	CALCIUM	ZINC	BIODIESEL
Appearance	1.00	0.05	0.13	−0.02	**0.64**	**0.85**	0.12	0.06	0.18	0.14	0.04	−0.03
Oxidation stability		1.00	−0.34	−0.03	−0.09	0.01	−0.01	−0.12	−0.03	0.06	−0.09	−0.23
TAN			1.00	0.11	*0.34*	0.13	0.08	0.01	0.21	0.20	0.23	**0.53**
Flash point (closed cup)				1.00	−0.08	0.07	0.06	0.12	0.01	0.00	−0.09	0.18
Water (Karl Fischer)					1.00	*0.40*	0.03	0.04	0.22	0.21	0.06	*0.29*
Water and sediment						1.00	0.17	−0.02	0.18	0.16	0.00	−0.04
Potassium							1.00	−0.01	*0.31*	*0.25*	0.06	−0.04
Sodium								1.00	−0.07	−0.12	−0.07	0.03
Magnesium									1.00	**0.60**	0.02	0.20
Calcium										1.00	0.07	0.11
Zinc											1.00	−0.09
Biodiesel												1.00

MIDDLE TANK SAMPLE ANALYSIS

The middle tank samples analyzed had very few indications of correlation. Table 6 presents all the correlation coefficients. The bolded data points indicate a significant association (a value greater than 0.50 or less than −0.50). From the data, it appears the following correlations might exist:

- Water (Karl Fischer) with water and sediment (0.56)
- Microbial count—bacterial with microbial count—mycological (0.54)
- Appearance with water and sediment (0.51)

While these three relationships present a statistically significant correlation, there are four others that present a minor relationship with a correlation coefficient between 0.25 – 0.50. These are italicized in Table 6 and include:

- Microbiological count—bacterial with appearance (0.43)
- Microbiological count—bacterial with water (Karl Fischer) (0.44)
- Microbiological count—bacterial with water and sediment (0.25)
- Ethanol with water and sediment (0.41)

TABLE 6: CORRELATION COEFFICIENTS BETWEEN FUEL PROPERTIES MEASURED FROM MIDDLE TANK SAMPLES

	APPEARANCE	MICROBIOLOGICAL COUNT—BACTERIAL	MICROBIOLOGICAL COUNT—MYCOLOGICAL	WATER (KARL FISCHER)	WATER AND SEDIMENT	BIODIESEL	ETHANOL
Appearance	1.00	*0.43*	0.24	0.24	**0.51**	−0.19	0.14
Microbiological count—bacterial		1.00	**0.54**	*0.44*	0.25	−0.09	0.01
Microbiological count—mycological			1.00	−0.02	0.01	−0.08	−0.05
Water (Karl Fischer)				1.00	**0.56**	−0.05	0.15
Biodiesel					−0.11	1.00	−0.03
Water and sediment					1.00		*0.41*
Ethanol							1.00

BOTTOM TANK SAMPLE ANALYSIS

When analyzed, the bottom tank samples showed no indications of significant association. Table 7 presents all the correlation coefficients.

While there were no relationships presenting a statistically significant correlation, there are five others that present a minor relationship with a correlation coefficient between 0.25 and 0.50. These are italicized in Table 7 and include:

- **Appearance with microbiological count—bacterial (0.37)**
- **Appearance with microbiological count—mycological (0.31)**
- **Appearance with water (Karl Fischer) (0.36)**
- **Appearance with water and sediment (0.33)**
- **Microbiological count—bacterial and microbiological count—mycological (0.46)**

TABLE 7: CORRELATION COEFFICIENTS BETWEEN FUEL PROPERTIES MEASURED FROM BOTTOM TANK SAMPLES

	APPEARANCE	MICROBIOLOGICAL COUNT—BACTERIAL	MICROBIOLOGICAL COUNT—MYCOLOGICAL	WATER (KARL FISCHER)	WATER AND SEDIMENT	BIODIESEL
Appearance	1.00	*0.37*	*0.31*	*0.36*	*0.33*	−0.21
Microbiological count—bacterial		1.00	*0.46*	0.04	0.20	−0.10
Microbiological count—mycological			1.00	0.06	0.06	−0.09
Water (Karl Fischer)				1.00	0.17	−0.09
Biodiesel					−0.12	1.00
Water and sediment					1.00	

TANK AND NOZZLE SAMPLE ANALYSIS

Nearly all tank samples were collected from the same location where a nozzle sample was collected, allowing for comparable analysis and potential correlations between fuel properties found within a tank and those measured from the nozzle it supplies. Tables 8 and 9 present the correlation coefficients between middle tank samples and nozzle samples and between bottom tank samples and nozzle samples, respectively. From these analyses, it appears there exists only one significant association (a value greater than 0.50 or less than −0.50), between TAN and biodiesel. This is consistent with the correlation between TAN and biodiesel in the nozzle samples themselves and are in bold in Tables 8 and 9:

- **Middle layer to nozzle sample: TAN and biodiesel (0.52)**
- **Bottom layer to nozzle sample: TAN and biodiesel (0.52)**
- **Individual nozzle samples: TAN and biodiesel (0.53)**

While these three relationships present a statistically significant correlation, there are others that present a minor relationship with a correlation coefficient between 0.25 and 0.50. These are italicized in Tables 8 and 9 and include:

- **Middle layer to nozzle sample: biodiesel with water (Karl Fischer) (0.27)**
- **Middle layer to nozzle sample: water and sediment with zinc (0.26)**
- **Bottom layer to nozzle sample: oxidation stability with microbiological count—bacterial (0.28)**
- **Bottom layer to nozzle sample: water and sediment with zinc (0.37)**

TABLE 8: CORRELATION COEFFICIENTS BETWEEN FUEL PROPERTIES MEASURED FROM MIDDLE TANK AND NOZZLE SAMPLE

	MICROBIOLOGICAL COUNT—BACTERIAL	MICROBIOLOGICAL COUNT—MYCOLOGICAL	WATER (KARL FISCHER)	WATER AND SEDIMENT	BIODIESEL	ETHANOL
Oxidation	0.21	0.20	−0.01	−0.20	−0.21	−0.18
TAN	−0.13	−0.03	−0.12	0.10	**0.52**	−0.19
Flash point (closed cup)	0.13	0.18	0.05	0.00	0.22	−0.22
Water (Karl Fischer)	−0.07	0.03	−0.05	−0.03	*0.27*	−0.04
Water and sediment	−0.01	−0.02	−0.02	0.05	−0.02	−0.05
Potassium	0.13	0.17	−0.03	0.02	−0.03	−0.16
Sodium	−0.09	0.12	−0.04	−0.05	0.01	−0.12
Magnesium	0.04	0.01	−0.06	−0.03	0.11	−0.10
Calcium	0.08	0.01	−0.06	−0.07	0.01	−0.09
Zinc	0.04	−0.07	−0.02	*0.26*	−0.14	−0.02

TABLE 9: CORRELATION COEFFICIENTS BETWEEN FUEL PROPERTIES MEASURED FROM BOTTOM TANK AND NOZZLE SAMPLES

	MICROBIOLOGICAL COUNT—BACTERIAL	MICROBIOLOGICAL COUNT—MYCOLOGICAL	WATER (KARL FISCHER)	WATER AND SEDIMENT	BIODIESEL
Oxidation	*0.28*	0.22	0.12	−0.15	−0.12
TAN	−0.07	−0.04	−0.05	0.06	**0.52**
Flash point (closed cup)	−0.04	0.14	−0.13	−0.11	0.16
Water (Karl Fischer)	−0.11	−0.01	0.22	−0.05	0.18
Water and sediment	−0.06	−0.06	0.12	0.01	−0.04
Potassium	0.07	0.10	−0.02	−0.02	−0.04
Sodium	−0.15	0.04	0.03	−0.10	−0.03
Magnesium	0.13	0.07	−0.02	0.03	0.12
Calcium	0.13	0.13	−0.06	0.00	0.02
Zinc	0.01	−0.11	0.11	*0.37*	−0.11

BIODIESEL CONTENT AND TOTAL ACID NUMBER

The only significant association found to exist between tank samples and nozzle samples was that between biodiesel content and TAN (0.52). There was also a statistically significant correlation between these fuel properties in the nozzle analysis (0.53). These correlations indicate that the more biodiesel a sample contained, the higher the TAN measurement. Figure 57 plots the TAN results with biodiesel volume percent, demonstrating the correlation between the two. Figure 58 simply demonstrates that the measured biodiesel content in the tank is consistent with that measured at the nozzle, which is to be expected and explains the similar correlation between these fuel properties regardless of where the samples were taken.

FIGURE 57: BIODIESEL AND TAN: NOZZLE SAMPLES

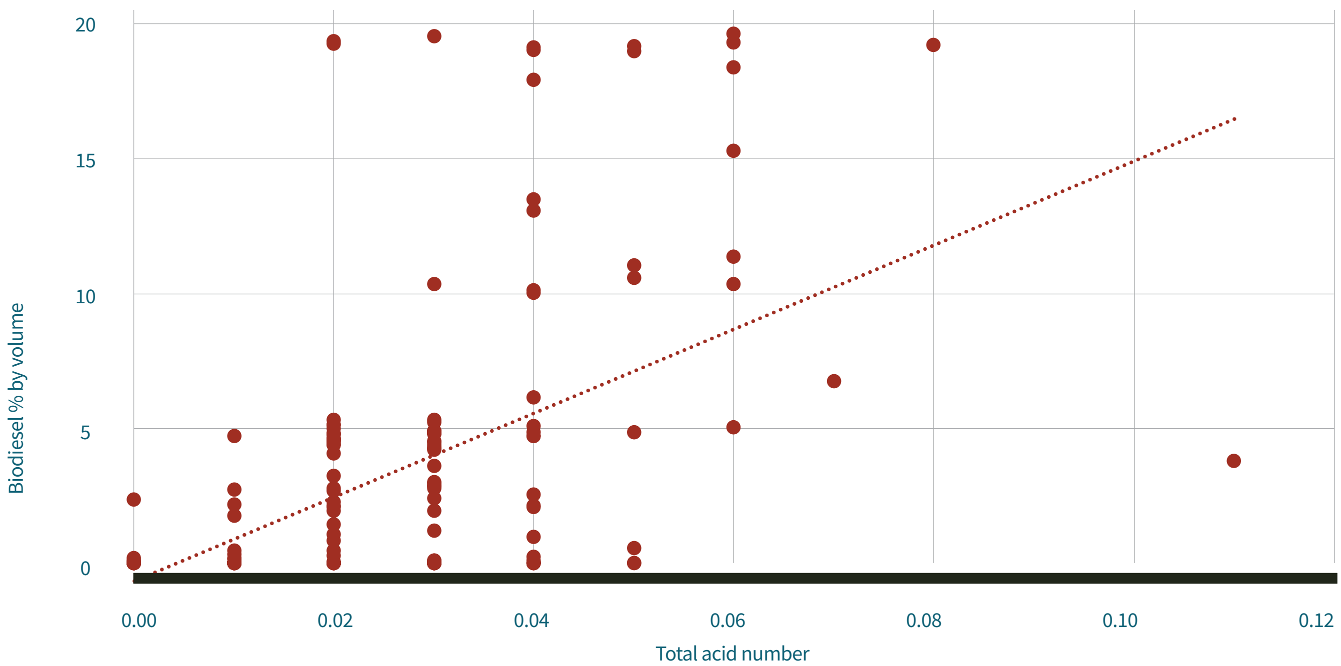
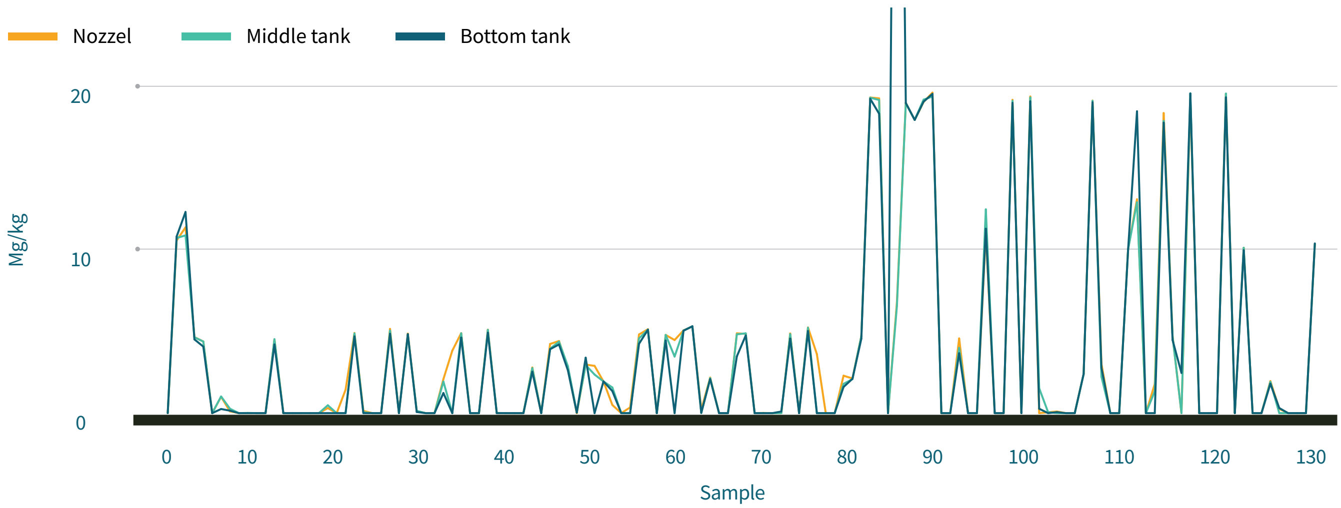


FIGURE 58: BIODIESEL PERCENT VOLUME: ALL SAMPLE SOURCES



Analysis of Water Measurements

As explained in the methodology section, all samples were subject to two laboratory tests to measure water: water (Karl Fischer) (D6304) and water and sediment (D2709). In addition, when samples were collected, technicians recorded the water content as reported by the ATG and conducted a dipstick reading with water-detecting paste to determine the presence of free water.

Tank owners rely upon field results from dipstick readings and the ATG for monitoring the water content of their fuel supply, with additional laboratory analysis typically only performed when these field results indicate a potential concern. Because this project performed all four tests on each sample collected, it is possible to compare the results to develop a greater understanding of the relative accuracy and consistency of these methods, keeping in mind the limitations noted in the methodology section. However, it must be noted that most of the dipstick readings were taken at the ATG riser, as were most of the samples. This does not guarantee that the measurements (or the samples) were being taken at the lowest point of the tank, which could be located elsewhere depending upon tank tilt. Consequently, the field tests may not detect water that might be present elsewhere in the tank. Tank owners conducting their own dipstick tests should strive to sample product at the lowest point in the tank to ensure any existing water is detected.

The following charts plot the results of ATG and dipstick water results against laboratory results for the nozzle, middle tank, and bottom tank samples for both the water (Karl Fischer) test and the water and sediment test. Note that 83% of the ATG readings and 79% of the stick readings recorded 0 inches of water. As shown in the following charts, many of these field results conflict with the laboratory results, further demonstrating the challenges with monitoring water content in diesel fuel storage tanks.

See Figures 59, 60, 61, 62,63, and 64.

FIGURE 59: FIELD AND WATER (KARL FISCHER) RESULTS: NOZZLE

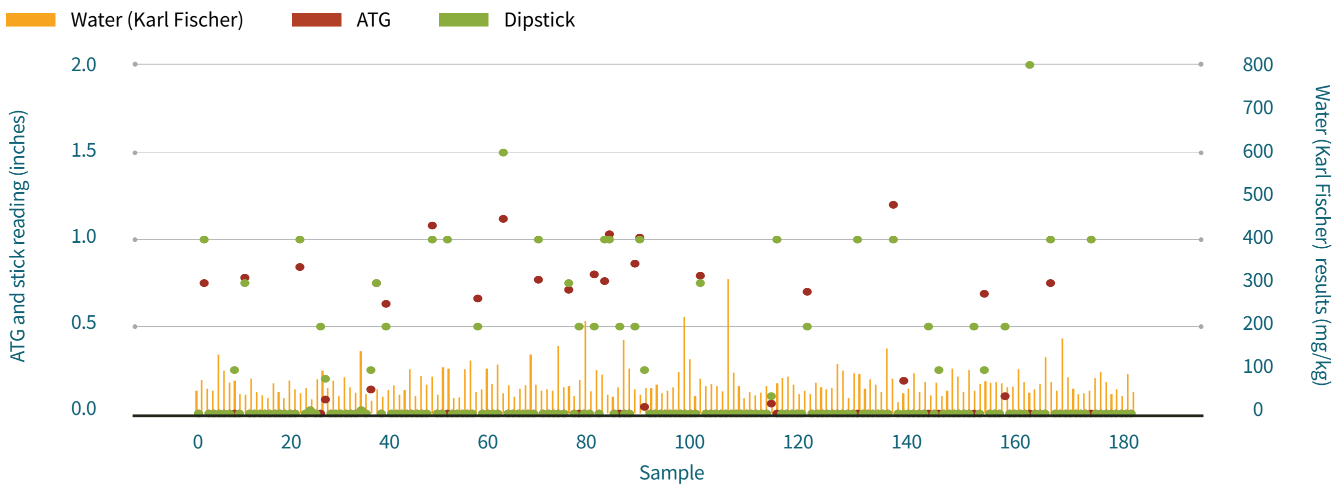


FIGURE 60: FIELD AND WATER (KARL FISCHER) RESULTS: MIDDLE TANK

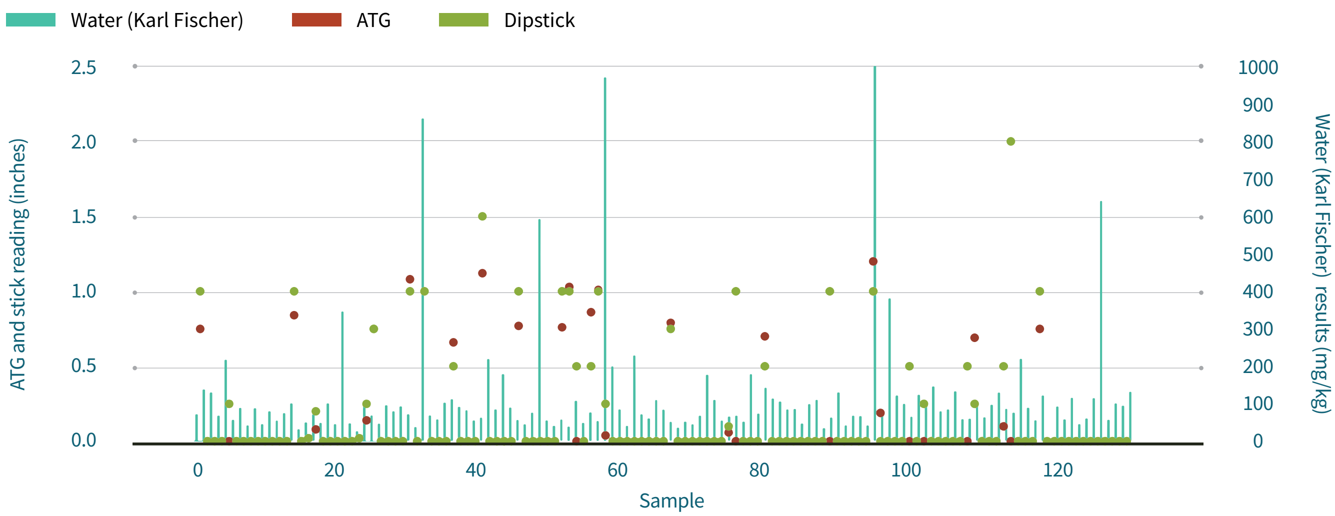


FIGURE 61: FIELD AND WATER (KARL FISCHER) RESULTS: BOTTOM TANK

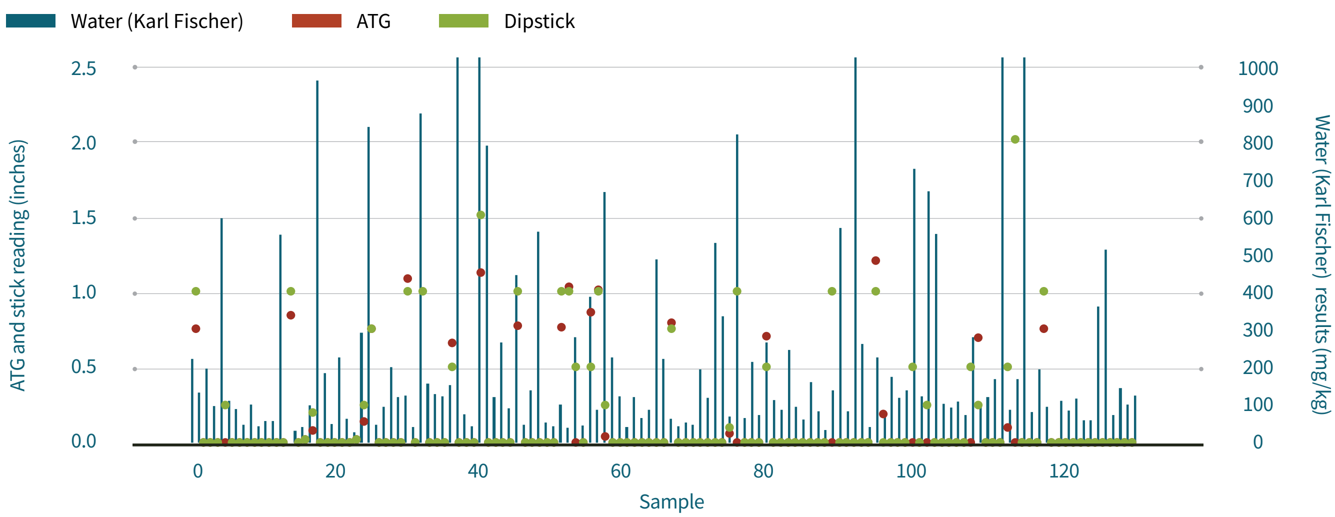


FIGURE 62: FIELD AND WATER AND SEDIMENT RESULTS: NOZZLE

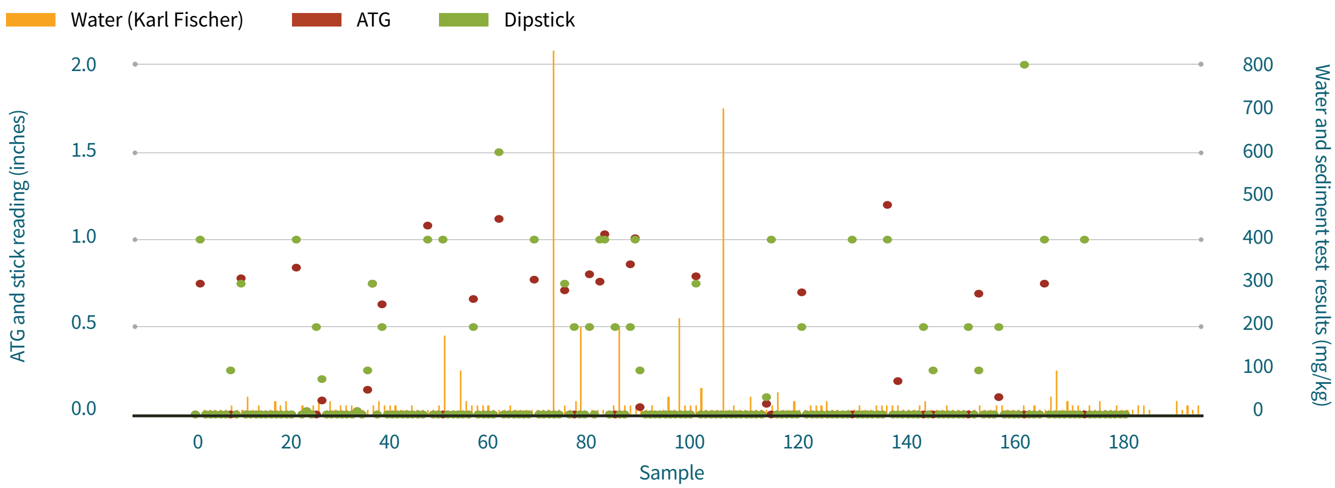


FIGURE 63: FIELD AND WATER AND SEDIMENT RESULTS: MIDDLE TANK

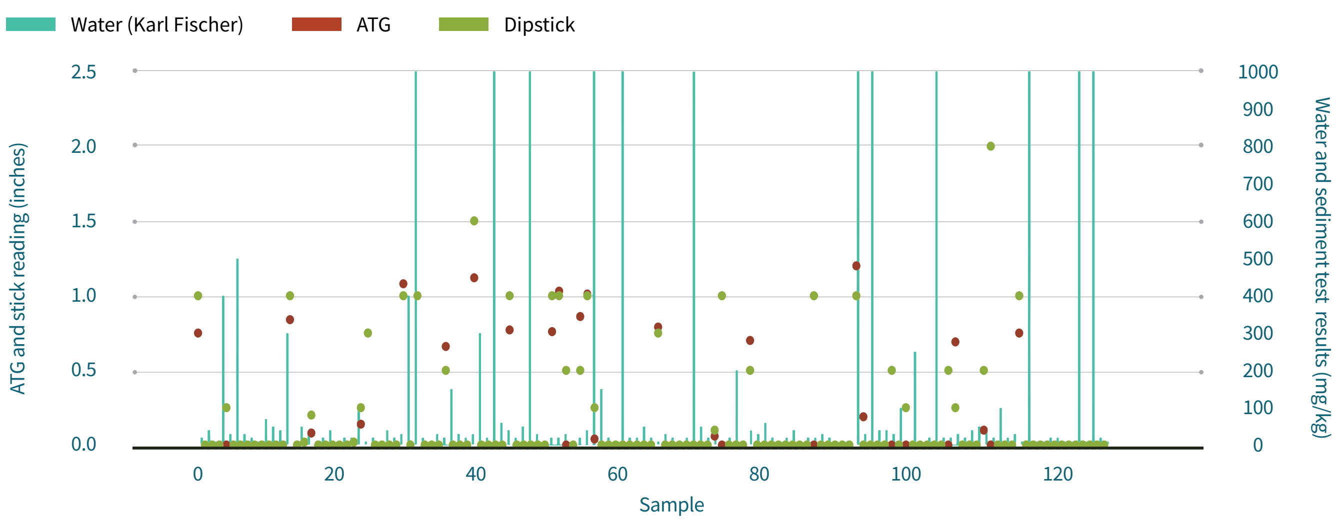
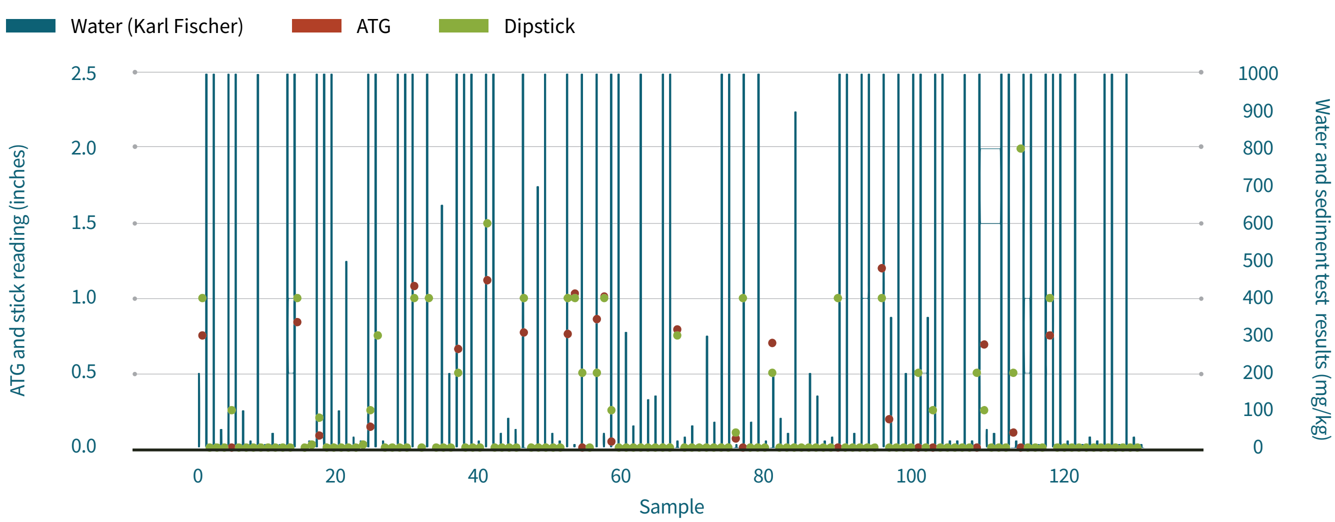


FIGURE 64: FIELD AND WATER AND SEDIMENT RESULTS: BOTTOM TANK



Effect of Outlier Sample Test Results

Within the results, there were samples for different fuel properties that were considered outliers[8] from the rest of the samples. Often, outliers are dismissed as anomalies.

But for this project, there was interest in understanding better how these outlier results might affect other fuel properties and whether such effects may provide insight into potential causal elements. The following is a more detailed evaluation of the outliers identified in the results.

SUMMARY

Within the nozzle samples analyzed, there were a total of 117 test results that were classified as outliers from a total pool of 2,090 results (190 samples subject to 11 tests each), for an outlier rate of 5.6%.

Within the tank samples analyzed, there were 81 test results classified as outliers from a total pool of 1,474 results (134 middle and bottom samples subject to six and five tests, respectively), for an outlier rate of 5.5% (Table 10).

TABLE 10: NUMBER OF TEST RESULTS CLASSIFIED AS OUTLIERS

SOURCE	OXIDATION	TAN	FLASH POINT (CLOSED CUP)	WATER (KARL FISCHER)	WATER AND SEDIMENT	SODIUM-POTASSIUM	CALCIUM-MAGNESIUM	ZINC	ETHANOL
Nozzle	0	6	6	14	15	35	19	20	--
Tanks	--	--	--	23	47	--	--	--	11

8 As noted on page 7, an outlier in this report is a result that is numerically distant from the rest of the data. Labeling a result as a statistical outlier does not infer any assumptions regarding accuracy of test results or sample collection. See Figure 5.

EFFECT OF NOZZLE OUTLIERS ON TEST RESULTS

Each group of outliers was reviewed within the context of test results for other fuel properties to determine if there were any correlations. Table 11 summarizes the effect of outliers with respect to other properties not meeting the appropriate benchmark (percent values presented in the headers reflect the percentage of all samples that did not meet the appropriate benchmark) (Table 11).

The outlier samples were then compared with the testing results of other fuel properties to determine if there were any significant correlations. Note, however, that the sample size for these calculations is very limited. While there may be some relationship indicated between these outlier samples and other properties, the data is not significant enough to provide confidence in these correlations.

There were six statistically significant correlations (defined as coefficients greater than 0.50 or −0.50). These are represented in the table in bold and existed between:

- **TAN outliers and oxidation stability (−0.94 versus −0.34 for all samples)**
- **TAN outliers and zinc (0.91 versus 0.23 for all samples)**
- **Flash point outliers and oxidation stability (0.87 versus 0.01 for all samples)**
- **Flash point outliers and calcium (−0.63 versus 0.00 for all samples)**
- **Flash point outliers and magnesium (−0.55 versus 0.01 for all samples)**
- **Water (Karl Fischer) outliers and water and sediment (0.84 versus 0.40 for all samples**
- **Water (Karl Fischer) outliers and calcium (0.60 versus 0.21 for all samples)**

TABLE 11: PERCENT OF NOZZLE OUTLIER SAMPLES NOT MEETING BENCHMARK FOR FUEL PROPERTIES

	TOTAL OUTLIER SAMPLES	OXIDA-TION (62%)	TAN (1%)	FLASH POINT (CLOSED CUP) (14%)	WATER (KARL FISCHER) (2%)	WATER AND SEDIMENT (1%)	SODIUM-POTASSIUM COMBINED (0%)	CALCIUM-MAGNESIUM COMBINED (0%)	ZINC (3%)
Oxidation	0	0%	0%	0%	0%	0%	0%	0%	0%
Acid	6	83%	17%	17%	17%	0%	0%	0%	17%
Flash point (closed cup)	6	83%	0%	50%	0%	0%	0%	0%	0%
Water	14	64%	0%	36%	0%	7%	0%	0%	0%
Water and sediment	15	60%	7%	13%	20%	13%	0%	0%	7%
Sodium-potassium	35	63%	6%	23%	3%	0%	0%	0%	3%
Calcium-magnesium	19	74%	0%	11%	5%	0%	0%	0%	0%
Zinc	20	70%	5%	20%	5%	0%	0%	0%	30%

Less significant correlation coefficients (0.25 to 0.50) were found to exist between 30 fuel properties. These are italicized in Table 12.

TABLE 12: CORRELATION COEFFICIENTS BETWEEN NOZZLE TEST RESULTS FOR SAMPLES WITH OUTLIERS

OUTLIERS N=# OF OUTLIER SAMPLES	OXIDATION	TAN	FLASH POINT (CLOSED CUP)	WATER (KARL FISCHER)	WATER AND SEDIMENT	BIODIESEL CONTENT	POTASS-IUM	SODIUM	CALCIUM	MAGNESIUM	ZINC
TAN (n=6)	**−0.94**	1.00	−0.40	0.18	*0.29*	*0.42*	*0.46*	−0.10	*0.32*	−0.03	**0.91**
Flash point (closed cup) (n=6)	**0.87**	0.07	1.00	**−0.32**	*−0.49*	*0.45*	**0.00**	0.00	**−0.63**	**−0.55**	−0.17
Water (Karl Fischer) (n=14)	0.16	*0.33*	*−0.25*	1.00	**0.84**	0.10	0.21	−0.11	**0.60**	*0.46*	*−0.39*
Water and sediment (n=15)	*0.35*	0.23	*0.33*	*0.34*	1.00	−0.16	*0.29*	−0.08	*0.41*	*0.34*	−0.13
Sodium-potassium combined (n=35)	*0.36*	−0.16	0.13	0.11	*0.27*	−0.21			*0.42*	*0.48*	
Calcium-magnesium combined (n=19)	0.03	*0.45*	−0.02	0.18	−0.02	*0.32*	0.06	*−0.28*			*0.48*
Zinc (n=20)	−0.08	*0.44*	−0.09	−0.15	−0.06	−0.20	*0.30*	*−0.32*	*−0.25*	−0.23	1.00

EFFECT OF MIDDLE TANK OUTLIERS ON TEST RESULTS

Each group of outliers was reviewed within the context of test results for other fuel properties to determine if there were any correlations. Table 13 summarizes the effect of outliers with respect to other properties meeting the appropriate benchmark (percent values presented in the headers reflect the percentage of all samples that did not meet the appropriate benchmark).

The outlier samples were then compared with the testing results of other fuel properties to determine if there were any significant correlations. Note, however, that the sample size for these calculations is very limited. While there may be some relationship indicated between these outlier samples and other properties, the data is not significant enough to provide confidence in these correlations.

There were two statistically significant correlations (defined as coefficients greater than 0.50 or −0.50). These are represented in Table 14 in bold and existed between:

- **Water (Karl Fischer) and microbiological count—bacterial (0.62 versus 0.44 for all samples)**
- **Water (Karl Fischer) and ethanol (0.53 versus 0.15 for all samples)**

Less significant correlation coefficients (0.25 to 0.50) were found to exist between two fuel properties. These are italicized in Table 14.

TABLE 13: PERCENT OF MIDDLE TANK OUTLIER SAMPLES NOT MEETING BENCHMARK FOR FUEL PROPERTIES

	TOTAL SAMPLES	WATER (KARL FISCHER) (10%)	WATER AND SEDIMENT (9.7%)	MICROBIOLOGICAL COUNT—BACTERIAL (4,000 CFU/L—8.2%)	MICROBIOLOGICAL COUNT—MYCOLOGICAL (4,000 CFU/L—3.4%)	ETHANOL (66%)
Water (Karl Fischer)	14	79%	79%	29%	7%	57%
Water and sediment	25	44%	80%	32%	12%	56%
Ethanol	11	9%	27%	9%	0%	100%

TABLE 14: CORRELATION COEFFICIENTS BETWEEN MIDDLE TANK TEST RESULTS FOR SAMPLES WITH OUTLIERS

	WATER (KARL FISCHER)	WATER AND SEDIMENT	MICROBIOLOGICAL COUNT—BACTERIAL	MICROBIOLOGICAL COUNT—MYCOLOGICAL	ETHANOL	BIODIESEL
Water (Karl Fischer) (n=14)	1.00	**0.46**	**0.62**	−0.16	**0.53**	−0.20
Water and sediment (n=25)	**0.45**	1.00	0.19	−0.19	*0.45*	*−0.35*
Ethanol (n=11)	−0.05	−0.05	−0.08	−0.16	1.00	0.13

EFFECT OF BOTTOM TANK OUTLIERS ON TEST RESULTS

Each group of outliers was reviewed within the context of test results for other fuel properties to determine if there were any correlations.

Table 15 summarizes the effect of outliers with respect to other properties meeting the appropriate benchmark (percent values presented in the headers reflect the percentage of all samples that did not meet the appropriate benchmark).

The outlier samples were then compared with the testing results of other fuel properties to determine if there were any significant correlations. Note, however, that the sample size for these calculations is very limited. While there may be some relationship indicated between these outlier samples and other properties, the data is not significant enough to provide confidence in these correlations.

There were no statistically significant correlations (defined as coefficients greater that 0.50 or −0.50). Less significant correlation coefficients (0.25 to 0.50) were found to exist between two fuel properties. These are italicized in Table 16.

TABLE 15: PERCENT OF BOTTOM TANK OUTLIER SAMPLES NOT MEETING BENCHMARK FOR OTHER PROPERTIES

	TOTAL SAMPLES	WATER (KARL FISCHER) (21%)	WATER AND SEDIMENT (47%)	MICROBIOLOGICAL COUNT—BACTERIAL (4,000 CFU/L—23.9%)	MICROBIOLOGICAL COUNT—MYCOLOGICAL (4,000 CFU/L—17.2%)
Water (Karl Fischer)	9	100%	100%	22%	22%
Water and sediment	22	68%	100%	41%	14%

TABLE 16: CORRELATION COEFFICIENTS BETWEEN BOTTOM TANK TEST RESULTS FOR SAMPLES WITH OUTLIERS

	WATER (KARL FISCHER)	WATER AND SEDIMENT	MICROBIOLOGICAL COUNT—BACTERIAL	MICROBIOLOGICAL COUNT—MYCOLOGICAL	BIODIESEL
Water (Karl Fischer) (n=9)	1.00	−0.08	*−0.32*	*−0.26*	−0.16
Water and sediment (n=22)	−0.07	1.00	0.20	−0.03	−0.17

Attributes of Fueling Facilities

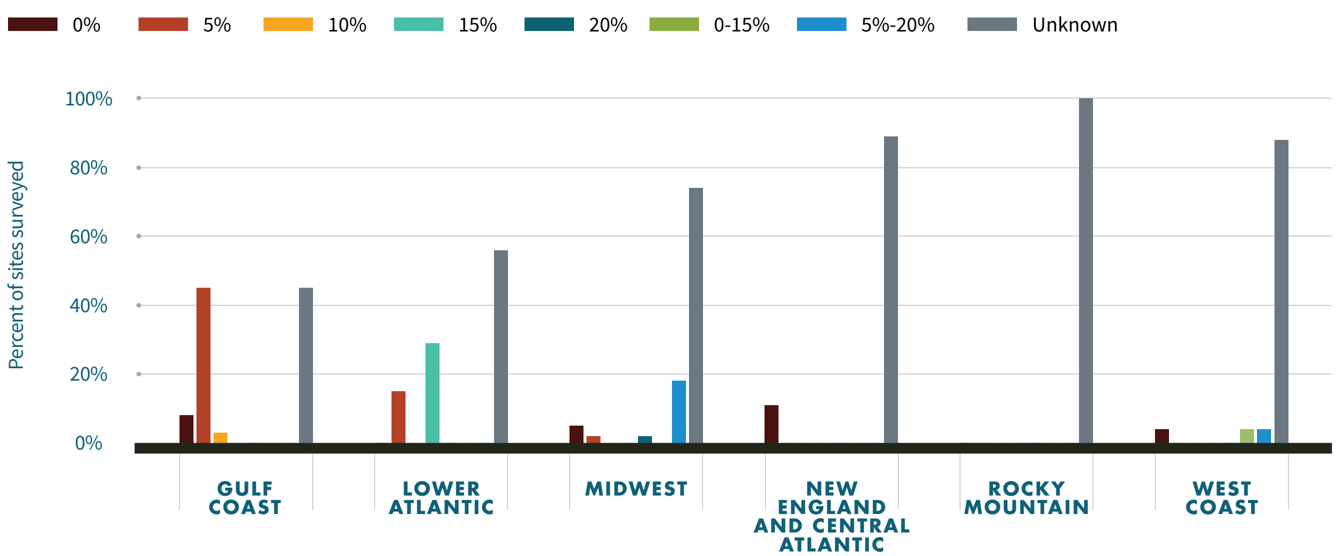
During sample collection, certain attributes of the fueling facility were captured to provide additional context to factors that might contribute to fuel quality including: information about dispenser filters (make/model/particulate size), monthly fuel throughput, and if the site performs routine preventative maintenance.

The results of this survey are presented in this section.

Q1: WHAT IS THE BIODIESEL CONTENT?

There were 17% respondents who claimed their biodiesel content was 0% or 5% (shown as "Diesel" in Figure 65) and 13% who claimed the biodiesel content was 10%, 15%, 20%, or "5-20%" (shown as "Biodiesel" in Figure 65). One site in the West Coast region claimed their biodiesel content was "0-15%," shown as "Both." The rest of the 190 sites (70%) answered "Unknown." These results contrast somewhat with laboratory test results of nozzle samples, which, as noted in the section on biodiesel, found 42.1% of samples contained no detectable biodiesel, 41.1% contained less than 5% biodiesel, and 16.8% contained more than 5% biodiesel.

FIGURE 65: SURVEY RESULT: FUEL TYPES BY REGION



Q2: MAKE/MODEL OF FILTER? FILTER PARTICULATE SIZE?

Of the records that included filter particulate size, 46.5% were rated 10 microns, 50% were rated 30 microns, and the balance were rated 20, 25, and 45 microns. Analysis of filter particulate size with nozzle samples testing results indicated no significant difference in selected fuel properties between those dispensers equipped with 10-micron versus 30-micron filters. In addition, there was no significant association between filter particulate size and nozzle samples results for appearance, water, or metals.

With regards to the efficacy of filters in preventing the transmission of metals through the nozzle samples, stakeholders agree that the particulate size of the metals (if they were not fully dissolved in the fuel) were likely much smaller than 10 microns, hence the lack of observed selected fuel properties difference between samples collected from dispensers equipped with 10-micron and 30-micron filters. See Figures 66, 67, and 68)

FIGURE 66: SURVEY RESULT: FILTER MODEL AND SIZE BY REGION

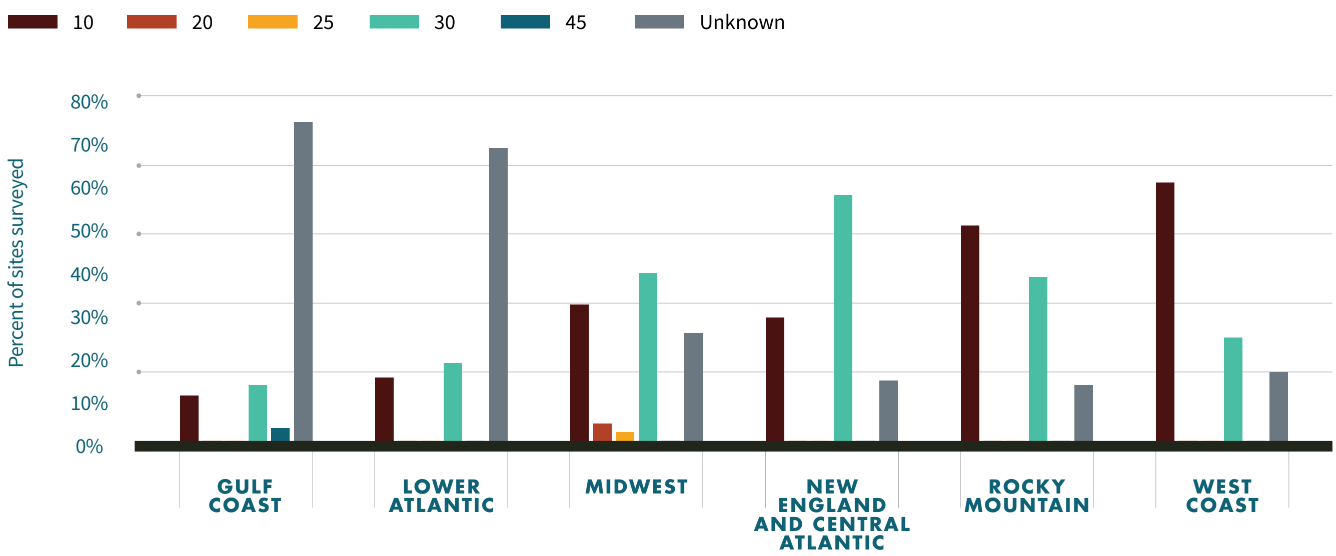


FIGURE 67: SURVEY RESULT: FILTER BRAND

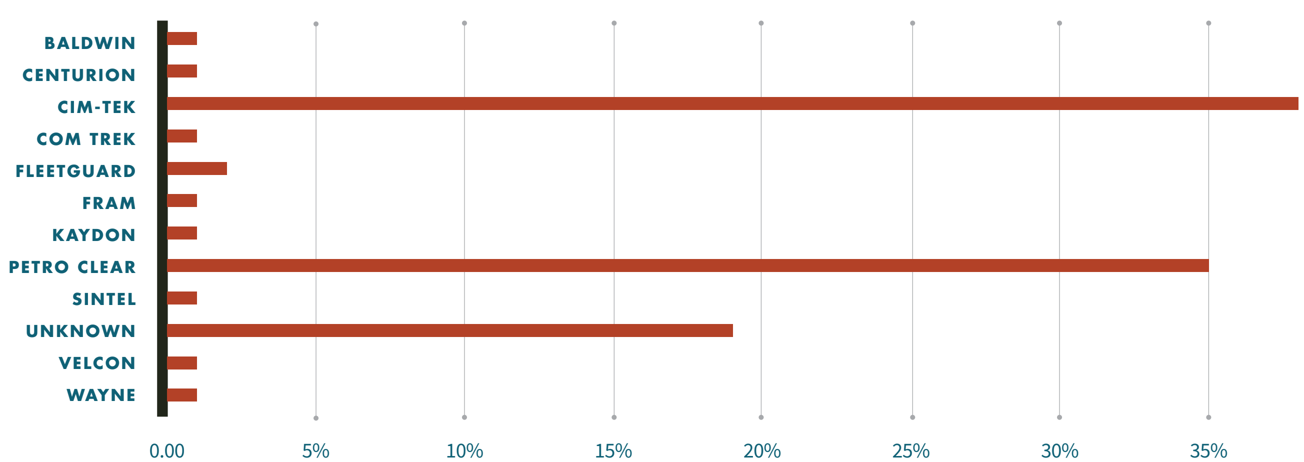
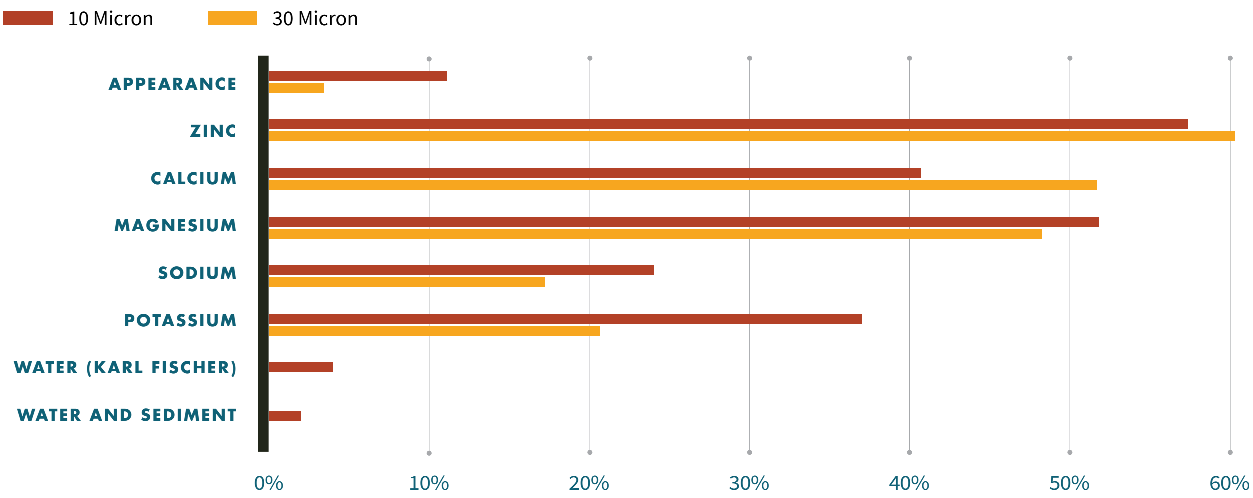


FIGURE 68: FAILURE PERCENTAGES BY FILTER SIZE



Q3: WHAT IS APPROXIMATE MONTHLY ULTRA-LOW SULFUR DIESEL THROUGHPUT?

Among the 190 site samples, 78% answered "Unknown," and 22% (42 out of 190) answered with the monthly throughput, shown in Figure 69. Among the answers, the majority of them were located with a range from 2,500 to 300,000 gallons. However, careful evaluation of the reported throughput raises questions regarding accuracy. The vast majority of retail samples were collected from auto-diesel dispensers, even when facilities were identified as truck stops. Yet, the average reported volume was 150,000 gallons per month. The NACS State of the Industry Report of 2019 Data indicates that top quartile performing facilities average less than 30,000 gallons of ultra-low sulfur diesel (ULSD) sales per month. The Fuels Institute assumes the reported throughput is not accurate for all locations as a monthly throughput of product dispensed and has decided to not conduct any analysis relative to fuel quality on the basis of this data (Figure 69).

FIGURE 69: DISTRIBUTION OF MONTHLY ULSD THROUGHPUT BY PADD REGION

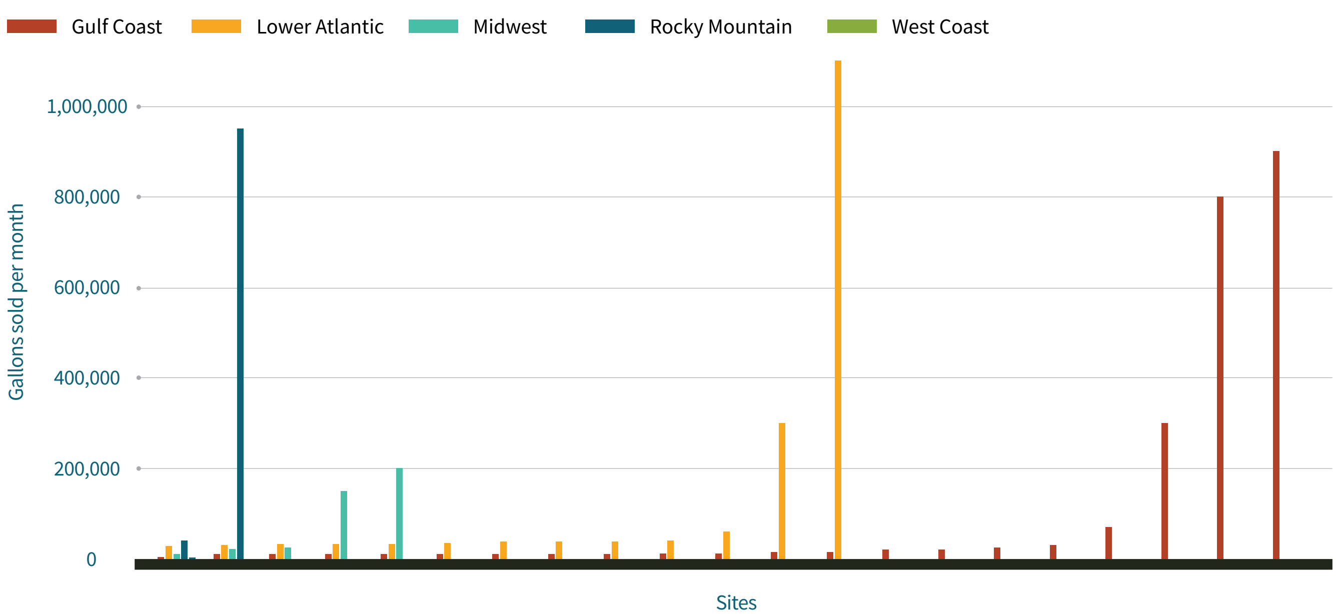
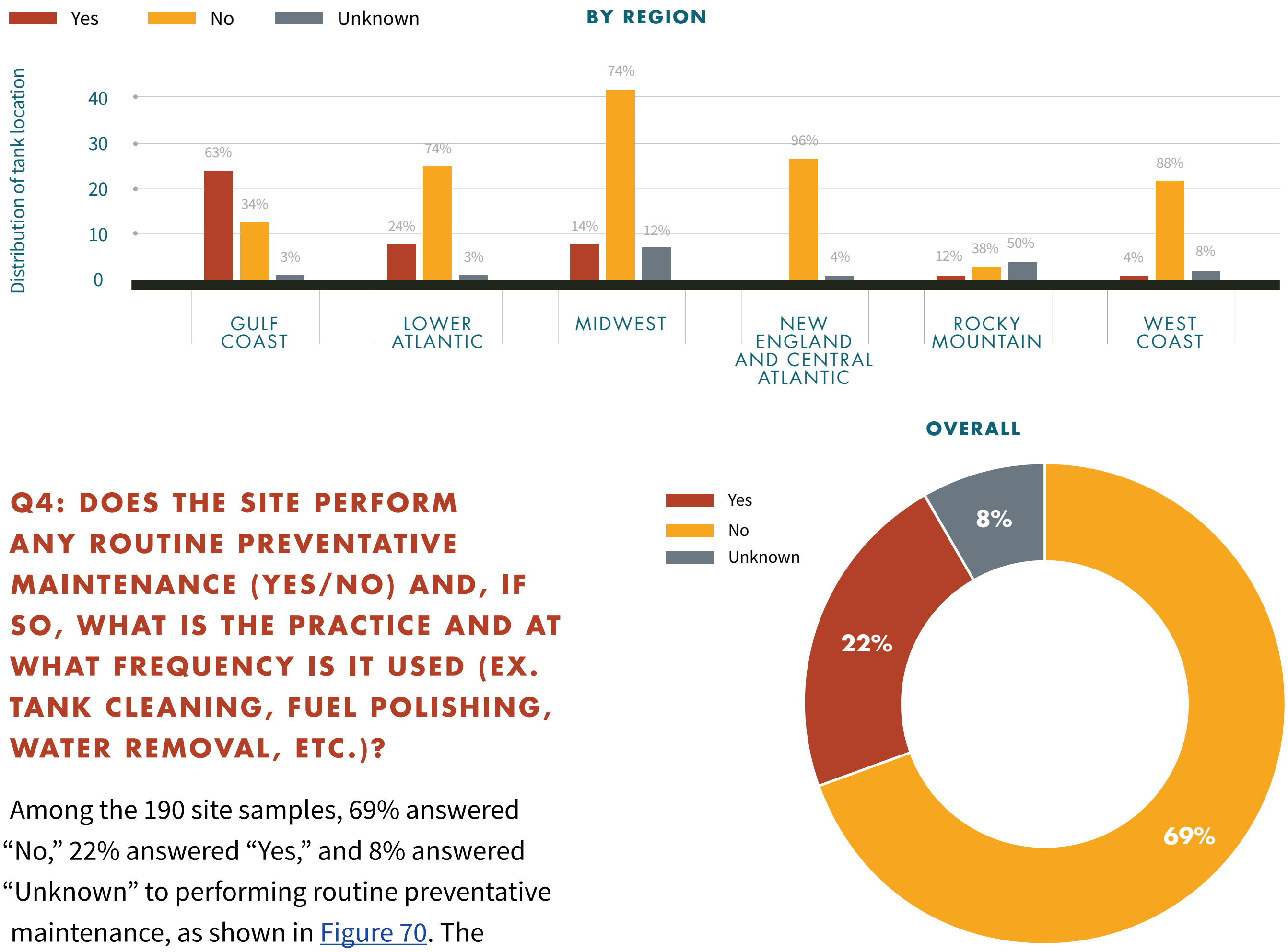


FIGURE 70: SURVEY ANSWER: PREVENTATIVE MAINTENANCE OVERALL AND BY PADD REGION

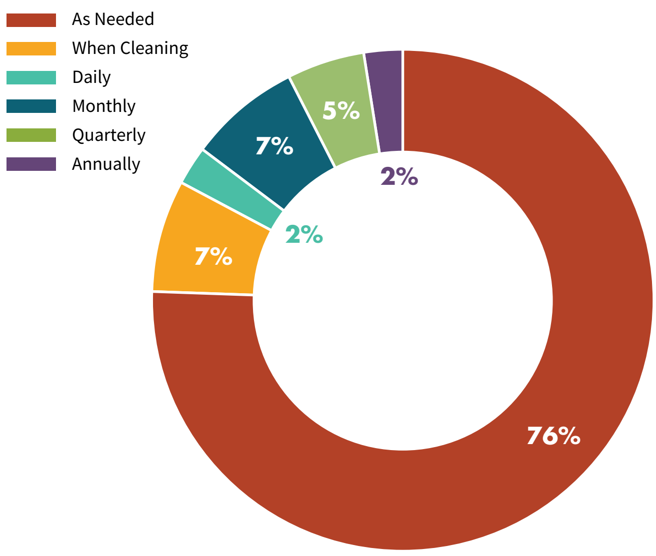


Q4: DOES THE SITE PERFORM ANY ROUTINE PREVENTATIVE MAINTENANCE (YES/NO) AND, IF SO, WHAT IS THE PRACTICE AND AT WHAT FREQUENCY IS IT USED (EX. TANK CLEANING, FUEL POLISHING, WATER REMOVAL, ETC.)?

Among the 190 site samples, 69% answered "No," 22% answered "Yes," and 8% answered "Unknown" to performing routine preventative maintenance, as shown in Figure 70. The answers to Question 4 by PADD region are also shown in Figure 70.

For those who answered "Yes" to routine preventative maintenance (41 out of 190), Figure 71 presents the frequency with which they perform such maintenance activities. Among the 41 sites that answered "Yes," about 76% of them specified "As needed."

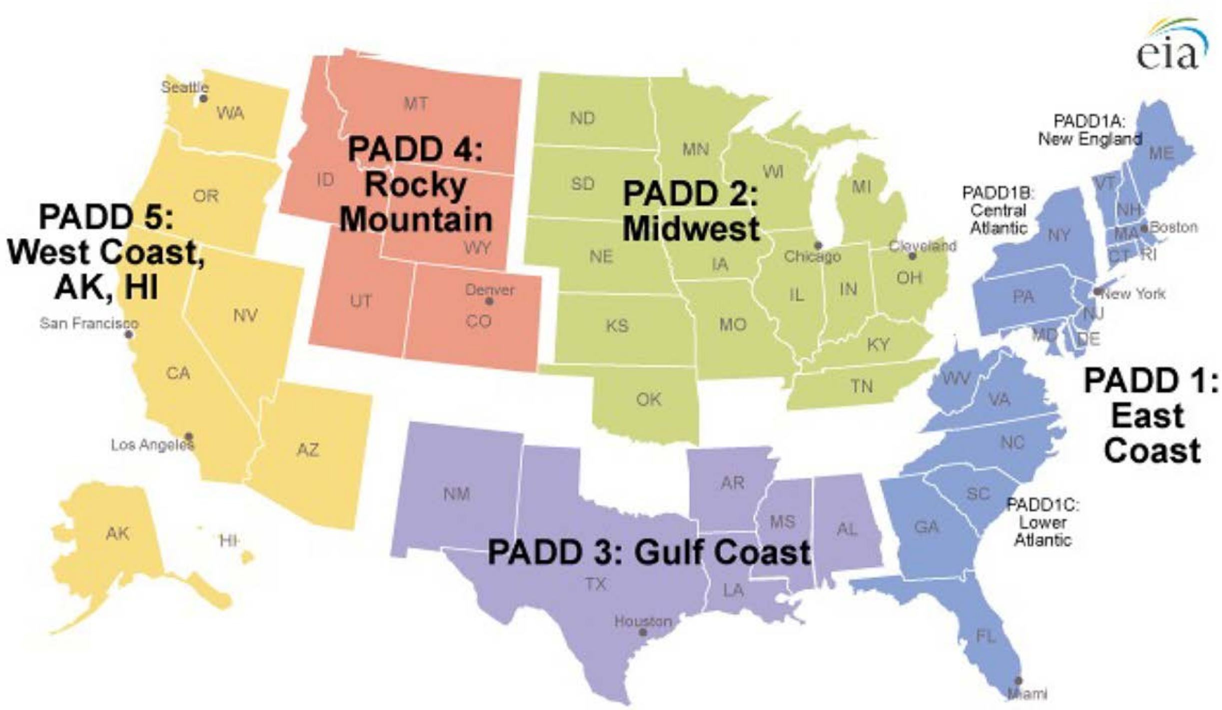
FIGURE 71: FREQUENCY OF TANK PREVENTATIVE MAINTENANCE



Regional Differences

The Fuels Institute was interested in understanding how fuel samples varied in different regions of the country. To achieve this comparison, sample collection was distributed among six PADDs, as detailed in the Sample Analysis section. For purposes of this report, PADD 1A (New England) and PADD 1B (Central Atlantic) were combined and treated as a region separate from PADD 1C (Lower Atlantic) to balance the sample counts across regions. This section presents comparisons of sample results among the regions. Table 17 presents the results of each test by region.

FIGURE 72: PETROLEUM ADMINISTRATION FOR DEFENSE DISTRICTS



Source: U.S. Energy Information Administration

SAMPLE RESULTS RELATIVE TO BENCHMARKS

The results of each test, segmented by region, are presented in the charts and tables below. When the nozzle results are compared against the applied benchmark, there appears to be very little variation in fuel properties by geographic grouping with the exception of oxidation stability, with sites in the New England/ Central Atlantic region outperforming sites in other regions. In the middle tank samples, there appears to be greater regional variation in the percent of sites that met the applied benchmark, with sites in the West Coast region recording the higher percentages of samples meeting applied benchmarks. (For list of benchmarks applied to sample results, see Table 4 on page 15.)

FIGURE 73: REGIONAL SAMPLE RESULTS RELATIVE TO BENCHMARK: NOZZLE

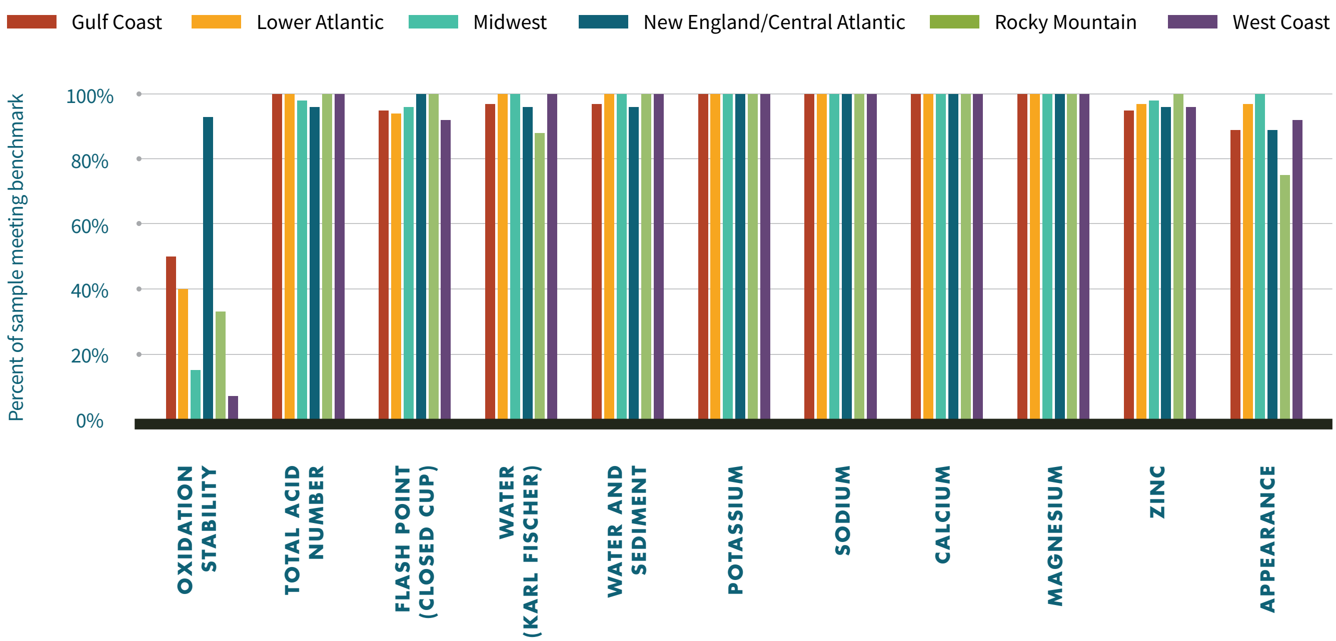


TABLE 17: PERCENT OF SAMPLES MEETING BENCHMARK: NOZZLE

	ALL SAMPLES	GULF COAST	LOWER ATLANTIC	MID WEST	NEW ENGLAND/ CENTRAL ATLANTIC	ROCKY MOUNTAIN	WEST COAST
Oxidation stability	37%	50%	40%	15%	93%	33%	7%
TAN	99%	100%	100%	98%	96%	100%	100%
Flash point (closed cup)	96%	95%	94%	96%	100%	100%	92%
Water (Karl Fischer)	98%	97%	100%	100%	96%	88%	100%
Water and Sediment	99%	97%	100%	100%	96%	100%	100%
Potassium	100%	100%	100%	100%	100%	100%	100%
Sodium	100%	100%	100%	100%	100%	100%	100%
Calcium	100%	100%	100%	100%	100%	100%	100%
Magnesium	100%	100%	100%	100%	100%	100%	100%
Zinc	97%	95%	97%	98%	96%	100%	96%
Appearance	94%	89%	97%	100%	89%	75%	92%

FIGURE 74: REGIONAL SAMPLE RESULTS RELATIVE TO BENCHMARK: MIDDLE TANK

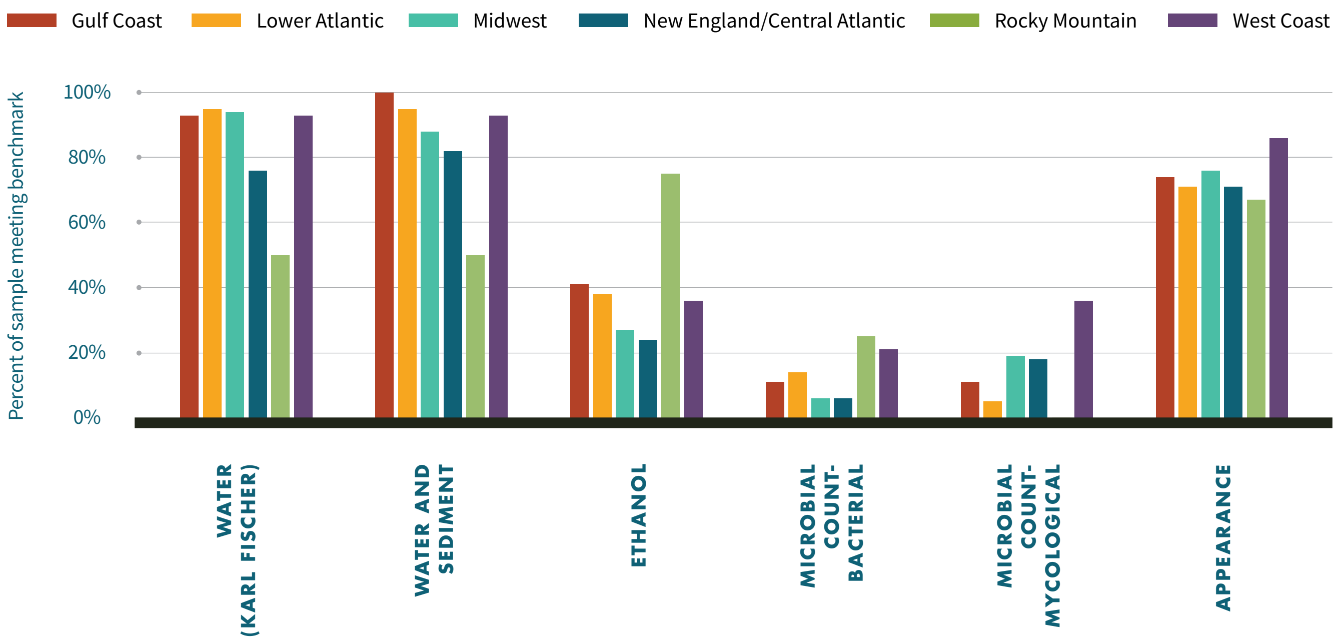


TABLE 18: PERCENT OF SAMPLES MEETING BENCHMARK: MIDDLE TANK

	ALL SAMPLES	GULF COAST	LOWER ATLANTIC	MID WEST	NEW ENGLAND/ CENTRAL ATLANTIC	ROCKY MOUNTAIN	WEST COAST
Water (Karl Fischer)	90%	93%	95%	94%	76%	50%	93%
Water and Sediment	90%	100%	95%	88%	82%	50%	93%
Ethanol	33%	41%	38%	27%	24%	75%	36%
Microbial count—bacterial	11%	11%	14%	6%	6%	25%	21%
Microbial count—mycological	16%	11%	5%	19%	18%	0%	36%
Appearance	75%	74%	71%	76%	71%	67%	86%

FIGURE 75: REGIONAL SAMPLE RESULTS RELATIVE TO BENCHMARK: BOTTOM TANK

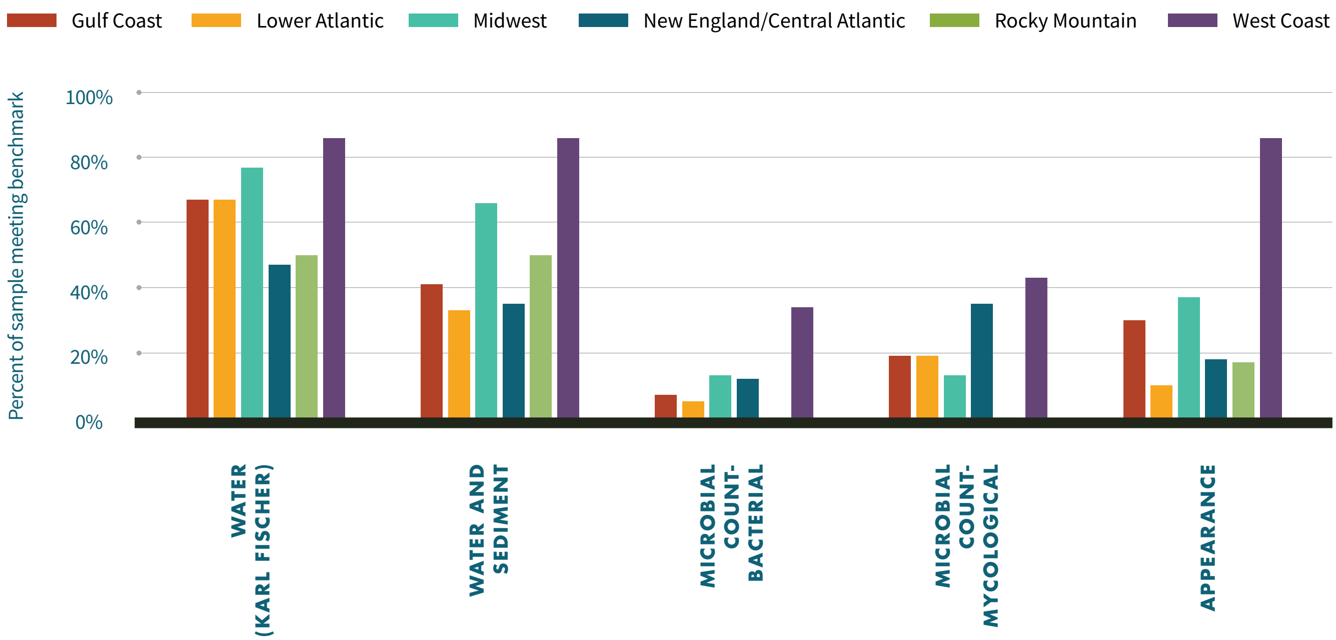


TABLE 19: PERCENT OF SAMPLES MEETING BENCHMARK: BOTTOM TANK

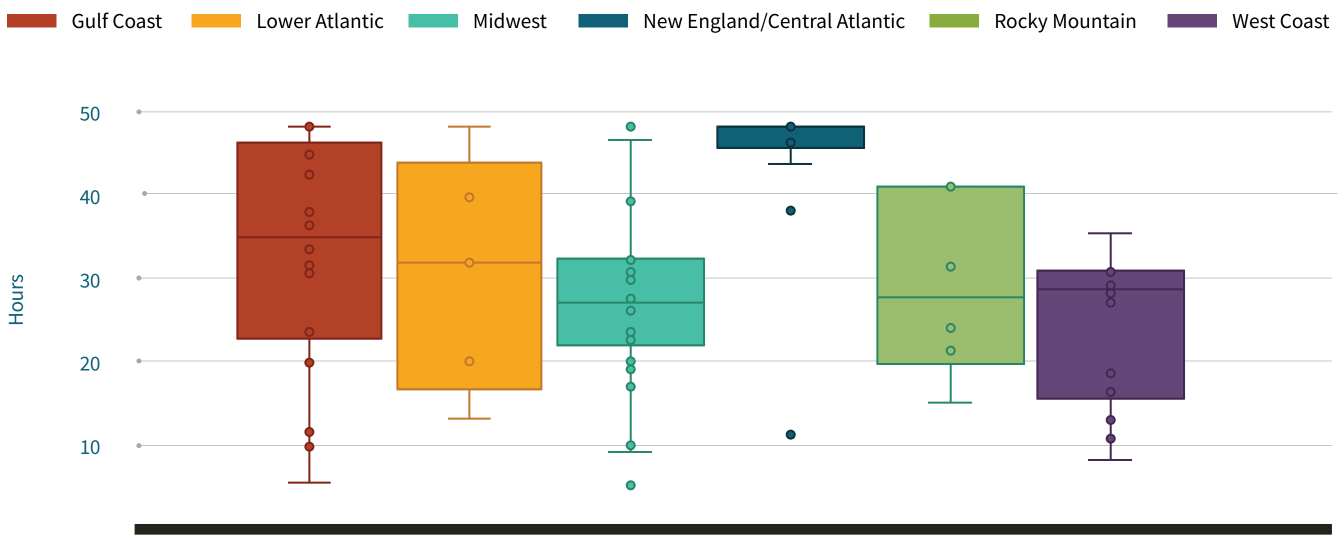
	ALL SAMPLES	GULF COAST	LOWER ATLANTIC	MID WEST	NEW ENGLAND/ CENTRAL ATLANTIC	ROCKY MOUNTAIN	WEST COAST
Water (Karl Fischer)	69%	67%	67%	77%	47%	50%	86%
Water and Sediment	53%	41%	33%	66%	35%	50%	86%
Microbial count—bacterial	12%	7%	5%	13%	12%	0%	34%
Microbial count—mycological	21%	19%	19%	13%	35%	0%	43%
Appearance	33%	30%	10%	37%	18%	17%	86%

REGIONAL NOZZLE SAMPLE ANALYSIS

Among the 190 nozzle samples, a majority of the samples met the corresponding industry benchmark with the notable exception of oxidation stability. Regional sample results are presented for each fuel property in Figures 76 through 86.

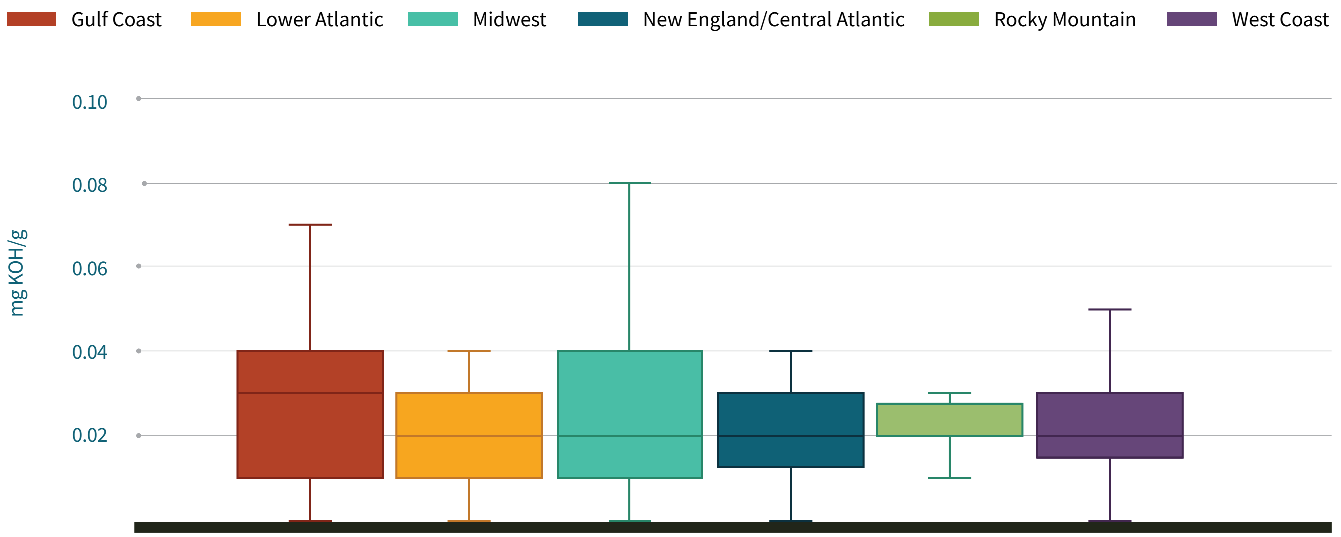
For visibility, two results were omitted from Figure 80: Gulf Coast (one site) and New England and Central Atlantic (one site) because they were much higher than the selected axis range.

FIGURE 76: REGIONAL OXIDATION STABILITY RESULTS: NOZZLE



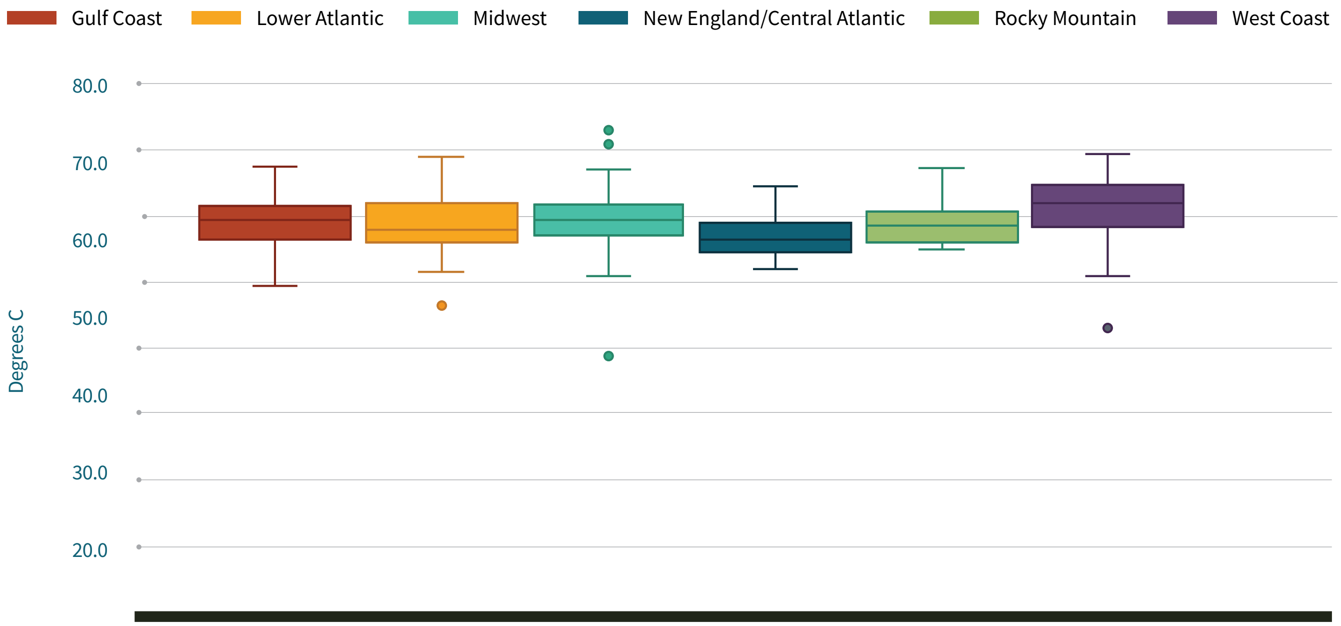
BENCHMARK: 35 HOURS, WWFC

FIGURE 77: REGIONAL TAN RESULTS: NOZZLE



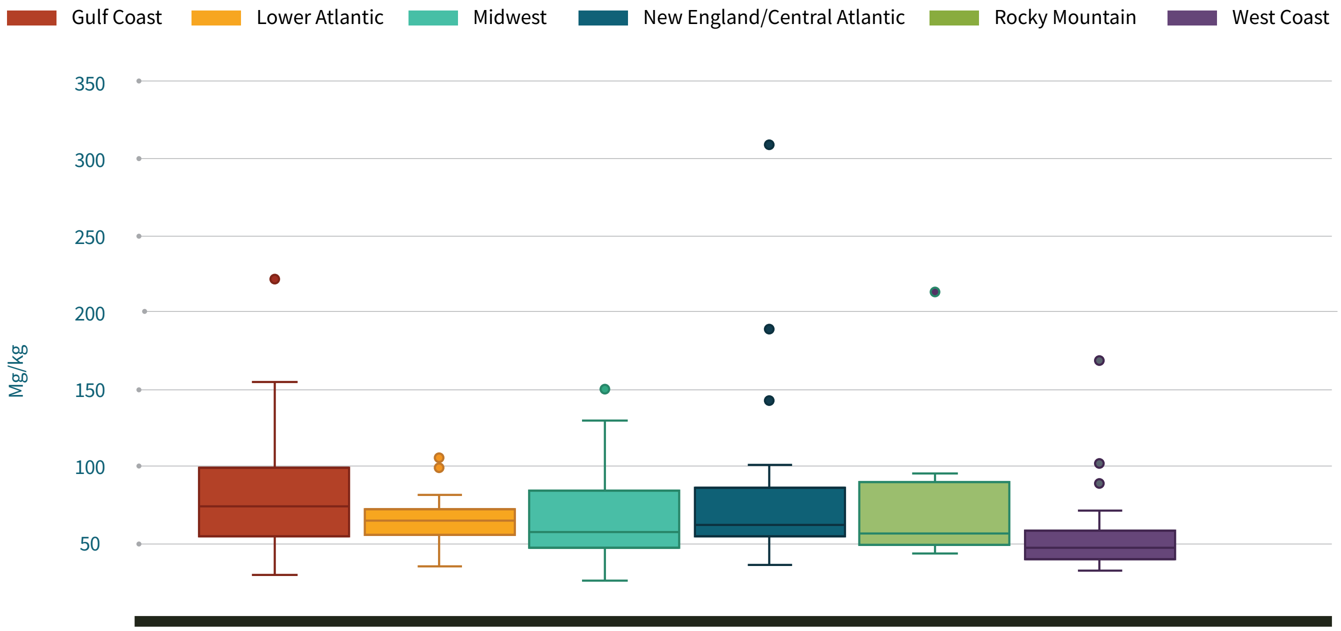
BENCHMARK: 0.08 KOH/G, WWFC

FIGURE 78: REGIONAL FLASH POINT RESULTS: NOZZLE



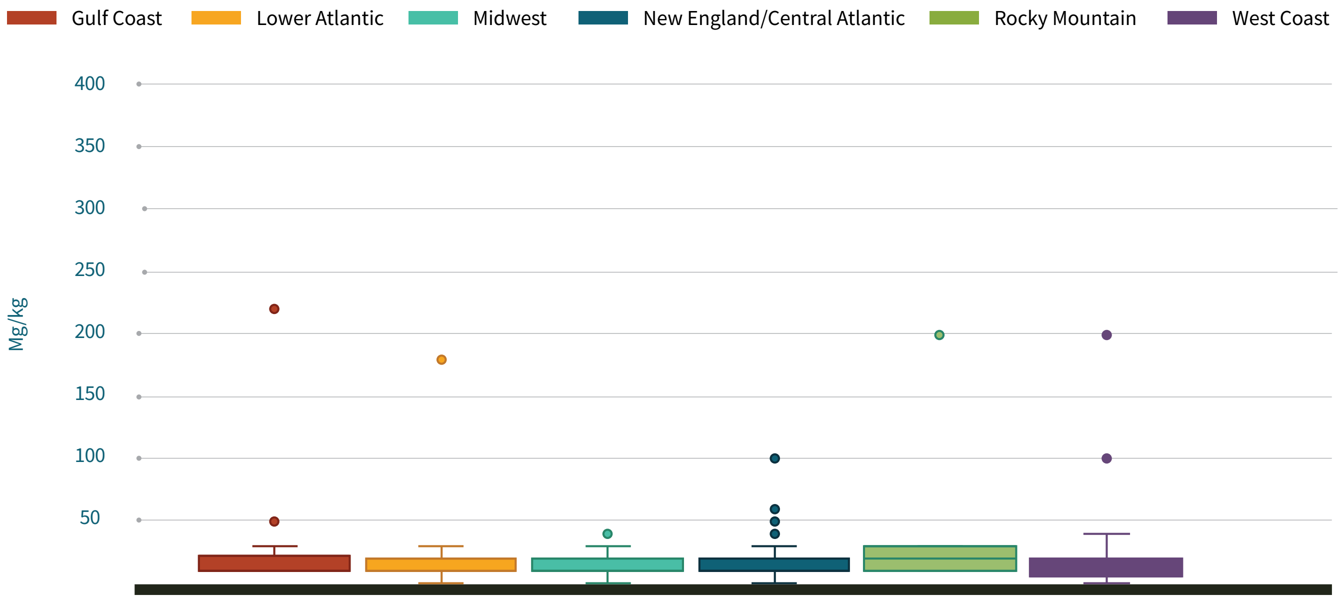
BENCHMARK: 52˚C, ASTM

FIGURE 79: REGIONAL WATER (KARL FISCHER) RESULTS: NOZZLE



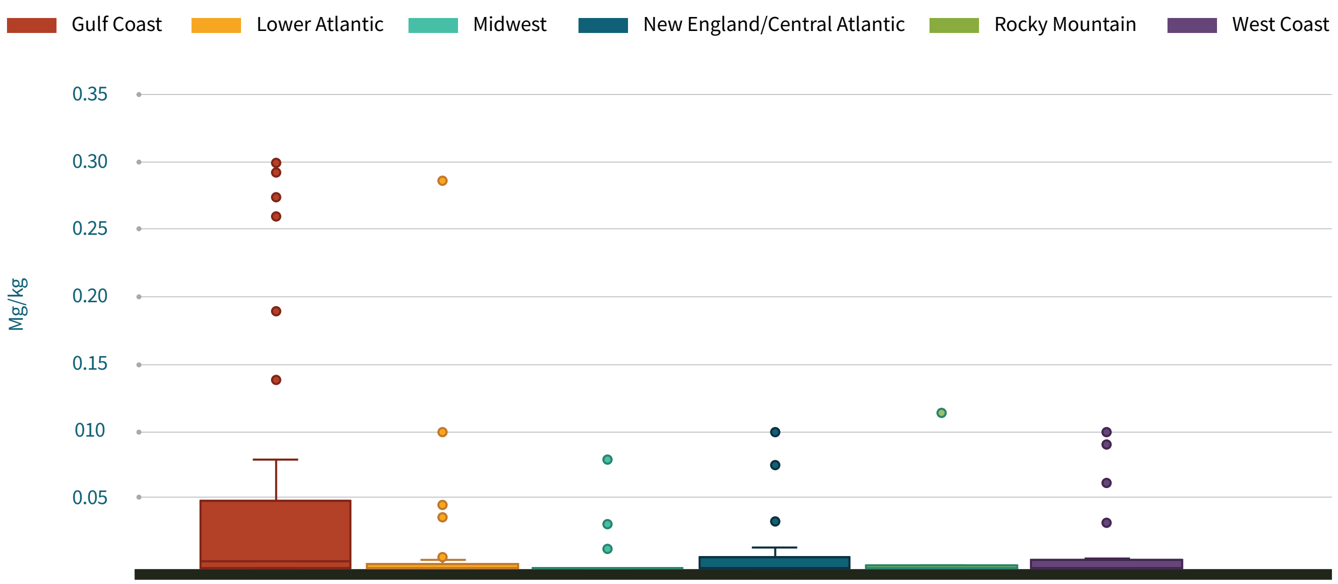
BENCHMARK: <200 MG/KG, WWFC

FIGURE 80: REGIONAL WATER AND SEDIMENT RESULTS: NOZZLE



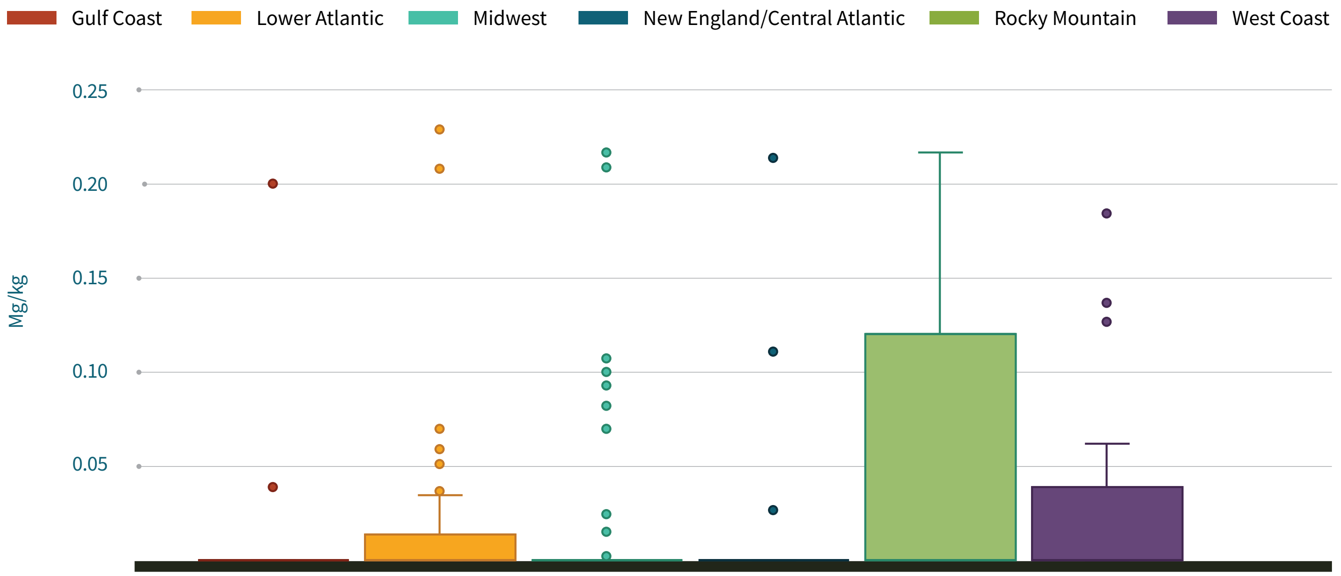
BENCHMARK: <500 MG/KG, ASTM

FIGURE 81: REGIONAL POTASSIUM RESULTS: NOZZLE



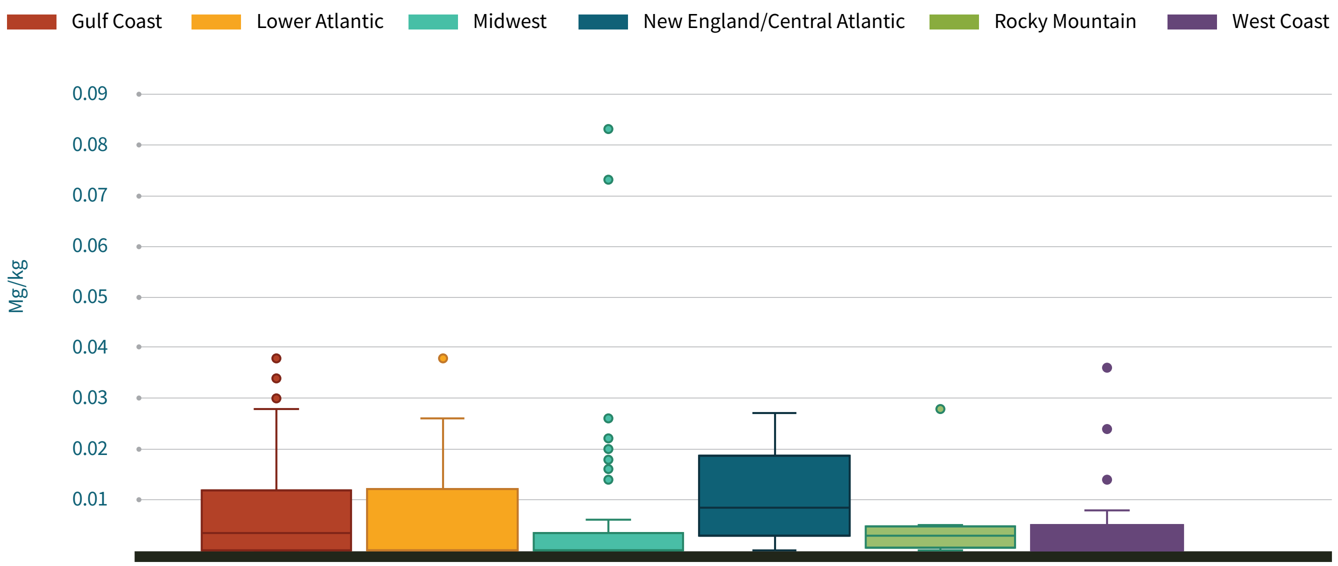
BENCHMARK: NON-DETECTABLE, WWFC

FIGURE 82: REGIONAL SODIUM RESULTS: NOZZLE



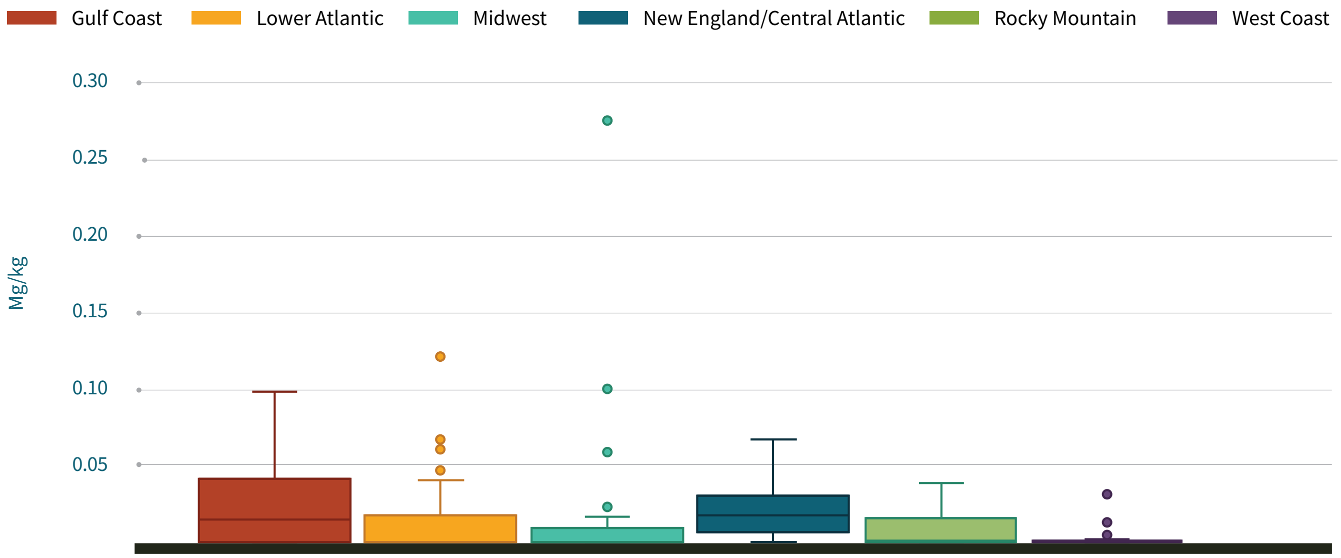
BENCHMARK: NON-DETECTABLE, WWFC

FIGURE 83: REGIONAL MAGNESIUM RESULTS: NOZZLE



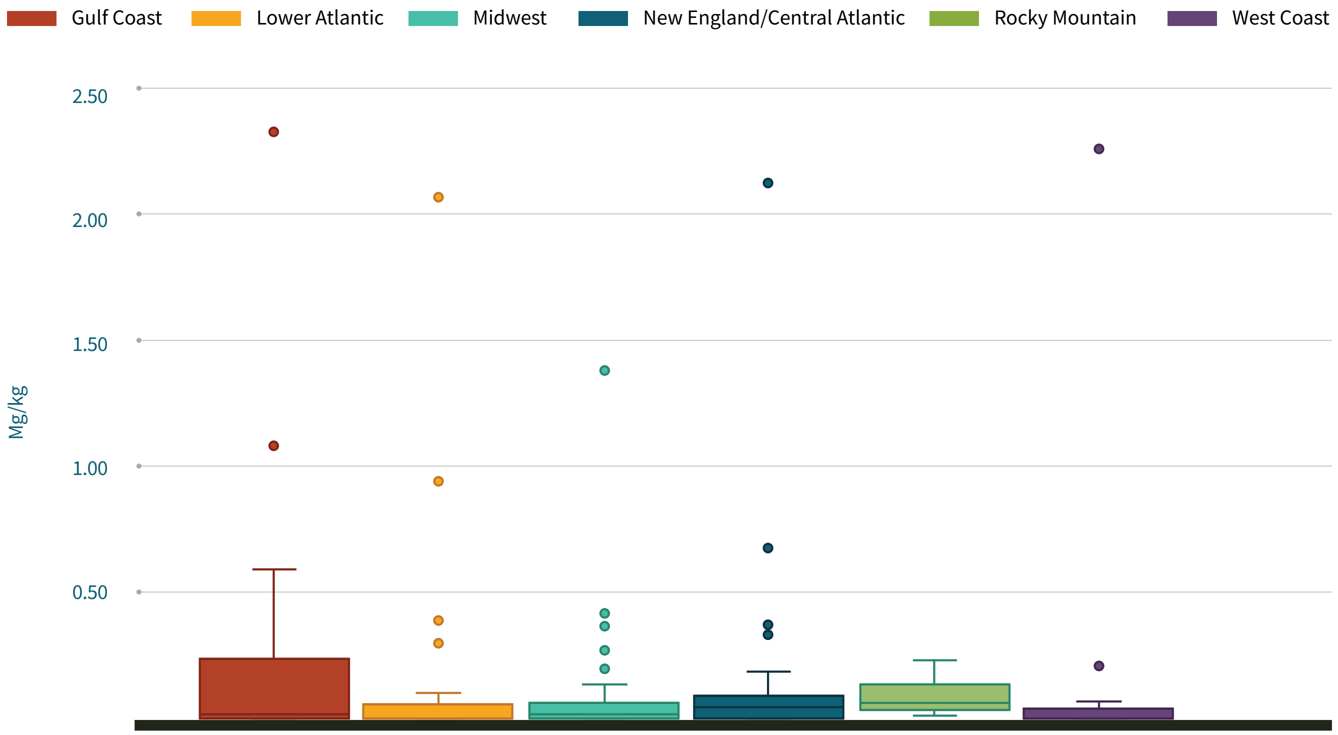
BENCHMARK: NON-DETECTABLE, WWFC

FIGURE 84: REGIONAL CALCIUM RESULTS: NOZZLE



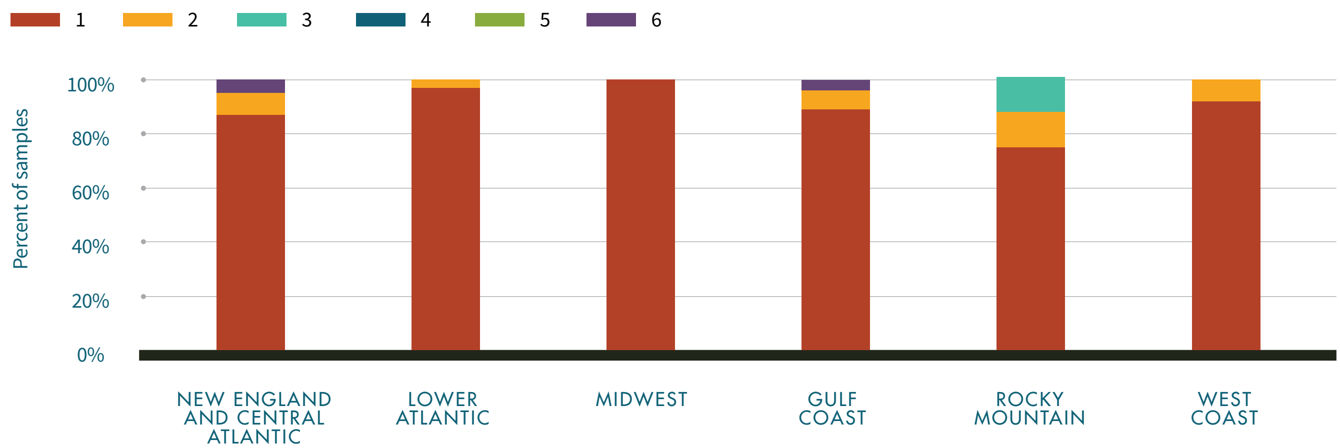
BENCHMARK: NON-DETECTABLE, WWFC

FIGURE 85: REGIONAL ZINC RESULTS: NOZZLE



BENCHMARK: NON-DETECTABLE, WWFC

FIGURE 86: REGIONAL APPEARANCE RESULTS: NOZZLE



BENCHMARK: "1", WWFC

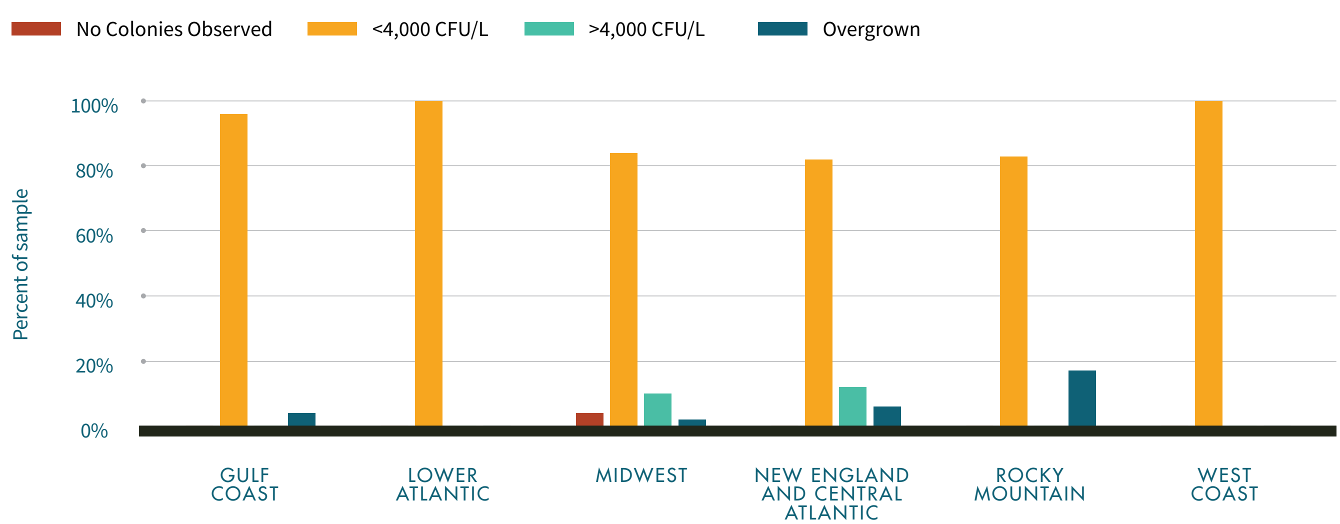
REGIONAL TANK SAMPLE ANALYSIS

Of the 268 tank samples (134 middle layer samples and 134 bottom layer samples), test results indicate that for most fuel properties, middle tank samples have a higher rate of meeting the corresponding industry benchmark. Regional sample results for both middle and bottom tank samples are presented together for each fuel property in Figures 87- 99.

For visibility, some results were omitted from various figures because they were above the limit of the selected axis:

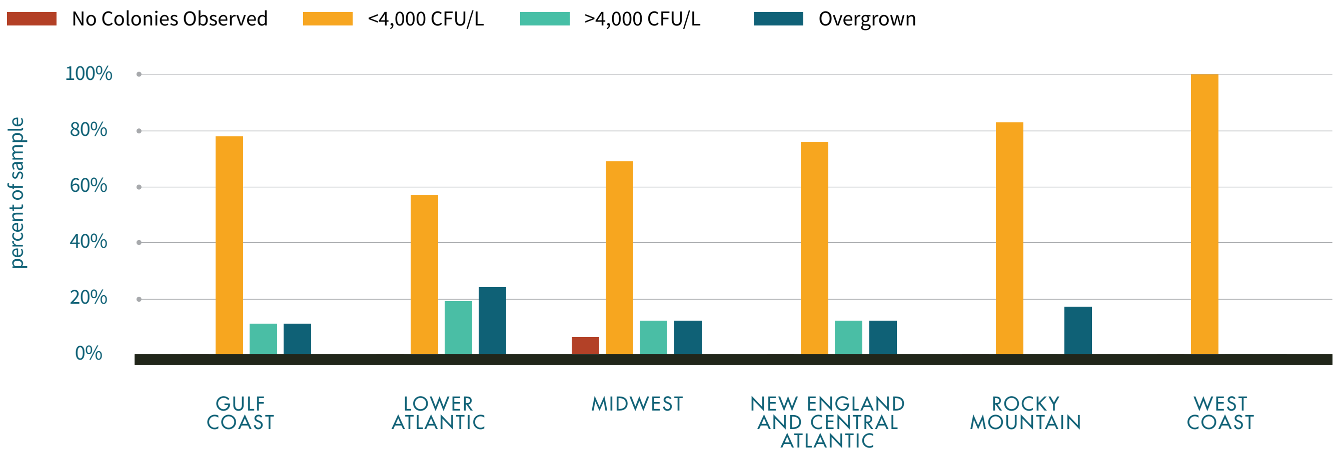
- three results omitted from Figure 92: Lower Atlantic (one site); Midwest (one site), and West Coast (one site)
- thirteen results omitted from Figure 93: Lower Atlantic (one site), Midwest (six sites), New England (three sites), Rocky Mountain (two sites), and West Coast (one site)
- twelve results were omitted from Figure 94: Gulf Coast (one site), Lower Atlantic (three sites), Midwest (five sites), New England and Central Atlantic (two sites), AND West Coast (one site)

FIGURE 87: REGIONAL MICROBIAL COUNT—BACTERIAL RESULTS: MIDDLE TANK



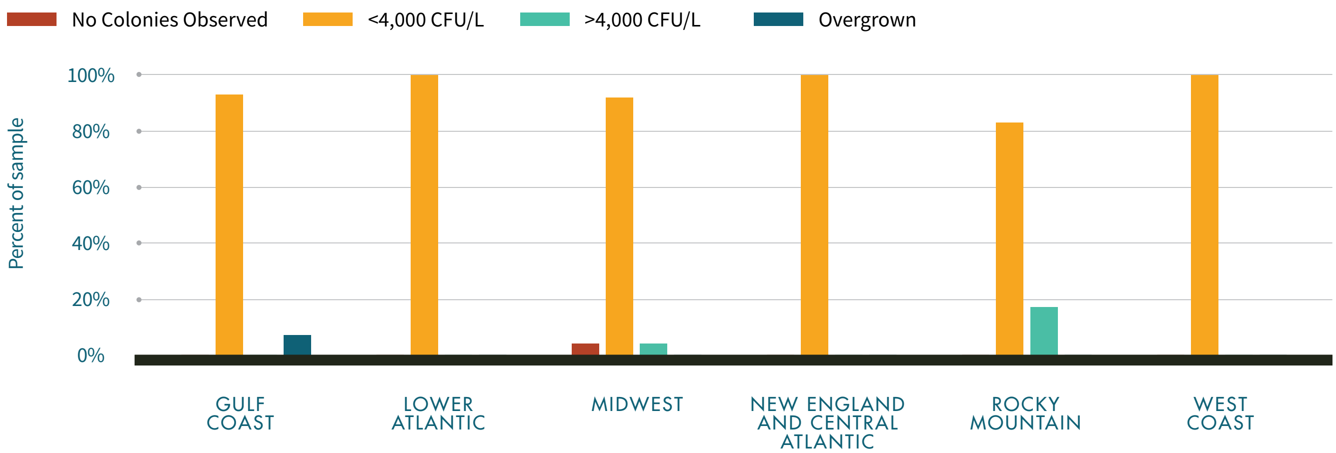
BENCHMARK: <4,000 CFU/L, INDUSTRY EXPERTS

FIGURE 88: REGIONAL MICROBIAL COUNT—BACTERIAL RESULTS: BOTTOM TANK



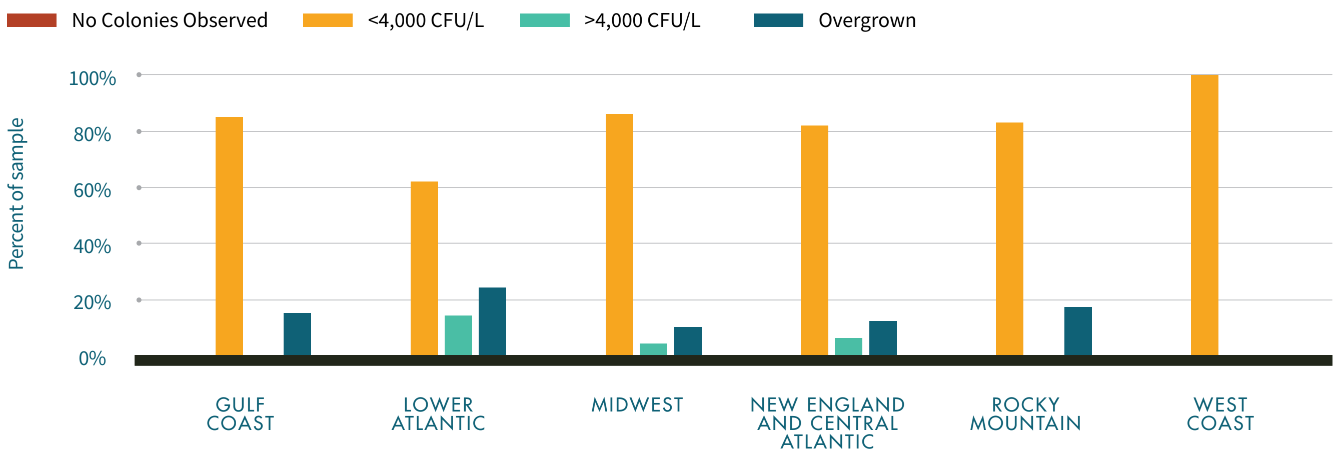
BENCHMARK: <4,000 CFU/L, INDUSTRY EXPERTS

FIGURE 89: REGIONAL MICROBIAL COUNT—MYCOLOGICAL RESULTS: MIDDLE TANK



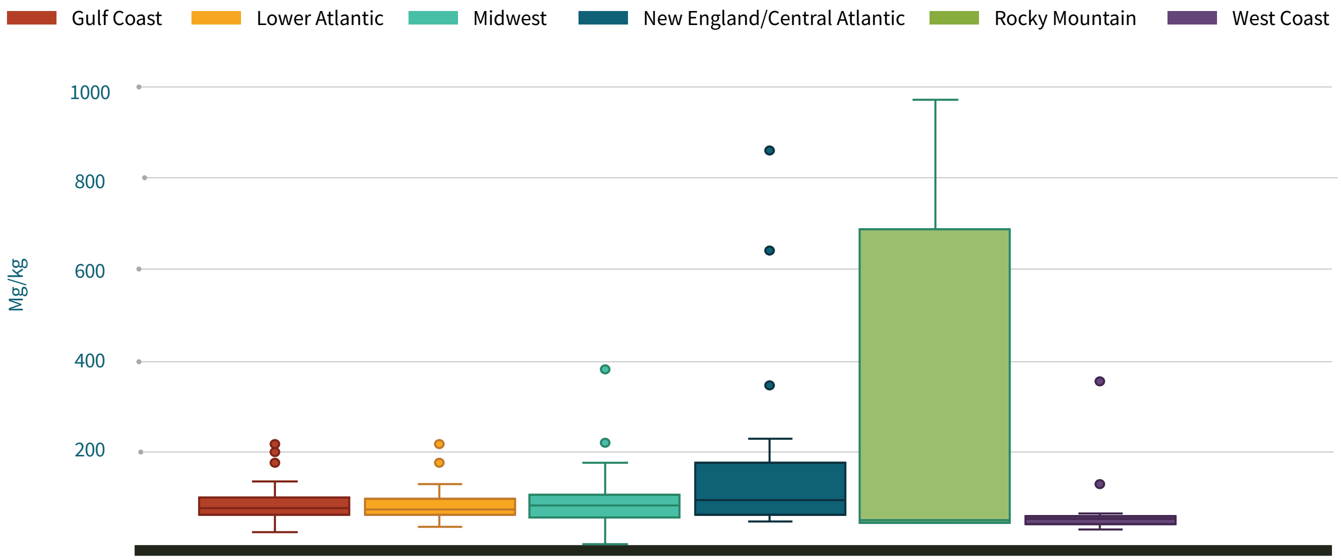
BENCHMARK: <4,000 CFU/L, INDUSTRY EXPERTS

FIGURE 90: REGIONAL MICROBIAL COUNT—MYCOLOGICAL RESULTS: BOTTOM TANK



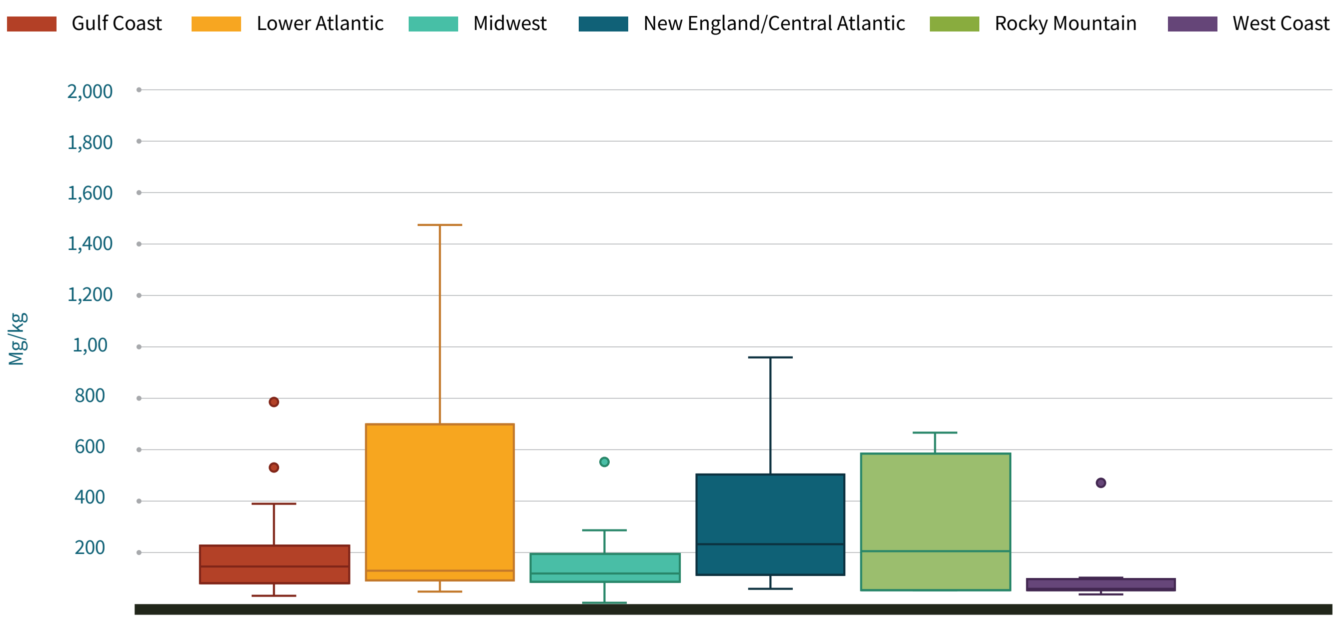
BENCHMARK: <4,000 CFU/L, INDUSTRY EXPERTS

FIGURE 91: REGIONAL WATER (KARL FISCHER) RESULTS: MIDDLE TANK



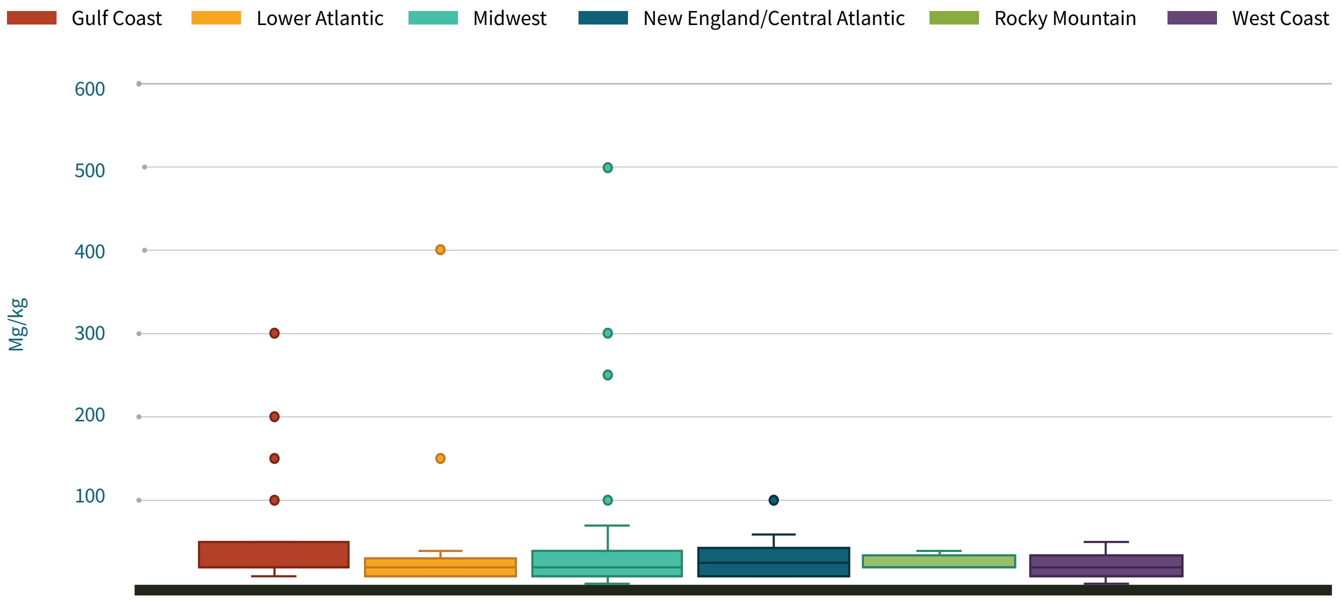
BENCHMARK: <200 MG/KG, WWFC

FIGURE 92: REGIONAL WATER (KARL FISCHER) RESULTS: BOTTOM TANK



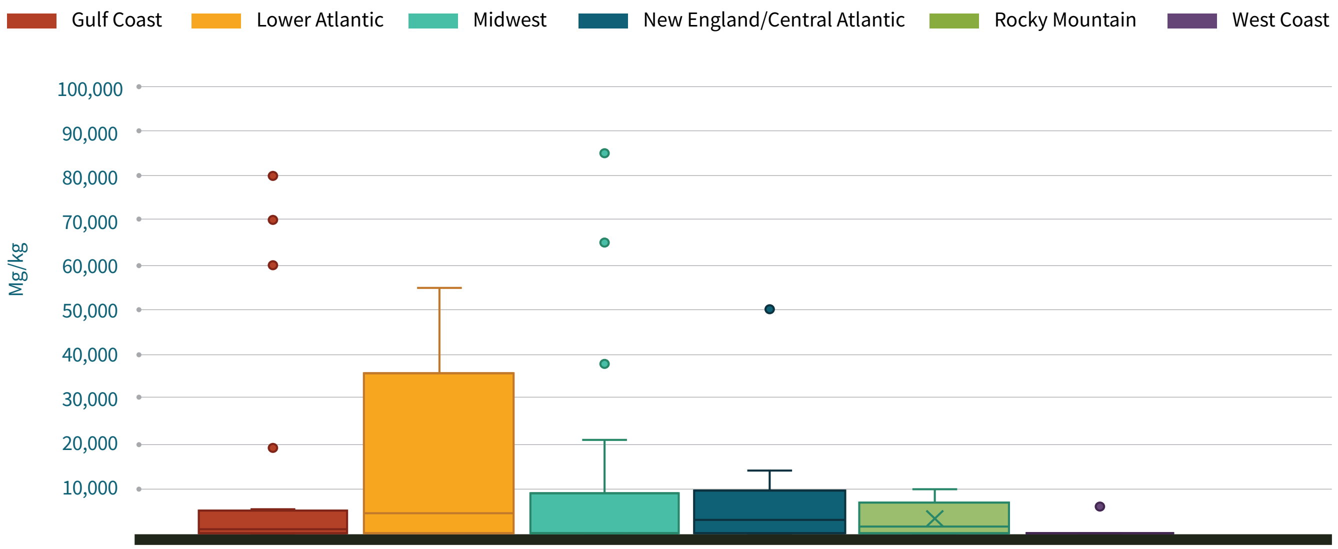
BENCHMARK: <200 MG/KG, WWFC

FIGURE 93: REGIONAL WATER AND SEDIMENT RESULTS: MIDDLE TANK



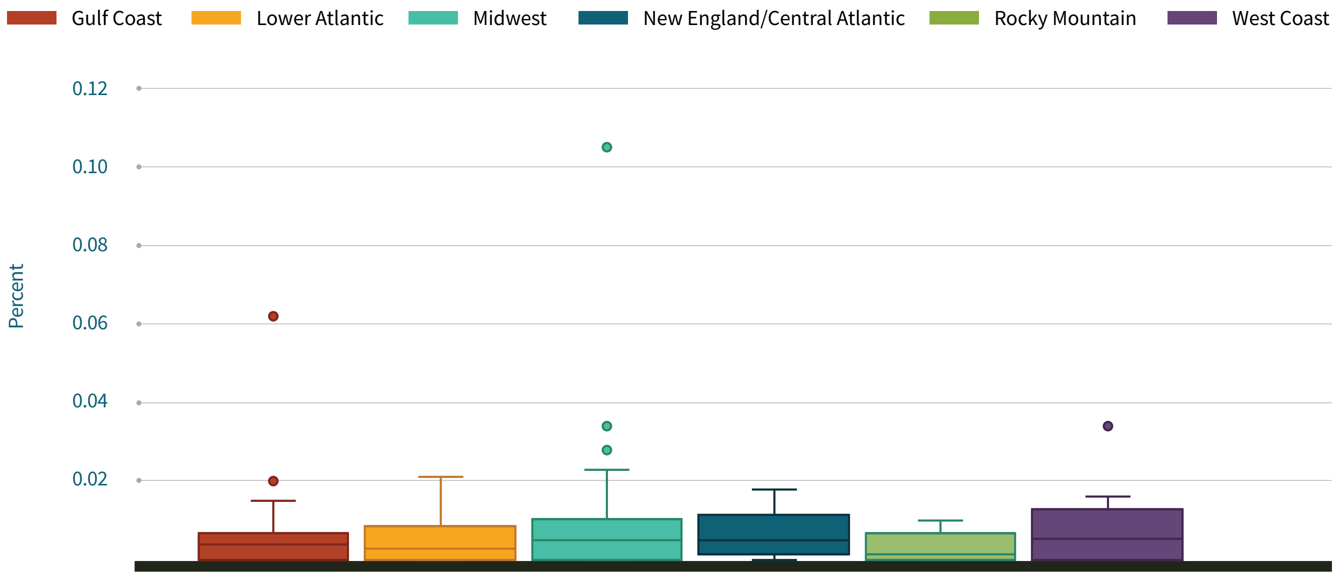
BENCHMARK: <500 MG/KG, ASTM

FIGURE 94: REGIONAL WATER AND SEDIMENT RESULTS: BOTTOM TANK



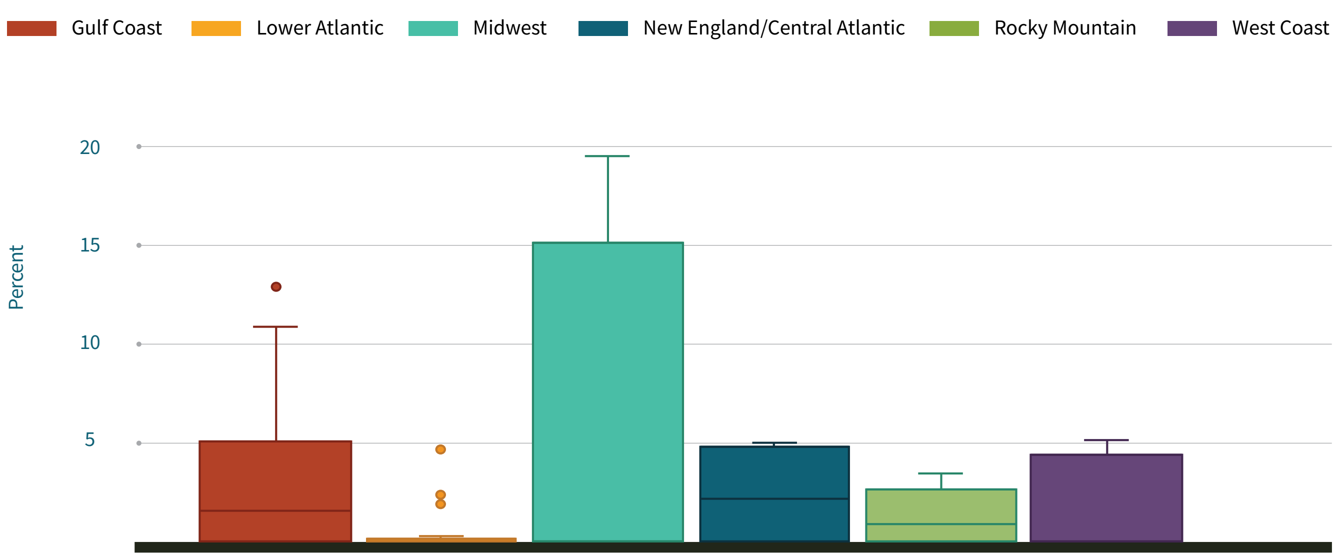
BENCHMARK: <500 MG/KG, ASTM

FIGURE 95: REGIONAL ETHANOL RESULTS: MIDDLE TANK



BENCHMARK: NON-DETECTABLE, WWFC

FIGURE 96: REGIONAL BIODIESEL RESULTS: MIDDLE TANK



NO BENCHMARK

FIGURE 97: REGIONAL BIODIESEL RESULTS: BOTTOM TANK

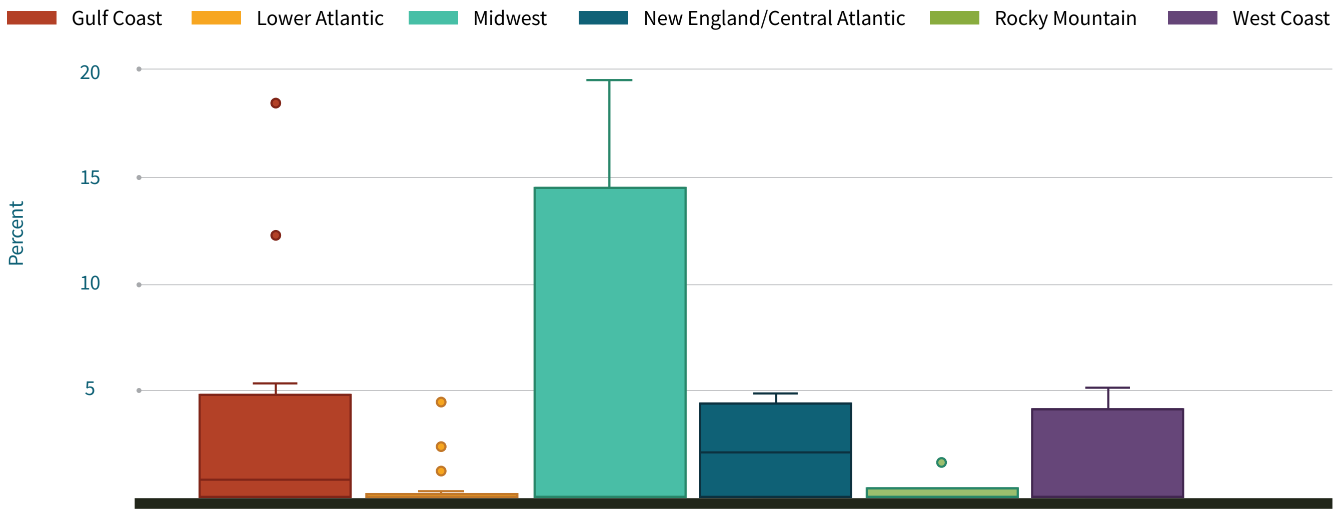
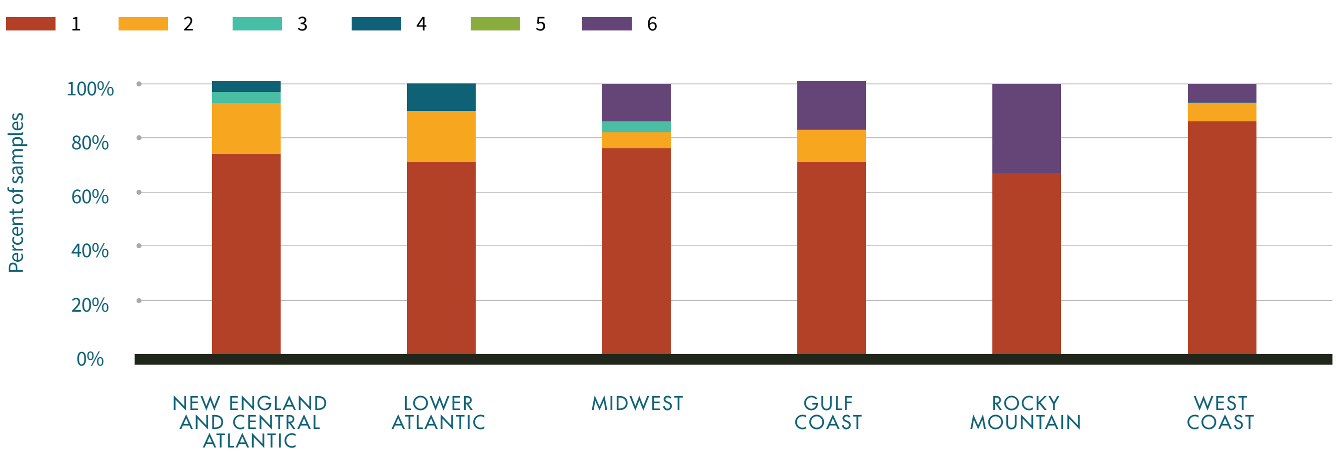
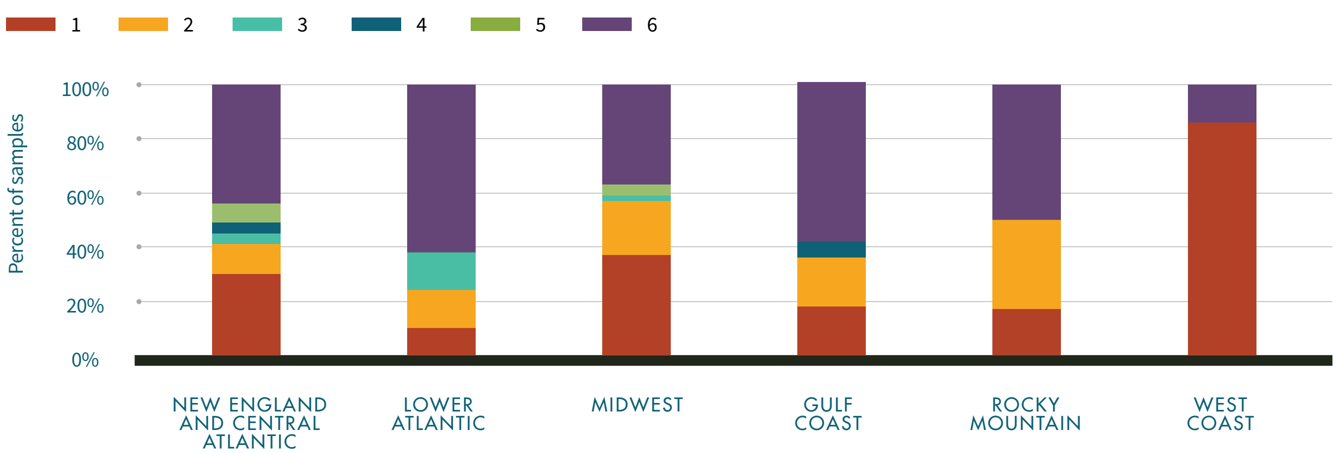


FIGURE 98: REGIONAL APPEARANCE RESULTS: MIDDLE TANK



BENCHMARK: "1", WWFC

FIGURE 99: REGIONAL APPEARANCE RESULTS: BOTTOM TANK



BENCHMARK: "1", WWFC

Summary of Findings

The analysis of the 190 nozzle samples, the 134 middle layers tank samples, and the 134 bottom layer tank samples found the following:

- **Oxidation stability:** 62.7% of nozzle samples failed to meet the WWFC benchmark of 35 hours for oxidation stability. When applying a different benchmark, EN590, 32.2% of samples failed to meet the less stringent value of 20 hours.
- **TAN:** Only one nozzle sample exceeded the WWFC benchmark of 0.08 mg KOH/g. When the benchmark was lowered to 0.05 mg KOH/g, 9.5% failed to meet the benchmark.
- **Flash point:** Only 4.2% failed to meet the ASTM benchmark of 52°C.
- **Metals:** The metals magnesium, calcium, and zinc were found in more than 50% of all nozzle samples while potassium and sodium were found in more than 20% of samples. Only three samples contained metals (zinc) in excess of 1 mg/kg. The WWFC benchmark for metals is “non-detectable.”
- **Water (Karl Fischer):** 1.6% of nozzle samples, 9.0% of middle samples, and 30.6% of bottom tank samples failed to meet the WWFC benchmark of <200 mg/kg.
- **Water and sediment:** 1.1% of nozzle samples, 9.7% of middle tank samples, and 47% of bottom tank samples failed to meet the ASTM benchmark of <500 mg/kg.
- **Appearance:** 6% of nozzle samples, 25.4% of middle tank samples, and 67.2% of bottom tank samples failed to meet the WWFC benchmark for “clear and bright” with a score of 1.
- **Microbial count—bacterial:** 8.2% of middle tank samples and 23.9% of bottom tank samples failed to meet the industry benchmark of <4,000 CFU/L
- **Microbial count—mycological:** 3.7% of middle tank samples and 17.2% of bottom tank samples failed to meet the industry benchmark of 4,000 CFU/L.
- **Ethanol:** 67.2% of middle tank samples failed to meet the WWFC benchmark of “non-detectable.”
- **Biodiesel content:** Laboratory analysis found 42.1% contained no detectable biodiesel, 41.1% contained less than 5% biodiesel, and 16.8% contained more than 5% biodiesel. When samples were collected, 17% of respondents on site claimed the biodiesel content of their diesel fuel was between 0% and 5%, 13% claimed biodiesel content was between 5% and 20%, and 70% said they did not know.
- **Retail and non-retail:** There were no significant differences in the rates of compliance between retail and non-retail fueling facilities, except for the bottom samples in which non-retail tanks more frequently failed to meet all of the benchmarks.
- **Nozzle correlations:** Significant correlations existed between 1) appearance and water (Karl

Fischer), 2) appearance and water and sediment, 3) magnesium and calcium, and 4) TAN and biodiesel.

- **Middle tank correlations:** Significant correlations existed between 1) water (Karl Fischer) and water and sediment, 2) microbial count—bacterial and microbial count—mycological, and 3) appearance and water and sediment.
- **Bottom tank correlations:** No significant correlations existed among bottom tank fuel properties.
- **Tank and nozzle correlations:** Significant correlations existed between TAN and biodiesel when comparing both middle tank and bottom tank samples with nozzle samples. The data indicates that the more biodiesel a sample contains, the higher the TAN of the sample.
- **Water measurements — field and laboratory:** The majority of field tests for water content (83% of automatic tank gauges and 79% of dipstick tests using water-finding paste) returned a measure of 0 inches of water present within a tank. Laboratory tests of bottom tank samples, however, found 30.6% of samples exceeded 200 mg/kg for water (Karl Fischer) and 47.0% exceeded 500 mg/kg for water and sediment.
- **Filters:** Filter size was evenly divided between 10-micron filters (46.5%) and 30-micron filters (50.0%). There was no significant difference in nozzle sample results for metals, water, or appearance between the two filter sizes.
- **Tank maintenance:** Only 41 sites (21.6%) said they perform routine preventative maintenance. Of these, 76% said they performed maintenance when needed and 16% said they perform maintenance on a regular schedule.
- **Regional analysis:** There was limited difference in fuel property testing results between the six regions evaluated. Some notable differences observed include:
  - A significantly higher percent of samples (93% versus 37% for all samples) from the New England/Central Atlantic region met the WWFC benchmark of 35 hours for oxidation stability. The Midwest and West Coast had the lowest percentage of samples meeting the benchmark, at 15% and 7%, respectively.
  - Bottom tank samples from the West Coast met all of the applied benchmarks with much greater frequency than samples from any other region. Example: 86% of West Coast bottom tank samples met the “clear and bright” benchmark for appearance compared with only 33% of all bottom tank samples.

Appendix A

Fuel Sampling Work Instructions

(PROVIDED BY TANKNOLOGY TO TECHNICIANS IN THE FIELD)

SAFETY, SAMPLE INTEGRITY, AND HANDLING

PRE-SAMPLE RECOMMENDATIONS

- **Fill out sample kit labels to avoid getting dirty**
- **Gather information for Fuel Sample report prior to handling fuel**
- **Clean/sterilize sampling equipment**
  - Use isopropanol alcohol (rubbing alcohol)
  - Flush the lines and sample bottle with product you are about to sample. Return fuel to the tank
  - Use a new tube for vacuum samplers, if needed.

SAMPLE KITS WILL BE PROVIDED TO TECHS BY IOWA CENTRAL LAB.

- **Keep kits in box until ready to use to avoid any dust/dirt accumulation.**
  - If needed, wash the sample bottles with a solvent (ASTM D4057 does not specify which solvent) and make sure they are dry.
  - The kits should include: bottle, label, absorbent pad, zip lock bag, chain of custody form, zip tie.

NOZZLE SAMPLES

- **Wear gloves**
- **Make sure sample bottle is clean and dry.**
  - If you are using an intermediate sample container (container used to catch sample, then used to pour into primary sample bottle), make sure it is clean and dry.
  - Pull one liter from the diesel nozzle at dispenser closest to DSL tank. Fill sample bottle to 75-80% capacity to allow for expansion.
- **Record data for filter type, model, and date filter was changed (if written on filter) for DSL.**
- **Photograph filter and include in your report.**
- **Stick tank using water-finding paste for DSL fuel, photograph stick, and include in the report.**
- **Include ATG tape of the DSL tank.**

TANK BOTTOM SAMPLES

- **Wear gloves.**
- **Make sure sample bottle is clean and dry.**
  - If you are using an intermediate sample container (container used to catch sample, then used to pour into primary sample bottle), make sure it is clean and dry.
  - Pull samples from the submersible turbine pump (if available) or the ATG.
  - Make sure vacuum sampler or bacon bomb is sterilized and clean.
- **For vacuum sampler, lower tube into tank until brass pipe is just above the fuel level.** Then swing tubing back and forth until freely swinging lengthwise in the tank. Release extra tubing to lower brass pipe to tank bottom. Create a vacuum with the hand pump and observe product in tubing.
- **For a bacon bomb,** lower device till it contacts tank bottom. Allow device enough time to completely fill. Remove device from tank and empty contents into sampling bottle. Repeat process if more fuel is needed to fill sample bottle to 75-80% capacity.
- **Make sure sample bottle is closed tightly. Remove from direct sunlight until ready to package.**
- **Stick tank using water finding paste for DSL fuel, photograph stick, and include in the report.**

MID-FUEL SAMPLES

(pull from same tank as Bottom sample)

- **Wear gloves.**
- **Based on the number of inches of product in the tank, lower sampling device to the mid-point of the fuel and retrieve a sample of the product.** (For example; if the tank has 60″ of product, lower the sampling device to the 30″ level in the fuel.)
- **Fill sample bottle to 75-80% capacity.**
- **Prior to leaving location, make sure all questions have been answered on the Fuel Sample Form.** Upload and include with your report.

PACKAGING AND SHIPPING

- **Chain of Custody form is filled out correctly and includes Tanknology work order number, site address, Tank ID or Number sample pulled from, and nozzle sample taken from.**
- **Make sure all questions are complete on the sample bottle.**
- **Follow the packaging directions that were included with the kit.**
- **All samples need to be shipped within 24 hours of collection.**

TANCS REPORT

- **Be sure to include photos of samples, photos of filters under dispenser, photo of stick with water finding paste, ATG tape for DSL tank.**

Appendix B

Questionnaire

Tanknology

Diesel Fuel Quality Council Fuel Sampling Report

W.O. #: ________________ Site Address: ______________________________________

Tank No.: ________ Product: _________ Tank Capacity: _______ Material: _________

Fuel Volume: _________ Water Level: __________ (from ATG – include photo - ☐)

Nozzle Sample Taken From Which Dispenser: ________________

Make/Model of Filter:___________ Filter Particulate Size:______ (Include photo - ☐)

Tank Bottom Sample Location: ATG Fill STP N/A (Include photo - ☐)

Tank Middle Sample Location: ATG Fill STP N/A (Include photo - ☐)

Measured Water Level (with water finding paste): ____________

Attempt to gather the following information from onsite personnel:

What is the biodiesel content? _________% (Include photo of dispenser - ☐)

What is approximate monthly ULSD throughput? _____________ gals

From what terminal(s) is the ULSD received? __________________________

What trucks are used? Common-carrier, Jobber, Company-owned

How often is the filter at the dispenser replaced? ___________________________

Does site blend biofuel on premise (Yes or No) or purchase biofuel blend (Yes or No)

Does site perform any routine preventative maintenance and if so, what is the practice and at what frequency is it used? (ex. Tank cleaning, fuel polishing, water removal, etc.)

Yes _____ No _____ Describe: ____

Technician: _____________________ Date: ________________________

Abbreviations

AST	Aboveground storage tank
ATG	Automatic tank gauge
DIS	Decisions Innovations Solutions
PADD	Petroleum Administration for Defense Districts
TAN	Total acid number
ULSD	Ultra-low sulfur diesel
UST	Underground storage tank
WWFC	Worldwide Fuel Charter

Fuels Institute

DFQC DIESEL FUEL QUALITY COUNCIL

About the Diesel Fuel Quality Council

The Diesel Fuel Quality Council is a non-advocacy organization comprised of a diverse range of stakeholders in the heavy-duty diesel industry. We got our start when in 2017, Mansfield Energy Corporation contacted the Fuels Institute to discuss a pervasive problem popping up amongst their customers. Many fleets were experiencing diesel engine problems and downtime presumably as a result of fuel quality. Perplexed as to why this was happening and looking for answers, Mansfield reached out to the Fuels Institute and asked us to start an industry-wide initiative to investigate the issue and see if we could come up with any mitigation strategies. Since then, we have been bringing stakeholders together to collaborate on research geared toward improving the relationship between diesel fuel quality and modern diesel engines. This report is the result of that initiative.

For more information on the Diesel Fuel Quality Council and a list of current members, please visit: fuelsinstitute.org/councils/fuel-quality-council

About the Fuels Institute

The Fuels Institute, founded by NACS in 2013, is a 501(c)(4) non-profit research-oriented think tank dedicated to evaluating the market issues related to vehicles and the fuels that power them. By bringing together diverse stakeholders of the transportation and fuels markets, the Institute helps to identify opportunities and challenges associated with new technologies and to facilitate industry coordination to help ensure that consumers derive the greatest benefit.

The Fuels Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders. Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Fuels Institute are dedicated to promoting facts and providing decision makers with the most credible information possible so that the market can deliver the best in vehicle and fueling options to the consumer.

For more about the Fuels Institute, visit fuelsinstitute.org.

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