Final Report

Confirmatory and Efficacy Testing of Additive-Based Alternative Diesel Fuel Formulations

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Disclaimer

The statements and conclusions in this report are those of the contractor and not necessarily those of California Air Resources Board. The mention of commercial products, their source, or their use in connection with material reported herein is not to be construed as actual or implied endorsement of such products.

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Abstract

The Alternative Diesel Fuels (ADF) regulation establishes a comprehensive, multi-stage process administering the commercialization of alternative diesel fuels in California. The ADF regulation governs the introduction and use of innovative alternative diesel fuels in California while preserving or enhancing the public health, environmental, and emission benefits of the existing motor vehicle diesel fuel regulations. The ADF regulation includes specific provisions designed to control potential increases in oxides of nitrogen (NOx) emissions that could otherwise be caused by the use of biodiesel under certain circumstances. Those provisions include a process for certification of additives or alternative diesel fuel formulations that have been shown to mitigate NOx increases from the use of biodiesel. Several additives have been approved and certified pursuant to Appendix 1(a)(2)(H) of the ADF regulation as providing emissions equivalence for blends of 20 percent biodiesel and below.

The purpose of this study was to confirm results of regulatory certification testing for two recently certified biodiesel additive packages, test the emissions from those two additives certified under Appendix 1 of the ADF regulation, and examine the potential efficacy of these, and other additives, in reducing NOx. This study included confirmation and efficacy testing including:

1. A confirmatory certification test of a B20 [20 percent biodiesel – 80 percent California Air Resources Board reference diesel fuel ("CARB reference fuel")] candidate fuel containing 20 parts per million on a volumetric basis (ppmv) of the BEST Corp BC-EC1c additive (Executive Order G-714-ADF05A issued on March 29, 2019);

2. A confirmatory certification test of a B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA™ 5100 additive (Executive Order G-714-ADF07 issued on June 1, 2018);

3. An efficacy test of B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive;

4. A confirmatory certification test of a B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA™ 1000 additive (Executive Order G-714-ADF01 issued July 20, 2017); and

5. An efficacy test of a B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive.

All testing was conducted using a 1991 model-year Detroit Diesel Corporation (DDC) Series 60 engine and results for the candidate fuels were compared to the results for a CARB reference fuel. Some testing of unadditized B20 fuel against the CARB reference fuel was also conducted to determine baseline B20 test fuel emissions and the percent increase in NOx emissions compared to the CARB reference fuel.

NO_x emissions results for the confirmatory and efficacy testing showed increases relative to the CARB reference fuel of 3.90%, 3.80%, 2.41%, 1.94%, 2.25% and 0.66%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the

VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. Statistical analysis for the NOx emission test criteria indicated that all of the candidate fuels did not pass the certification test criteria for NOx. It should be noted that while B10 is not currently included in the emissions equivalency testing provisions of the ADF regulation, and the B10 candidate fuel with the highest additive treat rate did not pass the statistical test, the percentage difference between the B10 candidate fuel and the CARB reference fuel was 0.66 based on a single day of testing.[1] The results did show that the VESTA™ additive did provide some NOx emissions benefits relative to the unadditized B20, while the Best additive candidate fuel had NOx emissions similar to those for the unadditized B20.

[1] For NOx, the certification criteria provides for a tolerance level of 1% that is reduced by a pooled standard deviation term that increases with the variability in the data and decreases with the number of tests performed.

Acronyms and Abbreviations

ADF	Alternative Diesel Fuel
BSFC	brake specific fuel consumption
CARB	California Air Resources Board
CE-CERT	College of Engineering-Center for Environmental Research and Technology (University of California, Riverside)
CCR	California Code of Regulations
CFR	Code of Federal Regulations
CO	carbon monoxide
CO_2	carbon dioxide
COA	Certificate of Analysis
CVS	Constant Volume Sampling
DDC	Detroit Diesel Corporation
EPA	U.S. Environmental Protection Agency
FTP	Federal Test Procedure
g/bhp-hr	grams per brake horsepower hour
hp	horsepower
MEL	CE-CERT's Mobile Emissions Laboratory
NMHC	non-methane hydrocarbons
NO_x	nitrogen oxides
NO_2	nitrogen dioxide
LCFS	Low Carbon Fuel Standard
PM	particulate matter
ppmv	parts per million by volume
QA	quality assurance
QC	quality control
THC	total hydrocarbons
SwRI	Southwest Research Institute
UCR	University of California at Riverside
ULSD	ultralow sulfur diesel

Executive Summary

The Alternative Diesel Fuels (ADF) regulation establishes a comprehensive, multi-stage process administering the commercialization of alternative diesel fuels in California. The ADF regulation governs the introduction and use of innovative alternative diesel fuels in California while preserving or enhancing the public health, environmental, and emission benefits of the existing motor vehicle diesel fuel regulations. The ADF regulation includes specific provisions designed to control potential increases in oxides of nitrogen (NOx) emissions that could otherwise be caused by the use of biodiesel under certain circumstances. Those provisions include a process for certification of additives or alternative diesel fuel formulations that have been shown to mitigate NOx increases from the use of biodiesel. Several additives have been approved and certified pursuant to Appendix 1(a)(2)(H) of the ADF regulation as providing emissions equivalence for blends of 20 percent biodiesel and below.

The purpose of this study was to confirm results of regulatory certification testing for two recently certified biodiesel additive packages, test the emissions from those two additives certified under Appendix 1 of the ADF regulation, and examine the potential efficacy of these, and other additives, in reducing NOx. This study included confirmation and efficacy testing including:

1. A confirmatory certification test of a B20 [20 percent biodiesel – 80 percent California Air Resources Board reference diesel fuel ("CARB reference fuel")] candidate fuel containing 20 parts per million on a volumetric basis (ppmv) of the BEST Corp BC-EC1c additive (Executive Order G-714-ADF05A issued on March 29, 2019);

2. A confirmatory certification test of a B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA™ 5100 additive (Executive Order G-714-ADF07 issued on June 1, 2018);

3. An efficacy test of B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive;

4. A confirmatory certification test of a B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA™ 1000 additive (Executive Order G-714-ADF01 issued July 20, 2017); and

5. An efficacy test of a B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive.

All testing was conducted using a 1991 model-year Detroit Diesel Corporation (DDC) Series 60 engine and results for the candidate fuels were compared to the results for CARB reference fuel. Some testing with the unadditized B20 fuel against the CARB reference fuel was also conducted to evaluate the percent increase in NOx emissions compared to the additized B20 fuels.

Test Fuels

The test fuels included:

- A CARB reference fuel, as the baseline fuel;
- An unadditized B20 fuel;
- A B20 candidate fuel containing 20 ppmv of the BEST Corp BC-EC1c additive (Executive Order G-714-ADF05A issued on March 29, 2019);
- A B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA™ 5100 additive (Executive Order G-714-ADF07 issued on June 1, 2018);
- A B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive;
- A B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA™ 1000 additive; and
- A B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive.

The baseline CARB reference fuel met the reference fuel specifications in Table A.9 of the ADF regulation.[2] The neat biodiesel used as the blendstock for the B20 baseline fuel and the B20 and B10 candidate fuels met the specifications in Table A.8 of the ADF regulation.

Test Engine

Testing was conducted on a 1991 DDC Series 60 engine. This engine is a 350 hp, 11.1 liter, in-line, six cylinder, four-stoke diesel engine equipped with a turbocharger with a charge air cooler. The 1991 DDC Series 60 engine is the engine that has traditionally been used for CARB's emissions equivalent diesel certification procedure.

Test Procedure

All testing was conducted in accordance with the Federal Test Procedure (FTP) for heavy-duty engines. The test sequence for the efficacy and confirmatory certification emissions testing was conducted using the hot start sequence described under California Code of Regulations, Title 13, Article 3, Appendix 1 of Subarticle 2, (a)(2)(F)3.b., Alternative 1. This test sequence is presented in Table ES-1. The efficacy testing consisted of one or two days of testing based on this sequence while confirmatory certification testing consisted of five days of testing with a minimum of 20 tests each on the CARB reference fuel and candidate fuels.

[2] CARB. 2018. Regulation on Commercialization of Alternative Diesel Fuels. Title 13, California Code of Regulations, Appendix 1 of Subarticle 2.

Table ES-1. Testing Protocol for Confirmatory Testing

Day	Fuel Test Sequence
1**	RC CR RC CR
2*	RC CR RC CR
3	RC CR RC CR
4	RC CR RC CR
5	RC CR RC CR

* Note that the test sequences for the unadditized B20 and the B20 candidate fuel with 2200 ppm of the active ingredient in the VESTA™ additive were conducted for only two test days.

** Note that the test sequence for the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive was conducted for only one test day.

The engine emissions testing was performed at the UCR's College of Engineering-Center for Environmental Research and Technology's (CE-CERT's) heavy-duty engine dynamometer laboratory. This engine dynamometer test laboratory is equipped with a 600-hp General Electric DC electric engine dynamometer.

For all tests, standard emissions measurements of non-methane hydrocarbons (NMHC), total hydrocarbons (THC), carbon monoxide (CO), NO_x, particulate matter (PM), and carbon dioxide (CO_2) were performed, along with fuel consumption via carbon balance. The emissions measurements were made using the standard analyzers in CE-CERT's heavy-duty Mobile Emissions Laboratory (MEL) trailer.

Results

Figure ES-1 shows the NO_x emission results for the confirmatory and efficacy testing of the different B20 additive blends on a gram per brake horsepower hour (g/bhp-hr) basis. A summary of all the results is as follows:

- NO_x emissions results for the confirmatory and efficacy testing showed increases relative to the CARB reference fuel of 3.90%, 3.80%, 2.41%, 1.94%, 2.25% and 0.66%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. The results did show that the VESTA™ additive did provide some emissions benefits relative to the unadditized B20, while the Best additive candidate fuel had NOx emissions similar to those for the unadditized B20.
- Statistical analysis of the NOx emission test results indicated that all of the candidate fuels did not pass the certification test criteria for NOx for the test sequences run in this program. It should be noted that while B10 is not currently included in the emissions equivalency testing provisions of the ADF regulation, and the B10 candidate fuel with the highest additive treat rate did not pass the statistical test, the percentage difference

between the B10 candidate fuel and the CARB reference fuel was 0.66 based on a single day of testing.[3]

- PM emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 27.3%, 28.3%, 29.6%, 29.9%, 30.6%, and 18.7%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. Statistical analysis of the PM emission test results indicated that all the candidate fuels passed the certification test criteria for PM. The PM reductions for the additized blends are similar to those found for the unadditized B20 blend.
- THC emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 7.6%, 8.0%, 14.3%, 16.1%, 17.0% and 13.0%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. The THC reductions for the additized blends were comparable to or less than those found for the unadditized B20 blend.
- CO emissions results showed consistent trends of reductions over all the B20 additive fuel blends relative to the CARB reference fuel. CO emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 12.1%, 12.7%, 17.0%, 18.0%, 21.1% and 13.8%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. The CO reductions for the additized blends were comparable to or greater than those found for the unadditized B20 blend.
- CO_2 emissions results for the candidate fuels were generally slightly higher than those for the corresponding CARB reference fuel tests, but these differences were within 1% for all test comparisons. It's worth noting that exhaust CO_2 is a minor contributor to lifecycle biofuel CO_2 emissions; biodiesel generally provides CO_2 emissions reductions on a lifecycle basis compared to conventional diesel, primarily dependent on feedstock composition.
- The brake specific fuel consumption values for the candidate fuels were generally slightly higher than those for the corresponding CARB reference fuel tests, with these differences being between 1.5% to 2.4% for all test comparisons. The greater fuel consumption for the biodiesel fuels can be attributed to the lower energy content of the biodiesel compared to the CARB reference fuel on a volumetric basis.

[3] For NOx, the certification criteria provides for a tolerance level of 1% that is reduced by a pooled standard deviation term that increases with the variability in the data and decreases with the number of tests performed.

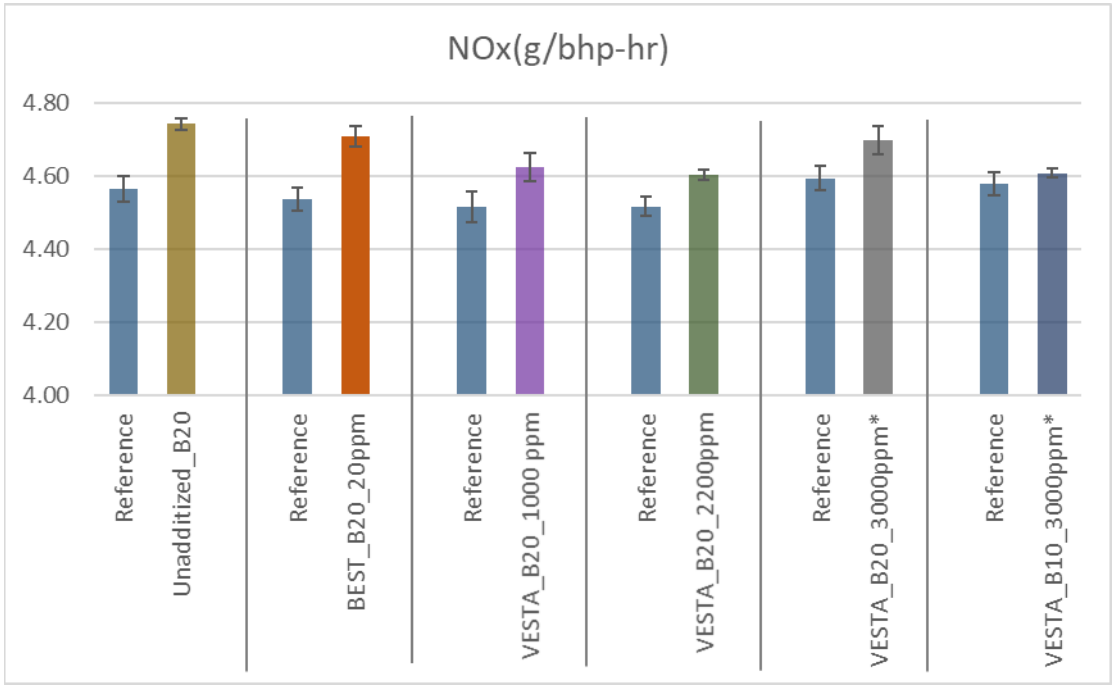


Figure ES-1. Average NO_x Emission Results for the Confirmatory and Efficacy Testing
* Active ingredient in VESTA™ Additive

1 Introduction

The ADF regulation establishes a comprehensive, multi-stage process administering the commercialization of alternative diesel fuels in California. The ADF regulation governs the introduction and use of innovative alternative diesel fuels in California while preserving or enhancing the public health, environmental and emission benefits of the existing motor vehicle diesel fuel regulations. The ADF regulations include specific provisions designed to control potential increases in NOx emissions that could otherwise be caused by the use of biodiesel under certain circumstances. Those provisions include a process for certification of additives or alternative diesel fuel formulations that have been shown to mitigate NOx increases from the use of biodiesel. Several additives have been approved and certified pursuant to Appendix 1(a)(2)(H) of the ADF regulation as providing emissions equivalence for blends B20 and below.

The purpose of this study was to confirm results of regulatory certification testing for two recently certified biodiesel additive packages, test the emissions from those two additives certified under Appendix 1 of the ADF regulation, and examine the efficacy of these, and other additives, in reducing NOx. This study included confirmation and efficacy testing including:

1. A confirmatory certification test of a B20 candidate fuel containing 20 parts per million on a volumetric basis (ppmv) of the BEST Corp BC-EC1c additive (Executive Order G-714-ADF05A issued on March 29, 2019);

2. A confirmatory certification test of a B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA^{TM} 5100 additive (Executive Order G-714-ADF07 issued on June 1, 2018);

3. An efficacy test of B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA^{TM} additive;

4. A confirmatory certification test of a B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA^{TM} 1000 additive (Executive Order G-714-ADF01 issued July 20, 2017); and

5. An efficacy test of a B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA^{TM} additive.

All testing was conducted using a 1991 DDC Series 60 engine and results for the candidate fuels were compared to the results for a CARB reference fuel. Some testing with the unadditized B20 fuel against the CARB reference fuel was also conducted to evaluate the percent increase in NOx emissions compared to the additized B20 fuels.

2 Experimental Procedures

2.1 Test Fuels

The test fuels included:

- A CARB reference fuel, as the baseline fuel;
- An unadditized B20 fuel mixed with the CARB reference fuel;
- A B20 candidate fuel containing 20 ppmv of the BEST Corp BC-EC1c additive (Executive Order G-714-ADF05A issued on March 29, 2019);
- A B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA™ 5100 additive (Executive Order G-714-ADF07 issued on June 1, 2018);
- A B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive;
- A B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA™ 1000 additive (Executive Order G-714-ADF01 issued July 20, 2017); and
- A B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive.

As a baseline fuel, the CARB reference fuel used in this study met the reference fuel specifications in Table A.9 of the ADF regulation,[4] and did not contain any renewable diesel or biodiesel. The CARB reference fuel was obtained from a single batch in a volume sufficient for the full test program to minimize variations in fuel properties over the course of the study. The certificate of analysis (COA) for this fuel is provided in Appendix A.

A neat biodiesel was used as the blendstock for the B20 baseline fuel and the B20 and B10 candidate fuels. The biodiesel met the specifications in Table A.8 of the ADF regulation. The neat biodiesel was sourced from a single batch in a volume sufficient for the full test program to minimize variations in fuel properties. The neat biodiesel fuel was obtained from a BQ-9000 supplier and was a low-saturation biodiesel. Blending of the biodiesel blends was performed at the CE-CERT facilities in Riverside, California. The B20 blends were blended in fuel totes large enough to provide for single batches of B20 fuels that were sufficient for the full test program and were stored under nitrogen blankets to minimize variations in fuel properties over the course of the study. A detailed description of the blending procedures is provided in Appendix B.

Fuel analyses were conducted by Southwest Research Institute (SwRI) on the CARB reference fuel, the neat biodiesel, and the unadditized and additized B20 candidate test fuels. The CARB reference fuel was analyzed for the properties in Table A.9 of the ADF regulation. These properties, as well as the results of the COA and the fuel specifications for the CARB reference

[4] CARB. 2018. Regulation on Commercialization of Alternative Diesel Fuels. Title 13, California Code of Regulations, Appendix 1 of Subarticle 2.

fuel, are shown in Table 2-1. The neat biodiesel fuel was analyzed for the properties in Table A.8 of the ADF regulation. These properties, as well as the results of the fuel analysis and the fuel specifications for the neat biodiesel, are shown in Table 2-2. The unadditized and additized B20 and additized B10 candidate fuels were analyzed for the properties in Table A.7 of the ADF regulation, as provided in Table 2-3. Full fuel analyses were conducted for one sample per fuel. Triplicate analyses were performed on cetane number and a single analysis was performed on all other fuel properties indicated in Tables 2-1 through 2-3. The fuel analysis results from SwRI for all test fuels are provided in Appendix C.

Table 2-1. CARB Reference Fuel Analysis Results and Specifications

Property	ASTM Test Method	Units	Certificate of Analysis Results	Fuel Analysis Results (SwRI)	Fuel Specifications
Sulfur	D5453	ppm	1	<0.5	15 max.
Aromatics	D5186	Vol. %	6.4	6.5	10 max.
Polycyclic aromatic hydrocarbons	D5186	Wt. %	None detected	0.2	1.4 max.
Nitrogen content	D4629	ppm	None detected	<0.1	10 max.
Unadditized Cetane Number	D613	unitless	51.5	53.3 53.2 51.9	48 min.
API Gravity	D287	unitless	37.9*	37.8	33-39
Density	D287	g/ml	0.835**	0.8353	-
Kinematic Viscosity, 40°C	D 445	mm^2/s	2.8	2.76	2.0 – 4.1
Flash Point	D93	°F	176	177	130 min.
Distillation Temperature, atmospheric, IBP	D86-IBP	°F	375	369.5	340 – 420
Distillation Temperature, atmospheric, T10	D86-T10	°F	431	434.1	400 – 490
Distillation Temperature, atmospheric, T50	D86-T50	°F	500	502.5	470 – 560
Distillation Temperature, atmospheric, T90	D86-T90	°F	569	574.2	550 – 610
Distillation Temperature, atmospheric, TEP	D86-EP	°F	614	611.9	580 – 660

*API gravity for certificate of analysis used ASTM Method D4052.

** Calculated from specific gravity 60/60 (0.836 g/ml) multiplied by density of water at 60oF (0.999007 g/ml).

Table 2-2. Biodiesel (B100) Fuel Analysis Results and Specifications

Property	ASTM Test Method	Units	Fuel Analysis Results (SwRI)	Specification
Distillation, 90% recovery	D1160	°F	665.6	620 - 680
API Gravity (by Meter)*	D287	°API	28.6	27 - 33
Density	D287	g/ml	0.8833	-
Kinematic Viscosity @ 40 °C	D445-40	mm^2/s	4.14	1.9 – 6.0
Trace Nitrogen in Liquid Petroleum Hydrocarbons*	D4629	ppm (wt/wt)	4.5	10 max
Sulfur by UVF	D5453	ppm (wt/wt)	2.86	15 max
Cetane Number	D613	unitless	48.4	47-50
			48.9	
			47.2	
Flash Point, Pensky Martens	D93	°F	340	266 min
FAME content	EN 14078	% Mass	99.8	Report

* D1160 was substituted for D86 to distillation 90% recovery

** EN 14078 was substituted for EN 14103:2011 to determine FAME content

Table 2-3. Biodiesel Blends Fuel Analysis Results

Property	ASTM Test Method	Units	Unadditized_B20 Analysis Results (SwRI)	Best_B20_20 ppm Analysis Results (SwRI)	Vesta_B20_1000 ppm Analysis Results (SwRI)	Vesta_B20_2200 ppm* Analysis Results (SwRI)	Vesta_B20_3000 ppm Analysis Results (SwRI)	Vesta_B10_3000 ppm* Analysis Results (SwRI)
Sulfur Content	D5453	ppm	0.96	0.8	1.20	1.6	1.70	0.84
Nitrogen Content	D4629	ppm	<1.0	1.1	92.7	206.8	287.1	287.7
Cetane Number Test #1	D613	unitless	50.5	48.9	55.0	61.7	62.2	61.2
Cetane Number Test #2	D613	unitless	50.3	49.4	55.3	62.7	63.1	60.9
Cetane Number Test #3	D613	unitless	50.3	49.6	54.5	62.8	62.9	61.1
Cetane Number - Average	D613	unitless	50.4	49.3	54.9	62.4	62.7	61.1
API Gravity	D287	degAPI	36	36	36	36.0	36.0	36.9
Viscosity at 40°C, cSt	D445	cSt	2.934	2.941	2.946	2.952	2.931	2.850
Flash Point, °F, minimum	D93	°F	185	184	183	181	183	179
Distillation Temperature, atmospheric, IBP	D86-IBP	°F	390.6	380.2	370.9	380.1	376.0	376.9
Distillation Temperature, atmospheric, T10	D86-T10	°F	450.1	446.7	443.0	443.7	443.8	438.4
Distillation Temperature, atmospheric, T50	D86-T50	°F	530.2	529.0	528.8	527.7	527.4	511.7
Distillation Temperature, atmospheric, T90	D86-T90	°F	620.3	619.4	620.6	618.7	619.7	598.6
Distillation Temperature, atmospheric, TEP	D86-EP	°F	645.8	641.7	640.7	641.2	640.5	630.2
FAME Content %	EN14078	% Mass	20.4	20.4	20.2	19.5	19.4	9.6

2.2 Test Engine

Testing was conducted on a 1991 DDC Series 60 engine. The 1991 DDC Series 60 engine is the engine that has traditionally been used for CARB's emissions equivalent diesel certification procedure. The engine specifications are provided in Table 2-4.

Table 2-4. Test Engine Specifications

Engine Manufacturer	Detroit Diesel Corp.
Engine Model	Series 60
Model Year	1991
Engine Family Name	MDD11.1FZA2
Engine Type	In-line 6 cylinder, 4 stroke
Displacement (liter)	11.1 L
Power Rating (hp)	350 @ 1800 rpm
Fuel Type	Diesel
Induction/exhaust	Turbocharger with after cooler

2.3 Emissions Testing

Testing was conducted in the University of California Riverside (UCR), College of Engineering – Center for Environmental Research and Technology's (CE-CERT) heavy-duty engine dynamometer test laboratory. This facility is equipped with a 600 hp General Electric DC electric engine dynamometer that was obtained from the United States Environmental Protection Agency's (EPA) National Vehicle and Fuels Emission Laboratory in Ann Arbor, MI. The system is installed as a fully Code of Federal Regulations (CFR) compliant laboratory by Dyne Systems of Jackson, Wisconsin. This facility is described in greater detail in Appendix D.

The emissions measurements for this project were conducted with CE-CERT's heavy-duty Mobile Emissions Laboratory (MEL) trailer. The heavy-duty dynamometer laboratory is in a location that has ready and full access to the MEL. CE-CERT's MEL is a heavy-duty emissions measurement laboratory with a full dilution tunnel and CFR compliant analytical instrumentation that can be utilized for either stationary or on-road measurements. The MEL is described in greater detail in section Appendix D.

2.4 Test Matrix and Test Sequence

All testing was conducted in accordance with the Federal Test Procedure (FTP) for heavy-duty engines. Standard emissions measurements of total hydrocarbons (THC), non-methane hydrocarbons (NMHC), carbon monoxide (CO), NOx, particulate matter (PM), and carbon dioxide (CO_2) were made for each test. A summary of the quality assurance/quality control (QA/QC) procedures for the emissions testing is provided in Appendix E.

The test sequence for the emissions testing was conducted using the hot start sequence described under California Code of Regulations, Title 13, Article 3, Appendix 1 of Subarticle 2,

(a)(2)(F)3.b., Alternative 1. Where "R" is the CARB reference fuel and "C" is the candidate fuel, the test sequence was performed as follows:

Alternative 1: RC CR RC CR (continuing in the same order for a given calendar day; a minimum of twenty individual hot start exhaust emission tests were completed with each fuel)

This test sequence and test schedule are presented in Table 2-5 and Table 2-6, respectively. For the B20 candidate fuel (ADF) containing 20 ppmv of the BEST Corp BC-EC1c additive, the B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA^{TM} 5100 additive, and the B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA^{TM} 1000 additive, this sequence was performed over five days until 20 tests each on the CARB reference fuel and candidate fuels were obtained, with an equal number of morning and afternoon tests. For the unadditized B20 and the B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA^{TM} additive, this test sequence was performed for only two days. The information from the unadditized B20 provides some indication of how much impact the additives have in reducing NOx emissions of unadditized B20. For the B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA^{TM} additive, this test sequence was performed for only one day. For this test sequence, the first four tests in a day are termed morning tests, while the last four tests in a day are considered afternoon tests.

Table 2-5. Testing Protocol

Day	Fuel Test Sequence
1**	**RC CR RC CR**
2*	**RC CR RC CR**
3	**RC CR RC CR**
4	**RC CR RC CR**
5	**RC CR RC CR**

* Note that the test sequences for the unadditized B20 and the B20 candidate fuel with 2200 ppm of the active ingredient in the VESTA^{TM} additive were conducted for only two test days.

** Note that the test sequence for the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA^{TM} additive was conducted for only one test day.

At the beginning of each test day, the engine was operated to bring it up to its operational temperature. An engine map was then conducted on the CARB reference fuel prior to beginning testing for each test day. The engine map obtained from the CARB reference fuel on the morning of the first day of testing was utilized for the emissions testing for all fuels for the remainder of the test program. After each fuel change, the engine was operated over a full FTP preconditioning cycle and then soaked for 20 minutes prior to conducting the official emissions tests on that fuel.

Table 2-6. Testing Schedule

Date	Unadditized _B20	BEST_B20 _20ppm	VESTA_B20 _1000 ppm	VESTA_B20 _2200ppm	Date	VESTA_B20 _3000ppm*	VESTA_B10 _3000ppm*
7-Aug					19-Sep		
8-Aug					20-Sep		
9-Aug					21-Sep		
10-Aug					22-Sep		
11-Aug					23-Sep		
12-Aug					24-Sep		
13-Aug					25-Sep		
14-Aug					26-Sep		
15-Aug					27-Sep		
16-Aug					28-Sep		
17-Aug					29-Sep		
18-Aug					30-Sep		
19-Aug							
20-Aug							
21-Aug							
22-Aug							
23-Aug							
24-Aug							
25-Aug							
26-Aug							
27-Aug							

3 Engine Testing Results

The results for each of the confirmatory and efficacy test comparisons are summarized in this section. The results presented in the figures represent the average of all test runs done on that fuel sequence. The error bars represent one standard deviation on the average value. The tables show the average emission values and the percentage differences for the different candidate fuels compared to the CARB reference fuel for the test sequence associated with each of the candidate fuels. More detailed test results are provided in Appendix F. The pass/fail determinations for NOx and PM emissions are based on additional statistical analyses of the NO_x and PM emissions results from the confirmatory and efficacy testing. More details regarding the statistical criteria and the statistical analyses of the NO_x and PM emissions results from the confirmatory and efficacy testing are provided in Appendix G.

3.1 NO_x Emissions

The NO_x emission results for the confirmatory and efficacy testing of the different B20 additive blends are presented in Figure 3-1 on a gram per brake horsepower hour (g/bhp-hr) basis. Table 3-1 shows the average emission values and percentage differences for the different fuels for each of the test sequences.

NO_x emissions results for the confirmatory and efficacy testing showed increases relative to the CARB reference fuel of 3.90%, 3.80%, 2.41%, 1.94%, 2.25% and 0.66%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels.

Statistical analyses were conducted using the methodology put forth in Appendix 1(a)(2)(G) of the ADF regulation to determine if the candidate fuels passed the certification test criteria. For NOx, the certification criteria provides for a tolerance level of 1% that is reduced by a pooled standard deviation term that increases with the variability in the data and decreases with the number of tests performed. It should be noted that although the statistical analysis was performed for all test sequences, the test sequences for the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive and for the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive included only eight and four tests pairs, respectively. Also, the test sequence for the unadditized B20 included only eight test pairs. The number of tests for these three candidate fuels were less than the number of tests typically used for the five-day certification test. Based on this statistical test, with the fewer numbers of tests for the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive and for the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive, none of the candidate fuels passed the certification test statistical criteria for NOx, as discussed in Appendix G. It should be noted that while B10 is not currently included in the emissions equivalency testing provisions of the ADF regulation, and the B10 candidate fuel with the highest additive

treat rate did not pass the statistical test, the percentage difference between the B10 candidate fuel and the CARB reference fuel was 0.66 based on a single day of testing.[5]

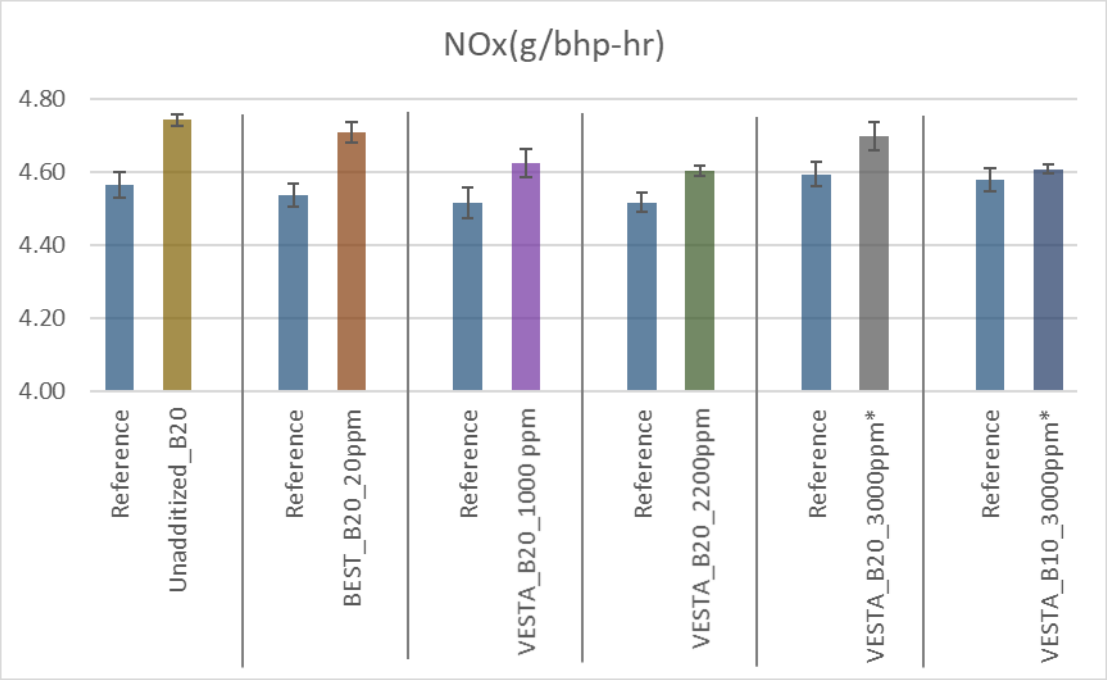


Figure 3-1. Average NO_x Emission Results for the Confirmatory and Efficacy Testing
* Active ingredient in VESTA™ Additive

Table 3-1. Average NO_x Emissions (g/bhp-hr) and Percentage Differences Between the Biodiesel Blend Candidate Fuels and the CARB Reference Fuel for the Confirmatory and Efficacy Testing

	Fuel Type	Ave. (g/bhp.hr)	% Diff vs. CARB
Unadditized_B20	CARB Reference Fuel	4.57	-
	B20 Unadditized	4.74	3.90
Best_B20_20ppm	CARB Reference Fuel	4.54	-
	B20 BEST Corp BC-EC1c Additive	4.71	3.80
Vesta_B20_1000ppm	CARB Reference Fuel	4.52	-
	B20 VESTA™ 5100 Additive	4.63	2.41
Vesta_B20_2200ppm*	CARB Reference Fuel	4.52	-
	B20 VESTA™ Active Ingredient	4.61	1.94
Vesta_B20_3000ppm	CARB Reference Fuel	4.60	-
	B20 VESTA™ 1000 Additive	4.70	2.25
Vesta_B10_3000ppm*	CARB Reference Fuel	4.58	-
	B10 VESTA™ Active Ingredient	4.61	0.66

* Active ingredient in VESTA™ Additive

[5] For NOx, the certification criteria provides for a tolerance level of 1% that is reduced by a pooled standard deviation term that increases with the variability in the data and decreases with the number of tests performed.

3.2 PM Emissions

The PM emission results for the confirmatory and efficacy testing are presented in Figure 3-2 on a g/bhp-hr basis. Table 3-2 shows the average emission values and percentage differences for the different fuels. PM emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 27.3%, 28.3%, 29.6%, 29.9%, 30.6%, and 18.7%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. Statistical analysis for the PM emission test criteria indicated that all the candidate fuels passed the certification test criteria for PM, as discussed in Appendix G. A tolerance of 2% is utilized for the PM that is reduced by pooled variance term that increases with the variability in the data, which was readily met as a PM reduction was found for the all the candidate fuels. The PM reductions for the additized blends are similar to those found for the unadditized B20 blend.

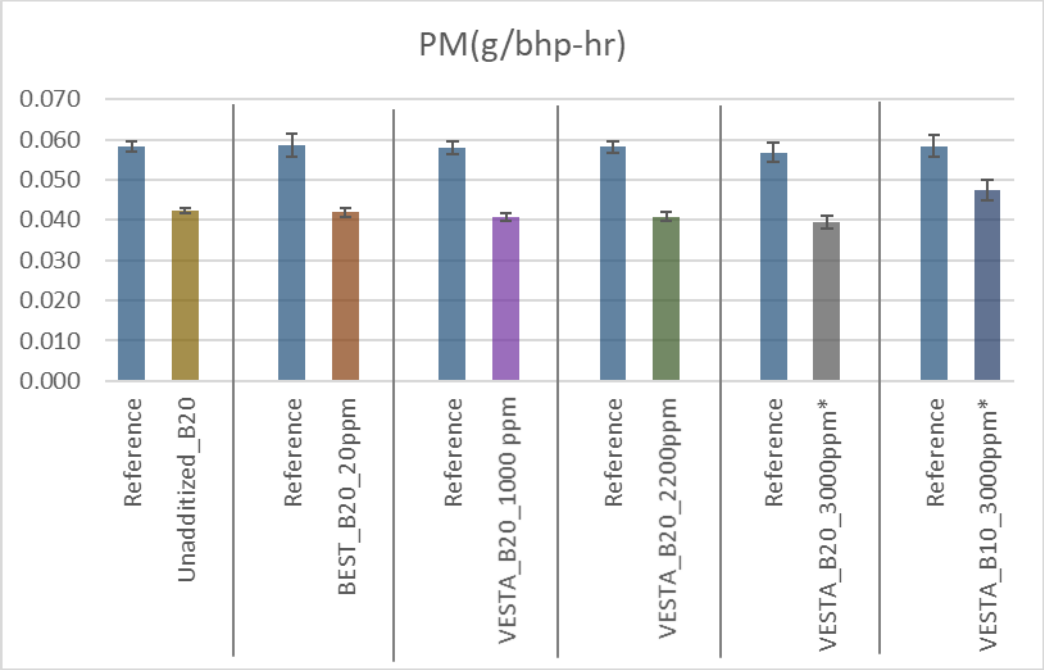


Figure 3-2. Average PM Emission Results for the Confirmatory and Efficacy Testing
* Active ingredient in VESTA™ Additive

Table 3-2. Average PM Emissions (g/bhp-hr) and Percentage Differences Between the Biodiesel Blend Candidate Fuels and the CARB Reference Fuel for the Confirmatory and Efficacy Testing

	Fuel Type	Ave. (g/bhp.hr)	% Diff vs. CARB
Unadditized_B20	CARB Reference Fuel	0.058	-
	B20 Unadditized	0.042	-27.3
Best_B20_20ppm	CARB Reference Fuel	0.058	-
	B20 BEST Corp BC-EC1c Additive	0.042	-28.3
Vesta_B20_1000ppm	CARB Reference Fuel	0.058	-
	B20 VESTA™ 5100 Additive	0.040	-29.6
Vesta_B20_2200ppm*	CARB Reference Fuel	0.058	-
	B20 VESTA™ Active Ingredient	0.041	-29.9
Vesta_B20_3000ppm	CARB Reference Fuel	0.057	-
	B20 VESTA™ 1000 Additive	0.040	-30.6
Vesta_B10_3000ppm*	CARB Reference Fuel	0.058	-
	B10 VESTA™ Active Ingredient	0.047	-18.7

* Active ingredient in VESTA™ Additive

3.3 THC Emissions

The THC emission results for the confirmatory and efficacy testing are presented in Figure 3-3 for the FTP cycle on a g/bhp-hr basis. Table 3-3 shows the percentage differences and the average emission values for the different fuels. THC emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 7.6%, 8.0%, 14.3%, 16.1%, 17.0% and 13.0%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. The THC reductions for the additized blends were comparable to or less than those found for the unadditized B20 blend. It should be noted that the pass/fail determinations for the full certification test do not include an evaluation of THC emissions.

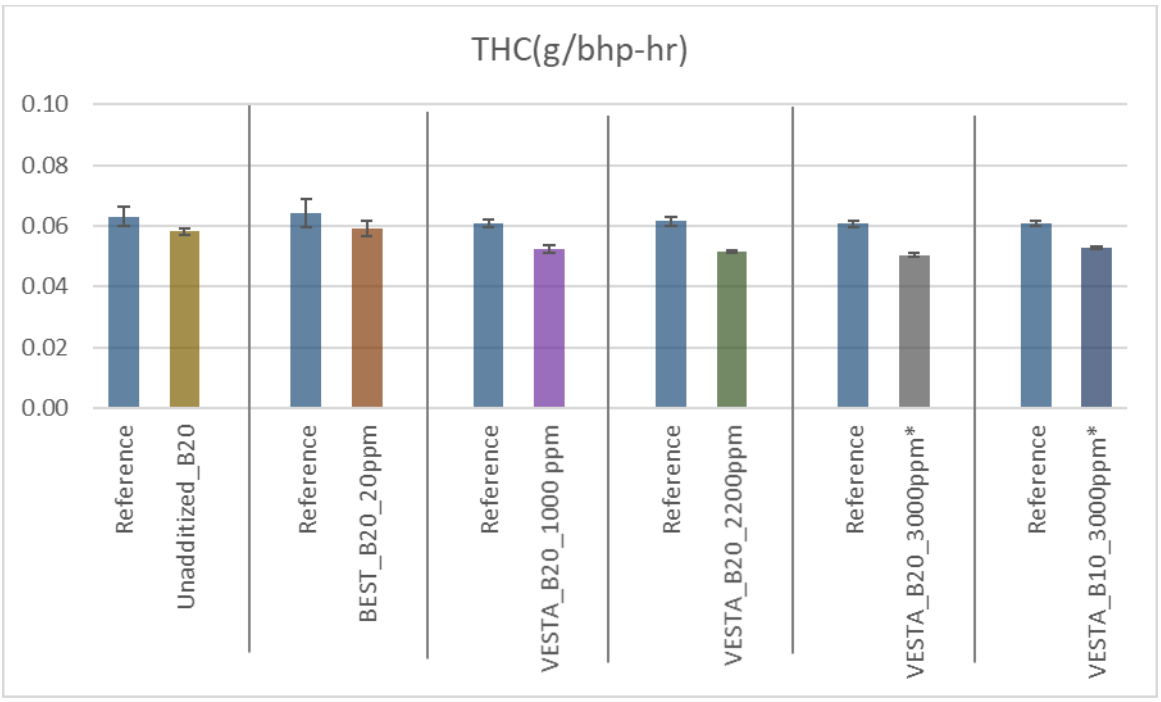


Figure 3-3. Average THC Emission Results for the Confirmatory and Efficacy Testing
* Active ingredient in VESTA™ Additive

Table 3-3. Average THC Emissions (g/bhp-hr) and Percentage Differences Between the Biodiesel Blend Candidate Fuels and the CARB Reference Fuel for the Confirmatory and Efficacy Testing

	Fuel Type	Ave. (g/bhp.hr)	% Diff vs. CARB
Unadditized_B20	CARB Reference Fuel	0.063	-
	B20 Unadditized	0.058	-7.6
Best_B20_20ppm	CARB Reference Fuel	0.064	-
	B20 BEST Corp BC-EC1c Additive	0.059	-8.0
Vesta_B20_1000ppm	CARB Reference Fuel	0.061	-
	B20 VESTA™ 5100 Additive	0.052	-14.3
Vesta_B20_2200ppm*	CARB Reference Fuel	0.062	-
	B20 VESTA™ Active Ingredient	0.052	-16.1
Vesta_B20_3000ppm	CARB Reference Fuel	0.061	-
	B20 VESTA™ 1000 Additive	0.050	-17.0
Vesta_B10_3000ppm*	CARB Reference Fuel	0.061	-
	B10 VESTA™ Active Ingredient	0.053	-13.0

* Active ingredient in VESTA™ Additive

3.4 CO Emissions

The CO emission results for the confirmatory and efficacy testing are presented in Figure 3-4 on a g/bhp-hr basis. Table 3-4 shows the average emission values and percentage differences for the different fuels. CO emissions results showed consistent trends of reductions over all the B20 additive fuel blends. CO emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 12.1%, 12.7%, 17.0%, 18.0%, 21.1% and 13.8%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. The CO reductions for the additized blends were comparable to or greater than those found for the unadditized B20 blend. It should be noted that the pass/fail determinations for the full certification test do not include an evaluation of CO emissions.

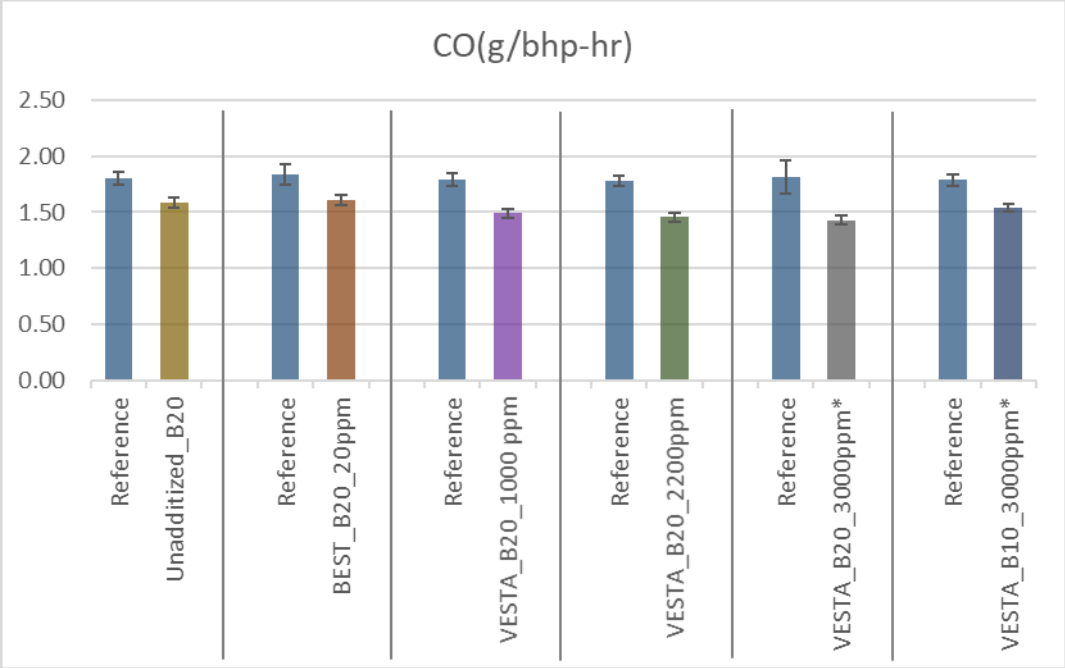


Figure 3-4. Average CO Emission Results for the Confirmatory and Efficacy Testing
* Active ingredient in VESTA™ Additive

Table 3-4. Average CO Emissions (g/bhp-hr) and Percentage Differences Between the Biodiesel Blend Candidate Fuels and the CARB Reference Fuel for the Confirmatory and Efficacy Testing

	Fuel Type	Ave. (g/bhp.hr)	% Diff vs. CARB
Unadditized_B20	CARB Reference Fuel	1.80	-
	B20 Unadditized	1.58	-12.1
Best_B20_20ppm	CARB Reference Fuel	1.84	-
	B20 BEST Corp BC-EC1c Additive	1.60	-12.7
Vesta_B20_1000ppm	CARB Reference Fuel	1.79	-
	B20 VESTA^{TM} 5100 Additive	1.49	-17.0
Vesta_B20_2200ppm*	CARB Reference Fuel	1.77	-
	B20 VESTA^{TM} Active Ingredient	1.45	-18.0
Vesta_B20_3000ppm	CARB Reference Fuel	1.81	-
	B20 VESTA^{TM} 1000 Additive	1.43	-21.1
Vesta_B10_3000ppm*	CARB Reference Fuel	1.79	-
	B10 VESTA^{TM} Active Ingredient	1.54	-13.8

* Active ingredient in VESTA^{TM} Additive

3.5 CO_2 Emissions

The CO_2 emission results for the confirmatory and efficacy testing are presented in Figure 3-5 on a g/bhp-hr basis. Table 3-5 shows the average emissions values and percentage differences for the different fuels. CO_2 emissions results for the candidate fuels were generally slightly higher than those for the corresponding CARB reference fuel tests, but these differences were within 1% for all test comparisons. It's worth noting that exhaust CO_2 is a minor contributor to lifecycle biofuel CO_2 emissions; biodiesel generally provides CO_2 emissions reductions on a lifecycle basis compared to conventional diesel, primarily dependent on feedstock composition. It should also be noted that the pass/fail determinations for the full certification test do not include an evaluation of CO_2 emissions.

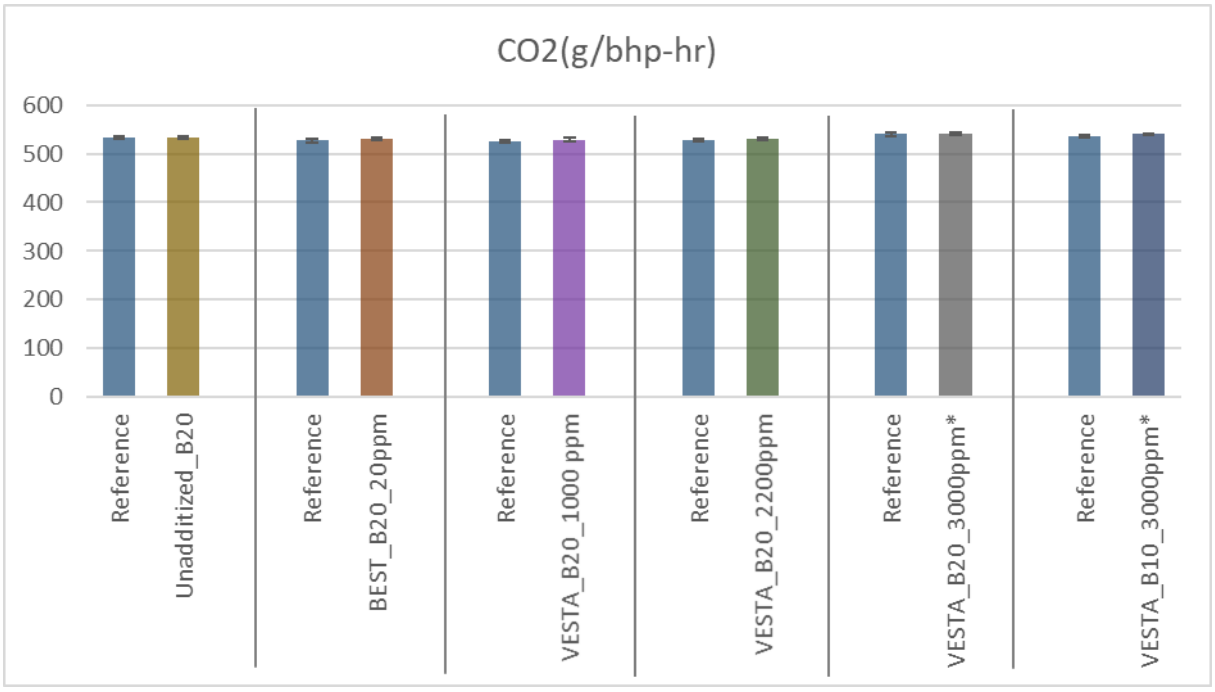


Figure 3-5. Average CO_2 Emission Results for the Confirmatory and Efficacy Testing
* Active ingredient in VESTA™ Additive

Table 3-5. Average CO_2 Emissions (g/bhp-hr) and Percentage Differences Between the Biodiesel Blend Candidate Fuels and the CARB Reference Fuel for the Confirmatory and Efficacy Testing

	Fuel Type	Ave. (g/bhp.hr)	% Diff vs. CARB
Unadditized_B20	CARB Reference Fuel	532.3	-
	B20 Unadditized	534.2	0.36
Best_B20_20ppm	CARB Reference Fuel	527.7	-
	B20 BEST Corp BC-EC1c Additive	530.6	0.53
Vesta_B20_1000ppm	CARB Reference Fuel	526.3	-
	B20 VESTA™ 5100 Additive	528.8	0.49
Vesta_B20_2200ppm*	CARB Reference Fuel	527.8	-
	B20 VESTA™ Active Ingredient	529.5	0.34
Vesta_B20_3000ppm	CARB Reference Fuel	540.0	-
	B20 VESTA™ 1000 Additive	540.8	0.15
Vesta_B10_3000ppm*	CARB Reference Fuel	536.5	-
	B10 VESTA™ Active Ingredient	540.0	0.66

* Active ingredient in VESTA™ Additive

3.6 Brake Specific Fuel Consumption

The brake specific fuel consumption (BSFC) results for the confirmatory and efficacy testing are presented in Figure 3-6 on a gallons/bhp-hr. The brake specific fuel consumption was calculated via the carbon balance method. Table 3-6 shows the average emissions values and percentage differences for the different fuels. The brake specific fuel consumption values for the candidate fuels were generally slightly higher than those for the corresponding CARB reference fuel tests, with these differences being between 1.5 to 2.4% for all test comparisons. The greater fuel consumption for the biodiesel fuels can be attributed to the lower energy content of the biodiesel compared to the CARB reference fuel on a volumetric basis. It should be noted that the pass/fail determinations for the full certification test do not include an evaluation of brake specific fuel consumption.

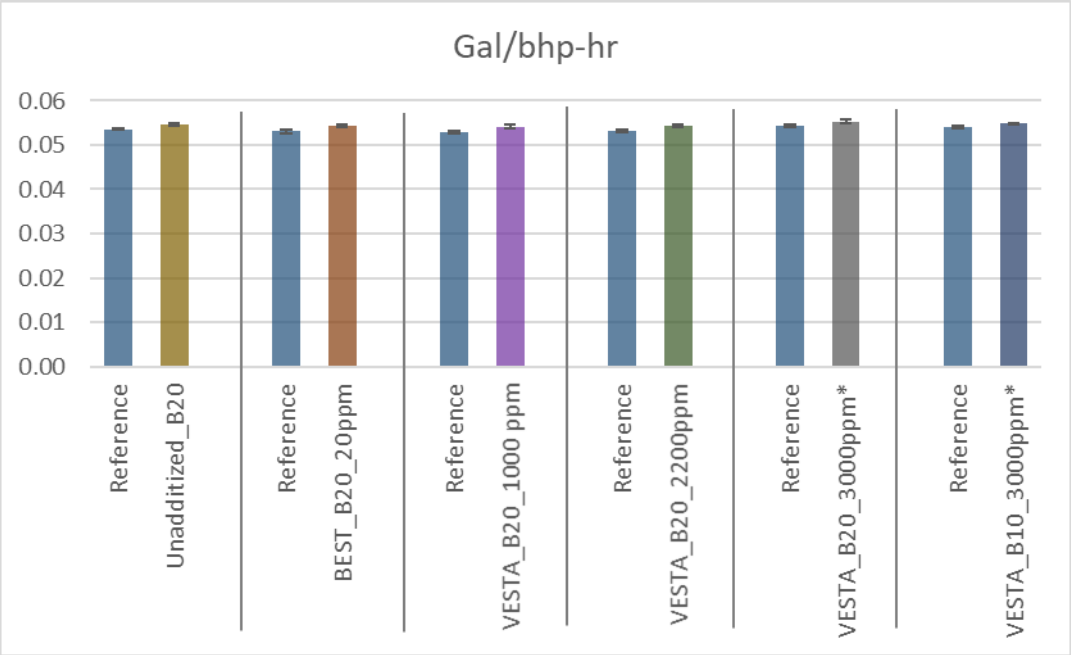


Figure 3-6. Average Brake Specific Fuel Consumption Results for the Confirmatory and Efficacy Testing

* Active ingredient in VESTA™ Additive

Table 3-6. Average BSFC (gal/bhp-hr) and Percentage Differences Between the Biodiesel Blend Candidate Fuels and the CARB Reference Fuel for the Confirmatory and Efficacy Testing

	Fuel Type	Ave. (gal/bhp.hr)	% Diff vs. CARB
Unadditized_B20	CARB Reference Fuel	0.054	-
	B20 Unadditized	0.055	2.1
Best_B20_20ppm	CARB Reference Fuel	0.053	-
	B20 BEST Corp BC-EC1c Additive	0.054	2.4
Vesta_B20_1000ppm	CARB Reference Fuel	0.053	-
	B20 VESTA™ 5100 Additive	0.054	2.2
Vesta_B20_2200ppm*	CARB Reference Fuel	0.053	-
	B20 VESTA™ Active Ingredient	0.054	2.0
Vesta_B20_3000ppm	CARB Reference Fuel	0.054	-
	B20 VESTA™ 1000 Additive	0.055	1.8
Vesta_B10_3000ppm*	CARB Reference Fuel	0.054	-
	B10 VESTA™ Active Ingredient	0.055	1.5

* Active ingredient in VESTA™ Additive

4 Summary

Confirmatory testing was performed on a B20 candidate fuel containing 20 parts per million on a volume basis (ppmv) of the BEST Corp BC-EC1c additive (Executive Order G-714-ADF05A issued on March 29, 2019), a B20 candidate fuel containing 1000 ppmv of the California Fueling, LLC VESTA™ 5100 additive (Executive Order G-714-ADF07 issued on June 1, 2018), and a B20 candidate fuel containing 3000 ppmv of the California Fueling, LLC VESTA™ 1000 additive (Executive Order G-714-ADF01 issued July 20, 2017), based on a full CARB emissions equivalent certification testing protocol. Efficacy testing was performed on a B20 candidate fuel containing 2200 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive, and a B10 candidate fuel containing 3000 ppmv of the active ingredient in the California Fueling, LLC VESTA™ additive. For reference, testing was also performed on an unadditized B20 candidate fuel. All of the candidate fuels were blended from the same B100 (Biodiesel Additive Certification Fuel) and same CARB reference fuel (Reference CARB Diesel) and tested back-to-back against that same CARB reference fuel. This study was conducted in CE-CERT's heavy-duty engine dynamometer laboratory with a 1991 DDC Series 60 engine.

A summary of the results is as follows:

- NO_x emissions results for the confirmatory and efficacy testing showed increases relative to the CARB reference fuel of 3.90%, 3.80%, 2.41%, 1.94%, 2.25% and 0.66%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. The results showed that the VESTA™ additive did provide some emissions benefits relative to the unadditized B20, while the Best additive candidate fuel had NOx emissions similar to those for the unadditized B20.
- Statistical analysis of the NOx emission test results indicated that all of the candidate fuels did not pass the certification test criteria for NOx for the test sequences run in this program It should be noted that while B10 is not currently included in the emissions equivalency testing provisions of the ADF regulation, and the B10 candidate fuel with the highest additive treat rate did not pass the statistical test, the percentage difference between the B10 candidate fuel and the CARB reference fuel was 0.66 based on a single day of testing.[6]
- PM emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 27.3%, 28.3%, 29.6%, 29.9%, 30.6%, and 18.7%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA™ 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA™ additive, the B20 candidate fuel with 3000 ppmv of the VESTA™ 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA™ additive for the test sequence associated with each of the candidate fuels. Statistical analysis of the PM emission test results indicated

[6] For NOx, the certification criteria provides for a tolerance level of 1% that is reduced by a pooled standard deviation term that increases with the variability in the data and decreases with the number of tests performed.

that all the candidate fuels passed the certification test criteria for PM. The PM reductions for the additized blends are similar to those found for the unadditized B20 blend.

- THC emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 7.6%, 8.0%, 14.3%, 16.1%, 17.0% and 13.0%, respectively, THC emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 7.6%, 8.0%, 14.3%, 16.1%, 17.0% and 13.0%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA^{TM} 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA^{TM} additive, the B20 candidate fuel with 3000 ppmv of the VESTA^{TM} 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA^{TM} additive for the test sequence associated with each of the candidate fuels. The THC reductions for the additized blends were comparable to or less than those found for the unadditized B20 blend.
- CO emissions results showed consistent trends of reductions over all the B20 additive fuel blends relative to the CARB reference fuel. CO emissions results for the confirmatory and efficacy testing showed decreases relative to the CARB reference fuel of 12.1%, 12.7%, 17.0%, 18.0%, 21.1% and 13.8%, respectively, for the B20 unadditized fuel, the B20 Best candidate fuel, the B20 candidate fuel with 1000 ppmv of the VESTA^{TM} 5100 additive, the B20 candidate fuel with 2200 ppmv of the active ingredient in the VESTA^{TM} additive, the B20 candidate fuel with 3000 ppmv of the VESTA^{TM} 1000 additive, and the B10 candidate fuel with 3000 ppmv of the active ingredient in the VESTA^{TM} additive for the test sequence associated with each of the candidate fuels. The CO reductions for the additized blends were comparable to or greater than those found for the unadditized B20 blend.
- CO_2 emissions results for the candidate fuels were generally slightly higher than those for the corresponding CARB reference fuel tests, but these differences were within 1% for all test comparisons. It's worth noting that exhaust CO_2 is a minor contributor to lifecycle biofuel CO_2 emissions; biodiesel generally provides CO_2 emissions reductions on a lifecycle basis compared to conventional diesel, primarily dependent on feedstock composition.
- The brake specific fuel consumption values for the candidate fuels were generally slightly higher than those for the corresponding CARB reference fuel tests, with these differences being between 1.5 to 2.4% for all test comparisons. The greater fuel consumption for the biodiesel fuels can be attributed to the lower energy content of the biodiesel compared to the CARB reference fuel on a volumetric basis.

Appendix A: CARB Reference Fuel Certificate of Analysis

haltermannsolutions

Telephone: (800) 969-2542

Certificate of Analysis

FAX: (281) 457-1469

PRODUCT: CARB REFERENCE DIESEL
Title 13, CCR 2281-2285

PRODUCT CODE: HF0128

Batch No.: HD2521GP01

Tank No.: TK96

Date: 5/7/2019

TEST	METHOD	UNITS	SPECIFICATIONS			RESULTS
			MIN	TARGET	MAX	
Distillation - IBP	ASTM D86[2]	°F	340		420	375
5%		°F				413
10%		°F	400		490	431
20%		°F				457
30%		°F				474
40%		°F				488
50%		°F	470		560	500
60%		°F				513
70%		°F				528
80%		°F				545
90%		°F	550		610	569
95%		°F				588
Distillation - EP		°F	580		660	614
Recovery		vol %		Report		98.2
Residue		vol %		Report		1.0
Loss		vol %		Report		0.8
Gravity	ASTM D4052[2]	°API	33		39	37.9
Specific Gravity 60/60 °	ASTM D4052[2]		0.830		0.860	0.836
Cloud Point	ASTM D2500[2]	°F		Report		-13
Flash Point	ASTM D93[2]	°F	130			176
Viscosity, 40°C	ASTM D445[2]	cSt	2.0		4.1	2.8
Sulfur	ASTM D5453[2]	ppm wt			15	1
Nitrogen	ASTM D4629[2]	ppm			10	None Detected
Total Aromatic	ASTM D5186[2]	vol %			10	6.4
Polycyclic Aromatics	ASTM D5186[2]	wt %			1.4	None Detected
Cetane Number	ASTM D613[2]		48.0			51.5
High Frequency Recip. Rig @25C	ASTM D6079[2]	microns			520	330

Quality Assurance Technician

[1] Haltermann Solutions is accredited to ISO/IEC 17025 by ANAB for the tests referred to with this footnote.
[2] Tested by ISO/IEC 17025 accredited subcontractor.

Appendix B: Blending Procedures for Candidate Fuels

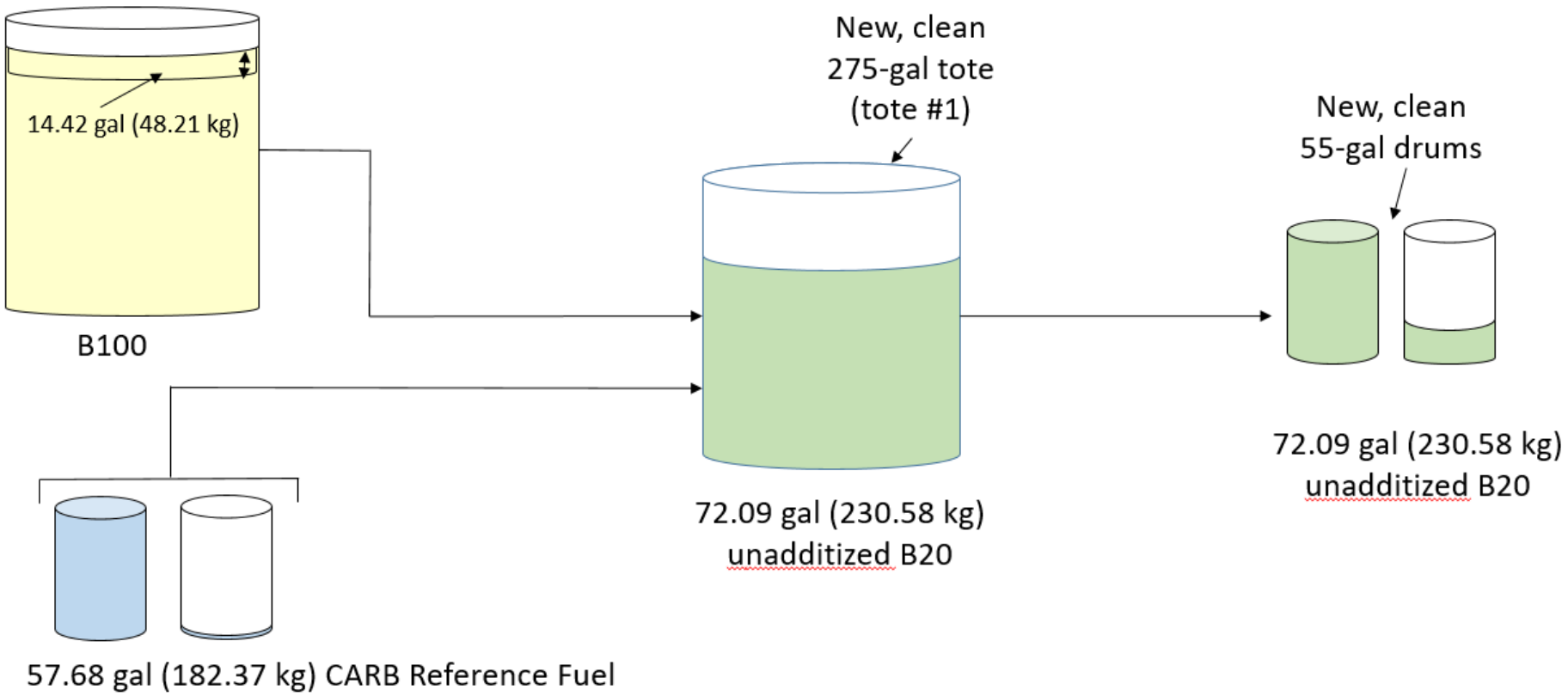
Blending Procedure for Unadditized B20

CE-CERT staff, under the observation of CARB staff, blended a total of 72.10 gallons (230.58 kilograms) of unadditized B20. The blending was completed in a series of ten main steps and employed a layered blending procedure (i.e., alternating addition of CARB reference fuel and B100). Fuels were measured gravimetrically in increments of five gallons or less using dedicated fuel containers for each fuel type. The blended B20 was stirred and then pumped from the blending tote to clean 55-gallon drums where a fuel sample was collected. A list of the main steps and a schematic diagram of the blending are provided below.

Main Blending Steps for Unadditized B20:

1. Added 27.58 gal (87.22 kg) CARB reference fuel, followed by 6.88 gal (23.02 kg) B100, to new, clean fuel tote (tote #1);
2. Added 25.59 gal (80.92 kg) CARB reference fuel, followed by 5.89 gal (19.68 kg) B100, to fuel tote #1;
3. Added 1.02 gal (3.42 kg) B100, followed by 5.17 gal (16.36 kg) CARB reference fuel, to fuel tote #1;
4. Mixed unadditized biodiesel blend thoroughly for 30 minutes with stirring device;
5. Pumped the unadditized blended fuel from fuel tote #1 to two new, clean 55-gal drums;
6. Pumped 71.31 gal (227.96 kg) of the blended fuel from two 55-gal drums to fuel tote #2;
7. Added 0.79 gal (2.62 kg) B100 to produce final B20 blend.
8. Mixed unadditized B20 for one hour with stirring device;
9. Pumped the unadditized B20 from fuel tote #2 to two new, clean 55-gal drums;
10. Collected five-liter fuel sample of unadditized B20 for fuel analysis.

Blending Schematic for Unadditized B20:



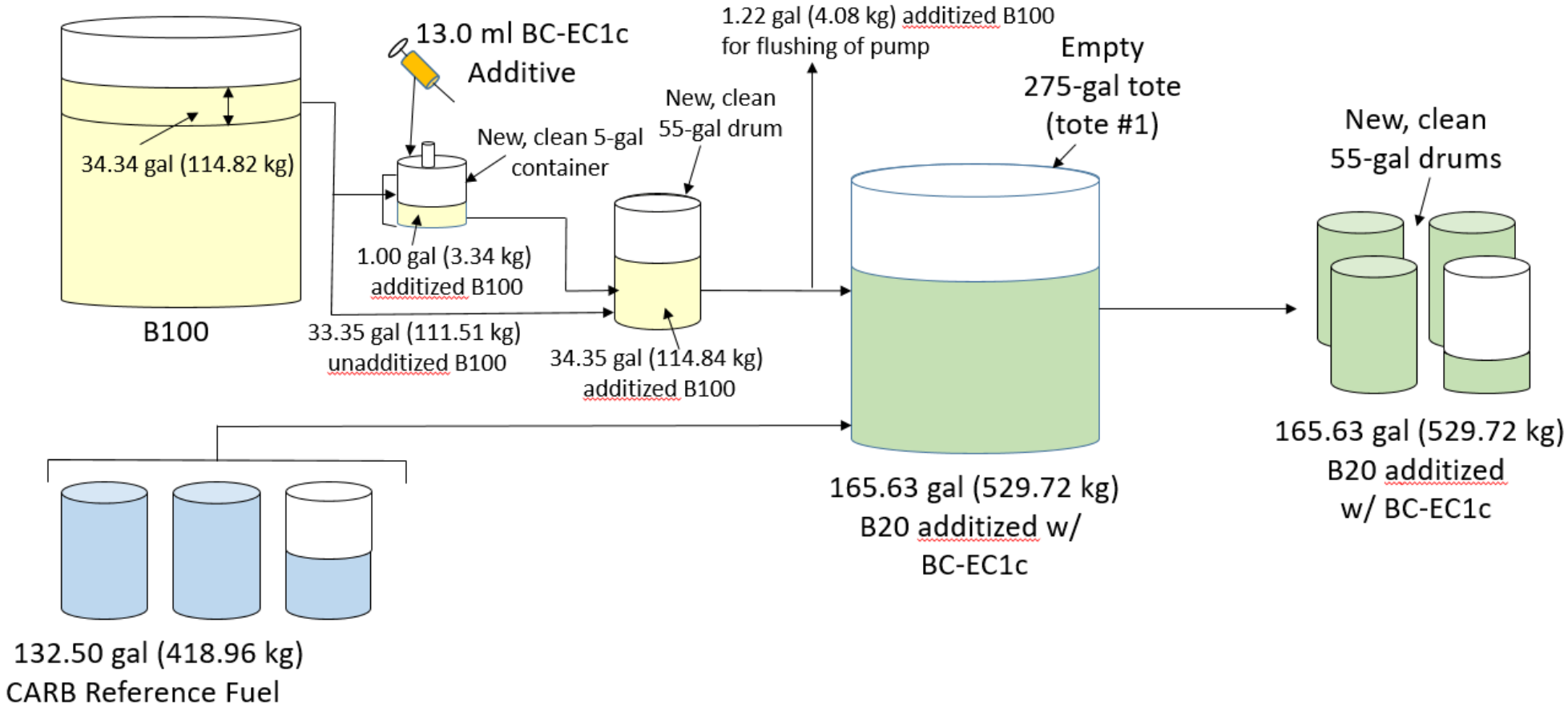
Blending Procedure for B20 with 20 ppm Best Corp BC-EC1c

CE-CERT staff, under the observation of CARB staff, blended a total of 165.63 gallons (529.72 kg) of B20 additized with 20 parts per million (ppm) Best Corp BC-EC1c. The blending was completed in a series of 12 main steps. First, the B100 was first additized with 100 ppm BC-EC1c additive. The additized B100 was then blended with the CARB reference fuel to produce B20 with 20 ppm BC-EC1c using a layered blending procedure. Fuels were measured gravimetrically in increments of five gallons or less using dedicated fuel containers for each fuel type. The additized B20 was then stirred and pumped from the blending tote to clean 55-gallon drums where a fuel sample was collected. A list of the main steps and a schematic diagram of the blending are provided below.

Main Blending Steps for B20 Additized with 20 ppm BC-EC1c:

1. Added 13.0 mL of Best Corp BC-EC1c, followed by 0.99 gal (3.32 kg) B100 to new, clean five-gal container;
2. Agitated additized B100 in five-gal container for 10 minutes;
3. Collected two-milliliter sample of additized B100 from five-gal container;
4. Transferred additized B100 (0.99 gal + 13.0 ml (3.33 kg)) from five-gallon container to new, clean 55-gal drum; add 33.35 gal (111.52 kg) B100 to 55-gal drum;
5. Mixed B100 with 100 ppm BC-EC1c in drum on drum roller for 30 minutes;
6. Added 49.99 gal (158.08 kg) CARB reference fuel, followed by 12.48 gal (41.74 kg) additized biodiesel (B100 with 100 ppm BC-EC1c), to fuel tote #1;
7. Added 50.00 gal (158.10 kg) CARB reference fuel, followed by 12.51 gal (41.82 kg) additized biodiesel (B100 with 100 ppm BC-EC1c), to fuel tote #1;
8. Added 19.99 gal (63.22 kg) CARB reference fuel, followed by 8.13 gal (27.20 kg) additized biodiesel (B100 with 100 ppm BC-EC1c) to fuel tote #1;
9. Added 12.51 gal (39.56 kg) CARB reference fuel to fuel tote #1 to produce final B20 blend additized with 20 ppm BC-EC1c;
10. Mixed B20 with 20 ppm BC-EC1c for one hour with stirring device;
11. Pumped the B20 with 20 ppm BC-EC1c from fuel tote #1 to four new, clean 55-gal drums;
12. Collected five-liter fuel sample of B20 with 20 ppm BC-EC1c for fuel analysis.

Blending Schematic for B20 with 20 ppm Best Corp BC-EC1c:



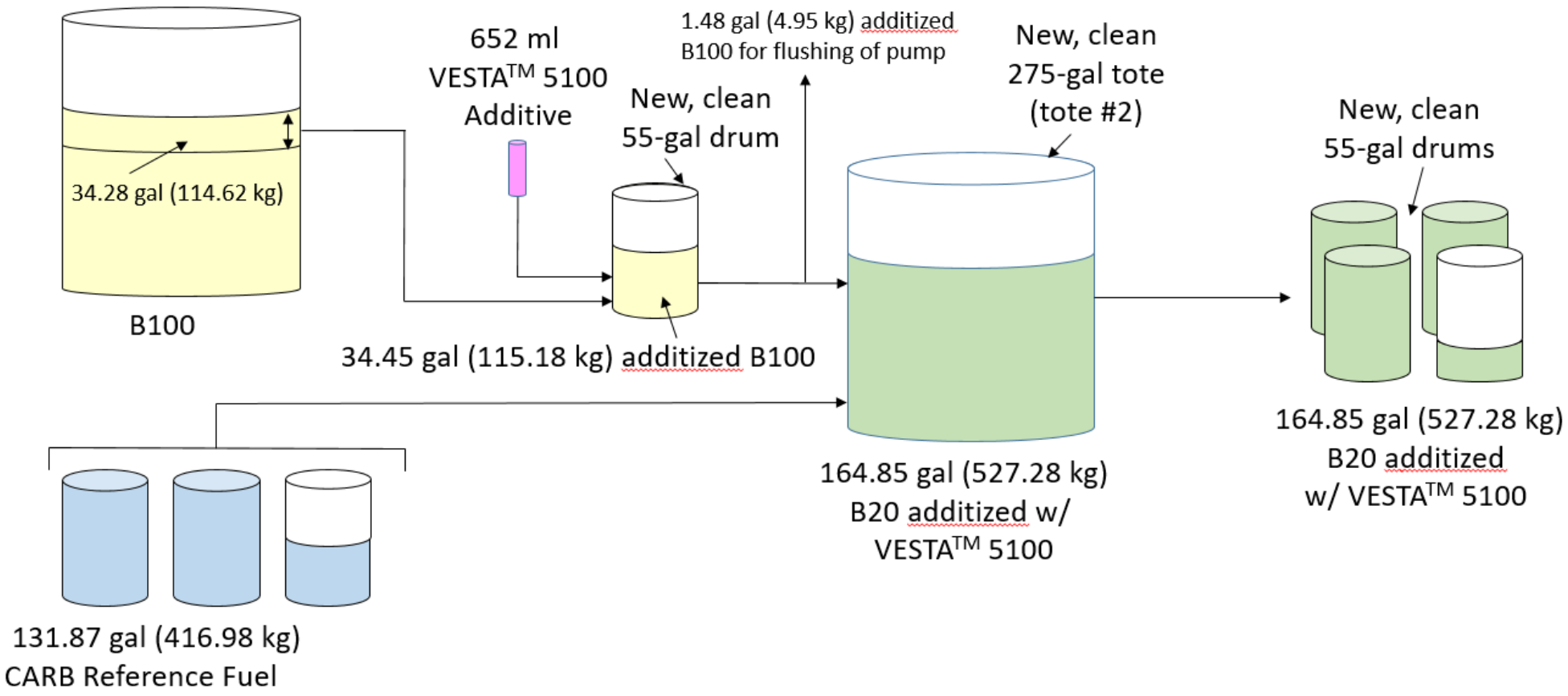
Blending Procedure for B20 with 1,000 ppm California Fueling VESTA™ 5100

CE-CERT staff, under the observation of CARB staff, blended a total of 164.85 gallons (527.28 kg) of B20 additized with 1,000 ppm California Fueling VESTA™ 5100. The blending was completed in ten main steps. First, the B100 was additized with 5,000 ppm VESTA™ 5100. The additized B100 was then blended with the CARB reference fuel to produce the additized B20 with 1,000 ppm VESTA™ 5100 using a layered blending procedure. Fuels were measured gravimetrically in increments of five gallons or less using dedicated fuel containers for each fuel type. The additized B20 was then stirred and pumped from the blending tote to clean 55-gallon drums where a fuel sample was collected. A list of the main steps and a schematic diagram of the blending are provided below.

Main Blending Steps for B20 Additized with 1000 ppm VESTA™ 5100:

1. Added 652 mL of VESTA™ 5100, followed by 34.28 gal (114.62 kg) B100, to clean 55-gal drum;
2. Mixed B100 with 5,000 ppm VESTA™ 5100 in drum on drum roller for 30 minutes;
3. Collected two-milliliter sample of B100 with 5,000 ppm VESTA™ 5100;
4. Added 50.00 gal (158.10 kg) CARB reference fuel, followed by 12.50 gal (41.82 kg) additized biodiesel (B100 with 5,000 ppm VESTA™ 5100), to new, clean fuel tote (fuel tote #2);
5. Added 50.00 gal (158.10 kg) CARB reference fuel, followed by 12.50 gal (41.82 kg) additized biodiesel (B100 with 5,000 ppm VESTA™ 5100), to fuel tote #2;
6. Added 19.96 gal (63.12 kg) CARB reference fuel, followed by 7.97 gal (26.66 kg) additized biodiesel (B100 with 5,000 ppm VESTA™ 5100) to fuel tote #2;
7. Added 11.91 gal (37.66 kg) CARB reference fuel to fuel tote #2 to produce final B20 blend additized with 1,000 ppm VESTA™ 5100;
8. Mixed B20 with 1,000 ppm VESTA™ 5100 for one hour with stirring device;
9. Pumped the B20 with 1,000 ppm VESTA™ 5100 from fuel tote #2 to four new, clean 55-gal drums;
10. Collected five-liter fuel sample of B20 with 1,000 ppm VESTA™ 5100 for fuel analysis.

Blending Schematic for B20 with 1,000 ppm California Fueling VESTA™ 5100



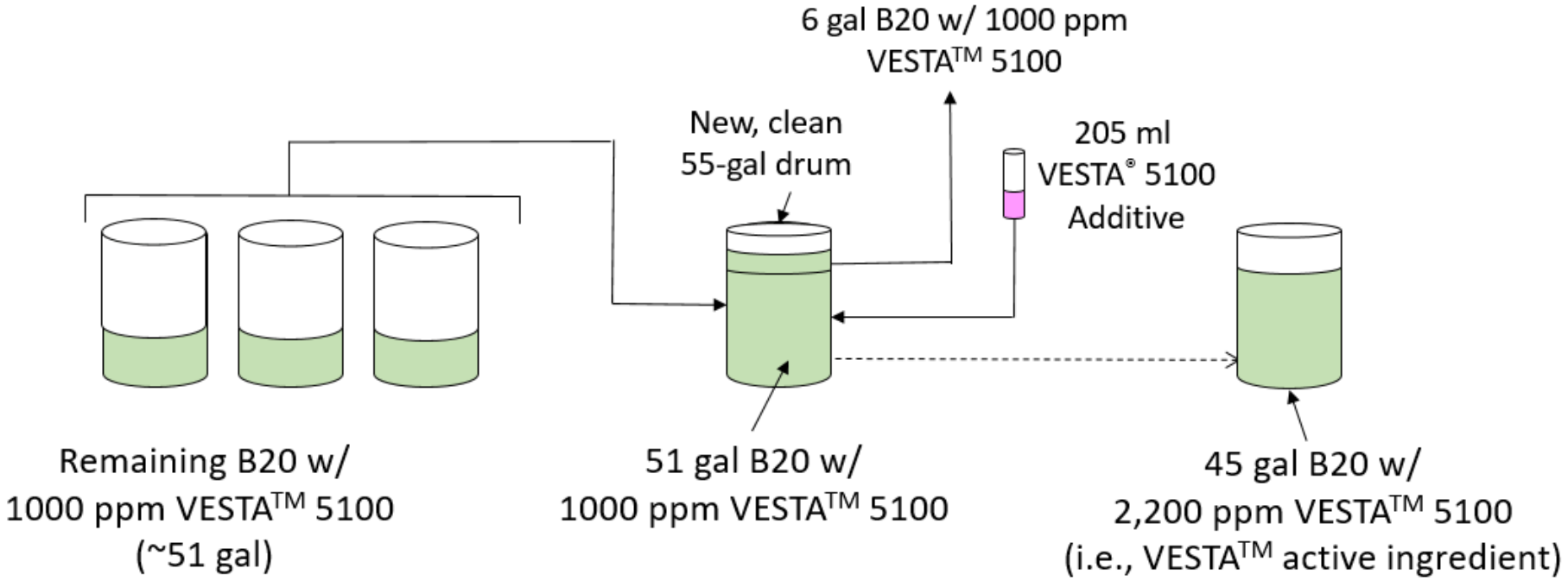
Blending Procedure for B20 with 2,200 ppm California Fueling VESTA™ Active Ingredient

CE-CERT staff, in coordination with CARB staff, blended approximately 45 gallons of B20 additized with approximately 2,200 ppm California Fueling VESTA™ 5100 (i.e., VESTA™ active ingredient). The blending was completed in six main steps. First, the remaining B20 with 1,000 ppm VESTA™ 5100 was consolidated into a single 55-gallon drum and the approximate volume was measured. Approximately six gallons of B20 with 1,000 ppm VESTA™ 5100 was pumped out of the drum, and additional VESTA™ 5100 was added to the drum to increase the concentration of additive to approximately 2,200 ppm VESTA™ 5100. The B20 with 2,200 ppm VESTA™ 5100 was then mixed on a drum roller and a fuel sample was collected. A list of the main steps and a schematic diagram of the blending are provided below.

Main Blending Steps for B20 Additized with 2,200 ppm VESTA™ active ingredient:

1. Consolidated remaining B20 with 1,000 ppm VESTA™ 5100 into a single 55-gallon drum;
2. Measured volume of consolidated B20 with 1,000 ppm VESTA™ 5100 using a drum measuring stick (approximately 51 gallons);
3. Pumped approximately six gallons of B20 with 1,000 ppm VESTA™ 5100 out of drum and confirmed remaining volume using drum measuring stick.
4. Added 205 milliliters of VESTA™ 5100 (i.e., VESTA™ active ingredient) to drum containing approximately 45 gallons B20 with 1,000 ppm VESTA™ 5100;
5. Mixed B20 with 2,200 ppm VESTA™ active ingredient in drum on drum roller for 30 minutes;
6. Collected five-liter fuel sample of B20 with 2,200 ppm VESTA™ active ingredient for fuel analysis.

Blending Schematic for B20 with 2,200 ppm California Fueling VESTA™ 5100 Active Ingredient



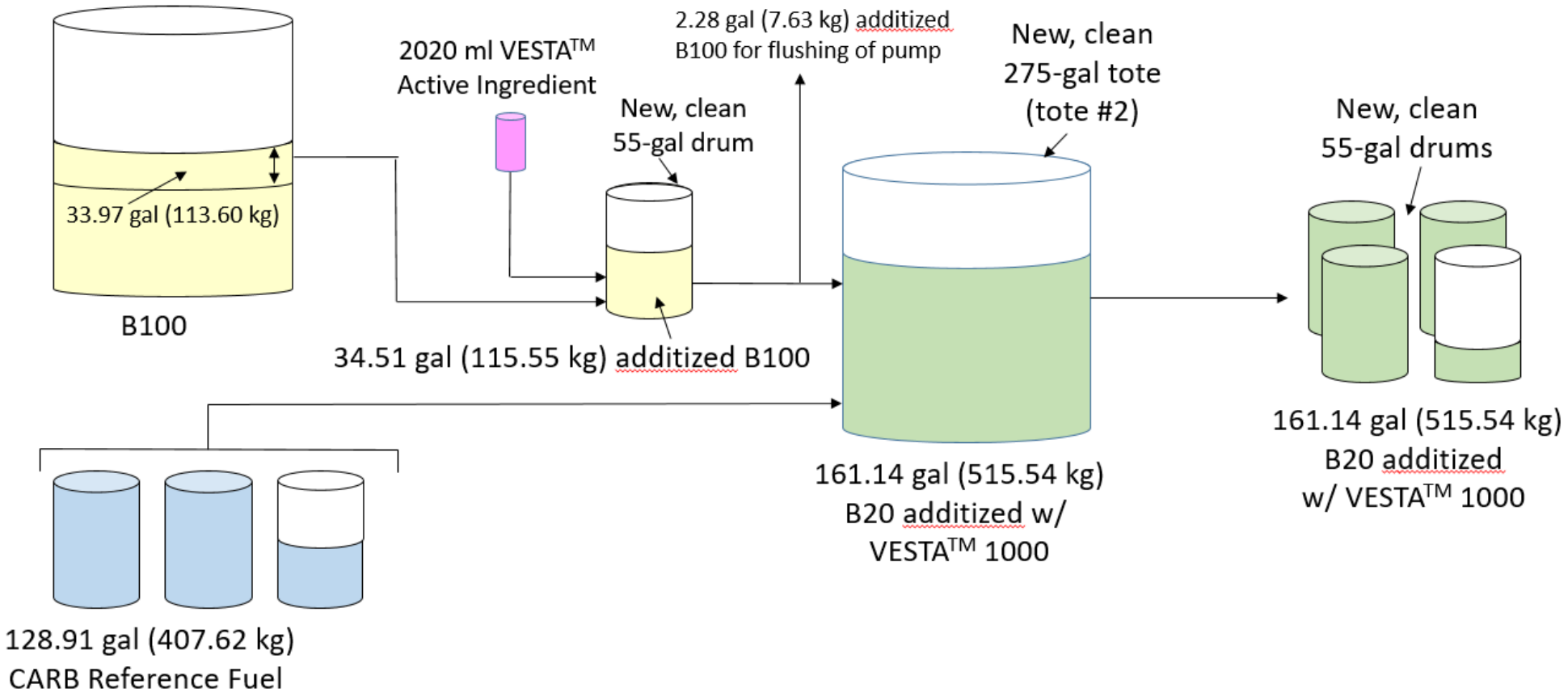
Blending Procedure for B20 with 3,000 ppm California Fueling VESTA™ 1000

CE-CERT staff, under the observation of CARB staff, blended a total of 161.14 gallons (515.54 kg) of B20 additized with 3,000 ppm California Fueling VESTA™ 1000. The blending was completed in ten main steps. First, the B100 was additized with 15,000 ppm of the VESTA™ active ingredient. The additized B100 was then blended with the CARB reference fuel to produce the additized B20 with 3,000 ppm VESTA™ active ingredient using a layered blending procedure. Fuels were measured gravimetrically in increments of five gallons or less using dedicated fuel containers for each fuel type. The additized B20 was then stirred and pumped from the blending tote to clean 55-gallon drums where a fuel sample was collected. A list of the main steps and a schematic diagram of the blending are provided below.

Main Blending Steps for B20 Additized with 3,000 ppm VESTA™ 1000:

1. Added 2020 mL of VESTA™ active ingredient, followed by 33.97 gal (113.60 kg) B100, to clean 55-gal drum;
2. Mixed B100 with 15,000 ppm VESTA™ active ingredient in drum on drum roller for 30 minutes;
3. Collected two-milliliter sample of B100 with 15,000 ppm VESTA™ active ingredient;
4. Added 50.00 gal (158.10 kg) CARB reference fuel, followed by 12.50 gal (41.86 kg) additized biodiesel (B100 with 15,000 ppm VESTA™ active ingredient), to empty fuel tote (fuel tote #2);
5. Added 50.01 gal (158.10 kg) CARB reference fuel, followed by 12.50 gal (41.86 kg) additized biodiesel (B100 with 15,000 ppm VESTA™ active ingredient), to fuel tote #2;
6. Added 25.01 gal (79.08 kg) CARB reference fuel, followed by 7.23 gal (24.20 kg) additized biodiesel (B100 with 15,000 ppm VESTA™ active ingredient) to fuel tote #2;
7. Added 3.90 gal (12.33 kg) CARB reference fuel to fuel tote #2 to produce final B20 blend additized with 3,000 ppm VESTA™ active ingredient (i.e., VESTA™ 1000);
8. Mixed B20 with 3,000 ppm VESTA™ 1000 for one hour with stirring device;
9. Pumped the B20 with 3,000 ppm VESTA™ 1000 from fuel tote #2 to four new, clean 55-gal drums;
10. Collected five-liter fuel sample of B20 with 3,000 ppm VESTA™ 1000 for fuel analysis.

Blending Schematic for B20 with 3,000 ppm California Fueling VESTA™ 1000



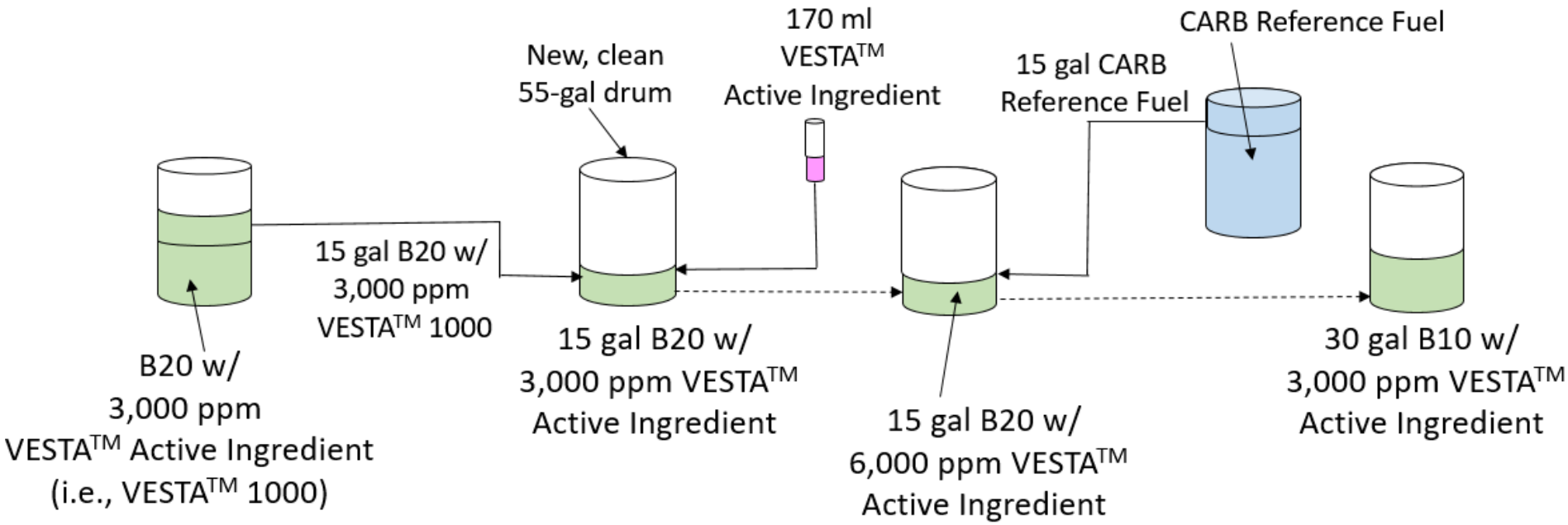
Blending Procedure for B10 with 3,000 ppm California Fueling VESTA™ Active Ingredient

CE-CERT staff, in coordination with CARB staff, blended approximately 30 gallons of B10 additized with approximately 3,000 ppm California Fueling VESTA™ 5100 active ingredient. The blending was completed in six main steps. First, 15 gallons of B20 with 3,000 ppm of the VESTA™ active ingredient was pumped to a clean 55-gallon drum. Additional VESTA™ active ingredient was then added to increase the concentration of additive to approximately 6,000 ppm. This blend was then diluted to B10 with approximately 3,000 ppm VESTA™ active ingredient by adding approximately 15 gallons of CARB reference fuel. The additized B10 with 3,000 ppm VESTA™ active ingredient was then mixed on a drum roller and a fuel sample was collected. A list of the main steps and a schematic diagram of the blending are provided below.

Main Blending Steps for B10 Additized with 3,000 ppm VESTA™ Active Ingredient:

1. Pumped approximately 15 gallons of B20 with 3,000 ppm VESTA™ 1000 (i.e., VESTA™ active ingredient) into a clean 55-gallon drum; volume confirmed with a drum measuring stick;
2. Added 170 milliliters of VESTA™ active ingredient to the drum containing 15 gallons of B20 with 3,000 ppm VESTA™ active ingredient;
3. Added 10 gallons of CARB reference fuel to the drum containing B20 with approximately 6,000 ppm VESTA™ active ingredient; volume confirmed with drum measuring stick;
4. Added five gallons of CARB reference fuel, in one gallon increments, to the drum containing the biodiesel blend with VESTA™ active ingredient to produce approximately 30 gallons of B10 with approximately 3,000 ppm VESTA™ active ingredient; volume confirmed with drum measuring stick;
5. Mixed drum containing B10 with approximately 3,000 ppm VESTA™ active ingredient for 30 minutes on drum roller.
6. Collected five-liter fuel sample of B10 with 3,000 ppm VESTA™ active ingredient for fuel analysis.

Blending Schematic for B10 with 3,000 ppm California Fueling VESTA™ Active Ingredient



Appendix C: Southwest Research Institute Fuel Analysis Results
CARB Reference Fuel and B100

	Project Name		ODDB	ODDB
	Lab Number		48206	48381
Method	Sample Code		FS19003	FS19004
			B100	Diesel
D1160	IBP	Deg C	325	
	05% AET	Deg C	344	
	10% AET	Deg C	345	
	20% AET	Deg C	347	
	30% AET	Deg C	348	
	40% AET	Deg C	348	
	50% AET	Deg C	349	
	60% AET	Deg C	350	
	70% AET	Deg C	350	
	80% AET	Deg C	351	
	90% AET	Deg C	352	
	95% AET	Deg C	353	
	FBP	Deg C	356	
	Pressure	mm Hg	10	
D287	API_60F	degAPI	28.6	37.8
	Specific Gravity	.	0.8838	0.8358
	Density	g/ml	0.8833	0.8353
D445 40c	Viscosity	cSt	4.14	2.76
D4629	Nitrogen	ppm	4.5	<1.0
D5186	Total Aromatics	Mass%		5.6
	MonoAromatics	Mass%		5.4
	PolyAromatics	Mass%		0.2
D5453	Sulfur	ppm	2.86	<0.5
D613	Cetane Number		48.4	53.3
	Cetane Number		48.9	53.2
	Cetane Number		47.2	51.9
D86	PCorrIBP	degF		369.5
	PCorrD05	degF		417.7
	PCorrD10	degF		434.1
	PCorrD15	degF		447.6
	PCorrD20	degF		459.2
	PCorrD30	degF		476.8
	PCorrD40	degF		489.7
	PCorrD50	degF		502.5
	PCorrD60	degF		515.0
	PCorrD70	degF		530.4
	PCorrD80	degF		548.9
	PCorrD90	degF		574.2
	PCorrD95	degF		596.0
	PCorrFBP	degF		611.9
	Recoverd	mL		97.8
	Residue	mL		1.3
	Loss	mL		0.9
D93	Flash Point	degF	340	177
		degC	171	81
EN14078	FAME Content	volume %	99.8	

Fuel Analysis Results Biodiesel Blends

	Project Name		ODDB	ODDB	ODDB
	Lab Number		49419	49420	49421
Method	Sample Code		FS19005	FS19006	FS19007
			Vesta_B20_1000 ppm	Best_B20_20 ppm	Unadditized_B20
D287	API_60F	degAPI	36	36	36
	Specific Gravity	.	0.8448	0.8448	0.8448
	Density	g/ml	0.8442	0.8442	0.8442
D445 40c	Viscosity	cSt	2.946	2.941	2.934
D4629	Nitrogen	ppm	92.7	1.1	<1.0
D5291	Carbon	wt%			83.90
	Hydrogen	wt%			13.46
D5453	Sulfur	ppm	1.20	0.80	0.96
D613	Cetane Number		55.0	48.9	50.5
	Cetane Number		55.3	49.4	50.3
	Cetane Number		54.5	49.6	50.3
D86	PCorrIBP	degF	370.9	380.2	390.6
	PCorrD05	degF	425.0	428.9	431.9
	PCorrD10	degF	443.0	446.7	450.1
	PCorrD15	degF	460.9	461.7	464.2
	PCorrD20	degF	473.6	473.5	475.3
	PCorrD30	degF	493.2	493.9	495.2
	PCorrD40	degF	510.5	511.4	512.3
	PCorrD50	degF	528.8	529.0	530.2
	PCorrD60	degF	549.0	549.4	550.7
	PCorrD70	degF	572.4	572.0	573.7
	PCorrD80	degF	596.5	596.3	597.7
	PCorrD90	degF	620.6	619.4	620.3
	PCorrD95	degF	635.8	632.1	634.8
	PCorrFBP	degF	640.7	641.7	645.8
	Recoverd	mL	97.7	98.3	98.5
	Residue	mL	1.4	1.3	0.6
	Loss	mL	0.9	0.4	0.9
D93	Flash Point	degF	183	184	185
		degC	84	85	85
EN14078	FAME Content	volume %	20.2	20.4	20.4

Fuel Analysis Results Biodiesel Blends Continued

	Project Name		ODDB	ODDB	ODDB
	Lab Number		50688	50689	50690
Method	Sample Code		FS19008	FS19009	FS19010
			Vesta_B20_2200 ppm	Vesta_B10_3000 ppm	Vesta_B20_3000 ppm
D287	API_60F	degAPI	36.0	36.9	36.0
	Specific Gravity	.	0.8448	0.8403	0.8448
	Density	g/ml	0.8442	0.8397	0.8442
D445 40c	Viscosity	cSt	2.952	2.850	2.931
D4629	Nitrogen	ppm	206.8	287.7	287.1
D5453	Sulfur	ppm	1.60	0.84	1.70
D613	Cetane Number		61.7	61.2	62.2
	Cetane Number		62.7	60.9	63.1
	Cetane Number		62.8	61.1	62.9
D86	PCorrIBP	degF	380.1	376.9	376.0
	PCorrD05	degF	426.7	417.5	426.0
	PCorrD10	degF	443.7	438.4	443.8
	PCorrD15	degF	460.4	451.6	458.9
	PCorrD20	degF	472.3	464.2	471.7
	PCorrD30	degF	490.8	482.0	491.5
	PCorrD40	degF	509.6	497.1	509.3
	PCorrD50	degF	527.7	511.7	527.4
	PCorrD60	degF	547.8	528.6	547.8
	PCorrD70	degF	570.3	547.6	570.8
	PCorrD80	degF	593.8	570.0	595.0
	PCorrD90	degF	618.7	598.6	619.7
	PCorrD95	degF	632.3	618.6	635.7
	PCorrFBP	degF	641.2	630.2	640.5
	Recoverd	mL	98.4	98.2	97.7
	Residue	mL	1.1	1.2	1.3
	Loss	mL	0.5	0.6	1.0
D93	Flash Point	degF	181	179	183
		degC	83	82	84
EN14078	FAME Content	volume %	19.5	9.6	19.4

Appendix D: Laboratory Resources

CE-CERT Mobile Emissions Laboratory

Controlling emissions from heavy-duty diesel engines is a major priority for the regulatory community and industry. To assist with this effort, CE-CERT has worked with regulatory agencies, engine manufacturers, exhaust aftertreatment companies, fuel companies, and vehicle end users over the past year and a half to understand the scope of the diesel exhaust issue and articulate a research program designed to improve our understanding of the problem and potential solutions. CE-CERT also has developed new research capabilities, including a unique emissions measurement laboratory and an enhanced environmental modeling group. Together, these resources can shed important light on critical emissions issues and contribute to efficient, effective environmental strategies and to greater industry/government/academic cooperation. This program plan describes the technical vision and contemplated approach for achieving these objectives.

CE-CERT has constructed an emissions laboratory contained within a 53-foot truck trailer, designed to make laboratory-quality emissions measurements of heavy-duty trucks under actual operating conditions (Figure D-1).

The laboratory contains a dilution tunnel, analyzers for gaseous emissions, and ports for particulate measurements. Although much of the system is custom-designed, the laboratory was designed to conform as closely as possible to Code of Federal Regulations requirements for gaseous and particulate emissions measurement. The laboratory is designed to operate as a class 8 tractor is pulling it over the road (or on a closed track over a repeatable cycle); it is not a roadside testing laboratory. It also is used to measure emissions from heavy-duty stationary engines, such as pipeline pumps and backup generators, as they operate under actual loads.

With laboratory development and validation nearly complete, CE-CERT intends to embark on a research program to explore the following topics:

- “Real world” emissions of gaseous and particulate pollutants from on-road heavy-duty engines.
- The effects of alternative diesel fuel formulations, alternative fuels, alternative powertrains, and emission control technologies on emissions and energy consumption.
- The effects of driving cycles on emissions.
- Modal emissions modeling for heavy-duty trucks.

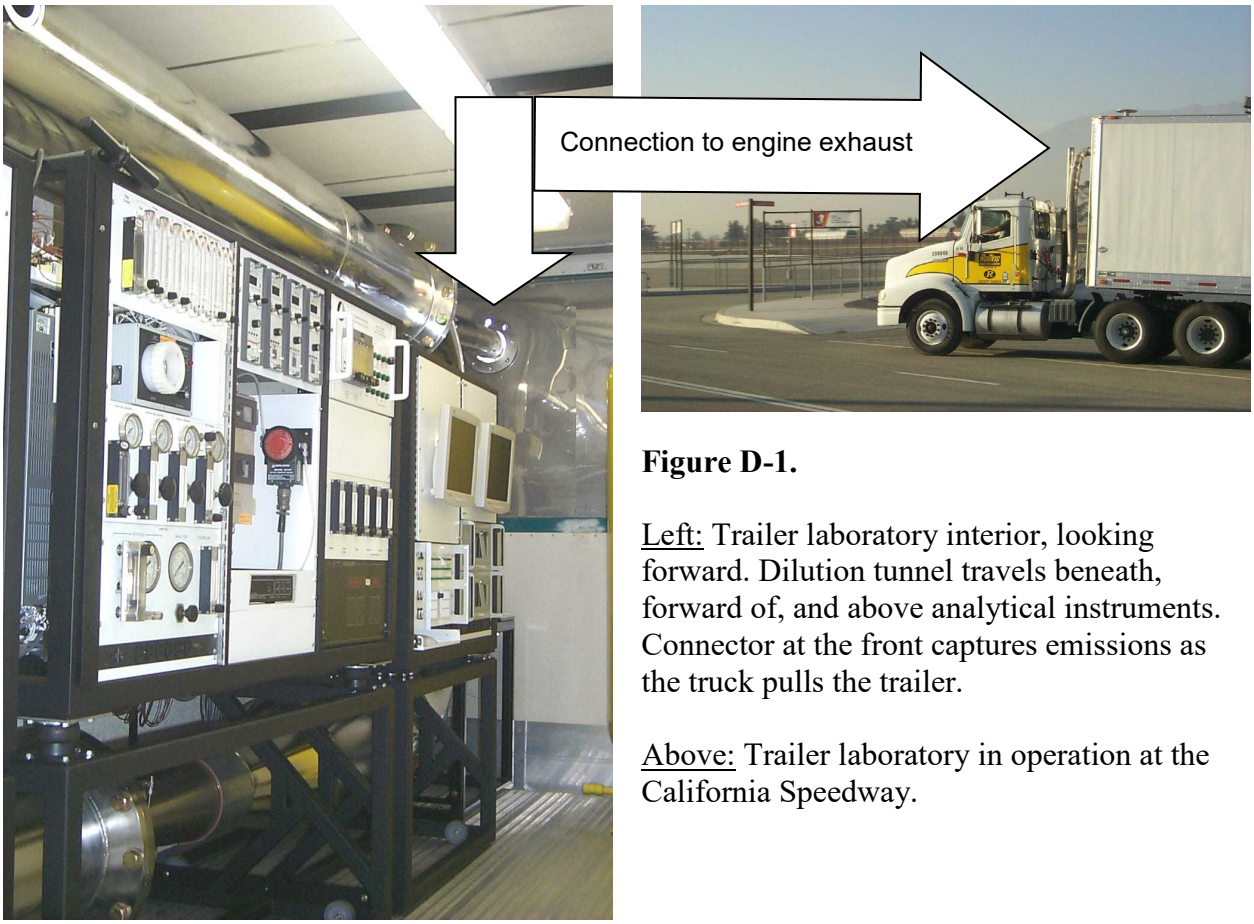


Figure D-1.

Left: Trailer laboratory interior, looking forward. Dilution tunnel travels beneath, forward of, and above analytical instruments. Connector at the front captures emissions as the truck pulls the trailer.

Above: Trailer laboratory in operation at the California Speedway.

CE-CERT Heavy-Duty Engine Dynamometer Test Facility

CE-CERT's Heavy-Duty Engine Dynamometer Test Facility is designed for a variety of applications including verification of diesel aftertreatment devices, certification of alternative diesel fuels, and fundamental research in diesel emissions and advanced diesel technologies. The engine dynamometer facility components were provided as a turnkey system by Dyne Systems of Wisconsin. CE-CERT's Mobile Emissions Laboratory (MEL) is used directly in conjunction with this facility for certification type emissions measurements.

The test cell is equipped with a 600 horsepower (hp) GE DC electric engine dynamometer that was obtained from the EPA's National Vehicle and Fuels Emission Laboratory in Ann Arbor, MI. The dynamometer is capable of testing approximately 85% of the engines used in on-road applications, and is primarily be used for engines in the 300 to 600 hp range. A charge air conditioning system was obtained from Dyno Air of North Carolina to provide temperature/ humidity control for the engine intake air, with an accuracy of ±2°C from the setpoint.

Figure D-2. Picture of CE-CERT's Heavy-Duty Engine Dynamometer Facility

Appendix E: QA/QC Procedures

Internal calibration and verification procedures are performed in MEL regularly in accordance with the CFR. A partial summary of routine calibrations performed by the MEL staff as part of the data quality assurance/quality control program is listed in Table E-1.

The soluble organic fraction (SOF) of the PM was also determined for each test. The extraction for the SOF test was performed on the sample Teflon filter used for the PM mass measurements. These filters were stored in a freezer subsequent to the final gravimetric mass measurements and prior to shipment for analysis. The SOF analyses was performed by the Desert Research Institute (DRI) of Reno, NV using standard procedures. A total of 45 SOF samples was collected for the analysis, including 40 samples from emissions tests and 5 background/blank samples over the course of the testing.

Table E-1. Sample of Verification and Calibration Quality Control Activities

EQUIPMENT	FREQUENCY	VERIFICATION PERFORMED	CALIBRATION PERFORMED
CVS	Daily	Differential Pressure	Electronic Cal
	Daily	Absolute Pressure	Electronic Cal
	Weekly	Propane Injection	
	Monthly	CO_2 Injection	
	Per Set-up	CVS Leak Check	
	Second by second	Back pressure tolerance ±5 inH_20	
Cal system MFCs	Annual	Primary Standard	MFCs: Drycal Bios Meter
	Monthly	Audit bottle check	
Analyzers	Pre/Post Test		Zero Span
	Daily	Zero span drifts	
	Monthly	Linearity Check	
Secondary System Integrity and MFCs	Semi-Annual	Propane Injection: 6 point primary vs secondary check	
	Semi-Annual		MFCs: Drycal Bios Meter & TSI Mass Meter
Data Validation	Variable	Integrated Modal Mass vs Bag Mass	
	Per test	Visual review	
PM Sample Media	Weekly	Tunnel Banks	
	Monthly	Static and Dynamic Blanks	

Temperature	Daily	Psychrometer	Performed if verification fails
Barometric Pressure	Daily	Aneroid barometer ATIS	Performed if verification fails
Dewpoint Sensors	Daily	Psychrometer Chilled mirror	Performed if verification fails

Appendix F-1: Detailed Emissions Test Results (NOx and PM)

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908150632	8/15/2019	Reference	24.19	4.574	0.060
201908151044	8/15/2019	Reference	24.22	4.565	0.059
201908151125	8/15/2019	Reference	24.20	4.584	0.059
201908151449	8/15/2019	Reference	24.33	4.559	0.058
201908160629	8/16/2019	Reference	24.23	4.482	0.059
201908160957	8/16/2019	Reference	24.27	4.572	0.057
201908161046	8/16/2019	Reference	24.23	4.582	0.057
201908161413	8/16/2019	Reference	24.21	4.602	0.058

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908150757	8/15/2019	Unadditized_B20	24.18	4.769	0.043
201908150840	8/15/2019	Unadditized_B20	24.28	4.734	0.041
201908151246	8/15/2019	Unadditized_B20	24.19	4.764	0.042
201908151328	8/15/2019	Unadditized_B20	24.23	4.747	0.042
201908160755	8/16/2019	Unadditized_B20	24.18	4.741	0.043
201908160837	8/16/2019	Unadditized_B20	24.10	4.743	0.043
201908161213	8/16/2019	Unadditized_B20	24.20	4.715	0.043
201908161255	8/16/2019	Unadditized_B20	24.22	4.732	0.042

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908070704	8/7/2019	Reference	24.20	4.486	0.068
201908071051	8/7/2019	Reference	24.28	4.524	0.059
201908071134	8/7/2019	Reference	24.10	4.533	0.059
201908071502	8/7/2019	Reference	24.22	4.508	0.058
201908080723	8/8/2019	Reference	24.12	4.527	0.064
201908081054	8/8/2019	Reference	24.26	4.526	0.057
201908081136	8/8/2019	Reference	24.20	4.544	0.057
201908081542	8/8/2019	Reference	24.20	4.527	0.057
201908120656	8/12/2019	Reference	24.12	4.482	0.059
201908121252	8/12/2019	Reference	24.26	4.551	0.058
201908121335	8/12/2019	Reference	24.23	4.582	0.056
201908121718	8/12/2019	Reference	24.24	4.501	0.057
201908130647	8/13/2019	Reference	24.20	4.523	0.059
201908131013	8/13/2019	Reference	24.25	4.589	0.056
201908131055	8/13/2019	Reference	24.30	4.571	0.058
201908131417	8/13/2019	Reference	24.37	4.546	0.057
201908140630	8/14/2019	Reference	24.17	4.553	0.059
201908140955	8/14/2019	Reference	24.21	4.590	0.057
201908141036	8/14/2019	Reference	24.31	4.532	0.057
201908141406	8/14/2019	Reference	24.27	4.559	0.058

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908070832	8/7/2019	BEST_B20_20ppm	24.22	4.670	0.044
201908070914	8/7/2019	BEST_B20_20ppm	24.26	4.654	0.044
201908071305	8/7/2019	BEST_B20_20ppm	24.24	4.692	0.042
201908071347	8/7/2019	BEST_B20_20ppm	24.25	4.683	0.041
201908080844	8/8/2019	BEST_B20_20ppm	24.17	4.689	0.041
201908080925	8/8/2019	BEST_B20_20ppm	24.14	4.709	0.040
201908081300	8/8/2019	BEST_B20_20ppm	24.26	4.689	0.042
201908081422	8/8/2019	BEST_B20_20ppm	24.22	4.682	0.043
201908121033	8/12/2019	BEST_B20_20ppm	24.19	4.737	0.043
201908121116	8/12/2019	BEST_B20_20ppm	24.20	4.746	0.042
201908121510	8/12/2019	BEST_B20_20ppm	24.23	4.707	0.041
201908121553	8/12/2019	BEST_B20_20ppm	24.16	4.709	0.041
201908130811	8/13/2019	BEST_B20_20ppm	24.17	4.736	0.043
201908130854	8/13/2019	BEST_B20_20ppm	24.17	4.759	0.040
201908131216	8/13/2019	BEST_B20_20ppm	24.25	4.703	0.044
201908131258	8/13/2019	BEST_B20_20ppm	24.22	4.702	0.041
201908140749	8/14/2019	BEST_B20_20ppm	24.22	4.731	0.042
201908140832	8/14/2019	BEST_B20_20ppm	24.27	4.723	0.042
201908141157	8/14/2019	BEST_B20_20ppm	24.19	4.740	0.041
201908141240	8/14/2019	BEST_B20_20ppm	24.22	4.744	0.042

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908170614	8/17/2019	Reference	24.18	4.528	0.059
201908170938	8/17/2019	Reference	24.22	4.594	0.056
201908171019	8/17/2019	Reference	24.28	4.567	0.055
201908171344	8/17/2019	Reference	24.43	4.539	0.055
201908190632	8/19/2019	Reference	24.17	4.526	0.060
201908190959	8/19/2019	Reference	24.17	4.546	0.057
201908191041	8/19/2019	Reference	24.30	4.508	0.056
201908191406	8/19/2019	Reference	24.26	4.554	0.057
201908200654	8/20/2019	Reference	24.35	4.470	0.060
201908201020	8/20/2019	Reference	24.21	4.481	0.058
201908201103	8/20/2019	Reference	24.23	4.532	0.057
201908201450	8/20/2019	Reference	24.33	4.490	0.057
201908210631	8/21/2019	Reference	24.29	4.427	0.059
201908210953	8/21/2019	Reference	24.28	4.493	0.058
201908211035	8/21/2019	Reference	24.28	4.507	0.059
201908211409	8/21/2019	Reference	24.28	4.521	0.058
201908220646	8/22/2019	Reference	24.26	4.438	0.061
201908221027	8/22/2019	Reference	24.27	4.557	0.057
201908221109	8/22/2019	Reference	24.31	4.534	0.058
201908221437	8/22/2019	Reference	24.31	4.518	0.059

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908170736	8/17/2019	Vesta_B20_1000ppm	24.13	4.684	0.039
201908170817	8/17/2019	Vesta_B20_1000ppm	24.25	4.689	0.040
201908171139	8/17/2019	Vesta_B20_1000ppm	24.22	4.668	0.041
201908171220	8/17/2019	Vesta_B20_1000ppm	24.29	4.668	0.041
201908190752	8/19/2019	Vesta_B20_1000ppm	24.26	4.642	0.039
201908190833	8/19/2019	Vesta_B20_1000ppm	24.20	4.612	0.042
201908191204	8/19/2019	Vesta_B20_1000ppm	24.29	4.577	0.040
201908191246	8/19/2019	Vesta_B20_1000ppm	24.28	4.626	0.040
201908200820	8/20/2019	Vesta_B20_1000ppm	24.24	4.582	0.040
201908200900	8/20/2019	Vesta_B20_1000ppm	24.34	4.600	0.041
201908201250	8/20/2019	Vesta_B20_1000ppm	24.26	4.605	0.041
201908201331	8/20/2019	Vesta_B20_1000ppm	24.32	4.623	0.041
201908210753	8/21/2019	Vesta_B20_1000ppm	24.25	4.584	0.041
201908210834	8/21/2019	Vesta_B20_1000ppm	24.20	4.595	0.042
201908211209	8/21/2019	Vesta_B20_1000ppm	24.27	4.564	0.041
201908211251	8/21/2019	Vesta_B20_1000ppm	24.24	4.623	0.040
201908220821	8/22/2019	Vesta_B20_1000ppm	24.22	4.630	0.042
201908220904	8/22/2019	Vesta_B20_1000ppm	24.10	4.683	0.040
201908221232	8/22/2019	Vesta_B20_1000ppm	24.26	4.613	0.042
201908221313	8/22/2019	Vesta_B20_1000ppm	24.31	4.644	0.043

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908260707	8/26/2019	Reference	24.23	4.469	0.060
201908261038	8/26/2019	Reference	24.23	4.519	0.058
201908261120	8/26/2019	Reference	24.24	4.552	0.057
201908261447	8/26/2019	Reference	24.36	4.521	0.060
201908270625	8/27/2019	Reference	24.28	4.497	0.059
201908270950	8/27/2019	Reference	24.17	4.544	0.057
201908271032	8/27/2019	Reference	24.26	4.528	0.056
201908271404	8/27/2019	Reference	24.30	4.512	0.059

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201908260831	8/26/2019	VESTA_B20_2200ppm*	24.28	4.584	0.041
201908260914	8/26/2019	VESTA_B20_2200ppm*	24.24	4.612	0.041
201908261241	8/26/2019	VESTA_B20_2200ppm*	24.28	4.611	0.043
201908261322	8/26/2019	VESTA_B20_2200ppm*	24.28	4.618	0.042
201908270745	8/27/2019	VESTA_B20_2200ppm*	24.35	4.619	0.041
201908270826	8/27/2019	VESTA_B20_2200ppm*	24.20	4.597	0.040
201908271157	8/27/2019	VESTA_B20_2200ppm*	24.20	4.588	0.040
201908271239	8/27/2019	VESTA_B20_2200ppm*	24.24	4.615	0.039

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201909190612	9/19/2019	Reference	24.18	4.582	0.061
201909190948	9/19/2019	Reference	24.30	4.623	0.053
201909191032	9/19/2019	Reference	24.27	4.622	0.056
201909191409	9/19/2019	Reference	24.16	4.654	0.055
201909200618	9/20/2019	Reference	24.21	4.589	0.059
201909200946	9/20/2019	Reference	24.24	4.644	0.058
201909201028	9/20/2019	Reference	24.22	4.653	0.056
201909201401	9/20/2019	Reference	24.34	4.626	0.057
201909250758	9/25/2019	Reference	24.25	4.547	0.059
201909251131	9/25/2019	Reference	24.11	4.593	0.055
201909251214	9/25/2019	Reference	24.25	4.590	0.056
201909251542	9/25/2019	Reference	24.14	4.584	0.055
201909260555	9/26/2019	Reference	24.36	4.546	0.058
201909260919	9/26/2019	Reference	24.28	4.573	0.053
201909261002	9/26/2019	Reference	24.27	4.594	0.055
201909261334	9/26/2019	Reference	24.31	4.585	0.054
201909270725	9/27/2019	Reference	24.32	4.541	0.057
201909271054	9/27/2019	Reference	24.33	4.569	0.060
201909271136	9/27/2019	Reference	24.20	4.604	0.060
201909271513	9/27/2019	Reference	24.35	4.580	0.060

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201909190745	9/19/2019	VESTA_B20_3000ppm	24.21	4.726	0.037
201909190828	9/19/2019	VESTA_B20_3000ppm	24.23	4.655	0.038
201909191202	9/19/2019	VESTA_B20_3000ppm	24.17	4.746	0.038
201909191245	9/19/2019	VESTA_B20_3000ppm	24.26	4.715	0.039
201909200741	9/20/2019	VESTA_B20_3000ppm	24.13	4.739	0.041
201909200823	9/20/2019	VESTA_B20_3000ppm	24.16	4.756	0.040
201909201149	9/20/2019	VESTA_B20_3000ppm	24.25	4.731	0.041
201909201232	9/20/2019	VESTA_B20_3000ppm	24.28	4.736	0.040
201909250922	9/25/2019	VESTA_B20_3000ppm	24.11	4.683	0.039
201909251005	9/25/2019	VESTA_B20_3000ppm	24.27	4.656	0.039
201909251336	9/25/2019	VESTA_B20_3000ppm	24.29	4.725	0.038
201909251419	9/25/2019	VESTA_B20_3000ppm	24.25	4.600	0.039
201909260715	9/26/2019	VESTA_B20_3000ppm	24.16	4.675	0.040
201909260756	9/26/2019	VESTA_B20_3000ppm	24.30	4.647	0.040
201909261125	9/26/2019	VESTA_B20_3000ppm	24.28	4.704	0.038
201909261208	9/26/2019	VESTA_B20_3000ppm	24.28	4.716	0.038
201909270849	9/27/2019	VESTA_B20_3000ppm	24.34	4.672	0.040
201909270930	9/27/2019	VESTA_B20_3000ppm	24.32	4.690	0.039
201909271302	9/27/2019	VESTA_B20_3000ppm	24.28	4.689	0.042
201909271344	9/27/2019	VESTA_B20_3000ppm	24.24	4.706	0.044

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201909300741	9/30/2019	Reference	24.31	4.535	0.062
201909301114	9/30/2019	Reference	24.30	4.595	0.057
201909301156	9/30/2019	Reference	24.40	4.575	0.058
201909301535	9/30/2019	Reference	24.21	4.610	0.056

			Work	EMISSION(g/bhp-hr)	
File name	Date	Fuel type	bhp-hr	NOx	PM
201909300909	9/30/1900	VESTA_B10_3000ppm*	24.17	4.610	0.051
201909300950	9/30/1900	VESTA_B10_3000ppm*	24.36	4.591	0.048
201909301326	9/30/1900	VESTA_B10_3000ppm*	24.28	4.620	0.046
201909301408	9/30/1900	VESTA_B10_3000ppm*	24.26	4.615	0.045

Appendix F-2: Detailed Emissions Test Results

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908150632	8/15/2019	Reference	45.91	12974.8	110.68	1.53	1.45	1.44	24.19	1.897	536.3	4.574	0.063	0.060	0.060	0.054
201908151044	8/15/2019	Reference	41.80	12897.5	110.56	3.20**	3.14**	1.43	24.22	1.726	532.6	4.565	0.132**	0.130**	0.059	0.054
201908151125	8/15/2019	Reference	42.57	12913.4	110.92	1.69	1.62	1.42	24.20	1.759	533.6	4.584	0.070	0.067	0.059	0.054
201908151449	8/15/2019	Reference	42.62	12906.1	110.89	1.53	1.46	1.40	24.33	1.752	530.6	4.559	0.063	0.060	0.058	0.053
201908160629	8/16/2019	Reference	45.45	12946.5	108.62	1.52	1.44	1.44	24.23	1.875	534.2	4.482	0.063	0.059	0.059	0.054
201908160957	8/16/2019	Reference	43.20	12821.8	110.94	1.48	1.42	1.38	24.27	1.781	528.4	4.572	0.061	0.058	0.057	0.053
201908161046	8/16/2019	Reference	43.95	12842.7	111.01	1.47	1.41	1.37	24.23	1.814	530.1	4.582	0.061	0.058	0.057	0.053
201908161413	8/16/2019	Reference	43.32	12895.8	111.40	1.47	1.42	1.41	24.21	1.789	532.7	4.602	0.061	0.059	0.058	0.054
		Average	43.60	12899.8	110.63	1.53	1.46	1.41	24.23	1.799	532.3	4.565	0.063	0.060	0.058	0.054
		STDEV	1.43	49.8	0.85	0.08	0.07	0.03	0.04	0.060	2.5	0.036	0.003	0.003	0.001	0.000

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name		Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908150757	8/15/2019	Unadditized_B20	39.50	13001.5	115.32	1.42	1.35	1.03	24.18	1.634	537.7	4.769	0.059	0.056	0.043	0.055
201908150840	8/15/2019	Unadditized_B20	38.52	12897.6	114.95	1.38	1.31	0.99	24.28	1.587	531.2	4.734	0.057	0.054	0.041	0.054
201908151246	8/15/2019	Unadditized_B20	36.51	12897.3	115.25	1.44	1.37	1.02	24.19	1.509	533.1	4.764	0.059	0.056	0.042	0.055
201908151328	8/15/2019	Unadditized_B20	38.21	12907.5	115.02	1.37	1.29	1.02	24.23	1.577	532.7	4.747	0.057	0.053	0.042	0.055
201908160755	8/16/2019	Unadditized_B20	39.59	12907.6	114.62	1.39	1.33	1.05	24.18	1.637	533.8	4.741	0.057	0.055	0.043	0.055
201908160837	8/16/2019	Unadditized_B20	38.71	12955.5	114.33	1.42	1.26	1.03	24.10	1.606	537.5	4.743	0.059	0.052	0.043	0.055
201908161213	8/16/2019	Unadditized_B20	37.44	12914.6	114.08	1.42	1.38	1.03	24.20	1.547	533.7	4.715	0.059	0.057	0.043	0.055
201908161255	8/16/2019	Unadditized_B20	37.80	12933.3	114.60	1.43	1.35	1.03	24.22	1.561	534.1	4.732	0.059	0.056	0.042	0.055
		Average	38.28	12926.9	114.77	1.41	1.33	1.02	24.20	1.582	534.2	4.743	0.058	0.055	0.042	0.055
		STDEV	1.04	36.0	0.44	0.03	0.04	0.02	0.05	0.044	2.3	0.018	0.001	0.002	0.001	0.000
									NOx Percent change vs reference			3.90%				

** THC/NMHC measurement issue, value not included in final averages

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908070704	8/7/2019	Reference	51.35	12949.5	108.54	1.83	1.69	1.65	24.20	2.122	535.2	4.486	0.076	0.070	0.068	0.054
201908071051	8/7/2019	Reference	44.27	12735.9	109.84	1.55	1.48	1.44	24.28	1.824	524.6	4.524	0.064	0.061	0.059	0.053
201908071134	8/7/2019	Reference	45.12	12677.1	109.26	1.55	1.48	1.43	24.10	1.872	525.9	4.533	0.064	0.061	0.059	0.053
201908071502	8/7/2019	Reference	43.10	12697.5	109.18	1.58	1.52	1.40	24.22	1.779	524.2	4.508	0.065	0.063	0.058	0.053
201908080723	8/8/2019	Reference	47.17	12843.0	109.21	1.88	1.82	1.53	24.12	1.956	532.4	4.527	0.078	0.075	0.064	0.054
201908081054	8/8/2019	Reference	44.13	12765.9	109.82	1.55	1.49	1.39	24.26	1.819	526.2	4.526	0.064	0.061	0.057	0.053
201908081136	8/8/2019	Reference	44.30	12748.0	109.94	1.54	1.46	1.39	24.20	1.831	526.9	4.544	0.063	0.060	0.057	0.053
201908081542	8/8/2019	Reference	44.00	12665.1	109.57	1.45	1.37	1.37	24.20	1.818	523.3	4.527	0.060	0.057	0.057	0.053
201908120656	8/12/2019	Reference	47.22	12767.2	108.10	1.50	1.46	1.43	24.12	1.958	529.3	4.482	0.062	0.061	0.059	0.052
201908121252	8/12/2019	Reference	42.81	12767.7	110.42	1.55	1.48	1.40	24.26	1.764	526.2	4.551	0.064	0.061	0.058	0.053
201908121335	8/12/2019	Reference	42.77	12827.7	111.03	1.57	1.49	1.35	24.23	1.765	529.3	4.582	0.065	0.061	0.056	0.053
201908121718	8/12/2019	Reference	41.97	12526.4	109.12	1.57	1.51	1.38	24.24	1.731	516.7	4.501	0.065	0.062	0.057	0.052
201908130647	8/13/2019	Reference	46.03	12831.6	109.46	1.57	1.50	1.43	24.20	1.902	530.2	4.523	0.065	0.062	0.059	0.053
201908131013	8/13/2019	Reference	41.85	12790.8	111.27	1.49	1.44	1.36	24.25	1.726	527.5	4.589	0.062	0.059	0.056	0.053
201908131055	8/13/2019	Reference	43.66	12847.8	111.09	1.48	1.40	1.40	24.30	1.797	528.7	4.571	0.061	0.058	0.058	0.053
201908131417	8/13/2019	Reference	44.15	12800.8	110.77	1.47	1.43	1.40	24.37	1.812	525.3	4.546	0.060	0.059	0.057	0.053
201908140630	8/14/2019	Reference	46.00	12927.0	110.06	1.53	1.45	1.43	24.17	1.903	534.8	4.553	0.063	0.060	0.059	0.054
201908140955	8/14/2019	Reference	43.53	12769.0	111.12	1.49	1.45	1.37	24.21	1.798	527.4	4.590	0.061	0.060	0.057	0.053
201908141036	8/14/2019	Reference	43.83	12932.9	110.18	1.48	1.41	1.39	24.31	1.803	531.9	4.532	0.061	0.058	0.057	0.054
201908141406	8/14/2019	Reference	43.01	12830.3	110.66	1.51	1.46	1.40	24.27	1.772	528.6	4.559	0.062	0.060	0.058	0.053
		Average	44.51	12785.1	109.93	1.56	1.49	1.42	24.23	1.838	527.7	4.538	0.064	0.061	0.058	0.053
		STDEV	2.21	99.5	0.89	0.11	0.10	0.07	0.07	0.094	4.2	0.031	0.005	0.004	0.003	0.001

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908070832	8/7/2019	BEST_B20_20ppm	41.17	12993.4	113.13	1.45	1.39	1.07	24.22	1.700	536.4	4.670	0.060	0.057	0.044	0.055
201908070914	8/7/2019	BEST_B20_20ppm	39.73	12826.8	112.89	1.48	1.41	1.06	24.26	1.638	528.8	4.654	0.061	0.058	0.044	0.054
201908071305	8/7/2019	BEST_B20_20ppm	39.07	12763.4	113.73	1.47	1.40	1.01	24.24	1.612	526.6	4.692	0.060	0.058	0.042	0.054
201908071347	8/7/2019	BEST_B20_20ppm	38.69	12837.0	113.58	1.47	1.39	1.00	24.25	1.595	529.3	4.683	0.061	0.057	0.041	0.054
201908080844	8/8/2019	BEST_B20_20ppm	39.08	12881.2	113.36	1.45	1.41	0.99	24.17	1.617	532.9	4.689	0.060	0.058	0.041	0.055
201908080925	8/8/2019	BEST_B20_20ppm	40.24	12846.5	113.66	1.42	1.34	0.97	24.14	1.667	532.3	4.709	0.059	0.055	0.040	0.054
201908081300	8/8/2019	BEST_B20_20ppm	39.28	12799.9	113.75	1.42	1.36	1.02	24.26	1.619	527.7	4.689	0.059	0.056	0.042	0.054
201908081422	8/8/2019	BEST_B20_20ppm	37.54	12840.3	113.41	1.54	1.15	1.04	24.22	1.550	530.2	4.682	0.064	0.047	0.043	0.054
201908121033	8/12/2019	BEST_B20_20ppm	38.74	12777.3	114.62	1.53	1.47	1.03	24.19	1.601	528.1	4.737	0.063	0.061	0.043	0.054
201908121116	8/12/2019	BEST_B20_20ppm	38.14	12859.2	114.86	1.47	1.41	1.02	24.20	1.576	531.4	4.746	0.061	0.058	0.042	0.054
201908121510	8/12/2019	BEST_B20_20ppm	38.61	12783.9	114.08	1.46	1.39	1.00	24.23	1.593	527.5	4.707	0.060	0.057	0.041	0.054
201908121553	8/12/2019	BEST_B20_20ppm	37.81	12723.2	113.78	1.43	1.37	0.99	24.16	1.565	526.6	4.709	0.059	0.057	0.041	0.054
201908130811	8/13/2019	BEST_B20_20ppm	39.35	12860.3	114.46	1.41	1.35	1.04	24.17	1.628	532.1	4.736	0.058	0.056	0.043	0.054
201908130854	8/13/2019	BEST_B20_20ppm	38.09	12890.5	115.03	1.38	1.32	0.96	24.17	1.576	533.3	4.759	0.057	0.054	0.040	0.055
201908131216	8/13/2019	BEST_B20_20ppm	40.07	12793.9	114.03	1.41	1.34	1.06	24.25	1.652	527.7	4.703	0.058	0.055	0.044	0.054
201908131258	8/13/2019	BEST_B20_20ppm	38.02	12848.4	113.87	1.39	1.32	1.00	24.22	1.570	530.5	4.702	0.058	0.054	0.041	0.054
201908140749	8/14/2019	BEST_B20_20ppm	38.86	12918.8	114.56	1.38	1.31	1.01	24.22	1.605	533.5	4.731	0.057	0.054	0.042	0.055
201908140832	8/14/2019	BEST_B20_20ppm	39.76	12906.0	114.61	1.35	1.28	1.02	24.27	1.639	531.8	4.723	0.056	0.053	0.042	0.054
201908141157	8/14/2019	BEST_B20_20ppm	37.41	12870.4	114.66	1.31	1.26	1.00	24.19	1.546	532.1	4.740	0.054	0.052	0.041	0.054
201908141240	8/14/2019	BEST_B20_20ppm	36.94	12896.9	114.89	1.38	1.36	1.02	24.22	1.525	532.5	4.744	0.057	0.056	0.042	0.054
		Average	38.83	12845.9	114.05	1.43	1.35	1.02	24.21	1.604	530.6	4.710	0.059	0.056	0.042	0.054
		STDEV	1.06	62.1	0.63	0.06	0.07	0.03	0.04	0.043	2.7	0.028	0.002	0.003	0.001	0.000
												Percent change vs reference				3.80%

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908170614	8/17/2019	Reference	45.09	12814.1	109.48	1.49	1.44	1.43	24.18	1.865	530.0	4.528	0.062	0.060	0.059	0.053
201908170938	8/17/2019	Reference	43.35	12831.3	111.25	1.47	1.42	1.36	24.22	1.790	529.9	4.594	0.061	0.059	0.056	0.053
201908171019	8/17/2019	Reference	42.94	12833.4	110.90	1.46	1.40	1.35	24.28	1.768	528.5	4.567	0.060	0.058	0.055	0.053
201908171344	8/17/2019	Reference	41.33	12849.0	110.87	1.46	1.38	1.35	24.43	1.692	526.0	4.539	0.060	0.057	0.055	0.053
201908190632	8/19/2019	Reference	46.62	12827.4	109.40	1.48	1.42	1.45	24.17	1.929	530.7	4.526	0.061	0.059	0.060	0.053
201908190959	8/19/2019	Reference	44.76	12829.1	109.87	1.47	1.42	1.37	24.17	1.852	530.9	4.546	0.061	0.059	0.057	0.053
201908191041	8/19/2019	Reference	42.34	12693.6	109.52	1.48	1.42	1.37	24.30	1.743	522.5	4.508	0.061	0.059	0.056	0.053
201908191406	8/19/2019	Reference	42.49	12732.5	110.49	1.45	1.41	1.37	24.26	1.751	524.8	4.554	0.060	0.058	0.057	0.053
201908200654	8/20/2019	Reference	44.78	12791.3	108.86	1.50	1.47	1.47	24.35	1.839	525.3	4.470	0.062	0.060	0.060	0.053
201908201020	8/20/2019	Reference	42.08	12702.9	108.48	1.43	1.41	1.39	24.21	1.738	524.8	4.481	0.059	0.058	0.058	0.053
201908201103	8/20/2019	Reference	42.28	12768.2	109.83	1.44	1.38	1.39	24.23	1.745	526.9	4.532	0.059	0.057	0.057	0.053
201908201450	8/20/2019	Reference	42.19	12744.6	109.24	1.42	1.38	1.39	24.33	1.734	523.9	4.490	0.058	0.057	0.057	0.053
201908210631	8/21/2019	Reference	45.12	12768.0	107.53	1.50	1.46	1.43	24.29	1.857	525.6	4.427	0.062	0.060	0.059	0.053
201908210953	8/21/2019	Reference	42.99	12719.0	109.08	1.53	1.47	1.41	24.28	1.771	523.9	4.493	0.063	0.061	0.058	0.053
201908211035	8/21/2019	Reference	43.94	12745.3	109.42	1.52	1.44	1.44	24.28	1.810	525.0	4.507	0.063	0.059	0.059	0.053
201908211409	8/21/2019	Reference	41.79	12674.4	109.76	1.49	1.45	1.42	24.28	1.721	522.0	4.521	0.061	0.060	0.058	0.053
201908220646	8/22/2019	Reference	44.89	12692.4	107.66	1.51	1.47	1.49	24.26	1.851	523.2	4.438	0.062	0.061	0.061	0.053
201908221027	8/22/2019	Reference	42.82	12789.5	110.61	1.47	1.44	1.38	24.27	1.764	526.9	4.557	0.061	0.059	0.057	0.053
201908221109	8/22/2019	Reference	44.56	12856.8	110.20	1.52	1.47	1.41	24.31	1.833	529.0	4.534	0.063	0.060	0.058	0.053
201908221437	8/22/2019	Reference	43.37	12772.1	109.83	1.52	1.47	1.43	24.31	1.784	525.4	4.518	0.062	0.060	0.059	0.053
		Average	43.49	12771.8	109.61	1.48	1.43	1.40	24.27	1.792	526.3	4.517	0.061	0.059	0.058	0.053
		STDEV	1.41	57.0	0.99	0.03	0.03	0.04	0.06	0.060	2.7	0.042	0.001	0.001	0.002	0.000

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908170736	8/17/2019	Vesta_B20_1000ppm	35.95	12829.9	113.02	1.26	1.21	0.93	24.13	1.490	531.8	4.684	0.052	0.050	0.039	0.054
201908170817	8/17/2019	Vesta_B20_1000ppm	37.26	12925.4	113.71	1.27	1.22	0.97	24.25	1.536	533.0	4.689	0.052	0.050	0.040	0.055
201908171139	8/17/2019	Vesta_B20_1000ppm	35.21	12855.8	113.06	1.25	1.20	0.98	24.22	1.454	530.8	4.668	0.052	0.049	0.041	0.054
201908171220	8/17/2019	Vesta_B20_1000ppm	35.84	12877.3	113.39	1.23	1.18	0.99	24.29	1.475	530.1	4.668	0.051	0.049	0.041	0.054
201908190752	8/19/2019	Vesta_B20_1000ppm	36.05	12896.4	112.61	1.23	1.20	0.95	24.26	1.486	531.6	4.642	0.051	0.049	0.039	0.054
201908190833	8/19/2019	Vesta_B20_1000ppm	35.41	12840.3	111.63	1.25	1.18	1.01	24.20	1.463	530.5	4.612	0.052	0.049	0.042	0.054
201908191204	8/19/2019	Vesta_B20_1000ppm	35.42	12748.2	111.18	1.26	1.22	0.96	24.29	1.458	524.8	4.577	0.052	0.050	0.040	0.054
201908191246	8/19/2019	Vesta_B20_1000ppm	35.56	12716.0	112.32	1.28	1.22	0.97	24.28	1.464	523.7	4.626	0.053	0.050	0.040	0.054
201908200820	8/20/2019	Vesta_B20_1000ppm	35.96	12817.1	111.04	1.27	1.24	0.98	24.24	1.484	528.8	4.582	0.052	0.051	0.040	0.054
201908200900	8/20/2019	Vesta_B20_1000ppm	37.11	12766.7	111.94	1.19	1.14	1.00	24.34	1.525	524.6	4.600	0.049	0.047	0.041	0.054
201908201250	8/20/2019	Vesta_B20_1000ppm	35.47	12784.2	111.74	1.30	1.23	1.00	24.26	1.462	526.9	4.605	0.054	0.051	0.041	0.054
201908201331	8/20/2019	Vesta_B20_1000ppm	34.64	12864.5	112.42	1.24	1.18	0.99	24.32	1.424	529.1	4.623	0.051	0.048	0.041	0.054
201908210753	8/21/2019	Vesta_B20_1000ppm	36.07	12746.7	111.13	1.29	1.24	1.00	24.25	1.488	525.7	4.584	0.053	0.051	0.041	0.054
201908210834	8/21/2019	Vesta_B20_1000ppm	37.46	12780.1	111.21	1.29	1.23	1.01	24.20	1.548	528.1	4.595	0.053	0.051	0.042	0.054
201908211209	8/21/2019	Vesta_B20_1000ppm	34.67	12684.0	110.76	1.30	1.26	0.98	24.27	1.428	522.7	4.564	0.054	0.052	0.041	0.053
201908211251	8/21/2019	Vesta_B20_1000ppm	34.94	12742.2	112.06	1.28	1.21	0.98	24.24	1.442	525.7	4.623	0.053	0.050	0.040	0.054
201908220821	8/22/2019	Vesta_B20_1000ppm	38.16	12933.1	112.14	1.27	1.20	1.02	24.22	1.576	534.0	4.630	0.052	0.050	0.042	0.055
201908220904	8/22/2019	Vesta_B20_1000ppm	36.09	12887.2	112.84	1.28	1.23	0.96	24.10	1.498	534.8	4.683	0.053	0.051	0.040	0.055
201908221232	8/22/2019	Vesta_B20_1000ppm	36.24	12813.6	111.92	1.29	1.23	1.01	24.26	1.494	528.1	4.613	0.053	0.051	0.042	0.054
201908221313	8/22/2019	Vesta_B20_1000ppm	38.04	12912.9	112.88	1.30	1.25	1.05	24.31	1.565	531.3	4.644	0.054	0.051	0.043	0.054
		Average	36.08	12821.1	112.15	1.27	1.21	0.99	24.25	1.488	528.8	4.626	0.052	0.050	0.041	0.054
		STDEV	1.03	73.1	0.84	0.03	0.03	0.03	0.06	0.043	3.5	0.038	0.001	0.001	0.001	0.000
												Percent change vs reference				2.41%

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908260707	8/26/2019	Reference	45.26	12911.7	108.28	1.49	1.44	1.45	24.23	1.868	532.8	4.469	0.061	0.060	0.060	0.054
201908261038	8/26/2019	Reference	42.77	12764.2	109.50	1.44	1.42	1.40	24.23	1.765	526.8	4.519	0.059	0.058	0.058	0.053
201908261120	8/26/2019	Reference	42.59	12811.7	110.32	1.52	1.45	1.38	24.24	1.757	528.6	4.552	0.063	0.060	0.057	0.053
201908261447	8/26/2019	Reference	42.49	12828.4	110.10	1.50	1.44	1.45	24.36	1.744	526.7	4.521	0.061	0.059	0.060	0.053
201908270625	8/27/2019	Reference	43.55	12793.1	109.17	1.55	1.48	1.44	24.28	1.794	527.0	4.497	0.064	0.061	0.059	0.053
201908270950	8/27/2019	Reference	43.09	12790.3	109.82	1.47	1.42	1.38	24.17	1.783	529.2	4.544	0.061	0.059	0.057	0.053
201908271032	8/27/2019	Reference	41.58	12773.5	109.85	1.52	1.47	1.36	24.26	1.714	526.6	4.528	0.063	0.061	0.056	0.053
201908271404	8/27/2019	Reference	42.66	12740.0	109.61	1.45	1.40	1.43	24.30	1.756	524.4	4.512	0.060	0.058	0.059	0.053
		Average	43.00	12801.6	109.58	1.49	1.44	1.41	24.26	1.773	527.8	4.518	0.062	0.059	0.058	0.053
		STDEV	1.07	52.3	0.63	0.04	0.03	0.04	0.05	0.045	2.5	0.026	0.001	0.001	0.001	0.000

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name		Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201908260831	8/26/2019	VESTA_B20_2200ppm*	36.00	12953.0	111.29	1.25	1.21	0.99	24.28	1.483	533.5	4.584	0.051	0.050	0.041	0.055
201908260914	8/26/2019	VESTA_B20_2200ppm*	36.64	12876.1	111.79	1.24	1.19	0.99	24.24	1.511	531.2	4.612	0.051	0.049	0.041	0.054
201908261241	8/26/2019	VESTA_B20_2200ppm*	35.70	12884.9	111.96	1.27	1.19	1.03	24.28	1.470	530.7	4.611	0.052	0.049	0.043	0.054
201908261322	8/26/2019	VESTA_B20_2200ppm*	34.22	12890.9	112.13	1.25	1.21	1.01	24.28	1.409	530.9	4.618	0.052	0.050	0.042	0.054
201908270745	8/27/2019	VESTA_B20_2200ppm*	34.66	12863.3	112.46	1.26	1.21	1.00	24.35	1.423	528.3	4.619	0.052	0.050	0.041	0.054
201908270826	8/27/2019	VESTA_B20_2200ppm*	35.92	12822.1	111.26	1.26	1.21	0.98	24.20	1.484	529.8	4.597	0.052	0.050	0.040	0.054
201908271157	8/27/2019	VESTA_B20_2200ppm*	34.54	12697.9	111.02	1.24	1.20	0.97	24.20	1.427	524.7	4.588	0.051	0.050	0.040	0.054
201908271239	8/27/2019	VESTA_B20_2200ppm*	34.50	12778.3	111.87	1.25	1.19	0.94	24.24	1.423	527.1	4.615	0.052	0.049	0.039	0.054
		Average	35.27	12845.8	111.72	1.25	1.20	0.99	24.26	1.454	529.5	4.605	0.052	0.050	0.041	0.054
		STDEV	0.89	78.6	0.49	0.01	0.01	0.03	0.05	0.038	2.7	0.014	0.000	0.000	0.001	0.000
												Percent change vs reference		1.94%		

Note: * Active ingredient in VESTA™

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201909190612	9/19/2019	Reference	48.34	13226.2	110.80	1.55	1.45	1.48	24.18	1.999	546.9	4.582	0.064	0.060	0.061	0.055
201909190948	9/19/2019	Reference	43.03	13142.8	112.34	1.47	1.41	1.28	24.30	1.770	540.8	4.623	0.060	0.058	0.053	0.054
201909191032	9/19/2019	Reference	43.46	13135.8	112.17	1.48	1.46	1.37	24.27	1.791	541.2	4.622	0.061	0.060	0.056	0.054
201909191409	9/19/2019	Reference	43.58	13087.3	112.43	1.48	1.42	1.32	24.16	1.804	541.8	4.654	0.061	0.059	0.055	0.055
201909200618	9/20/2019	Reference	45.92	13111.2	111.08	1.50	1.45	1.43	24.21	1.897	541.6	4.589	0.062	0.060	0.059	0.055
201909200946	9/20/2019	Reference	41.42	13091.6	112.58	1.44	1.39	1.41	24.24	1.709	540.0	4.644	0.059	0.057	0.058	0.054
201909201028	9/20/2019	Reference	42.64	13158.8	112.72	1.47	1.41	1.35	24.22	1.760	543.2	4.653	0.061	0.058	0.056	0.055
201909201401	9/20/2019	Reference	56.62	13158.1	112.60	1.49	1.43	1.39	24.34	2.326	540.6	4.626	0.061	0.059	0.057	0.054
201909250758	9/25/2019	Reference	46.39	13165.1	110.27	1.43	1.38	1.43	24.25	1.913	542.9	4.547	0.059	0.057	0.059	0.055
201909251131	9/25/2019	Reference	41.81	13043.0	110.75	1.48	1.43	1.32	24.11	1.734	540.9	4.593	0.061	0.059	0.055	0.054
201909251214	9/25/2019	Reference	43.29	13115.6	111.33	1.48	1.42	1.35	24.25	1.785	540.8	4.590	0.061	0.059	0.056	0.054
201909251542	9/25/2019	Reference	41.23	13050.5	110.65	1.46	1.43	1.33	24.14	1.708	540.7	4.584	0.060	0.059	0.055	0.054
201909260555	9/26/2019	Reference	43.47	13116.5	110.74	1.48	1.42	1.42	24.36	1.785	538.5	4.546	0.061	0.058	0.058	0.054
201909260919	9/26/2019	Reference	40.19	12996.1	111.06	1.44	1.36	1.29	24.28	1.655	535.1	4.573	0.059	0.056	0.053	0.054
201909261002	9/26/2019	Reference	41.40	13054.4	111.48	1.46	1.41	1.33	24.27	1.706	538.0	4.594	0.060	0.058	0.055	0.054
201909261334	9/26/2019	Reference	40.89	13042.5	111.45	1.46	1.41	1.32	24.31	1.682	536.6	4.585	0.060	0.058	0.054	0.054
201909270725	9/27/2019	Reference	44.48	13084.6	110.42	1.47	1.42	1.39	24.32	1.829	538.1	4.541	0.060	0.058	0.057	0.054
201909271054	9/27/2019	Reference	43.65	13042.7	111.17	1.46	1.41	1.47	24.33	1.794	536.0	4.569	0.060	0.058	0.060	0.054
201909271136	9/27/2019	Reference	43.21	13054.0	111.43	1.47	1.43	1.45	24.20	1.785	539.3	4.604	0.061	0.059	0.060	0.054
201909271513	9/27/2019	Reference	42.08	13066.7	111.50	1.49	1.42	1.46	24.35	1.729	536.7	4.580	0.061	0.058	0.060	0.054
		Average	43.86	13097.2	111.45	1.47	1.42	1.38	24.25	1.808	540.0	4.595	0.061	0.058	0.057	0.054
		STDEV	3.60	55.9	0.77	0.03	0.02	0.06	0.07	0.147	2.8	0.033	0.001	0.001	0.002	0.000

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201909190745	9/19/2019	VESTA_B20_3000ppm	35.30	13206.9	114.44	1.22	1.17	0.89	24.21	1.458	545.4	4.726	0.050	0.048	0.037	0.056
201909190828	9/19/2019	VESTA_B20_3000ppm	34.10	13237.4	112.77	1.19	1.14	0.92	24.23	1.407	546.4	4.655	0.049	0.047	0.038	0.056
201909191202	9/19/2019	VESTA_B20_3000ppm	34.75	13130.4	114.74	1.24	1.18	0.92	24.17	1.437	543.1	4.746	0.051	0.049	0.038	0.056
201909191245	9/19/2019	VESTA_B20_3000ppm	34.85	13118.5	114.37	1.25	1.19	0.95	24.26	1.437	540.9	4.715	0.051	0.049	0.039	0.055
201909200741	9/20/2019	VESTA_B20_3000ppm	34.13	13128.2	114.33	1.22	1.17	0.99	24.13	1.415	544.1	4.739	0.050	0.049	0.041	0.056
201909200823	9/20/2019	VESTA_B20_3000ppm	35.77	13132.1	114.90	1.21	1.18	0.96	24.16	1.481	543.6	4.756	0.050	0.049	0.040	0.056
201909201149	9/20/2019	VESTA_B20_3000ppm	35.44	13203.1	114.71	1.22	1.18	0.99	24.25	1.462	544.5	4.731	0.050	0.049	0.041	0.056
201909201232	9/20/2019	VESTA_B20_3000ppm	31.33	13193.8	114.99	1.20	1.15	0.97	24.28	1.290	543.4	4.736	0.050	0.047	0.040	0.056
201909250922	9/25/2019	VESTA_B20_3000ppm	35.77	13065.8	112.92	1.22	1.18	0.94	24.11	1.483	541.8	4.683	0.050	0.049	0.039	0.055
201909251005	9/25/2019	VESTA_B20_3000ppm	34.78	13084.0	113.01	1.21	1.15	0.94	24.27	1.433	539.0	4.656	0.050	0.047	0.039	0.055
201909251336	9/25/2019	VESTA_B20_3000ppm	34.60	13133.9	114.77	1.23	1.18	0.92	24.29	1.424	540.7	4.725	0.050	0.049	0.038	0.055
201909251419	9/25/2019	VESTA_B20_3000ppm	35.48	13015.6	111.55	1.25	1.18	0.95	24.25	1.463	536.8	4.600	0.051	0.049	0.039	0.055
201909260715	9/26/2019	VESTA_B20_3000ppm	34.31	12919.7	112.94	1.22	1.18	0.96	24.16	1.420	534.8	4.675	0.050	0.049	0.040	0.055
201909260756	9/26/2019	VESTA_B20_3000ppm	34.83	13004.8	112.93	1.22	1.17	0.96	24.30	1.433	535.1	4.647	0.050	0.048	0.040	0.055
201909261125	9/26/2019	VESTA_B20_3000ppm	33.05	13082.3	114.19	1.22	1.20	0.92	24.28	1.362	538.9	4.704	0.050	0.049	0.038	0.055
201909261208	9/26/2019	VESTA_B20_3000ppm	34.15	13135.5	114.48	1.23	1.19	0.91	24.28	1.407	541.1	4.716	0.051	0.049	0.038	0.055
201909270849	9/27/2019	VESTA_B20_3000ppm	34.89	13073.0	113.72	1.22	1.17	0.99	24.34	1.433	537.1	4.672	0.050	0.048	0.040	0.055
201909270930	9/27/2019	VESTA_B20_3000ppm	34.52	13132.5	114.04	1.21	1.15	0.95	24.32	1.420	540.1	4.690	0.050	0.047	0.039	0.055
201909271302	9/27/2019	VESTA_B20_3000ppm	35.26	13105.4	113.84	1.24	1.20	1.02	24.28	1.452	539.8	4.689	0.051	0.050	0.042	0.055
201909271344	9/27/2019	VESTA_B20_3000ppm	34.33	13069.1	114.08	1.22	1.18	1.07	24.24	1.416	539.2	4.706	0.050	0.049	0.044	0.055
		Average	34.58	13108.6	113.89	1.22	1.17	0.96	24.240	1.427	540.8	4.698	0.050	0.048	0.039	0.055
		STDEV	1.01	75.0	0.92	0.02	0.02	0.04	0.063	0.043	3.3	0.039	0.001	0.001	0.002	0.000
												Percent change vs reference		2.25%		

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201909300741	9/30/2019	Reference	44.74	13119.3	110.25	1.50	1.43	1.51	24.31	1.840	539.7	4.535	0.062	0.059	0.062	0.054
201909301114	9/30/2019	Reference	42.04	13003.1	111.68	1.48	1.44	1.38	24.30	1.730	535.0	4.595	0.061	0.059	0.057	0.054
201909301156	9/30/2019	Reference	44.23	13052.8	111.62	1.46	1.40	1.42	24.40	1.813	535.0	4.575	0.060	0.057	0.058	0.054
201909301535	9/30/2019	Reference	42.64	12980.7	111.64	1.46	1.42	1.36	24.21	1.761	536.1	4.610	0.060	0.059	0.056	0.054
		Average	43.41	13039.0	111.30	1.48	1.42	1.42	24.31	1.786	536.5	4.579	0.061	0.058	0.058	0.054
		STDEV	1.28	61.5	0.70	0.02	0.02	0.07	0.07	0.050	2.2	0.033	0.001	0.001	0.003	0.000

			EMISSIONS (g)						Work	EMISSIONS (g/bhp-hr)						Fuel
File name	Date	Fuel type	CO	CO2	NOx	THC	NMHC	PM	bhp-hr	CO	CO2	NOx	THC	NMHC	PM	Gal/bhp-hr
201909300909	9/30/2019	VESTA_B10_3000ppm*	38.17	13027.3	111.41	1.29	1.25	1.23	24.17	1.580	539.1	4.610	0.053	0.052	0.051	0.055
201909300950	9/30/2019	VESTA_B10_3000ppm*	36.87	13141.9	111.84	1.29	1.23	1.17	24.36	1.514	539.5	4.591	0.053	0.050	0.048	0.055
201909301326	9/30/2019	VESTA_B10_3000ppm*	37.64	13107.0	112.20	1.28	1.23	1.11	24.28	1.550	539.8	4.620	0.053	0.051	0.046	0.055
201909301408	9/30/2019	VESTA_B10_3000ppm*	36.80	13138.4	111.94	1.27	1.23	1.09	24.26	1.517	541.7	4.615	0.052	0.051	0.045	0.055
		Average	37.37	13103.6	111.85	1.28	1.23	1.15	24.27	1.540	540.0	4.609	0.053	0.051	0.047	0.055
		STDEV	0.65	53.3	0.33	0.01	0.01	0.06	0.08	0.031	1.1	0.013	0.000	0.001	0.003	0.000
										NOx Percent change vs reference		0.66%				

Note: * Active ingredient in VESTA™

Appendix G: Statistical Calculations for Certification Testing

The certification pass/fail determinations are based on the criteria in California Code of Regulations, Title 13, Article 3, Appendix 1 of Subarticle 2, (a)(2)(G)3. The criteria are evaluated for NO_x and PM emissions separately. The statistical criteria include a tolerance of 1% and 2%, respectively, for NO_x and PM emissions. The tolerance is reduced by a pooled standard deviation term that increases with the variability in the data and decreases with the number of tests.

Statistical Evaluation for B20 Unadditized

Testing Conducted: 08/15/2019 - 08/16/2019

NOx

Day	n	R		C	
1	1	R1	4.574	C2	4.769
	2	R4	4.565	C3	4.734
	3	R5	4.584	C6	4.764
	4	R8	4.559	C7	4.747
2	5	R9	4.482	C10	4.741
	6	R12	4.572	C11	4.743
	7	R13	4.582	C14	4.715
	8	R16	4.602	C15	4.732

PM

Day	n	R		C	
1	1	R1	0.060	C2	0.043
	2	R4	0.059	C3	0.041
	3	R5	0.059	C6	0.042
	4	R8	0.058	C7	0.042
2	5	R9	0.059	C10	0.043
	6	R12	0.057	C11	0.043
	7	R13	0.057	C14	0.043
	8	R16	0.058	C15	0.042

Below values are auto calculated:

		x_R	x_C
NOx	AVERAGE	4.565	4.743
	STD. DEV.	0.036	0.018

		x_R	x_C
PM	AVERAGE	0.058	0.042
	STD. DEV.	0.001	0.001

Notes: δ is 1 % of X_R for NOx and 2 % of X_R for PM. For n=20, df=2n-2=38.

Number of Tests of candidate or reference fuels: 8

Note:

		x_R	x_C
NOx	AVERAGE	4.565	4.743
PM	AVERAGE	0.058	0.042

x_R	+ δ	$-S_p$	* √(2/n)	* t(0.15,df)		$x_{R\,Adjusted}$
4.565	0.046	0.028	0.500	1.076	=	4.596
0.058	0.001	0.001	0.500	1.076	=	0.059

Final Determination

	x_C		$x_{R\,Adjusted}$
NOx	4.743	< Fail	4.596
PM	0.042	Pass	0.059

Note: The Final (Pass/Fail) Determination is based on a comparison of $X_{R,Adjusted}$ to X_C. However, the percent change in emissions for the candidate fuel compared to the reference fuel is based on X_R (unadjusted) and X_C.

Statistical Evaluation for B20 Additized with Best Corp BC-EC1c at 20 ppmv
Testing Conducted: 08/07/2019 - 08/14/2019

NOx

Day	n	R		C	
1	1	R1	4.486	C2	4.670
	2	R4	4.524	C3	4.654
	3	R5	4.533	C6	4.692
	4	R8	4.508	C7	4.683
2	5	R9	4.527	C10	4.689
	6	R12	4.526	C11	4.709
	7	R13	4.544	C14	4.689
	8	R16	4.527	C15	4.682
3	9	R17	4.482	C18	4.737
	10	R20	4.551	C19	4.746
	11	R21	4.582	C22	4.707
	12	R24	4.501	C23	4.709
4	13	R25	4.523	C26	4.736
	14	R28	4.589	C27	4.759
	15	R29	4.571	C30	4.703
	16	R32	4.546	C31	4.702
5	17	R33	4.553	C34	4.731
	18	R36	4.590	C35	4.723
	19	R37	4.532	C38	4.740
	20	R40	4.559	C39	4.744

PM

Day	n	R		C	
1	1	R1	0.068	C2	0.044
	2	R4	0.059	C3	0.044
	3	R5	0.059	C6	0.042
	4	R8	0.058	C7	0.041
2	5	R9	0.064	C10	0.041
	6	R12	0.057	C11	0.040
	7	R13	0.057	C14	0.042
	8	R16	0.057	C15	0.043
3	9	R17	0.059	C18	0.043
	10	R20	0.058	C19	0.042
	11	R21	0.056	C22	0.041
	12	R24	0.057	C23	0.041
4	13	R25	0.059	C26	0.043
	14	R28	0.056	C27	0.040
	15	R29	0.058	C30	0.044
	16	R32	0.057	C31	0.041
5	17	R33	0.059	C34	0.042
	18	R36	0.057	C35	0.042
	19	R37	0.057	C38	0.041
	20	R40	0.058	C39	0.042

Below values are auto calculated:

		x_R	x_C
NOx	AVERAGE	4.538	4.710
	STD. DEV.	0.031	0.028

		x_R	x_C
PM	AVERAGE	0.058	0.042
	STD. DEV.	0.003	0.001

Notes: δ is 1 % of X_R for NOx and 2 % of X_R for PM. For n=20, df=2n-2=38.

Number of Tests of candidate or reference fuels: 20

Note:

		x_R	x_C
NOx	AVERAGE	4.538	4.710
PM	AVERAGE	0.058	0.042

x_R	+ δ	$-S_p$	* √(2/n)	*t(0.15,df)		$x_{R\,Adjusted}$
4.538	0.045	0.030	0.316	1.051	=	4.573
0.058	0.001	0.002	0.316	1.051	=	0.059

Final Determination

	x_C		$x_{R\,Adjusted}$
NOx	4.710	Fail	4.573
PM	0.042	Pass	0.059

Note: The Final (Pass/Fail) Determination is based on a comparison of $X_{R,Adjusted}$ to X_C. However, the percent change in emissions for the candidate fuel compared to the reference fuel is based on X_R (unadjusted) and X_C.

Statistical Evaluation for B20 Additized with VESTA 5100 at 1000 ppmv
Testing Conducted: 08/17/2019 - 08/22/2019

NOx

Day	n	R		C	
1	1	R1	4.528	C2	4.684
	2	R4	4.594	C3	4.689
	3	R5	4.567	C6	4.668
	4	R8	4.539	C7	4.668
2	5	R9	4.526	C10	4.642
	6	R12	4.546	C11	4.612
	7	R13	4.508	C14	4.577
	8	R16	4.554	C15	4.626
3	9	R17	4.470	C18	4.582
	10	R20	4.481	C19	4.600
	11	R21	4.532	C22	4.605
	12	R24	4.490	C23	4.623
4	13	R25	4.427	C26	4.584
	14	R28	4.493	C27	4.595
	15	R29	4.507	C30	4.564
	16	R32	4.521	C31	4.623
5	17	R33	4.438	C34	4.630
	18	R36	4.557	C35	4.683
	19	R37	4.534	C38	4.613
	20	R40	4.518	C39	4.644

PM

Day	n	R		C	
1	1	R1	0.059	C2	0.039
	2	R4	0.056	C3	0.040
	3	R5	0.055	C6	0.041
	4	R8	0.055	C7	0.041
2	5	R9	0.060	C10	0.039
	6	R12	0.057	C11	0.042
	7	R13	0.056	C14	0.040
	8	R16	0.057	C15	0.040
3	9	R17	0.060	C18	0.040
	10	R20	0.058	C19	0.041
	11	R21	0.057	C22	0.041
	12	R24	0.057	C23	0.041
4	13	R25	0.059	C26	0.041
	14	R28	0.058	C27	0.042
	15	R29	0.059	C30	0.041
	16	R32	0.058	C31	0.040
5	17	R33	0.061	C34	0.042
	18	R36	0.057	C35	0.040
	19	R37	0.058	C38	0.042
	20	R40	0.059	C39	0.043

Below values are auto calculated:

		x_R	x_C
NOx	AVERAGE	4.517	4.626
	STD. DEV.	0.042	0.038

		x_R	x_C
PM	AVERAGE	0.058	0.041
	STD. DEV.	0.002	0.001

Notes: δ is 1 % of X_R for NOx and 2 % of X_R for PM. For n=20, df=2n-2=38.

Number of Tests of candidate or reference fuels: 20

Note:

		x_R	x_C
NOx	AVERAGE	4.517	4.626
PM	AVERAGE	0.058	0.041

x_R	+ δ	$-S_p$	* √(2/n)	* t(0.15,df)		$x_{R\ Adjusted}$
4.517	0.045	0.040	0.316	1.051	=	4.549
0.058	0.001	0.001	0.316	1.051	=	0.059

Final Determination

	x_C		$x_{R\ Adjusted}$
NOx	4.626	Fail	4.549
PM	0.041	Pass	0.059

Note: The Final (Pass/Fail) Determination is based on a comparison of $X_{R,Adjusted}$ to X_C. However, the percent change in emissions for the candidate fuel compared to the reference fuel is based on X_R (unadjusted) and X_C.

Statistical Evaluation for B20 Additized with VESTA™ at 2200 ppmv
Testing Conducted: 08/26/2019 - 08/27/2019

NOx

Day	n	R		C	
1	1	R1	4.469	C2	4.584
	2	R4	4.519	C3	4.612
	3	R5	4.552	C6	4.611
	4	R8	4.521	C7	4.618
2	5	R9	4.497	C10	4.619
	6	R12	4.544	C11	4.597
	7	R13	4.528	C14	4.588
	8	R16	4.512	C15	4.615

Below values are auto calculated:

		x_R	x_C
NOx	AVERAGE	4.518	4.605
	STD. DEV.	0.026	0.014

PM

Day	n	R		C	
1	1	R1	0.060	C2	0.041
	2	R4	0.058	C3	0.041
	3	R5	0.057	C6	0.043
	4	R8	0.060	C7	0.042
2	5	R9	0.059	C10	0.041
	6	R12	0.057	C11	0.040
	7	R13	0.056	C14	0.040
	8	R16	0.059	C15	0.039

		x_R	x_C
PM	AVERAGE	0.058	0.041
	STD. DEV.	0.001	0.001

Notes: δ is 1 % of X_R for NOx and 2 % of X_R for PM. For n=20, df=2n-2=38.

Number of Tests of candidate or reference fuels: 8

Note:

		x_R	x_C
NOx	AVERAGE	4.518	4.605
PM	AVERAGE	0.058	0.041

x_R	+ δ	$-S_p * \sqrt{(2/n)} * t(0.15,df)$				$x_{R\ Adjusted}$
4.518	0.045	0.021	0.500	1.076	=	4.552
0.058	0.001	0.001	0.500	1.076	=	0.059

Final Determination

	x_C		$x_{R\ Adjusted}$
NOx	4.605	Fail	4.552
PM	0.041	Pass	0.059

Note: The Final (Pass/Fail) Determination is based on a comparison of $X_{R,Adjusted}$ to X_C. However, the percent change in emissions for the candidate fuel compared to the reference fuel is based on X_R (unadjusted) and X_C.

Statistical Evaluation for B20 Additized with VESTA™ at 3000 ppmv
Testing Conducted: 09/19/2019 - 09/27/2019

NOx

Day	n	R		C	
1	1	R1	4.582	C2	4.726
	2	R4	4.623	C3	4.655
	3	R5	4.622	C6	4.746
	4	R8	4.654	C7	4.715
2	5	R9	4.589	C10	4.739
	6	R12	4.644	C11	4.756
	7	R13	4.653	C14	4.731
	8	R16	4.626	C15	4.736
3	9	R17	4.547	C18	4.683
	10	R20	4.593	C19	4.656
	11	R21	4.590	C22	4.725
	12	R24	4.584	C23	4.600
4	13	R25	4.546	C26	4.675
	14	R28	4.573	C27	4.647
	15	R29	4.594	C30	4.704
	16	R32	4.585	C31	4.716
5	17	R33	4.541	C34	4.672
	18	R36	4.569	C35	4.690
	19	R37	4.604	C38	4.689
	20	R40	4.580	C39	4.706

PM

Day	n	R		C	
1	1	R1	0.061	C2	0.037
	2	R4	0.053	C3	0.038
	3	R5	0.056	C6	0.038
	4	R8	0.055	C7	0.039
2	5	R9	0.059	C10	0.041
	6	R12	0.058	C11	0.040
	7	R13	0.056	C14	0.041
	8	R16	0.057	C15	0.040
3	9	R17	0.059	C18	0.039
	10	R20	0.055	C19	0.039
	11	R21	0.056	C22	0.038
	12	R24	0.055	C23	0.039
4	13	R25	0.058	C26	0.040
	14	R28	0.053	C27	0.040
	15	R29	0.055	C30	0.038
	16	R32	0.054	C31	0.038
5	17	R33	0.057	C34	0.040
	18	R36	0.060	C35	0.039
	19	R37	0.060	C38	0.042
	20	R40	0.060	C39	0.044

Below values are auto calculated:

		x_R	x_C
NOx	AVERAGE	4.595	4.698
	STD. DEV.	0.033	0.039

		x_R	x_C
PM	AVERAGE	0.057	0.039
	STD. DEV.	0.002	0.002

Notes: δ is 1 % of X_R for NOx and 2 % of X_R for PM. For n=20, df=2n-2=38.

Number of Tests of candidate or reference fuels: 20

Note:

		x_R	x_C
NOx	AVERAGE	4.595	4.698
PM	AVERAGE	0.057	0.039

x_R	+ δ	$-S_p$	* √(2/n)	* t(0.15,df)		$x_{R\ Adjusted}$
4.595	0.046	0.036	0.316	1.051	=	4.629
0.057	0.001	0.002	0.316	1.051	=	0.057

Final Determination

	x_C		$x_{R\ Adjusted}$
NOx	4.698	Fail	4.629
PM	0.039	Pass	0.057

Note: The Final (Pass/Fail) Determination is based on a comparison of $X_{R,Adjusted}$ to X_C. However, the percent change in emissions for the candidate fuel compared to the reference fuel is based on X_R (unadjusted) and X_C.

Statistical Evaluation for B10 Additized with VESTA™ at 3000 ppmv
Testing Conducted: 9/30/2019

NOx

Day	n	R		C	
1	1	R1	4.535	C2	4.610
	2	R4	4.595	C3	4.591
	3	R5	4.575	C6	4.620
	4	R8	4.610	C7	4.615

PM

Day	n	R		C	
1	1	R1	0.062	C2	0.051
	2	R4	0.057	C3	0.048
	3	R5	0.058	C6	0.046
	4	R8	0.056	C7	0.045

Below values are auto calculated:

		x_R	x_C
NOx	AVERAGE	4.579	4.609
	STD. DEV.	0.033	0.013

		x_R	x_C
PM	AVERAGE	0.058	0.047
	STD. DEV.	0.003	0.003

Notes: δ is 1 % of X_R for NOx and 2 % of X_R for PM. For n=20, df=2n-2=38.

Number of Tests of candidate or reference fuels: 4

Note:

		x_R	x_C
NOx	AVERAGE	4.579	4.609
PM	AVERAGE	0.058	0.047

x_R	+ δ	$-S_p * \sqrt{(2/n)} * t(0.15,df)$				$x_{R\ Adjusted}$
4.579	0.046	0.025	0.707	1.134	=	4.605
0.058	0.001	0.003	0.707	1.134	=	0.057

Final Determination

	x_C		$x_{R\ Adjusted}$
NOx	4.609	Fail	4.605
PM	0.047	Pass	0.057

Note: The Final (Pass/Fail) Determination is based on a comparison of $X_{R,Adjusted}$ to X_C. However, the percent change in emissions for the candidate fuel compared to the reference fuel is based on X_R (unadjusted) and X_C.