Draft Test Plan

for the CE-CERT Engine Testing Portion for the CARB Assessment of the Emissions from the Use of Biodiesel as a Motor Vehicle Fuel in California "Biodiesel Characterization Study, NOx Impact Study"

Prepared for:
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1. Objective

The goal of the proposed work is to conduct emissions tests on two engines and three biofuel-derived diesel fuels. The test fuels will include a soy-based and animal-based biodiesel, each at four blend levels (B5, B20, B50, and B100) and a renewable diesel feedstock at three blend levels (R20, R50, and R100). Testing will include regulated emissions, as well as some possible toxic emissions.

2. Test Fuels

A CARB-certified ultralow sulfur diesel (ULSD) fuel will serve as the baseline for testing. The CARB fuel will be obtained from a California refinery and will be evaluated by CARB staff to ensure its properties are consistent with those of a typical ULSD in California.

Two biodiesel feedstocks will be utilized for testing, including one soy-based and animal-based biodiesel fuel. These fuels are selected to provide a range of characteristics that can representative feedstock, but also feedstocks representing different characteristics of biodiesel in terms of cetane number and degree of saturation. Both fuels will be provided by the National Biodiesel Board.

A renewable diesel feedstock will also be used for testing. This renewable feedstock will be provided by Neste Oil, and it is known as NExBTL. This fuel is produced from renewable biomass sources such as fatty acids from vegetable oils and animal fats via a biomass to liquid diesel technology.

The biodiesel and renewable diesel feedstocks will be blended with the ULSD base in different blending ratios. The soy-based and animal-based biodiesels will be blended at levels of B5, B20, B50, as well as using the straight B100. The renewable diesel fuel will be blended at levels of R20 and R50, as well as using the straight R100.

The ULSD and the NExBTL will be tested in triplicate upon arrival to the fuel storage facility for all properties under ASTM D975 and density. The pure biodiesel feedstocks will be tested in triplicate upon arrival to the fuel storage facility for all properties under ASTM D6751 and for density. The density will be utilized for the fuel blending.

Blending of the biodiesel fuels will be performed at the fuel storage facility. Fuels will be blended on a gravimetric basis to achieve the appropriate volumetric blend levels. After blending, the biodiesel blends will be tested via ASTM-D7371 to ensure the blending was uniform and consistent with the targeted blend values.

Blending for the renewable diesel blends will be conducted at the facilities at CE-CERT using a gravimetric method. The finished blends will be tested in triplicate for the properties under ASTM D975.

3. Engine Selection

The engines will be selected from 2 model year categories; 2002-2006 and 2007+. The 2002-2006 engines are estimated to represent an important contribution to the emissions inventory from the present through 2017. The 2007 engine model year represents the latest technology that is available at present.

The 2002-2006 engine will be a 2006 model year Cummins engine. This engine will be pulled from a truck that will be used for complementary testing at CARB's chassis dynamometer laboratory in Los Angeles, CA.

The 2007 model year engine has yet to be selected.

4. Test Cycles

The test cycles for the engine testing will include the standard Federal Testing Procedure for heavy-duty engines and two other cycles that will be based on cycles being utilized for the chassis dynamometer testing. The two additional cycles will be a lightly loaded Urban Dynamometer Driving Schedule (UDDS) cycle and a more aggressive CARB heavy heavy-duty diesel truck (HHDDT) cruise cycle. The different cycles will provide a range of operating conditions and operational loads and a direct connection to the chassis dynamometer testing being conducted in CARB's Los Angeles laboratory.

The chassis dynamometer cycles will be developed utilizing engine parameters downloaded while the light UDDS and the CARB HHDDT cruise cycle are run with the test vehicle on the chassis dynamometer. The light UDDS cycle will be run over the standard chassis dynamometer UDDS cycle, with the test vehicle loaded for a fairly low weight. This represents the most lightly loaded test cycle. The CARB HHDDT cruise cycle represents the most heavily loaded cycle and will be based on the vehicle being run at its fully loaded weight. The FTP is considered a medium load test cycle on the engine dynamometer and is similar in load to that of a chassis dynamometer UDDS at a medium test weight.

The torque and engine rpm will be directly obtained from the J1939 signal for the test vehicle while it is driven. These cycles will then be programmed into the CE-CERT engine dynamometer software prior to engine testing. It should be noted that some trial runs with the light UDDS and CARB HHDDT cruise cycle will likely be required prior to initiating testing to ensure adequate engine operation and develop validation criteria for these tests.

5. Test Matrix

The test matrix is based on providing a randomized test matrix with long range replication. The test matrix provides replication of all test blends with replication of the base ULSD every 2 days. The test matrix also includes randomization within the test day with different fuels being tested in the morning vs. the afternoon. The test matrix was developed in conjunction with statisticians at CARB and the US EPA based on estimated of the magnitude of the impact biodiesel can have on NO_x emissions at a B20 level and estimates of test-to-test repeatability. Since the expected

Engine 1-pre-2007

			Main program																		Supplemental								B5			
		test days	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 1		Day 2		Day 3		Day 4		Day 1		Day 2	
Soy based biodiese	main	9	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
	Supplement	4	CAR	A	B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	C	B5	C
	B5	2		B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
			B	C		C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C
			B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	A	B5	C	CAR	C
				B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
				C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C	B	C

																													B5			
Animal based BDSL		test days	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 1		Day 2		Day 3		Day 4		Day 1		Day 2	
	main	9	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
	Supplement	4	CAR	A	B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	C	B5	C
	B5	2		B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
			B	C		C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C
			B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	A	B5	C	CAR	C
				B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
				C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C	B	C

Renewable Diesel		test days	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 1		Day 2		Day 3		Day 4	
	main	9	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
	Supplement	4	CAR	A	R20	A	R50	A	CAR	A	R100	A	R20	A	CAR	A	R50	A	R100	A	CAR	A	R20	A	R50	A	R100	A
				B		B		B		B		B		B		B		B		B		B		B		B		B
			B	C		C		C	B	C		C		C	B	C		C		C	B	C		C		C		C
			R20	A	R50	A	CAR	A	R100	A	R20	A	CAR	A	R50	A	R100	A	CAR	A	R20	A	R50	A	R100	A	CAR	A
				B		B		B		B		B		B		B		B		B		B		B		B		B
				C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C

Engine 2-2007

Soy based biodiese

		Main program																		Supplemental								B5			
	test days	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 1		Day 2		Day 3		Day 4		Day 1		Day 2	
main	9	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
Supplement	4	CAR	A	B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	C	B5	C
B5	2		B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
		B	C		C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C
		B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	A	B5	C	CAR	C
			B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
			C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C	B	C

Animal based BDSL

																												B5			
	test days	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8		Day 9		Day 1		Day 2		Day 3		Day 4		Day 1		Day 2	
main	9	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
Supplement	4	CAR	A	B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	C	B5	C
B5	2		B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
		B	C		C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C
		B20	A	B50	A	CAR	A	B100	A	B20	A	CAR	A	B50	A	B100	A	CAR	A	B20	A	B50	A	B100	A	CAR	A	B5	C	CAR	C
			B		B		B		B		B		B		B		B		B		B		B		B		B		C		C
			C		C	B	C		C		C	B	C		C		C	B	C		C		C		C	B	C		C	B	C

total Eng 2 30

NO_x impact for the B5 level should be less than that of B20, and hence more difficult to statistically differentiate from the testing variability, the B5 blend will be run outside the sequence for the other test blends and only on the highest load cycle. Preliminary test matrices for both test engines are provided below.

6. Preliminary Testing

Prior to initiating the full testing on the test matrix, several preliminary tests will be conducted utilizing the test fuels in the first test engine. These preliminary tests will include tests on both the baseline and one of more biodiesel fuels/blends. The objective of these preliminary tests are to verify the experimental parameters such as test repeatability and the biodiesel NO_x differential are consistent with the estimates used in developing the test matrix.

7. Emissions Testing

The engine emissions testing under this test plan will be performed at the University of California at Riverside's College of Engineering-Center for Environmental Research and Technology (CE-CERT). The tests will be conducted in CE-CERT's heavy-duty engine dynamometer test laboratory which is equipped with a 600 hp General Electric DC electric engine dynamometer that is a fully Code of Federal Regulations (CFR) compliant laboratory.

An engine map will be conducted prior to beginning testing on any new fuel or after refueling. In order to provide a consistent basis for comparison of the emissions, all cycles will be developed and run based on the initial engine map from operating the engine on the baseline ULSD.

Testing will be conducted on an FTP, a light-UDDS, and CARB HHDDT cruise cycle. For all tests, standard emissions measurements of total hydrocarbons (THC), CO, NO_x, PM, and CO_2 will be measured. The emissions measurements utilizing the standard analyzers in CE-CERT's heavy-duty Mobile Emissions Laboratory (MEL) trailer.

The possibility of additional toxics testing is also being considered on a subset of testing, with samples being collected for subsequent analysis for unregulated emissions to include measurements of BTEX compounds (benzene, toluene, ethyl-benzene, and xylenes) 1-3 butadiene, formaldehyde, and acetaldehyde. An option for up to 69 such analyses is being considered.

Samples for carbonyls would be collected through a heated line onto dinitrophenyl-hydrazine (DNPH)-coated silica gel cartridges. The DNPH cartridges would subsequently be eluted using acetonitrile to provide samples for analysis. The resulting extract would be analyzed using a Agilent 1200 Series high performance liquid chromatograph (HPLC) equipped with a Diode Array and Multiple Wavelength Detector, Vacuum Degasser, Thermostatted Column Compartment, and Quaternary Pump. The HPLC sample injection, column, and operating conditions would be set up according to the specifications of the HPLC method used in the Auto Oil program.

Samples for benzene and 1-3 butadiene would be collected in 8L black Tedlar GC bags. The Tedlar bag samples would be analyzed using an Agilent 5890 Series II GC with a FID maintained at 300°C. Tedlar bag samples would be analyzed within 2 hours of completion of the test, if possible, to ensure stability of 1-3 butadiene.