Draft Test Plan

Assessment of the Emissions from the Use of California Air Resources Board Qualified Diesel Fuels in Comparison with Federal Diesel Fuels - Overview

Prepared for:
Mr. Dean Bloudoff
California Air Resources Board
1001 "I" Street
P.O. Box 2815
Sacramento, CA 95812

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Submitted by:
Dr. Thomas D. Durbin
University of California
CE-CERT
Riverside, CA 92521
951-781-5794
951-781-5790 (fax)

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1. Objective

California has had in place a diesel fuel regulation that promotes and mandates clean burning diesel within the state. Recently, Federal diesel fuel regulations have been modified to reduce sulfur levels to accommodate advanced diesel engines and aftertreatment systems. The objective of this test program is to better understand and quantify the benefits of continued use of CARB diesel fuel in the State. This test program will compare CARB diesel fuels with Federal diesel fuels over a range of vehicle technologies. The primary testing will be conducted using both heavy-duty engine and chassis dynamometer testing at the University of California at Riverside. It is initially planned that a total of 3 fuels will be tested, including a blend designed to represent an average CARB ultralow sulfur diesel fuel and 2 Federal ultralow sulfur highway diesel fuels, on at least three heavy-duty on-road engines and a fleet of in-use vehicles. Both the engines and the vehicles will include a range of engine/vehicle technologies that are representative of California's in-use fleet. Additionally, tests will be conducted on newer technologies where fuel effects may differ from those found in the older technology engines.

2. Stakeholders

For the purposes of this study, a panel of interested parties will be convened. These interested parties may consist of representatives from government, industry, and academia. This could include, but will not be limited to, representatives from the engine manufacturer's association, the California Trucking Association, the oil industry, and other collaborative research groups such as the Coordinating Research Council. University of California at Riverside's College of Engineering-Center for Environmental Research and Technology (CE-CERT) will work in conjunction with ARB and appropriate stakeholders to review the relevant literature with respect to the impacts of diesel fuels and their properties on emissions. CE-CERT will work in conjunction with ARB and other interested parties to develop a test matrix and matrix of fuel properties, blends, or additives for testing. It is expected that representatives from the petroleum industry will provide significant input into this process.

3. Test Fuels

It is anticipated that a total of three fuels will be used during test program. These test fuels will include one representative CARB ultralow sulfur (CARB) diesel fuel and two Federal ultralow sulfur highway (Federal) diesel fuels. The specific CARB and Federal diesel fuels will be determined as part of the planning process, but will likely include a range of formulations designed to span a full range of emissions characteristics.

Fuel analyses according to D975 will be conducted on each of the CARB and Federal diesel fuels selected prior to starting the test program.

4. Engines for Testing

This program is being conducted to the extent possible in conjunction with a corresponding ARB program entitled "Assessment of the Emissions from the Use of Biodiesel as a Motor Vehicle Fuel in California – Biodiesel Characterization and NO_x Formation and Mitigation Study"

(Biodiesel Research Study). This will allow considerable cost savings during the implementation of both programs, as well as allow a broader comparison with other data collected under similar test conditions.

For the current program, a total of three engines are specified for engine dynamometer testing. Two of the test engines will be the same as being used in the corresponding Biodiesel Research Study. The engines were selected from 2 model year categories; 2002-2006 and 2007+. Model year 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 engine selected from the model year 2002-2006 category 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 MTA chassis dynamometer laboratory located in Los Angeles, CA. The specifications of the engine are provided in Table 1.

Table 1. Test Engine Specifications

Engine Manufacturer	Cummins, Inc.
Engine Model	ISM 370
Model Year	2006
Engine Family Name	6CEXH0661MAT
Engine Type	In-line 6 cylinder, 4 stroke
Displacement (liter)	10.8
Power Rating (hp)	385 @ 1800 rpm
Fuel Type	Diesel
Induction	Turbocharger with charge air cooler

The 2007 model year engine has yet to be selected. However, two candidates that are currently under review are a Caterpillar C13 and a Detroit Diesel MBE 4000. Both engines employ the latest technology in exhaust emissions aftertreatment. The Caterpillar C13 is a 12.5 liter diesel engine that employs cooled exhaust gas recirculation (EGR) and an actively regenerated diesel particulate filter (DPF). The Detroit Diesel MBE 4000 is a 12.8 liter diesel engine that also employs cooled EGR and a passive/active diesel oxidation catalyst (DOC)/DPF combination.

The third engine proposed for testing will be CE-CERT's in-house 1991 Detroit Diesel series 60 engine. This is the same engine platform that is the basis of CARB's alternative fuel certification program. The specifications for this engine are provided in Table 2.

Table 2. 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
Power Rating (hp)	360 @ 1800 rpm
Fuel Type	Diesel
Induction	Turbocharger with after cooler

5. Engine Dynamometer Test Cycles

The test cycles for the engine dynamometer testing will include both the standard Federal Testing Procedure (FTP) for heavy-duty diesel engines and one other cycle to be determined as part of the planning process. The additional cycle could include a cycle being developed in the corresponding Biodiesel Research Study such as a lightly loaded Urban Dynamometer Driving Schedule (UDDS) cycle or a more aggressive CARB heavy heavy-duty diesel truck (HHDDT) cruise cycle. These chassis dynamometer test cycles will be 'translated' to engine dynamometer test cycles as part of the Biodiesel Research Study.

The different cycles will provide a range of operating conditions and operational loads and a direct connection to the Biodiesel Research Study. A normally loaded UDDS cycle could also be considered as a possible test cycle. However, since the most significant test effects are likely to occur at the highest load, it is recommended that the CARB HHDDT cruise cycle be selected as the second engine test cycle.

As previously stated, the test cycle data for the CARB HHDDT cruise or the light UDDS will be developed as part of the Biodiesel Research Study and will be directly applicable for the 2006 Cummins engine and the 2007 engine selected. The parameters for the engine testing, including torque and engine rpm, will be directly obtained from the J1939 signal from a truck equipped with the test engine that is operated over the test cycles on a chassis dynamometer. The CARB HHDDT cruise cycle represents the most heavily loaded cycle and would be based on the vehicle being run at its fully loaded weight. The light UDDS cycle, if selected, would 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 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. Some trial runs with the CARB HHDDT cruise cycle or light UDDS will likely be required prior to initiating testing to ensure adequate engine operation and develop validation criteria for these tests. These trial runs will be conducted under the corresponding Biodiesel Research Study.

For the 1991 DDC series 60, some additional work may be required. This could include utilizing the cycles obtained from the E-55/59 CRC program that are currently being used in other test programs. These cycles were developed from a range of different engines, so they would likely

better simulate average engine behavior rather the behavior of this specific 1991 DDC series 60. The incorporation of these cycles for the 1991 DDC engine will also require additional time for cycle validation and practice test runs.

The proposed test matrix includes the testing of each fuel in triplicate on each test cycle. The test matrix for the engine dynamometer testing is provided below in Table 3. Additionally, a replicate of the CARB baseline will be repeated to provide a measure of the test repeatability and ensure drift is minimal over the test sequence.

Table 3. Engine Dynamometer Test Matrix
For each Test Engine

Fuel	FTP	Test cycle B (to be determined)
CARB	3	3
Federal – A	3	3
Federal – B	3	3
CARB	3	3

6. Engine Dynamometer 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 and a second engine dynamometer cycle. For all tests, standard emissions measurements of total hydrocarbons (THC), carbon monoxide (CO), oxides of nitrogen ($NO_{x)}$, nitric oxides (NO), carbon dioxide (CO_2), and particulate matter (PM), will be measured. The standard analyzers in CE-CERT's heavy-duty Mobile Emissions Laboratory (MEL) trailer will be used for all emissions measurements.

7. Chassis Dynamometer Vehicle Selection

A larger fleet of up to 15 vehicles will be selected for the chassis dynamometer testing to help verify the trend observed from the engine testing. The vehicles will be selected in conjunction with CARB and other stakeholders and will be selected to represent a range of different technologies. The vehicle selection will be based on California's in-use heavy-duty on-road fleet but will include provisions for selecting and testing newer technologies where appropriate. A number of methods will likely be used in the acquisition of vehicles for this program. CE-CERT is currently conducting a program which requires recruitment of class 8 trucks for in-use testing. CE-CERT has used various means of recruiting for this program including advertisement, local

rental agencies, private owners that are accessed from local repair and other truck service industries, and through programs associated with the ports of Los Angeles and Long Beach. Additional strategies may also be deployed for the recruitment of buses, including working with local municipalities or recruiting through the University of California fleet system. The budget incorporates resources for the recruitment of vehicles and engines, rental charges, and finders or usage incentives as needed.

8. Chassis Dynamometer Testing

Chassis dynamometer testing will be performed at CE-CERT using a heavy-duty chassis dynamometer. The chassis dynamometer will be a 48" electric AC chassis dynamometer with dual, direct connected, 300 hp motors.

Testing will be conducted on each vehicle/fuel combination over 3 different test cycles. It is proposed that one cycle be the UDDS, with a second cycle matched to the cycle performed on the engine dynamometer (i.e., either a lightly loaded UDDS or a more heavily loaded ARB HHDDT cruise cycle). The third cycle would be utilized to represent an additional type of roadway driving condition. The could include a cycle consistent with operation of a transit (CBD or other bus cycle), a cycle consistent with operation in the waste hauling industry, or a cycle representative of stop and go driving (e.g., the CARB creep cycle). It is uncertain how many cycle replicates can be performed in a typical test day, so a total of 3-4 test iterations on each cycle/fuel is utilized for this test plan. No replicate of the baseline CARB testing is proposed under this scenario to allow for the testing of a greater numbers of vehicles. If the engine dynamometer results indicate that further replicate testing is prudent, subsequent modifications can be made. The test matrix for the chassis dynamometer testing is provided below in Table 4.

Table 4. Chassis Dynamometer Test Matrix
For each Test Engine

Fuel	UDDS	Test cycle B (to be determined)	Test cycle C (to be determined)
CARB	3-4	3-4	3-4
Federal – A	3-4	3-4	3-4
Federal – B	3-4	3-4	3-4

The emissions sampling for the chassis dynamometer will utilize the same MEL sampling train as used in the engine dynamometer testing. For all tests, standard emissions measurements will include THC, CO, NO_x, NO, CO_2, and PM.