**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

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**May 2008**
**Revised October 2008**

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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. One of the Federal diesel fuels, referred to as "Federal A", will represent an average Federal ultralow sulfur diesel fuel. The second, referred to as "Federal B", will be a commercially available Federal ultralow sulfur diesel fuel that due to its properties may contribute to higher exhaust emissions. The specific CARB and Federal diesel fuels will be determined as part of the planning process an 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 those being used in the corresponding Biodiesel Research Study. The engines were selected from 2 model year categories; 2002-2006 and 2007+. Engines in the 2002-2006 model year category are estimated to represent an important contribution to the emissions inventory from the present through 2017. Engines in the 2007+ model year category represent the latest technology that is currently commercially available.

**Update:** Several heavy-duty diesel engine manufactures are currently testing prototype engines designed to meet the stringent 2010 NOx and NMHC requirements. Originally, the ability to test an engine that meets these new 2010 emissions standards was not possible due to the timing of the study. However, we are currently seeking input from several engine manufacturers regarding the possibility of including a prototype 2010 engine for engine dynamometer testing in the current program.

The engine selected from the model year 2002-2006 category will be a 2006 model year Cummins ISM engine. This engine will be removed from a truck that will be used for complementary testing at ARB's MTA chassis dynamometer laboratory located in Los Angeles, California. 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 engine selected from the 2007+ model year category will be a 2007 Detroit Diesel MBE 4000. This engine will also be removed from a truck purchased specifically for complementary testing at ARB's MTA chassis dynamometer laboratory located in Los Angeles, California. 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 specifications of the engine are provided in Table 2.

**Table 2. Test Engine Specifications**

| | |
|---|---|
| Engine Manufacturer | Detroit Diesel Corp. |
| Engine Model | MBE4000 |
| Model Year | 2007 |
| Engine Family Name | 7DDXH12.8DJA |
| Engine Type | In-line 6 cylinder, 4 stroke |
| Displacement (liter) | 12.8 |
| Power Rating (hp) | Varies, 350-450 hp @ 1900 rpm |
| Fuel Type | Diesel |
| Induction | Turbocharger with after cooler |

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 has formed the basis of ARB's alternative fuel certification program. The specifications for this engine are provided in Table 3.

**Table 3. 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 heavy-duty Federal Testing Procedure (FTP) transient cycle and the recently translated ARB heavy heavy-duty diesel truck (HHDDT) cruise cycle. The HHDDT cruise cycle was recently 'translated' to an engine dynamometer test cycle as part of the Biodiesel Research Study.

These test cycles will provide a range of operating conditions and operational loads and a direct connection to the Biodiesel Research Study. Since the most significant test effects are likely to occur at the highest load, the ARB HHDDT cruise cycle has been selected as the second engine test cycle.

As previously stated, the test cycle data for the ARB HHDDT cruise was developed as part of the Biodiesel Research Study and will be directly applicable for the 2006 Cummins engine and the 2007 DDC engine, and the 2010 engine if available. The parameters for the engine testing, including torque and engine rpm, were directly obtained from the J1939 signal from a truck equipped with the test engine that was

operated over the test cycles on a chassis dynamometer. The ARB HHDDT cruise cycle represents the most heavily loaded cycle and will be based on the vehicle being run at its fully loaded weight. The heavy-duty 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 ARB HHDDT cruise cycle will likely be required prior to initiating testing to ensure adequate engine operation and to 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 than 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 requires an equal number of tests be conducted using each test fuel on each test engine. On any given calendar day, three test replicates each of two different test fuels will be run for a total of six test replicates per day (three in the morning and three in the afternoon). In addition, testing on each subsequent day will begin with the test fuel that was tested at the end of the preceding day. This has the effect of completing triplicate tests using each fuel during both morning and afternoon testing. This should help ensure engine drift is minimal over the test sequence and provide a measure of test repeatability. All tests will be hot start tests and each days testing will begin with an engine warm up period with operation at rated speed and load prior to the start of the appropriate test cycle.

In all, each fuel will be used to complete six replicate tests cycles on each engine using both the heavy-duty FTP cycle and the ARB HHDDT cruise cycle. The test matrix for the engine dynamometer testing is provided below in Table 4.

**Table 4. Engine Dynamometer Test Matrix**
**For each Test Engine**

| Test Day | Morning Schedule (assumes 3 replicates) | Afternoon Schedule (assumes 3 replicates) |
|---|---|---|
| **Heavy-Duty FTP Test Cycle** | | |
| Day 1 | CCC | AAA |
| Day 2 | AAA | BBB |
| Day 3 | BBB | CCC |
| **ARB HHDDT Cruise Test Cycle** | | |
| Day 4 | CCC | AAA |
| Day 5 | AAA | BBB |
| Day 6 | BBB | CCC |

C = CARB diesel fuel, A = Federal A diesel fuel, B = Federal B diesel fuel

## 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 a fully Code of Federal Regulations (CFR) compliant laboratory equipped with a 600 hp General Electric DC electric engine dynamometer.

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 the heavy-duty FTP and the ARB HHDDT test cycles. 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 fleet of up to 9 vehicles will be selected for the chassis dynamometer testing to help verify any trends 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 has conducted a number of programs that have required recruitment of class 8 trucks for in-use testing. CE-CERT has used various means of recruiting for these programs 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 using the ARB HHDDT cruise cycle. Initially, several test cycles were proposed to represent additional types of roadway driving conditions. However, since resources are limited and test-to-test

variability is historically somewhat greater as compared to engine dynamometer testing, the ability to increase the number replicates per fuel type was deemed more significant than the inclusion of an additional test cycle.

It is anticipated that a total of six test cycle replicates can be performed in a typical test day, so a total of 12 test iterations on each fuel is utilized for this test plan. This test plan now includes several replicates of the baseline CARB diesel fuel at various times throughout the six-day test matrix. This same matrix would be repeated for each vehicle tested. All tests will be hot start tests and each days testing will begin with a vehicle warm up period prior to the start of the appropriate test cycle.

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 5.

**Table 5. Chassis Dynamometer Test Matrix**
**For each Test Vehicle**

| Test Day | Morning Schedule (assumes 3 replicates) | Afternoon Schedule (assumes 3 replicates) |
|---|---|---|
| **ARB HHDDT Cruise Test Cycle** | | |
| Day 1 | CCC | AAA |
| Day 2 | AAA | BBB |
| Day 3 | BBB | CCC |
| Day 4 | CCC | AAA |
| Day 5 | AAA | BBB |
| Day 6 | BBB | CCC |

C = CARB diesel fuel, A = Federal A diesel fuel, B = Federal B diesel fuel

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.