

Draft Test Plan
Vehicle Emissions Tests at ARB's MTA Facility
Biodiesel Characterization Study
Part two: Emissions Tests

Prepared in collaboration with Tom Durbin

1. Objective

The purpose of the chassis emissions study is to compare real world emissions from on-road vehicles fueled on biodiesel, renewable and California Air Resources Board (CARB) diesel. Regulated and unregulated emissions will be measured and health effects tests will be performed to assess the impact of biodiesel and renewable diesel use in California.

2. Vehicle Selection

The vehicles will be selected for testing at CARB's Heavy-Duty Diesel Engine Test Facility's (MTA) chassis dynamometer in Los Angeles, CA. Three vehicles will be tested.

- 2006 Truck equipped with an 11 liter Cummins ISM engine.
- 2007 Truck equipped with an 15 liter Caterpillar engine
- 1998-2006 bus or medium duty vehicle. The vehicle will be tested with and without a retrofitted after treatment device.

3. Test Cycles and Translating Chassis Test Cycles to Engine Test Cycles

Vehicles will be run on two test cycles, a medium load UDDS cycle and a higher load CARB heavy heavy-duty diesel truck (HHDDT) cruise cycle. These test cycles will provide a range of operating conditions and operational loads, as well as a direct connection to the engine dynamometer testing being conducted in CE-CERT. More detailed information on these cycles is provided in Attachment A.

The test cycles will be run at two different loads to allow a better understanding of biodiesel impacts under different load conditions. For the UDDS cycle, the truck will be loaded at a mid-load test weight. For the 2006 Truck, this represents approximately 40,000 lbs. For the CARB HHDDT Cruise cycle, the truck will be loaded at its full loaded weight or slightly below this value. For the 2006 truck, this will be 66,000 lbs.

Data collected from the chassis dynamometer driving cycles will also be used to directly develop cycles for the engine dynamometer testing. These engine dynamometer cycles will be developed from the speed and torque values in the J1939 data stream during the running of standard test cycles on the chassis dynamometer. For one engine cycle

called the “light UDDS”, the 2006 Truck will be operated over the UDDS cycle using its empty weight of 13,200 lbs. For the other cycle, the CARB HHDDT Cruise cycle, the 2006 truck will be operated over the CARB HHDDT Cruise cycle with the truck loaded to its full capacity of 66,000 lbs. In each case, the truck will be operated over the specified cycle for as many iterations as can reasonably be done in a single day. It is anticipated that this will provide between 5-7 test runs for data. The data will be averaged from these test runs for the development of the engine cycle. It is anticipated that the J1939 signal will also be monitored as part of the standard parameters collected during the main test matrix.

4. Test Fuel Matrix and Lubrication Oil.

The fuel test matrix consists of two biodiesel feedstocks, soy and animal fat and one renewable diesel fuel at the following blend levels, where the numbers reflect the percent of biodiesel or renewable in the fuel blend.

- Biodiesel, B20, B50, and B100
- Renewable diesel, R20, R50, and R100

All vehicles will use APICJ4 lubrication oil. The lubrication oil will be changed before a vehicle is tested and will be used throughout all the testing conducted on that vehicle. The vehicle will be driven for at least 100 miles following the oil change prior to testing.

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 was based on the test matrix used for the NO_x impact study, which was developed in conjunction with statisticians at CARB and the US EPA.

Prior to initiating the full testing on the test matrix, several preliminary tests will be conducted utilizing the test fuels in the vehicle equipped with the 2006 Cummins ISM engine. These preliminary tests will include tests on both the baseline and one or more biodiesel fuels/blends. The objective of these preliminary tests is to provide range finding for the toxics sampling and health effects testing and to construct engine dynamometer test cycles from vehicle test cycles.

5. Toxic Emissions Tests and Health Effects Tests.

Tables 1-4 provide detailed information on the toxics emission tests and health effects tests.

Table 1. List of chemical species

PAHs	Nitro-PAHs	Carbonyls-bisulfite (cont)	Carbonyls-DNPH cont
1 1-methylnaphthalene	1 1-nitronaphthalene	21 2,3-butanedione	11 crotonaldehyde
2 2-methylnaphthalene	2 5-nitroacenaphthene	22 2,3-pentanedione	12 valeraldehyde
3 2,6-dimethylnaphthalene	3 2-nitrofluorene	23 3,4-hexanedione	13 m-tolualdehyde
4 2,3,5-trimethylnaphthalene	4 9-nitroanthracene	24 2,4-pentanedione	
5 1-methylphenanthrene	5 3-nitrofluoranthene	25 2,3-hexanedione	Ions
6 3-methylcholanthrene	6 1-nitropyrene	26 glyoxal	1 sodium
7 2-methylfluoranthene	7 6-nitrochrysene	27 methyl glyoxal	2 ammonium
8 5-methylchrysene	8 7-nitrobenz(a)anthracene	28 2-furaldehyde	3 potassium
9 7,12-dimethylbenz(a)anthracene	9 6-nitrobenzo(a)pyrene	29 nopinone	4 nitrate
10 naphthalene		30 pionaldehyde	5 sulfate
11 acenaphthylene	Carbonyls-bisulfite		Others
12 acenaphthene	1 acetaldehyde	VOCs	1 N2O
13 fluorene	2 propanal	1 1,3-butadiene	2 NO/NO2
14 phenanthrene	3 butanal	2 benzene	3 EC/OC
15 anthracene	4 pentanal	3 toluene	4 Elements
16 fluoranthene	5 3-methylbutanal	4 ethyl benzene	5 Ultrafines
17 pyrene	6 hexanal	5 m/p-xylene	
18 chrysene	7 octanal	6 o-xylene	
19 benza[a]anthracene	8 2-methylpropanal	7 styrene	
20 benzo[b]fluoranthene	9 acrolein		
21 benzo[j]fluoranthene	10 crotonaldehyde	Carbonyls-DNPH	
22 benzo[k]fluoranthene	11 3-methyl-2-butanal	1 formaldehyde	
23 benzo[e]pyrene	12 2-hexenal	2 acetaldehyde	
24 benzo[a]pyrene	13 2-heptenal	3 acrolein	
25 perylene	14 benzaldehyde	4 acetone	
26 indeno[1,2,3-cd]pyrene	15 o,m-tolualdehyde	5 propionaldehyde	
27 dibenz[a,h]anthracene	16 2-ethylbenzaldehyde	6 butyraldehyde	
28 dibenzo[a,e]pyrene	17 p-tolualdehyde	7 hexanal	
29 dibenzo[a,l]pyrene	18 3,4-dimethylbenzaldehyde	8 benzaldehyde	
30 dibenzo[a,h]pyrene	19 4-methoxybenzaldehyde	9 methyl ethyl ketone	
31 dibenzo[a,i]pyrene	20 1-naphthaldehyde	10 methacrolein	

Table 2. Target detection limit and sampling information

Target Analyte	Detection Limit mass per sample	Sample Flow Rate	Total Exhaust Flow Rate	Number of cycles composited 2006/2007	2006 Vehicle UDDS mass per mile	2007 Vehicle UDDS mass per mile
PAHs (sorbant)	0.5 ng	120 L/min	2500 cfm	2/4	26 ng/mi	13 ng/mi
PAHs (filter)	0.05 ng	120 L/min	2500 cfm	2/4	2.6 ng/mi	1.3 ng/mi
Nitro-PAHs (sorbant)	2.5 ng	120 L/min	2500 cfm	2/4	130 ng/mi	65 ng/mi
Nitro-PAHs (filter)	.25 ng	120 L/min	2500 cfm	2/4	13 ng/mi	7 ng/mi
Unsaturated Carbonyls (bisulfite)	50 ng	15 L/min	2500 cfm	1/1	20 ug/mi	20 ug/mi
EC/OC	0.31 ug	40 L/min	2500 cfm	1/1	0.005 mg/mi	0.005 mg/mi
Ions	0.06-.16 ug	40 L/min	2500 cfm	1/1	0.020-.0040 mg/mi	0.020-.0040 mg/mi
Carbonyls (DNPH)	0.02 ug	1 L/min	2500 cfm	1/1	0.13 mg/mi	0.25 mg/mi
Target Analytes	Detection limit concentration				2006 Vehicle UDDS mass per mile	2007 Vehicle UDDS mass per mile
Volatile organics	0.1 ppm(C)				12 mg(C)/mi	12 mg(C)/mi
Nitrous Oxide	0.1 ppm				43 mg/mi	43 mg/mi

Table 3. A summary of the chemical species sampling, storage, and analysis

Target Analyte	Sampling	Storage	Analysis
PAHs (sorbant)	PUF/XAD	Wrapped in aluminum foil, shipped on blue ice and stored in a freezer	Extracted and analyzed by high resolution gas chromatography/mass spectrometry (GC/MS)
PAHs (filter)	Filter	Wrapped in aluminum foil, shipped on blue ice and stored in a freezer	Extracted in dichloromethane, clean up, and analyzed by GC/MS
Nitro-PAHs (sorbant)	PUF/XAD	Wrapped in aluminum foil, shipped on blue ice and stored in a freezer	Extracted and analyzed by high resolution gas chromatography/ negative chemical ionization mass spectrometry (GC/NCIMS)
Nitro-PAHs (filter)	Filter	Wrapped in aluminum foil, shipped on blue ice and stored in a freezer	Extracted, cleanup, and analyzed by GC/NCIMS
Unsaturated Carbonyls (bisulfite)	Bisulfite mist chamber	Extract frozen	The carbonyl is liberated from the bisulfite adduct and derivitized and analyzed by GC/NCIMS
EC/OC (ARB SOP 139)	Quartz filter	Stored in refrigerator or desiccator	OC and EC are converted to CO ₂ and converted to methane and analyzed by FID via the IMPROVE test protocol
Ions (ARB SOP 142)	Teflon filter	Filters are frozen and stored up to 30 days	Ion chromatography
DNPH method Carbonyls (ARB SOP 104)	Two DNPH coated cartridges, exhaust and background samples collected	Store below 40 °F for up to 30 days	Cartridges eluted in acetonitrile and analyzed by HPLC UV/Visible detector

<p>Volatile organics (VOCs) (ARB SOP 119)</p>	<p>Tedlar bags-parallel exhaust and background samples collected. Separate pair of Tedlar bags samples collected for 1,3-butadiene analysis</p>	<p>Shipped in black plastic bags and analyzed in 8 hours except 1,3-butadiene which is analyzed in 2 hours</p>	<p>Samples pre-concentrated and analyzed by GC/FID</p>
<p>Nitrous Oxide (ARB SOP 136)</p>	<p>Tedlar bags</p>	<p>Stable for at least 4 days</p>	<p>Analyzed by FTIR</p>
<p>Biological samples- Comet/lung macrophage</p>	<p>Filter</p>	<p>Shielded from light and stored under reduced temperature</p>	<p>See Table</p>
<p>Ames tests</p>	<p>Filter/PUF</p>	<p>Shielded from light and stored under reduced temperature</p>	<p>See Table</p>
<p>Ultrafines particle number, particle size distribution, real-time mass, and surface area</p>	<p>Direct partial flow sampling, pre-trap and post-trap</p>	<p>NA</p>	

6. Health Effects Tests

Table 4 summarizes the health effects tests planned for this study.

Table 4. Summary of health effects tests

Biological Test
Mutagenicity TA-98 +/-S9 TA100 +/-S9 TA102 TA104
DNA damage Comet Assay
Oxidative stress and inflammation Human lung and macrophage assays Endpoints Cytokine IL-8 and TNF (tumor necrosis factor) COX-2 prostaglandin synthase HO-1 heme oxygenase-1 C-reactive protein cardiovascular stress and acute inflammatory marker

The following is the estimated minimum amount of particulate matter that needs to be collected per sample in order to conduct health effects tests.

- Comet assay-200 micrograms of PM
- Lung macrophage-200 micrograms of PM
- TA100, TA98, TA102, and TA104 Mutagenicity-200 micrograms of PM

7. Sampling Test Matrix.

Three vehicles will be tested. The study is divided in two parts, in-depth testing and less comprehensive testing. Given in Figure 1 is the sampling test matrix. Given in Figure 2 is the test schedule for vehicle one and two where the in-depth toxics testing will be conducted. Given in Figure 3 is the test schedule for vehicle three.

Less-comprehensive testing

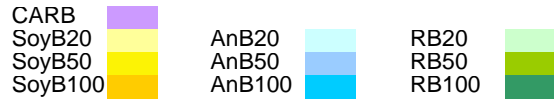
- Includes testing of volatile organics, carbonyl, NO/NO₂, and ultrafines
- Samples collected on the UDDS and CARB HHDDT Cruise cycle
- All fuels and blends will be tested.
- All three vehicles will be tested.

In-depth testing

- Includes all toxics including N₂O, NO/NO₂, ultrafines, VOCs, carbonyls, EC/OC, ions, reactive carbonyls, PAHs, and nitro-PAHs and health effects testing.
- Samples collected only on the UDDS test cycle
- For vehicle one (truck equipped with a 2006 ISM Cummins engine), all blends levels and feedstocks will be tested
- For vehicle two (truck equipped with a 2007 Caterpillar engine) only the soy-based biodiesel will be tested.

Figure 1. Sampling test matrix

Vehicle: 3 vehicles, 4 configurations
 Cycles: UDDS and ARB 55mph Transient
 Feedstocks/fuels: soy, animal fat, and renewable diesel



A=UDDS

B=ARB transient

AA means two UDDS back to back runs composited into one sample for UCD

AAAA means four UDDS back to back runs composited into one sample

F/C/C means fuel change and tunnel conditioning

Bold cycle mean samples collected for MLD. For composite samples only one of the composite samples collected for MLD
 2 bags for VOCs, one sample each for all carbonyl, ions, ec/oc

In Depth Toxics Characterization Matrix			VOCs and Carbonyls					
Vehicle 1	A	B	Vehicle 1	A	B	Vehicle 3	A	B
TB	1		TB			TB		
CARB	3	0	CARB	3	3	CARB	3	3
SoyB20	3	0	SoyB20	3	3	SoyB20	3	3
SoyB50	3	0	SoyB50	3	3	SoyB50	0	0
SoyB100	3	0	SoyB100	3	3	SoyB100	3	3
TB	1		TB			TB		
CARB	3	0	CARB	3	3	CARB	3	3
AnB20	3	0	AnB20	3	3	AnB20	3	3
AnB50	3	0	AnB50	3	3	AnB50	0	0
AnB100	3	0	AnB100	3	3	AnB100	3	3
TB	1		TB			TB		
CARB	3	0	CARB	3	3	Totals	18	18
R20	3	0	R20	3	3			
R50	3	0	R50	3	3			
R100	3	0	R100	3	3			
TB	1		TB					
Totals	39	0	Totals	36	36			
Vehicle 2	A	B	Vehicle 2	A	B	Vehicle 3r	A	B
TB	1		TB			TB		
CARB	3	0	CARB	3	3	CARB	3	3
SoyB20	3	0	SoyB20	3	3	SoyB20	3	3
SoyB50	3	0	SoyB50	3	3	SoyB50	0	0
SoyB100	3	0	SoyB100	3	3	SoyB100	3	3
TB	1		TB			TB		
Totals	13	0	CARB	3	3	CARB	3	3
5 samples for NOx mit			AnB20	3	3	AnB20	3	3
			AnB50	0	0	AnB50	0	0
			AnB100	3	3	AnB100	3	3
			TB			TB		
			Totals	21	21	Totals	18	18

Figure 2. Test matrix for vehicle one and two.

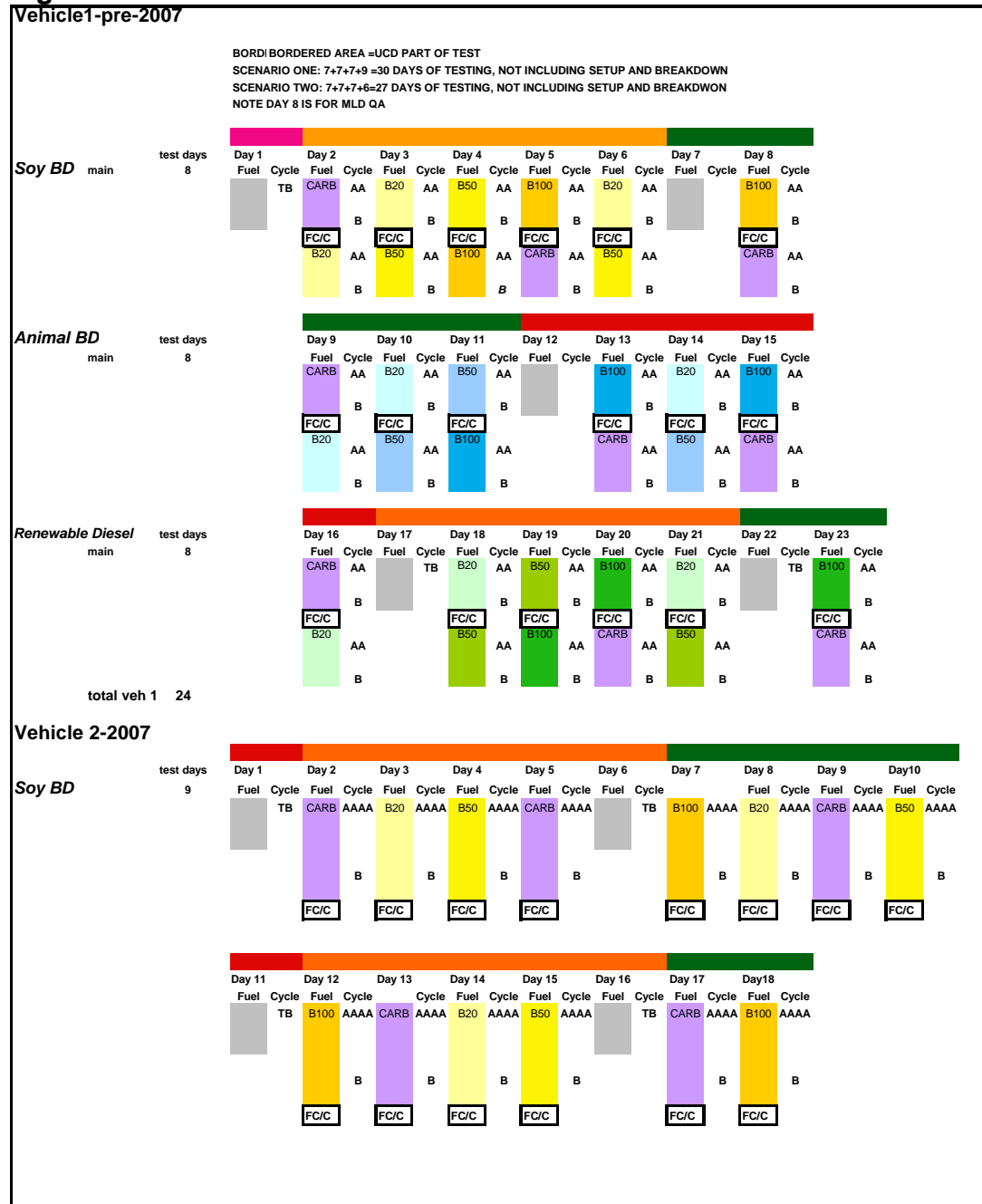


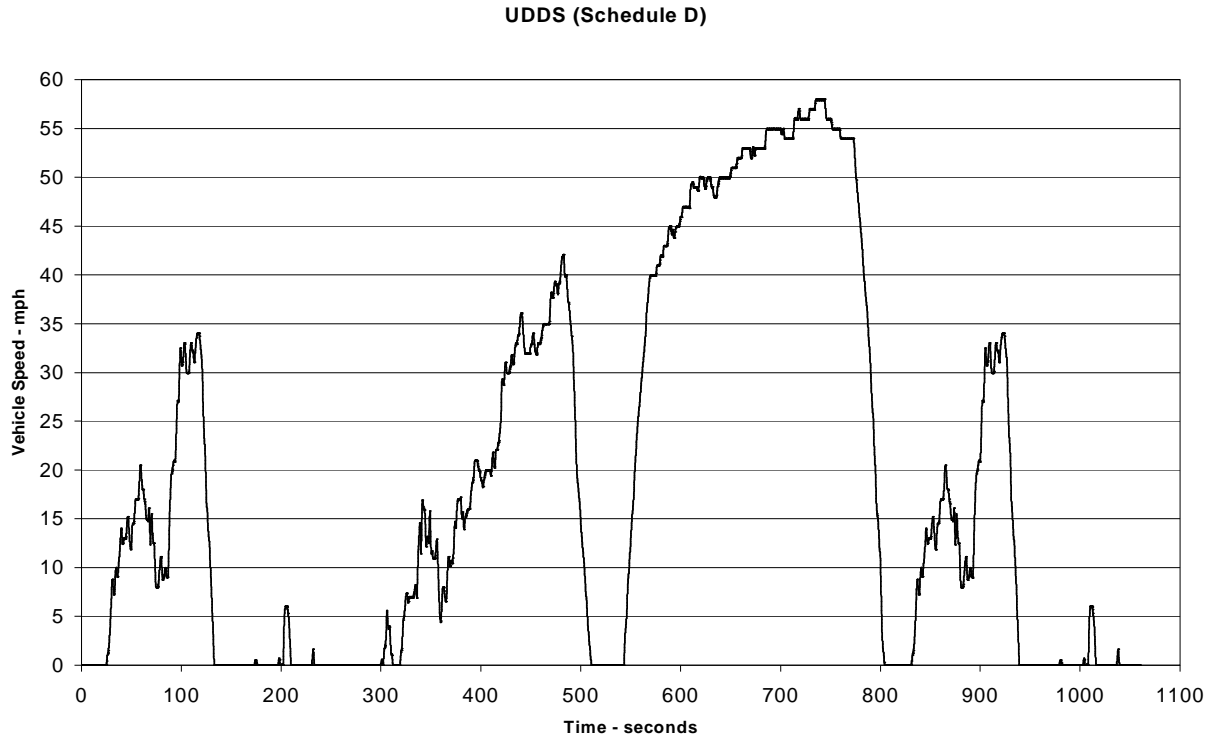
Figure 3. Test matrix for vehicle 3.

		Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Day 8	
test days	8	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle	Fuel	Cycle
Vehicie 3																	
Soy BD			TB	CARB	A	B20	A	B50	A	B100	A		TB	B20	A	B100	A
				FC/C	B	FC/C	B	FC/C	B	FC/C	B			FC/C	B	FC/C	B
				B20	A	B50	A	B100	A	CARB	A			B50	A	CARB	A
					B		B		B		B				B		B
Animal BD			TB	CARB	A	B20	A	B50	A	B100	A		TB	B20	A	B100	A
				FC/C	B	FC/C	B	FC/C	B	FC/C	B			FC/C	B	FC/C	B
				B20	A	B50	A	B100	A	CARB	A			B50	A	CARB	A
					B		B		B		B				B		B
Total Veh : 16																	
Vehicie 3R																	
Soy BD			TB	CARB	A	B20	A	B50	A	B100	A		TB	B20	A	B100	A
				FC/C	B	FC/C	B	FC/C	B	FC/C	B			FC/C	B	FC/C	B
				B20	A	B50	A	B100	A	CARB	A			B50	A	CARB	A
					B		B		B		B				B		B
Animal BD			TB	CARB	A	B20	A	B50	A	B100	A		TB	B20	A	B100	A
				FC/C	B	FC/C	B	FC/C	B	FC/C	B			FC/C	B	FC/C	B
				B20	A	B50	A	B100	A	CARB	A			B50	A	CARB	A
					B		B		B		B				B		B

Attachment A – Test Cycles

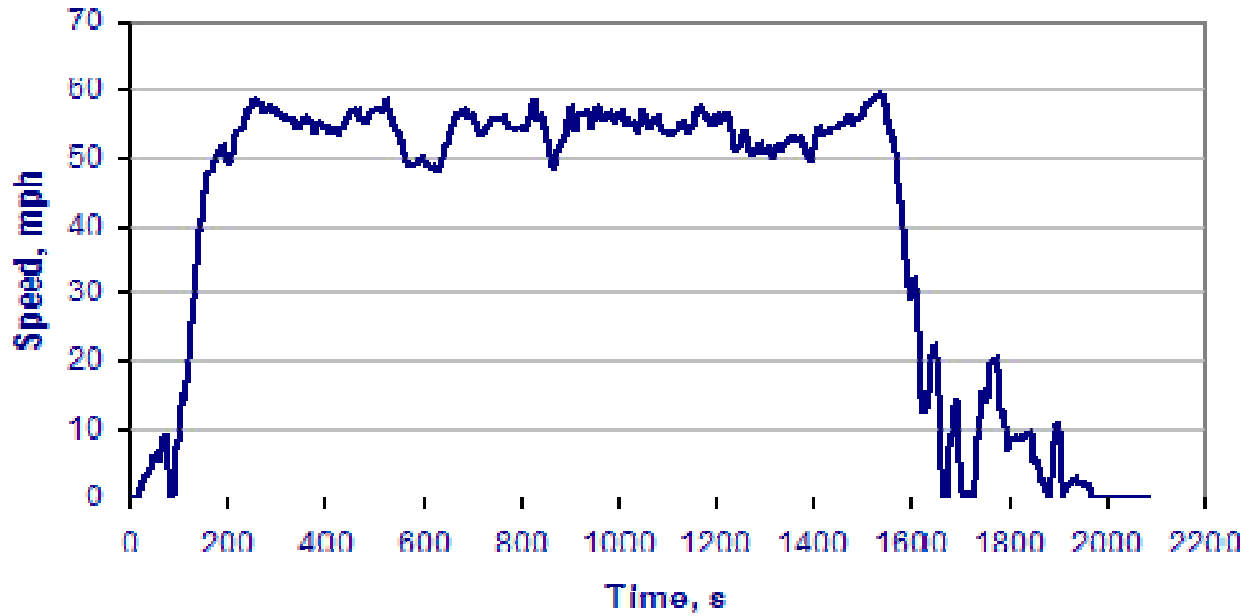
UDDS

Federal heavy-duty vehicle Urban Dynamometer Driving Schedule (UDDS) is a cycle commonly used to collect emissions data on engines already in heavy, heavy-duty diesel (HHD) trucks. This cycle covers a distance of 5.55 miles with an average speed of 18.8 mph and maximum speed of 58 mph.



CARB Heavy Heavy-Duty Diesel Truck (HHDDT) Cruise Schedule

The CARB Heavy Heavy-Duty Diesel Truck (HHDDT) Cruise schedule is part of a four mode test cycle developed for chassis dynamometer testing by the California Air Resources Board with the cooperation of West Virginia University. This cycle covers a distance of 23.1 miles with an average speed of 39.9 mph and maximum speed of 59.3 mph.



CARB HHDDT Cruise Schedule