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

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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
1	1-methylnaphthalene
2	2-methylnaphthalene
3	2,6-dimethylnaphthalene
4	2,3,5-trimethylnaphthalene
5	1-methylphenanthrene
6	3-methylcholanthrene
7	2-methylflluoranthene
8	5-methylchrysene
9	7,12-dimethylbenz(a)anthracene
10	naphthalene
11	acenaphthylene
12	acenaphthene
13	fluorene
14	phenanthrene
15	anthracene
16	fluoranthene
17	pyrene
18	chrysene
19	benza[a]anthracene
20	benzo[b]fluoranthene
21	benzo[j]fluoranthene
22	benzo[l]fluoranthene
23	benzo[e]pyrene
24	benzo[a]pyrene
25	perylene
26	indeno[1,2,3-cd]pyrene
27	dibenz[a,h]anthracene
28	dibenzo[a,e]pyrene
29	dibenzo[a,l]pyrene
30	dibenzo[a,h]pyrene
31	dibenzo[a,i]pyrene

	Nitro-PAHs
1	1-nitronaphthalene
2	5-nitroacenaphthene
3	2-nitrofluorene
4	9-nitroanthracene
5	3-nitrofluoranthene
6	1-nitropyrene
7	6-nitrochrysene
8	7-nitrobenz(a)anthracene
9	6-nitrobenzo(a)pyrene

	Carbonyls-bisulfite
1	acetaldehyde
2	propanal
3	butanal
4	pentanal
5	3-methylbutanal
6	hexanal
7	octanal
8	2-methlpropanal
9	acrolein
10	crotonaldehyde
11	3-methyl-2-butenal
12	2-hexenal
13	2-heptenal
14	benzaldehyde
15	o,m-tolualdehyde
16	2-ethylbenzaldehyde
17	p-tolualdehyde
18	3,4-dimethylbenzaldehyde
19	4-methoxybenzaldehyde
20	1-naphthaldehyde

	Carbonyls-bisulfite (cont)
21	2,3-butanedione
22	2,3-pentanedione
23	3,4-hexanedione
24	2,4-pentanedione
25	2,3-hexandedione
26	glyoxal
27	methyl glyoxal
28	2-furaldehyde
29	nopinone
30	pionaldehyde

	VOCs
1	1,3-butadiene
2	benzene
3	toluene
4	ethyl benzene
5	m/p-xylene
6	o-xylene
7	styrene

	Carbonyls-DNPH
1	formaldehyde
2	acetaldehyde
3	acrolein
4	acetone
5	propionaldehyde
6	butyraldehyde
7	hexanal
8	benzaldehyde
9	methyl ethyl ketone
10	methacrolein

	Carbonyls-DNPH cont
11	crotnaldehyde
12	valeradehyde
13	m-tolualdehyde

	Ions
1	sodium
2	ammonium
3	potassium
4	nitrate
5	sulfate

	Others
1	N2O
2	NO/NO2
3	EC/OC
4	Elements
5	Ultrafines

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 EÇ 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 ^{0}F for up to 30 days	Cartridges eluted in acetonitrile and analyzed by HPLC UV/Visible detector

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

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
Oxiative stress and inflammation
Human lung and marcophage assays
Endpoints
Cytokine IL-8 and TNF (tumor necrosis factor)
COX-2 prostaglandin synthase
HO-1 heme oxygenase-1
C-reactive protein cardiovasccular 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 Mutagencity-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/NO_2, 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 N_2O, NO/NO_2, 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 configuations
Cycles: UDDS and ARB 55mph Transient
Feedstocks/fuels: soy, animal fat, and renewable diesel

CARB			
SoyB20	AnB20	RB20	
SoyB50	AnB50	RB50	
SoyB100	AnB100	RB100	

A=UDDS **B=ARB transient**

AA 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**

FC/C **means fuel change and tunnel conditioning**

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

In Depth Toxics Characterization Matrix

Vehicle 1	A	B
TB	1	
CARB	3	0
SoyB20	3	0
SoyB50	3	0
SoyB100	3	0
TB	1	
CARB	3	0
AnB20	3	0
AnB50	3	0
AnB100	3	0
TB	1	
CARB	3	0
R20	3	0
R50	3	0
R100	3	0
TB		
Totals	39	0

Vehicle 2	A	B
TB	1	
CARB	3	0
SoyB20	3	0
SoyB50	3	0
SoyB100	3	0
TB		
Totals	13	0

5 samples for NOx mit

VOCs and Carbonyls

Vehicle 1	A	B
TB		
CARB	3	3
SoyB20	3	3
SoyB50	3	3
SoyB100	3	3
TB		
CARB	3	3
AnB20	3	3
AnB50	3	3
AnB100	3	3
TB		
CARB	3	3
R20	3	3
R50	3	3
R100	3	3
TB		
Totals	36	36

Vehicle 2	A	B
TB		
CARB	3	3
SoyB20	3	3
SoyB50	3	3
SoyB100	3	3
TB		
CARB	3	3
AnB20	3	3
AnB50	0	0
AnB100	3	3
TB		
Totals	21	21

Vehicle 3	A	B
TB		
CARB	3	3
SoyB20	3	3
SoyB50	0	0
SoyB100	3	3
TB		
CARB	3	3
AnB20	3	3
AnB50	0	0
AnB100	3	3
TB		
Totals	18	18

Vehicle 3r	A	B
TB		
CARB	3	3
SoyB20	3	3
SoyB50	0	0
SoyB100	3	3
TB		
CARB	3	3
AnB20	3	3
AnB50	0	0
AnB100	3	3
TB		
Totals	18	18

Figure 2. Test matrix for vehicle one and two.

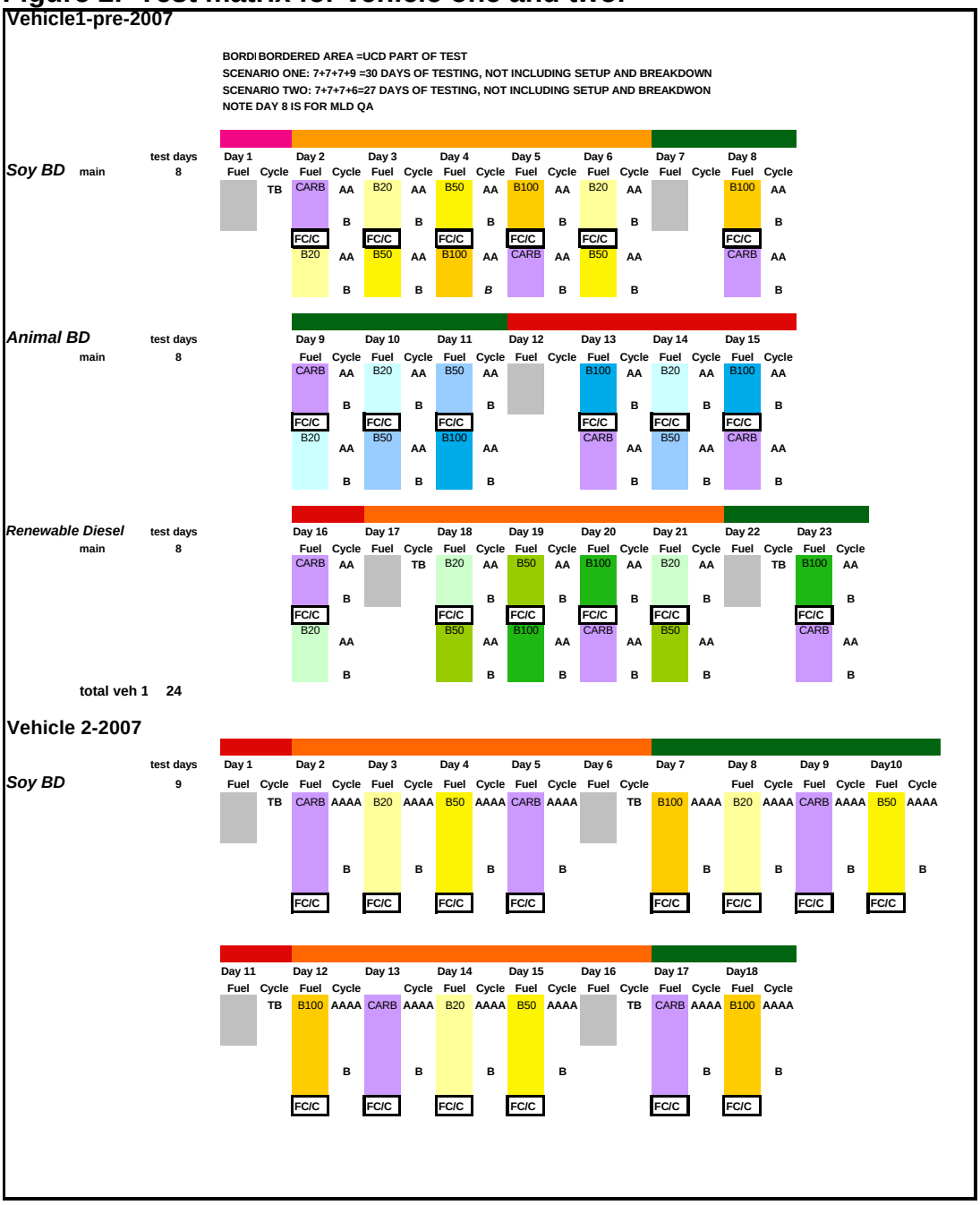
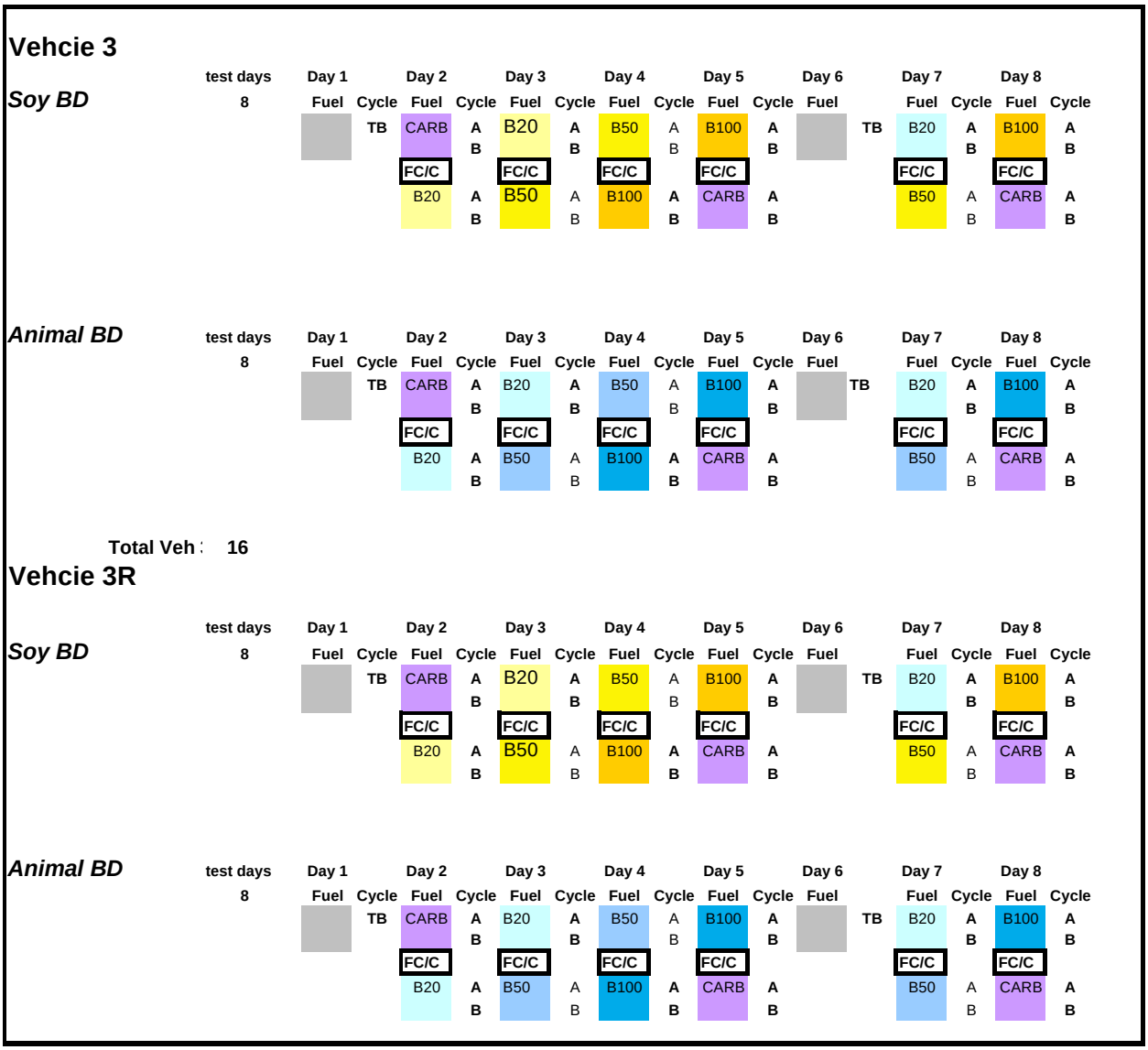


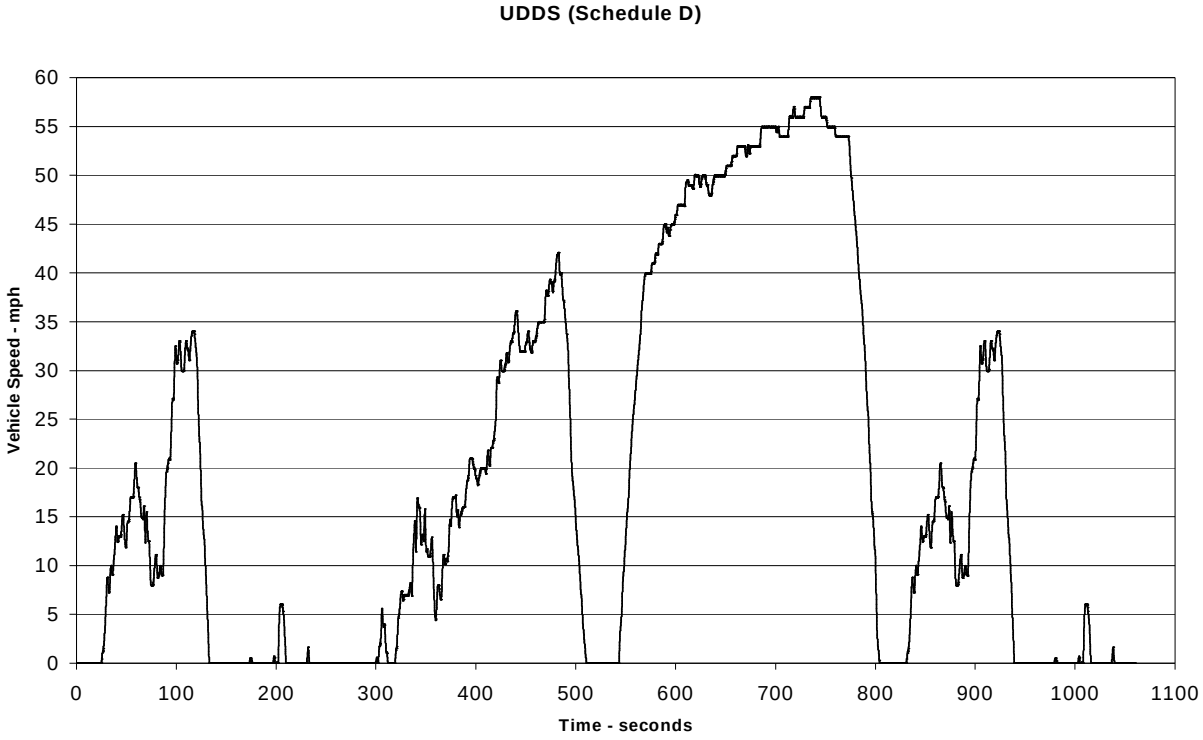
Figure 3. Test matrix for vehicle 3.



Attachment A – Test Cycles

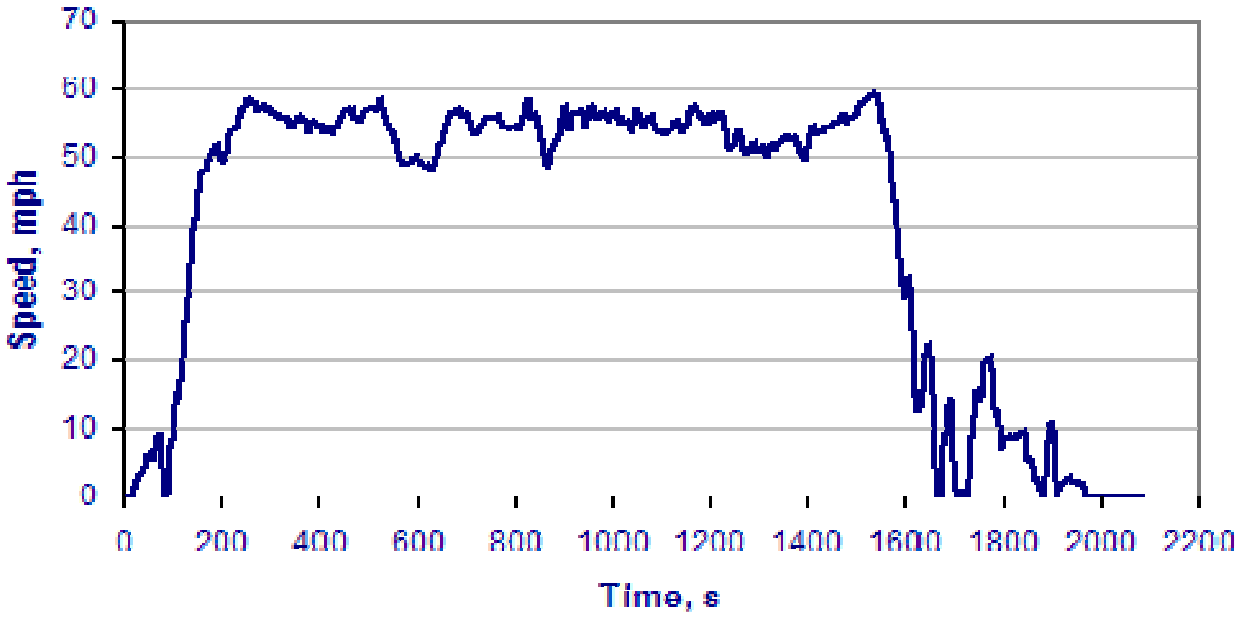
UDDS

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