This executive summary report is pursuant to paragraphs 59.b and 59.f of the Consent Decree.

In October, 2019, Sensors, Inc. was retained by Fiat-Chrysler as an independent third-party emissions tester pursuant to the Consent Decree dated 05/03/19 with reference to paragraphs 59.b. Project scope included the independent testing of two FCA vehicles ("RAM") and ("JEEP") on three well-known EPA defined routes in and around the Ann Arbor, Michigan area. These routes (A, B, and C) included a mix of urban, rural and highway drive cycles (with route C offering wide-open throttle accelerations) which characterized vehicle emissions across all vehicle specific power bins as defined in the EPA MOVES model. These routes were repeated at least three times in random order to vary the cold start route. Final route selections were in this order: ABCBC, BCACA, and CABBA. For each of these eighteen routes, Sensors, Inc. reported tailpipe emissions for carbon dioxide, carbon monoxide, nitrogen oxide, nitrogen dioxide, total hydrocarbons, and non-methane hydrocarbons, vehicle exhaust flow, vehicle interface parameters, GPS and ambient temperature, humidity, and barometric pressure.

As approved by EPA and California ARB, Sensors, Inc.'s testing under Paragraph 59.b of the Consent Decree for both 2020 RAM 1500 Rebel Diesel (RAM) and 2020 DURANGO vehicles utilized the above route selection, analytical methodology, and post-processor calculations to provide emissions trends during each route segment. Eighteen large output files include exhaust gas pollutants, vehicle characteristics, ambient conditions, and vehicle ECM data. This information is available for each second of test time, and where possible, includes a summary or average by route. Output data has also been parsed into an additional fifty-four files which include vehicle interface parameters for engine load and vehicle speed in DAT format, and csv file extensions for instantaneous mass and distance-specific results as mandated by paragraph 59.g of the Consent Decree.

In the RAM and DURANGO Summary Reports, on-road emissions results have been displayed by test day and also test route. Several appendices are available for each report, including:

- Appendix A mapped route description and vehicle speed profile
- Appendix B a correlation of SEMTECH LDV PEMS to Mahle modal and bag bench results based on *Regulation EU 2016.427, Appendix 3, Section 3.*
- Appendix C screenshots for post-processing of raw data files.
- Appendix D pictures of the test vehicle and installation of Sensors, Inc. instrumentation.

Sensors, Inc.'s instrumentation utilized standard laboratory and field practices that comply with known or applicable regulations including, but not limited to 40CFR1065, 40CFR86, and other Environmental Protection Agency (EPA) guidelines and requirements.

The nature of Sensors, Inc.'s test instrumentation is described in the analytical methods report which included SEMTECH LDV analytical methods for carbon monoxide and carbon dioxide (via non-dispersive infra-red analysis), nitric oxide, and nitrogen dioxide (via non-dispersive ultraviolet analysis), total hydrocarbons analysis (by flame ionization detector), and exhaust flow measurement. The analytical methods report also includes product performance specifications (such as concentration range, accuracy, and drift), and mass calculations as used by the SensorTECH post-processor software to generate the various report files as listed in the RAM and DURANGO Summary Reports. This analytical methods report is located after the RAM and DURANGO Summary Reports.

Test Information

Test Date	July 14, 15, 16th, 2020
Vehicle Owner	Fiat Chrysler
Test Location	Ann Arbor, MI
Type / Descr	No. V0DT61577
Make	RAM
Model	Rebel
Model Year	2020
VIN	Redacted – PII
Vehicle Emissions Tag	Redacted – PII
Engine Family	LCRXT03.05PW
License Plate	Redacted – PII

Participants

Name	Affiliation / Title
Viorel Filip	Sensors, Inc./ TSS Supervisor
Louie Moret	Sensors, Inc./ Field Engineer
Chad Neff	Mahle/ Emissions Engineer
V Filip	Sensors, Inc. /Driver

Test Summary

This is the summary report for FCA 2020 RAM1500 Rebel Diesel (V0DT61577) who's on-road emissions testing was completed on July 14, 15 and 16th, 2020, pursuant to an EPA and California ARB approved test plan.

In October, 2019, Sensors, Inc. was retained by Fiat-Chrysler as an independent third-party emissions tester pursuant to the Consent Decree dated 05/03/19 with reference to paragraph 59.b PEMS testing. Project scope included the independent testing of two FCA vehicles on three well-known EPA defined routes in and around the Ann Arbor, Michigan area.
These routes (A, B, and C) include a mix of urban, rural and highway drive cycles (with route C offering wide-open throttle accelerations) which characterize vehicle emissions across all vehicle specific power bins as defined in the EPA MOVES model. These routes were repeated at least three times in random order to vary the cold start route. Final route selections were in this order: ABCBC, BCACA, and CABBA. For each of these eighteen routes, Sensors, Inc. reported tailpipe emissions for carbon monoxide, carbon dioxide, nitric oxide, nitrogen dioxide, total hydrocarbons, and non-methane hydrocarbons, vehicle exhaust flow, vehicle interface parameters, GPS and ambient temperature, humidity, and barometric pressure.

As approved by EPA and California ARB, Sensors, Inc.'s testing under Paragraph 59.b of the Consent Decree for both RAM and DURANGO utilized the above route selection, analytical methodology, and post-processor calculations to provide emissions trends during each route segment. Eighteen large output files include exhaust gas pollutants, vehicle characteristics, ambient conditions, and vehicle ECM data. This information is available for each second of test time, and where possible, includes a summary or average by route. Output data has also been parsed into an additional fifty-four files which include vehicle interface parameters for engine load and vehicle speed in DAT format, and csv file extensions for instantaneous mass and distance-specific results as mandated by paragraph 59.g of the Consent Decree.

In this RAM summary report, on-road emissions results have been displayed by test day and also test route both with average and standard deviation values for hot starts. Several appendices are available in this report, including:

Appendix A mapped route description and vehicle speed profile
Appendix B a correlation of SEMTECH LDV PEMS to Mahle modal and bag bench results based on *Regulation EU 2016.427, Appendix 3, Section 3.*
Appendix C screenshots for post-processing of raw data files.
Appendix D pictures of the test vehicle and installation of Sensors, Inc. instrumentation.

Sensors, Inc.'s instrumentation utilized standard laboratory and field practices that comply with known or applicable regulations including, but not limited to 40CFR1065, 40CFR86, and other Environmental Protection Agency (EPA) guidelines and requirements.

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The nature of Sensors, Inc.'s test instrumentation is described in the analytical methods report which included SEMTECH LDV analytical methods for carbon monoxide and carbon dioxide (via non-dispersive infra-red analysis), nitric oxide, and nitrogen dioxide (via non-dispersive ultraviolet analysis), total hydrocarbons analysis (by flame ionization detector), and exhaust flow measurement. The analytical methods report also includes product performance specifications (such as concentration range, accuracy, and drift), and mass calculations as used by the SensorTECH post-processor software to generate the various report files as listed in the RAM and DURANGO Summary Reports. This analytical methods report is located after the RAM and DURANGO Summary Reports.

Equipment Used

Component	SN	Verified 1065 Compliant	Expiration Date	Initials
SEMTECH-LDV Module				
SCS Asset 1111	K15127978	YES	01-12-2021	BF
Gaseous Module	C15122161	YES	07-21-2020	BF
FID Hydrocarbon Module	C16131218	YES	07-22-2020	BF
EFM4 Exhaust Flowmeter, 3"	A19512194	YES	12-17-2020	CE
FID Fuel bottle LOT: 70001824UG	FF59616	YES	09-04-2021	BF
Weather Probe RH Sensor VAISALA	F5040022	YES	02-21-2021	MC
GPS by Garmin	1A4176211	-	-	JE
Vehicle Interface	H17500656	-	-	JE

Calibration Gases Used

Bottle	SN	Listed Concentrations	Expiration Date	Initials
Quad Span Cylinder: CO2, CO, NO, Propane LOT_700019024GK	FF62631	15.7 %, CO2, 4536 ppm CO, 1013 ppm NO, 258 ppm C3H8	01-29-22	BF
NO2 Span Cylinder Ref# 122-401692822-1	CC277471	504.6 ppm NO2	12-31-2022	BF
Zero Nitrogen Cylinder LOT_700019298F2 Praxair 200002298242	FF64302	100% N2	11-08-22	BF

Gaseous Emission Results

A. On-Road Test Strategy

Sensors, Inc. tested each vehicle on well-known EPA defined routes A, B, and C in the Ann Arbor, Michigan area. These routes were a mixture of urban, rural, and highway surfaces, and elevations designed to adequately characterize vehicle emissions across all Vehicle Specific power (VSP) bins as defined in the EPA MOVES model. The EPA test routes (A, B, and C) and Sensors, Inc.'s test plan was approved by EPA and California ARB organizations. Sensors, Inc. understands that the EPA and CARB have had very strong agreement with results when these routes were previously used.

Pursuant to Paragraph 59.b of the Consent Decree, Sensors, Inc. implemented the following strategy:

- A mix of urban, rural and highway routes (defined as routes A, B, and C),
- Portions of select routes(s) contained multiple wide-open throttle (WOT) accelerations in order to detect when or if fuel enrichments occur,
- All routes were repeated at least three times in a manner where each route had a cold start,
- The route order was also purposely mixed, to minimize dependency,
- Each day of testing featured a twelve-hour minimum cold soak prior to testing which was conducted according to the following sequence:

Test 1: Cold start on Route 1A, then routes 1B1, 1C1, 1B2, 1C2.
Test 2: Cold start on Route 2B, then routes 2C1, 2A1, 2C2, 2A2
Test 3: Cold start on Route 3C, then routes 3A1, 3B1, 3B2, 3A2

The test vehicle was cold-soaked at Sensors facility and transported on a trailer to a parking lot located near USEPA parking lot adjacent to the starting point. Each test day had one cold start and four hot starts. The added hot start routes provided sufficient data to determine if outliers existed, in which case additional testing could be performed upon request.

PEMS gas analyzers were pre-test and post-test calibrated at Sensors facility. Analyzers were usually zeroed between the routes.

Test Records

The following table provides a list of post-processed files (pp) as well as the raw data file for each day of on-road tests. Incorporated in the name of the processed file is the vehicle tested, test date, test sequence, processing marker, and unique test number. For example, "3B2" means the third test day, the "B" route, and the second route occurrence.

No.	File Name	Duration (seconds)	Comment
1	RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1.csv pp_RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1_M1-M15.csv pp_RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1_M4-M5_1A.csv pp_RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1_M6-M7_1B1.csv pp_RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1_M8-M9_1C1.csv pp_RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1_M10-M11_1B2.csv pp_RAM_V0DT61577_MY2020_ABCBC_20200714_Rev1_M12-M13_1C2.csv	na 11508 1062 1286 2332 1318 2260	Test_1 Datafile Pp Test_1 results pp Route 1A cold start pp Route 1B1 (first) pp Route 1C1 (first) pp Route 1B2 (second) pp Route 1C2 (second)
2	RAM_V0DT61577_MY2020_BCACA_20200715_Rev1.csv pp_RAM_V0DT61577_MY2020_BCACA_20200715_Rev1_M1-M14.csv pp_RAM_V0DT61577_MY2020_BCACA_20200715_Rev1_M4-M5_2B.csv pp_RAM_V0DT61577_MY2020_BCACA_20200715_Rev1_M6-M7_2C1.csv pp_RAM_V0DT61577_MY2020_BCACA_20200715_Rev1_M8-M9_2A1.csv pp_RAM_V0DT61577_MY2020_BCACA_20200715_Rev1_M10-M11_2C2.csv pp_RAM_V0DT61577_MY2020_BCACA_20200715_Rev1_M12-M13_2A2.csv	na 12105 1284 2221 935 2272 998	Test_2 Datafile pp Test_2 results pp Route 2B cold start pp Route 2C1 (first) pp Route 2A1 (first) pp Route 2C2 (second) pp Route 2A2 (second)
3	RAM_V0DT61577_MY2020_CABBA_20200716_Rev1.csv pp_RAM_V0DT61577_MY2020_CABBA_20200716_Rev1_M1-M13.csv pp_RAM_V0DT61577_MY2020_CABBA_20200716_Rev1_M3-M4_3C.csv pp_RAM_V0DT61577_MY2020_CABBA_20200716_Rev1_M5-M6_3A1.csv pp_RAM_V0DT61577_MY2020_CABBA_20200716_Rev1_M7-M8_3B1.csv pp_RAM_V0DT61577_MY2020_CABBA_20200716_Rev1_M9-M10_3B2.csv pp_RAM_V0DT61577_MY2020_CABBA_20200716_Rev1_M11-M12_3A2.csv	na 15005 2277 953 1403 1362 953	Test_3 Datafile pp Test_3 results pp Route 3C cold start pp Route 3A1 (first) pp Route 3B1 (first) pp Route 3B2 (second) pp Route 3A2 (second)

Parsed Report Files

Pursuant to paragraph 59.g of the Consent Decree, the test records were further parsed into summary data such as instantaneous vehicle interface engine load and engine speed parameters, instantaneous distance-specific emissions parameters, and average emissions per mile values.

Name	Date modified	Size
Redacted – PII MY2020_ABCBC_20200714_1A_Rev1_Gram-mile.csv	12/3/2020 7:16 PM	1 KB
Redacted – PII MY2020_ABCBC_20200714_1A_Rev1_Gram-sec.csv	12/3/2020 7:16 PM	60 KB
Redacted – PII MY2020_ABCBC_20200714_1A_Rev1_Load_speed.DAT	12/3/2020 7:16 PM	37 KB
MY2020_ABCBC_20200714_1B1_Rev1_Gram-mile.csv	12/3/2020 7:16 PM	1 KB
Redacted – PII MY2020_ABCBC_20200714_1B1_Rev1_Gram-sec.csv	12/3/2020 7:16 PM	71 KB
_MY2020_ABCBC_20200714_1B1_Rev1_Load_speed.DAT	12/3/2020 7:16 PM	45 KB
Redacted – PII MY2020_ABCBC_20200714_1B2_Rev1_Gram-mile.csv	12/3/2020 7:16 PM	1 KB
MY2020_ABCBC_20200714_1B2_Rev1_Gram-sec.csv	12/3/2020 7:16 PM	74 KB
Redacted – PII MY2020_ABCBC_20200714_1B2_Rev1_Load_speed.DAT	12/3/2020 7:16 PM	46 KB
MY2020_ABCBC_20200714_1C1_Rev1_Gram-mile.csv	12/3/2020 7:16 PM	1 KB
Redacted – PII MY2020_ABCBC_20200714_1C1_Rev1_Gram-sec.csv	12/3/2020 7:16 PM	132 KB
MY2020_ABCBC_20200714_1C1_Rev1_Load_speed.DAT	12/3/2020 7:16 PM	82 KB
Redacted – PII MY2020_ABCBC_20200714_1C2_Rev1_Gram-mile.csv	12/3/2020 7:16 PM	1 KB
MY2020_ABCBC_20200714_1C2_Rev1_Gram-sec.csv	12/3/2020 7:16 PM	130 KB
Redacted – PII MY2020_ABCBC_20200714_1C2_Rev1_Load_speed.DAT	12/3/2020 7:16 PM	79 KB
_MY2020_BCACA_20200715_2A1_Rev1_Gram-mile.csv	12/3/2020 7:47 PM	1 KB
Redacted – PII MY2020_BCACA_20200715_2A1_Rev1_Gram-sec.csv	12/3/2020 7:47 PM	54 KB
MY2020_BCACA_20200715_2A1_Rev1_Load_speed.DAT	12/3/2020 7:47 PM	33 KB
Redacted – PII MY2020_BCACA_20200715_2A2_Rev1_Gram-mile.csv	12/3/2020 7:47 PM	1 KB
MY2020_BCACA_20200715_2A2_Rev1_Gram-sec.csv	12/3/2020 7:47 PM	61 KB
Redacted – PII MY2020_BCACA_20200715_2A2_Rev1_Load_speed.DAT	12/3/2020 7:47 PM	35 KB
MY2020_BCACA_20200715_2B_Rev1_Gram-mile.csv	12/3/2020 7:47 PM	1 KB
Redacted – PII MY2020_BCACA_20200715_2B_Rev1_Gram-sec.csv	12/3/2020 7:47 PM	73 KB
Redacted – PII MY2020_BCACA_20200715_2B_Rev1_Load_speed.DAT	12/3/2020 7:47 PM	45 KB
MY2020_BCACA_20200715_2C1_Rev1_Gram-mile.csv	12/3/2020 7:47 PM	1 KB
MY2020_BCACA_20200715_2C1_Rev1_Gram-sec.csv	12/3/2020 7:47 PM	125 KB
Redacted – PII MY2020_BCACA_20200715_2C1_Rev1_Load_speed.DAT	12/3/2020 7:47 PM	78 KB
MY2020_BCACA_20200715_2C2_Rev1_Gram-mile.csv	12/3/2020 7:47 PM	1 KB
Redacted – PII MY2020_BCACA_20200715_2C2_Rev1_Gram-sec.csv	12/3/2020 7:47 PM	127 KB
_MY2020_BCACA_20200715_2C2_Rev1_Load_speed.DAT	12/3/2020 7:47 PM	80 KB
Redacted – PII MY2020_CABBA_20200716_3A1_Rev1_Gram-mile.csv	12/3/2020 7:52 PM	1 KB
MY2020_CABBA_20200716_3A1_Rev1_Gram-sec.csv	12/3/2020 7:52 PM	55 KB
Redacted – PII MY2020_CABBA_20200716_3A1_Rev1_Load_speed.DAT	12/3/2020 7:52 PM	34 KB
MY2020_CABBA_20200716_3A2_Rev1_Gram-mile.csv	12/3/2020 7:52 PM	1 KB
Redacted – PII MY2020_CABBA_20200716_3A2_Rev1_Gram-sec.csv	12/3/2020 7:52 PM	56 KB
MY2020_CABBA_20200716_3A2_Rev1_Load_speed.DAT	12/3/2020 7:52 PM	34 KB
Redacted – PII MY2020_CABBA_20200716_3B1_Rev1_Gram-mile.csv	12/3/2020 7:52 PM	1 KB
MY2020_CABBA_20200716_3B1_Rev1_Gram-sec.csv	12/3/2020 7:52 PM	83 KB
Redacted – PII MY2020_CABBA_20200716_3B1_Rev1_Load_speed.DAT	12/3/2020 7:52 PM	49 KB
_MY2020_CABBA_20200716_3B2_Rev1_Gram-mile.csv	12/3/2020 7:52 PM	1 KB
Redacted – PII MY2020_CABBA_20200716_3B2_Rev1_Gram-sec.csv	12/3/2020 7:52 PM	79 KB
MY2020_CABBA_20200716_3B2_Rev1_Load_speed.DAT	12/3/2020 7:52 PM	48 KB
Redacted – PII MY2020_CABBA_20200716_3C_Rev1_Gram-mile.csv	12/3/2020 7:52 PM	1 KB
MY2020_CABBA_20200716_3C_Rev1_Gram-sec.csv	12/3/2020 7:52 PM	132 KB
_MY2020_CABBA_20200716_3C_Rev1_Load_speed.DAT	12/3/2020 7:52 PM	80 KB

B. On-Road Test Results by Test Day

The tables below summarizes daily test results by route, and includes total and average values. During Test 1 and Test 2, Route C and its duplicate account for two-thirds of total mileage, and along with its multiple wide-open throttle, accounts for three-quarters of all on-road emissions. PEMS gas analyzers were pre-test and post-test calibrated at Sensors facility. Analyzers were usually zeroed between the routes.

Test 1

7/14/2020		COLD 1A	HOT 1B1	HOT 1C1	HOT 1B2	HOT 1C2	Total	Average
		Route A	Route B	Route C	Route B	Route C		
Distance	(mi)	7.728	10.777	30.477	10.778	30.468	90.228	
Length	(sec)	1062	1286	2332	1318	2260	8258	
Fuel Economy	mpg	21.624	25.988	22.976	25.321	22.513		23.6844
CO2	(g)	3669.647	4249.304	13620.11	4372.843	13891.04		7960.589
CO	(g)	3.656	1.913	5.779	2.088	6.205		3.9282
kNOx	(g)	0.675	0.014	0.159	0.054	0.781		0.3366
THC	(g)	0.39	0.104	0.18	0.117	0.177		0.1936
NMCH	(g)	0.383	0.102	0.176	0.115	0.173		0.1898
CO2	(g/mi)	474.857	394.287	446.896	405.725	455.925		435.538
CO	(g/mi)	0.473	0.177	0.19	0.194	0.204		0.2476
kNOx	(g/mi)	0.087	0.001	0.005	0.005	0.026		0.0248
THC	(g/mi)	0.051	0.01	0.006	0.011	0.006		0.0168
NMCH	(g/mi)	0.05	0.009	0.006	0.011	0.006		0.0164
							Std. Dev.	Average
Ambient Temp	Deg C	26.714	26.818	28.184	28.538	29.217	1.009662	27.8942
Ambient Press.	mbar	990.601	993.688	990.742	993.143	990.692	1.573919	991.7732
Relative Humid.	%	54.721	52.963	46.093	44.358	41.746	4.794034	47.9762
Absol. Humidity	grains	85.753	83.339	78.692	77.019	75.645	3.350443	80.0896
AVG kh Factor		1.028	1.023	1.012	1.008	1.005	0.007874	1.0152

Test 2

7/15/2020		COLD 2B	HOT 2C1	HOT 2A1	HOT 2C2	HOT 2A2	Total	Average
		Route B	Route C	Route A	Route C	Route A		
Distance	(mi)	10.909	30.485	7.666	30.487	7.667	87.214	
Length	(sec)	1284	2221	935	2272	998	7710	
Fuel Economy	mpg	23.615	21.691	28.764	21.932	23.086		23.8176
CO2	(g)	4725.427	14392.41	2727.037	14221.69	3403.41		7893.994
CO	(g)	4.962	5.751	1.156	5.877	1.365		3.8222
kNOx	(g)	0.988	0.713	0.058	0.729	0.276		0.5528
THC	(g)	0.252	0.191	0.09	0.164	0.119		0.1632
NMCH	(g)	0.247	0.187	0.088	0.161	0.116		0.1598
CO2	(g/mi)	433.152	472.109	355.74	466.482	443.887		434.274
CO	(g/mi)	0.455	0.189	0.151	0.193	0.178		0.2332
kNOx	(g/mi)	0.091	0.023	0.008	0.024	0.036		0.0364
THC	(g/mi)	0.023	0.006	0.012	0.005	0.015		0.0122
NMCH	(g/mi)	0.023	0.006	0.012	0.005	0.015		0.0122
							Std. Dev.	Average
Ambient Temp	Deg C	26.838	27.886	29.235	29.862	31.224	1.38657	29.009
Ambient Press.	mbar	994.551	991.804	992.558	991.114	992.491	0.677147	992.5036
Relative Humid.	%	53.622	51.8	48.141	46.851	43.706	3.349354	48.824
Absol. Humidity	grains	84.378	86.98	87.379	88.27	88.95	0.886403	87.1914
AVG kh Factor		1.025	1.031	1.032	1.034	1.035	0.001826	1.0314

Test 3

7/16/2020		COLD 3C	HOT 3A1	HOT 3B1	HOT 3B2	HOT 3A2	Total	Average
		Route C	Route A	Route B	Route B	Route A		
Distance	(mi)	30.601	7.662	10.78	10.776	7.666	67.485	
Length	(sec)	2277	953	1403	1362	953	6948	
Fuel Economy	mpg	21.49	27.697	27.509	27.238	28.525		26.4918
CO2	(g)	14541.25	2824.748	4000.494	4037.535	2741.97		5629.199
CO	(g)	8.935	1.249	1.559	1.644	1.224		2.9222
kNOx	(g)	4.784	0.251	0.506	0.381	0.248		1.234
THC	(g)	0.296	0.116	0.155	0.129	0.252		0.1896
NMCH	(g)	0.29	0.114	0.152	0.127	0.247		0.186
CO2	(g/mi)	475.194	368.675	371.12	374.694	357.667		389.47
CO	(g/mi)	0.292	0.163	0.145	0.153	0.16		0.1826
kNOx	(g/mi)	0.156	0.033	0.047	0.035	0.032		0.0606
THC	(g/mi)	0.01	0.015	0.014	0.012	0.033		0.0168
NMCH	(g/mi)	0.009	0.015	0.014	0.012	0.032		0.0164
							Std. Dev.	Average
Ambient Temp	Deg C	23.042	23.588	24.156	24.641	24.96	0.598416	24.0774
Ambient Press.	mbar	986.881	987.843	989.688	989.674	988.063	1.001712	988.4298
Relative Humid.	%	91.781	89.674	87.684	85.294	83.153	2.835693	87.5172
Absol. Humidity	grains	117	118.083	119.276	119.448	118.852	0.608441	118.5318
AVG kh Factor		1.099	1.102	1.105	1.105	1.104	0.001414	1.103

C. Emissions Trends by Route

The tables below summarize on-road emissions by route.
Results for average and standard deviation columns are based on hot routes only.

		Route A Only						
		COLD 1A	HOT 2A1	HOT2A2	HOT 3A1	HOT 3A2	Average	Std. Dev.
Distance	(mi)	7.728	7.666	7.667	7.662	7.666	7.6778	0.028128
Length	(sec)	1062	935	998	953	953	980.2	51.30984
Fuel Economy	mpg	21.624	28.764	23.086	27.697	28.525	25.9392	3.336069
CO2	(g)	3669.647	2727.037	3403.41	2824.748	2741.97	3073.362	434.758
CO	(g)	3.656	1.156	1.365	1.249	1.224	1.73	1.079302
kNOx	(g)	0.675	0.058	0.276	0.251	0.248	0.3016	0.226306
THC	(g)	0.39	0.09	0.119	0.116	0.252	0.1934	0.12679
NMCH	(g)	0.383	0.088	0.116	0.114	0.247	0.1896	0.124653
CO2	(g/mi)	474.857	355.74	443.887	368.675	357.667	400.1652	55.36648
CO	(g/mi)	0.473	0.151	0.178	0.163	0.16	0.225	0.138977
kNOx	(g/mi)	0.087	0.008	0.036	0.033	0.032	0.0392	0.028978
THC	(g/mi)	0.051	0.012	0.015	0.015	0.033	0.0252	0.016649
NMCH	(g/mi)	0.05	0.012	0.015	0.015	0.032	0.0248	0.016146
Ambient Temp	DegC	26.7	29.2	31.2	23.6	25.0	27.25	3.58
Ambient Press	mbar	990.6	992.6	992.5	987.8	988.1	990.24	2.64
Relative Humid.	%	54.7	48.1	43.7	89.7	83.2	66.17	23.60
Absol. Humid.	grains	85.8	87.4	89.0	118.1	118.9	103.32	17.51
AVG. kH Factor		1.0	1.0	1.0	1.1	1.1	1.07	0.04

		Route B Only						
		COLD 2B	HOT 1B1	HOT 1B2	HOT 3B1	HOT 3B2	Average	Std. Dev.
Distance	(mi)	10.909	10.777	10.778	10.78	10.776	10.804	0.058715
Length	(sec)	1284	1286	1318	1403	1362	1330.6	51.34978
Fuel Economy	mpg	23.615	25.988	25.321	27.509	27.238	25.9342	1.576189
CO2	(g)	4725.427	4249.304	4372.843	4000.494	4037.535	4277.121	293.6148
CO	(g)	4.962	1.913	2.088	1.559	1.644	2.4332	1.429306
kNOx	(g)	0.988	0.014	0.054	0.506	0.381	0.3886	0.395412
THC	(g)	0.252	0.104	0.117	0.155	0.129	0.1514	0.059298
NMCH	(g)	0.247	0.102	0.115	0.152	0.127	0.1486	0.058011
CO2	(g/mi)	433.152	394.287	405.725	371.12	374.694	395.7956	25.2514
CO	(g/mi)	0.455	0.177	0.194	0.145	0.153	0.2248	0.130143
kNOx	(g/mi)	0.091	0.001	0.005	0.047	0.035	0.0358	0.036513
THC	(g/mi)	0.023	0.01	0.011	0.014	0.012	0.014	0.005244
NMCH	(g/mi)	0.023	0.009	0.011	0.014	0.012	0.0138	0.00545
Ambient Temp	DegC	26.8	26.8	28.5	24.2	24.6	26.04	2.03
Ambient Press	mbar	994.6	993.7	993.1	989.7	989.7	991.55	2.17
Relative Humid.	%	53.6	53.0	44.4	87.7	85.3	67.57	22.14
Absol. Humid.	grains	84.4	83.3	77.0	119.3	119.4	99.77	22.77
AVG. kH Factor		1.0	1.0	1.0	1.1	1.1	1.06	0.05

		Route C Only						
		COLD 3C	HOT 1C1	HOT 1C2	HOT 2C1	HOT 2C2	Average	Std. Dev.
Distance	(mi)	30.601	30.477	30.468	30.485	30.487	30.5036	0.054962
Length	(sec)	2277	2332	2260	2221	2272	2272.4	39.90363
Fuel Economy	mpg	21.49	22.976	22.513	21.691	21.932	22.1204	0.61308
CO2	(g)	14541.25	13620.11	13891.04	14392.41	14221.69	14133.3	375.3083
CO	(g)	8.935	5.779	6.205	5.751	5.877	6.5094	1.367916
kNOx	(g)	4.784	0.159	0.781	0.713	0.729	1.4332	1.890198
THC	(g)	0.296	0.18	0.177	0.191	0.164	0.2016	0.05364
NMCH	(g)	0.29	0.176	0.173	0.187	0.161	0.1974	0.052586
CO2	(g/mi)	475.194	446.896	455.925	472.109	466.482	463.3212	11.75447
CO	(g/mi)	0.292	0.19	0.204	0.189	0.193	0.2136	0.04423
kNOx	(g/mi)	0.156	0.005	0.026	0.023	0.024	0.0468	0.061625
THC	(g/mi)	0.01	0.006	0.006	0.006	0.005	0.0066	0.001949
NMCH	(g/mi)	0.009	0.006	0.006	0.006	0.005	0.0064	0.001517
Ambient Temp	DegC	23.0	28.2	29.2	27.9	29.9	28.79	0.92
Ambient Press	mbar	986.9	990.7	990.7	991.8	991.1	991.09	0.51
Relative Humid.	%	91.8	46.1	41.7	51.8	46.9	46.62	4.12
Absol. Humid.	grains	117.0	78.7	75.6	87.0	88.3	82.40	6.19
AVG. kH Factor		1.1	1.0	1.0	1.0	1.0	1.02	0.01

D. Recorded Vehicle Parameters
The following list includes several RAM vehicle interface parameters not required by the Consent Decree but requested separately by the Agencies and agreed to by FCA where available.

No. of DTCs	sMAL_FUN_IND	#	EGR Temp. 1-2	EGRTC	degC
Load Percent	iENG_LOAD	%	Commanded Fuel Rail Pressure A	CMD_FUELRAIL_PRESS_A	kPa
Coolant Temp.	iCOOL_TEMP	degF	Fuel Rail Pressure A	FUELRAIL_PRESS_A	kPa
Manifold Pressure	iMAP	kPa	Fuel Rail Temperature A	FUELRAIL_TEMP_A	degC
Engine RPM	iENG_SPEED	RPM	Turbo Compressor Pressure A	TURBO_COMP_PRES_A	kPa
Vehicle Speed	iVEH_SPEED	mph	Cmd Boost Pressure A	CMD_BOOST_PRESS_A	kPa
Mass Air Flow Rate	iMAF	g/s	Boost Pressure A	BOOST_PRESS_A	kPa
Abs Throttle Postn	TP	%	Boost Pressure Status A	BOOST_PRESS_STAT_A	
OBD REQUIREMENT LEVEL	OBD_REQ_LEVEL		Cmd VGT A Pos	CMD_VGT_A_POS	%
Time Since Start	RUNTM	S	VGT A Pos	VGT_A_POS	%
MIL Dist. Traveled	MIL_DIST	km	VGT A Status	VGT_A_STAT	
Fuel Rail Pressure	FRP1	kPa	Exhaust Press. 1	EP_1	kPa
No. of Warm Ups	WARM_UPS		CAC Temp. 1-1	CACT11	degC
Distance Cleared	CLR_DIST	km	CAC Temp. 1-2	CACT12	degC
Baro. Pressure	iBAR_PRESS	kPa	Exh. Gas Temp. 1-1	EGT11	degC
Catalyst Temp. 1-1	CATEMP11	degC	Exh. Gas Temp. 1-2	EGT12	degC
Driving Cycle Status	DRV_CYC_STAT		Exh. Gas Temp. 1-3	iDPF_OUT_TEMP	degC
Control Voltage	VPWR	V	DPF Delta Press. 1	DPF1_DP	kPa
Abs. Load Value	LOAD_ABS	%	NOx 1-1	NOX11	ppm
Rel. Throttle Postn	TP_R	%	NOx 1-2	NOX12	ppm
Amb. Air Temp.	AAT	degC	Reagent Rate	REAG_RATE	L/h
Accel. Postn D	APP_D	%	Reagent Demand	REAG_DEMD	L/h
Accel. Postn E	APP_E	%	Reagent Tank Lvl.	REAG_LVL	%
Throttle Act. Ctrl.	TAC_PCT	%	NOx Warning Time	NWI_TIME	min
Ext Test Equipment Conf	EXT_TEST_CFG		DPF Regen Status	sPT_REGEN_STATUS	
Current Fuel Type	FUEL_TYPE		Norm. DPF Trig. Pct	DPF_REG_PCT	%
Eng. Oil Temp.	EOT	degC	Avg. Time Btwn Rgns	DPF_REG_AVGT	min
Fuel Inj. Timing	FUEL_TIMING	Deg	Avg. Dist. Btwn Rgns	DPF_REG_AVGD	km
DD Eng. Pct. Torque	TQ_DD	%	O2 Conc. 1-1	O2S11_PCT	%
Act. Eng. Pct. Torque	iPCNT_TORQUE	%	Eng. Frictn Pct. Tq	iFRICT_TORQUE	%
Eng. Ref. Torque	sREF_ENG_TORQUE	lb-ft	PM Sensor 1-1	PM11	%
In. Air Temp. 1-1	IAT11	degC	Diesel Fluid Type	DEF_TYPE	
In. Air Temp. 1-2	IAT12	degC	DEF Concentration	DEF_CONC	%
In. Air Temp. 1-3	IAT13	degC	DEF Tank Temperature	DEF_TEMP	degC
Cmd. EGR A Duty	EGR_A_CMD	%	DEF Tank Level	DEF_LEVEL	%
Act. EGR A Duty	EGR_A_ACT	%	Engine Fuel Rate	ENG_FUEL_RATE	g/s
EGR A Duty Error	EGR_A_ERR	%	Eng. Exh. Flow Rate	EXH_RATE	kg/hr
Cmd. EGR B Duty	EGR_B_CMD	%	Corr. NOx 1-1	NOXC11	ppm
Act. EGR B Duty	EGR_B_ACT	%	Corr. NOx 1-2	NOXC12	ppm
EGR B Duty Error	EGR_B_ERR	%	Cylinder Fuel Rate	CYL_RATE	mg/str
Cmd. In. Air Flow A	IAF_A_CMD	%	DEF Dosing	DEF_DOSING	
Act. In. Air Flow A	IAF_A_REL	%	Vehicle Odometer	Odometer	hm
EGR Temp. 1-1	EGRTA	degC			

Appendix 1A. SEMTECH LDV (PEMS) Tests by Route with Vehicle Speed Profile

Route Description

The picture below provides the typical start location for three approved routes.

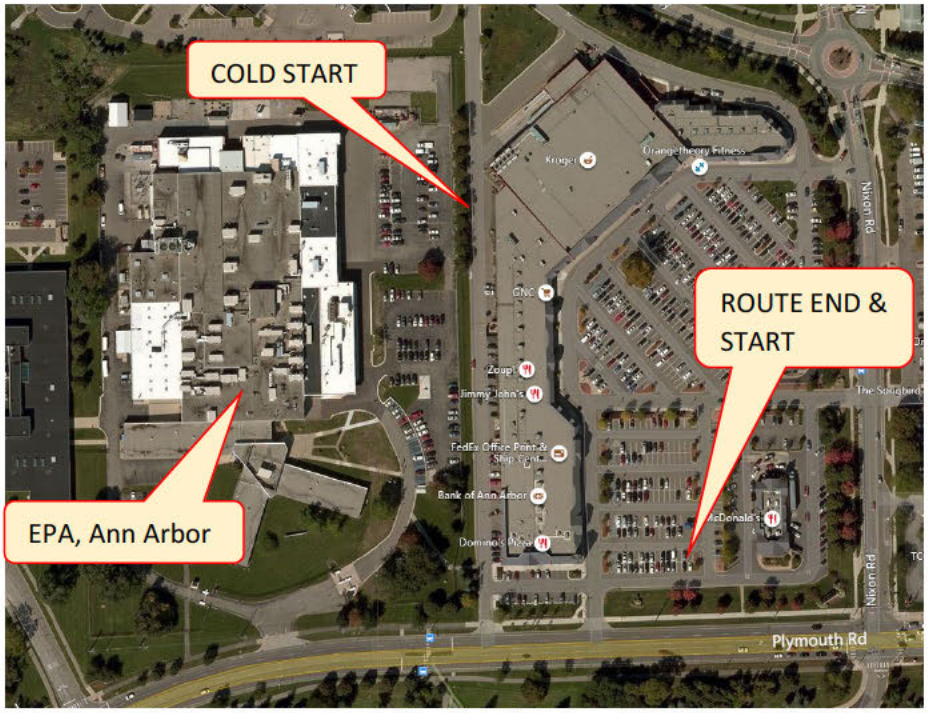


Figure 1 - Routes A, B and C Start and Stop for all routes at 2675 Plymouth Rd. Ann Arbor

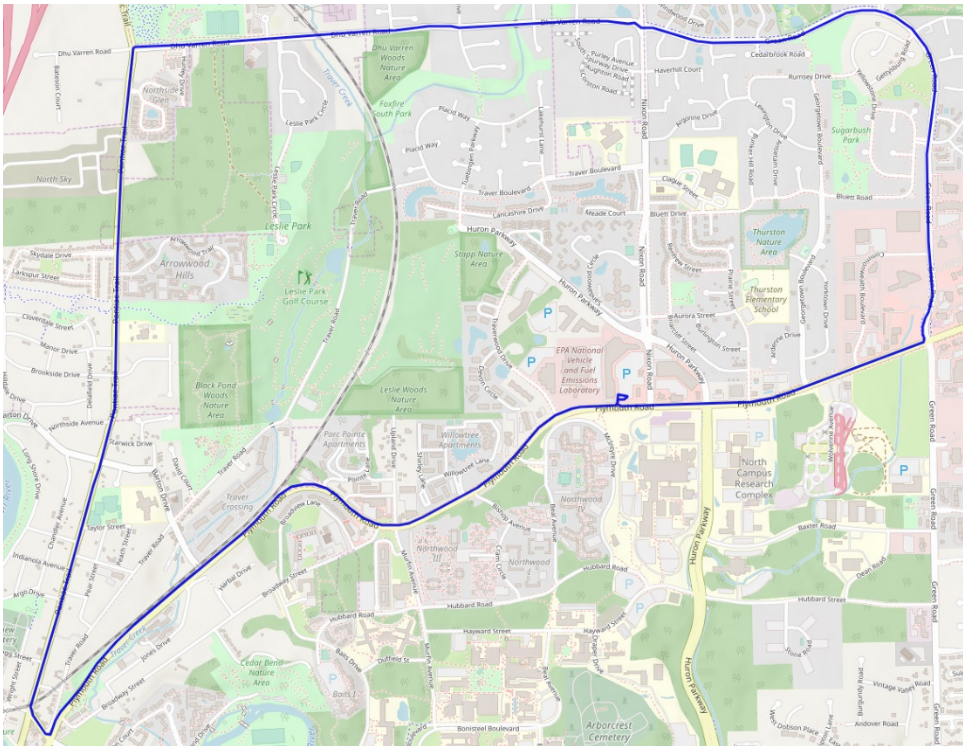


Figure 2 - Route A -- Map

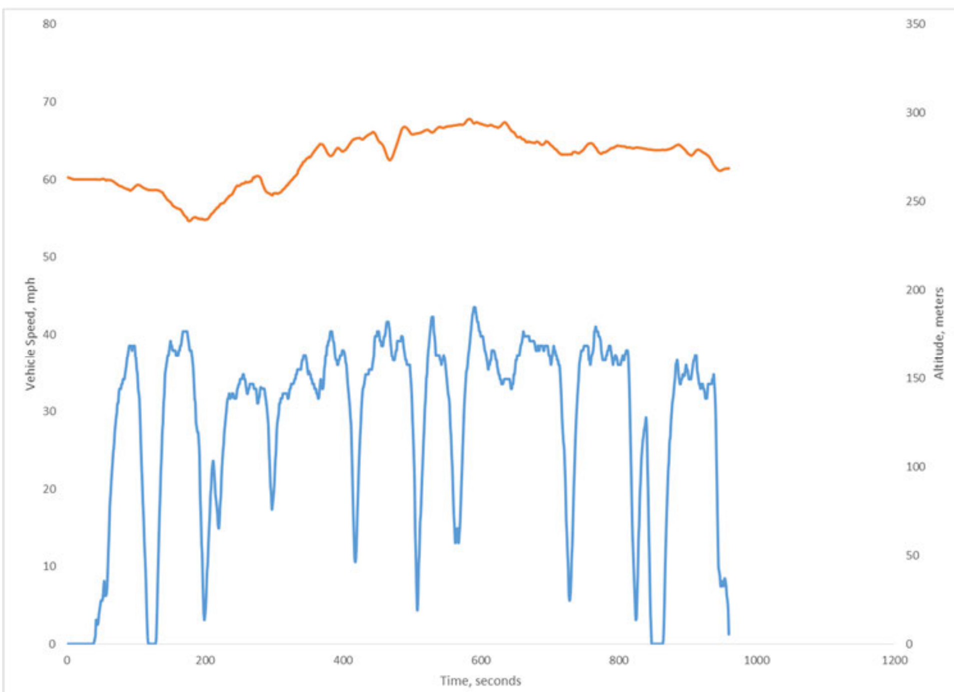


Figure 3 - Route A – Vehicle Speed and Altitude Profile

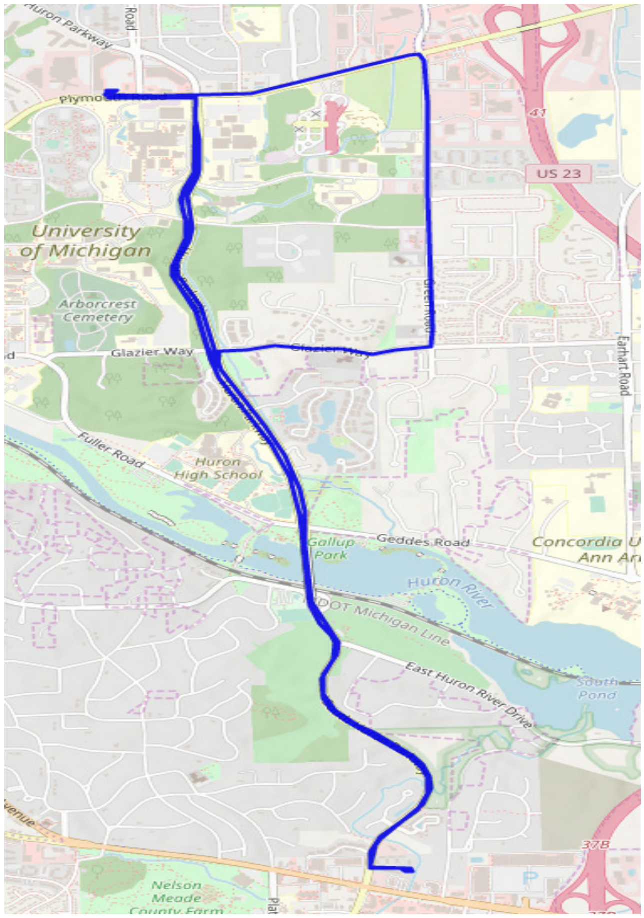


Figure 4 - Route B – Map

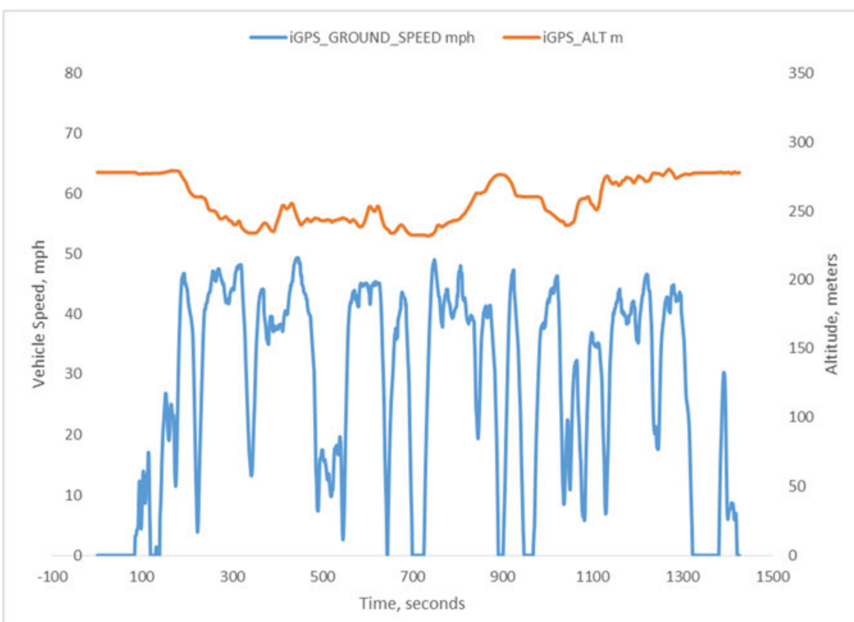


Figure 5 - Route B – Vehicle Speed and Altitude

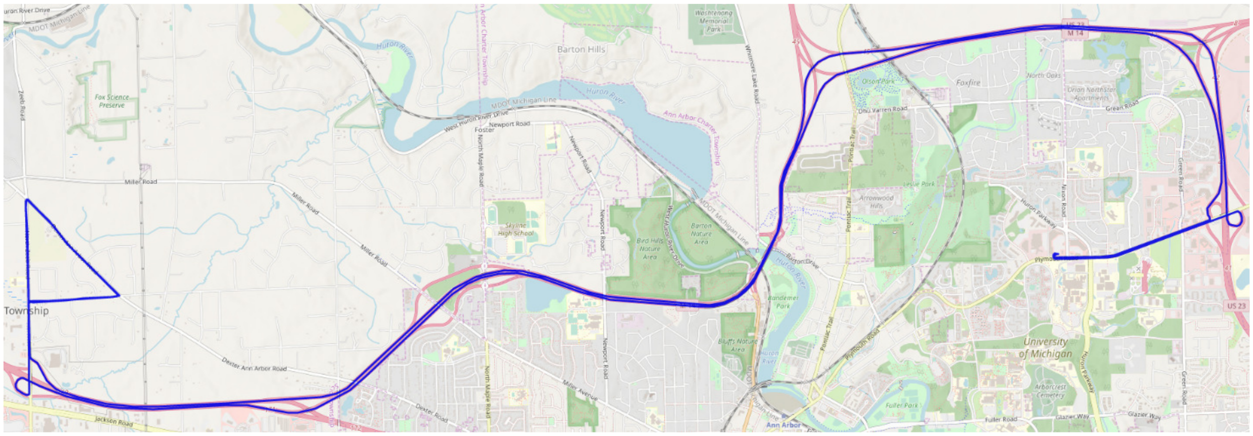


Figure 6 - Route C – Map

Route C included one triangular loop which was driven three times. Each side of the triangle featured a segment of wide-open throttle for a total of nine wide-open throttles as recorded in the middle of the vehicle speed graph.

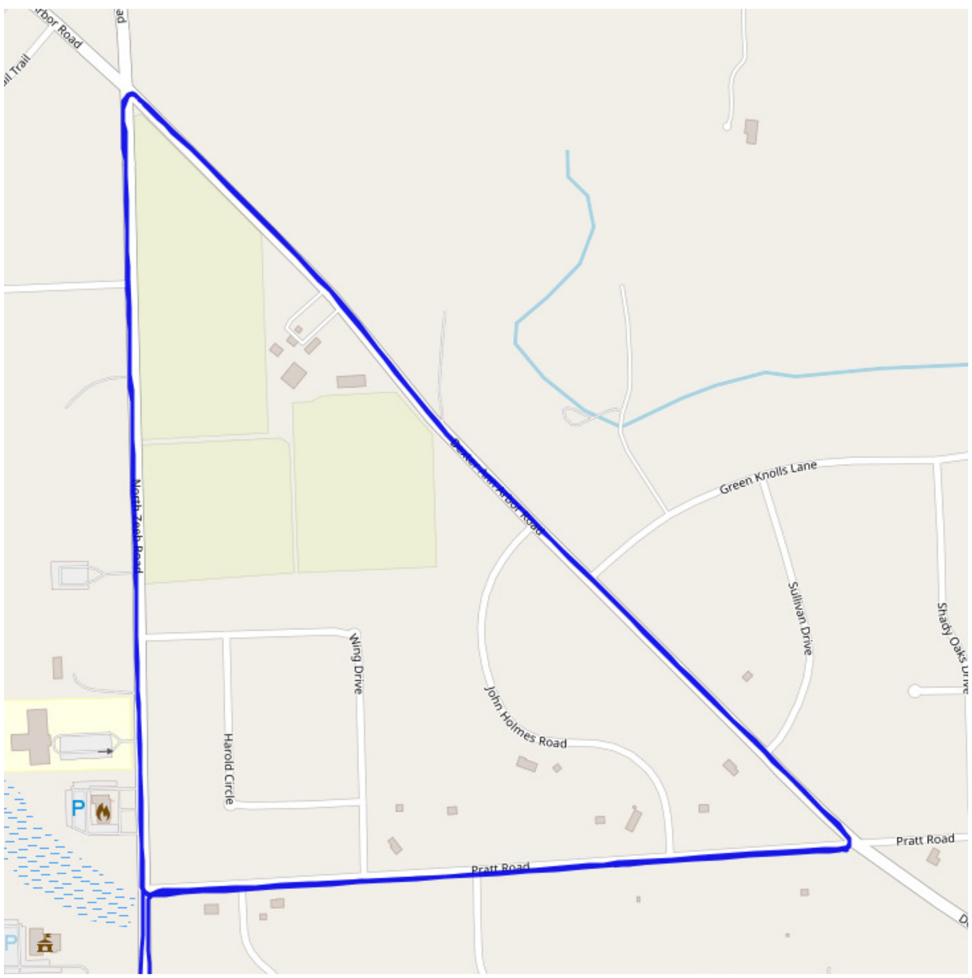


Figure 7 - Wide Open Throttle Loop

Figure 8 - Route C – Vehicle Speed and Altitude Profile

Appendix 1B. Correlation of Sensors, Inc. SEMTECH LDV (PEMS) versus Mahle Dynamometer modal and bag benches

This report includes a correlation test between the SEMTECH LDV PEMS and the Mahle Dynamometer modal and bag benches. A correlation is a well-accepted quality check to confirm the performance of the PEMS during the testing period and is an excellent reference to validate road data. This correlation test is a regulatory requirement in some regions/countries such as in Europe. Since there are no standards by which to evaluate correlation tests in the United States, Sensors, Inc. utilized European Real Drive Emission standards, based on *Regulation EU 2016.427, Appendix 3, Section 3.3 Permissible Tolerances for PEMS Validation*:

Pollutant	Tolerance		Alternative
Total Hydrocarbons	+/- 15 mg/km	or	15 % of the laboratory reference
Carbon Monoxide	+/- 150 mg/km	or	15 % of the laboratory reference
Carbon Dioxide	+/- 10 mg/km	or	10% of the laboratory reference
Oxides of Nitrogen	+/- 15 mg/km	or	15% of the laboratory reference

The following tables reflect differences in gram values for the LDV PEMS as correlated to Mahle modal and bag bench analyzers. The PEMS equipment met European Union tolerances as required for a valid correlation.

Ram 1500 -- 2020 Test

Correlation Summary

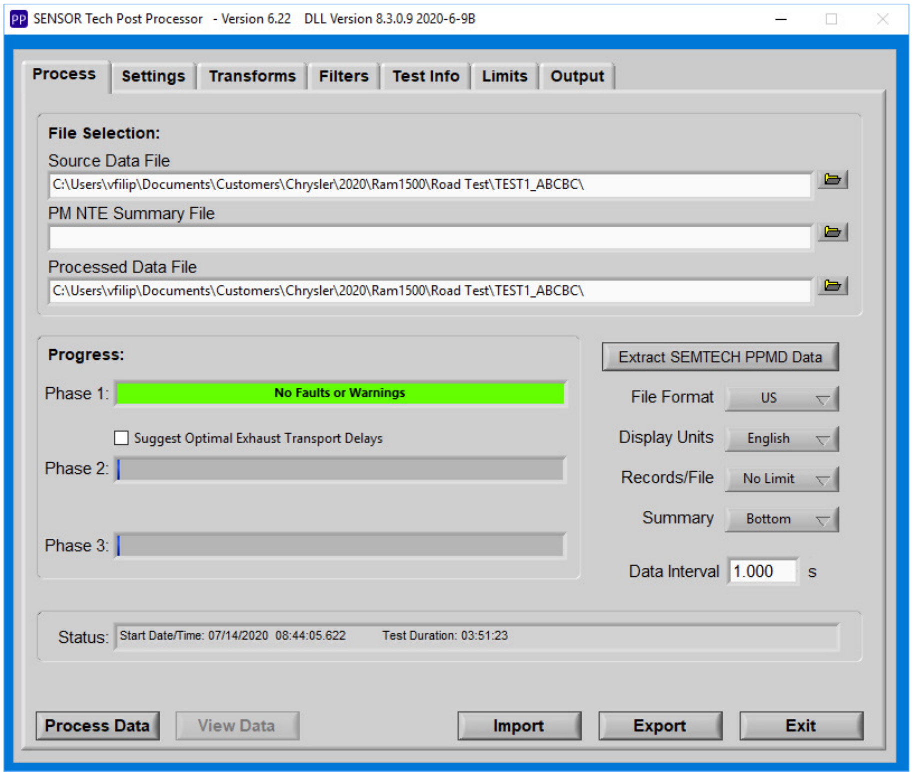
Dyno. distance :	11.05	miles
Dyno. distance :	17.68	km

	PEMS (SEMTECH LDV)			Dynamometer Bag Bench		
Overall Emissions:	**grams**	**g/mi**	**g/km**	**grams**	**g/mi**	**g/km**
CO2	4892.00	443.12	276.95	4753.05	430.53	269.08
CO	4.7730	0.4323	0.2702	4.2010	0.3805	0.2378
kNOx	0.6510	0.0590	0.0369	0.4620	0.0418	0.0262
THC[A]	0.3750	0.0340	0.0212	0.4580	0.0415	0.0259

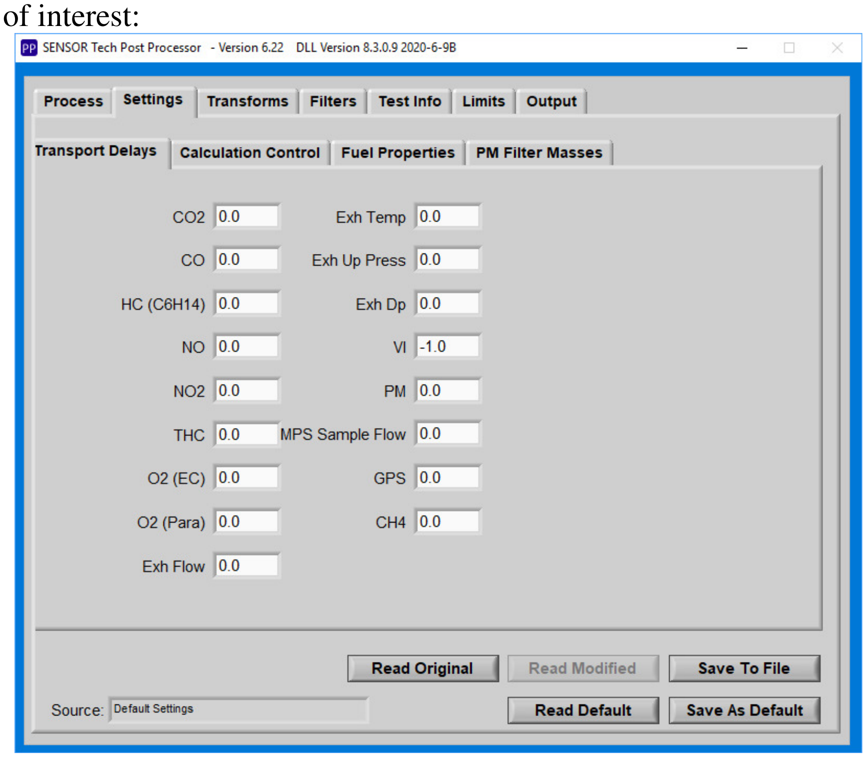
	Correlation versus EU Tolerance			Difference versus Dynmometer		
Overall Emissions:	**Difference**	**Tolerance**	**Percent**	**% Diff**	**% Tolerance**	**Abs diff (g/km)**
CO2	7.8663	10.0000	0.7866	2.9%	10.0%	7.866
CO	0.0324	0.1500	0.2159	13.6%	15.0%	0.032
kNOx	0.0107	0.0150	0.7133	40.9%	15.0%	0.011
THC[A]	-0.0047	0.0150	-0.3133	-18.1%	15.0%	0.005

Appendix 1C: Post-processing raw data files.

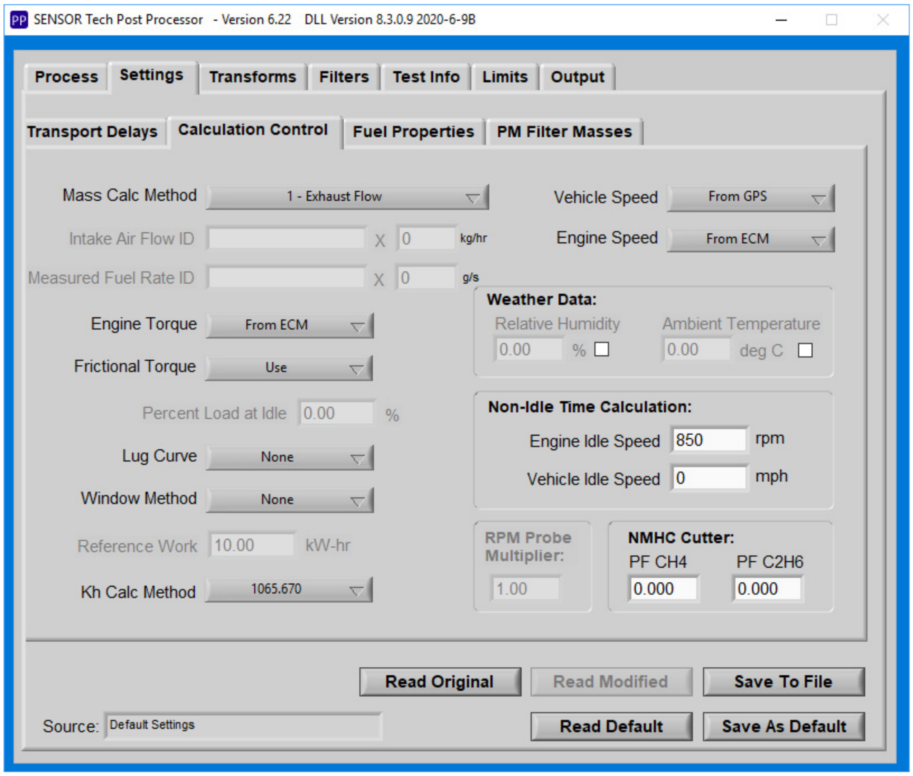
Open SENSORTech Post Processor and select the raw datafile of interest:



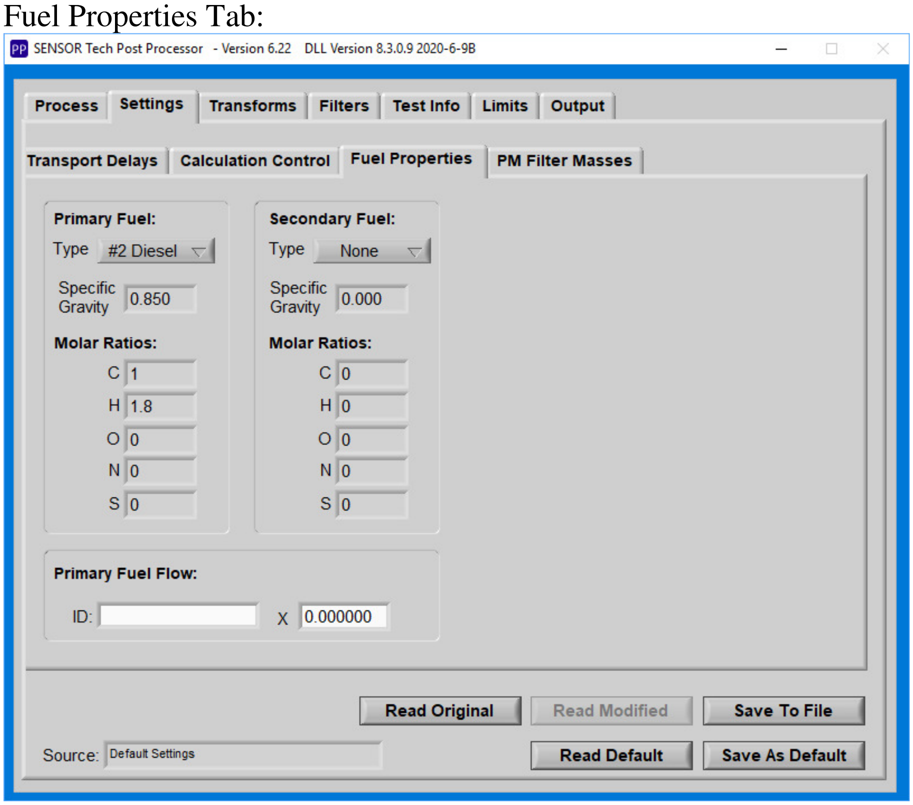
Select options of interest:



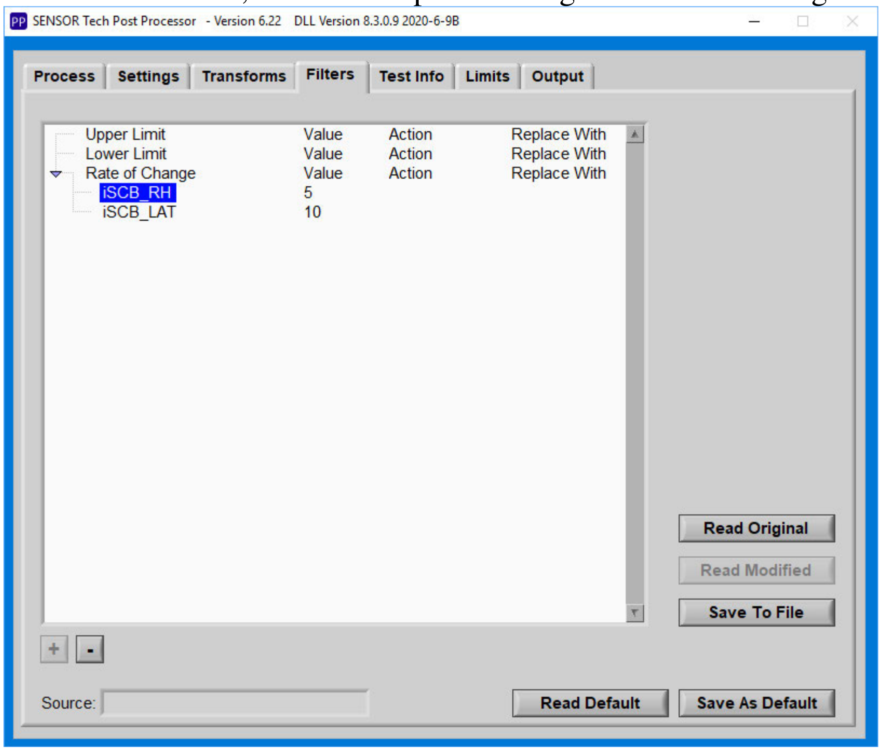
Calculation Control Tab:



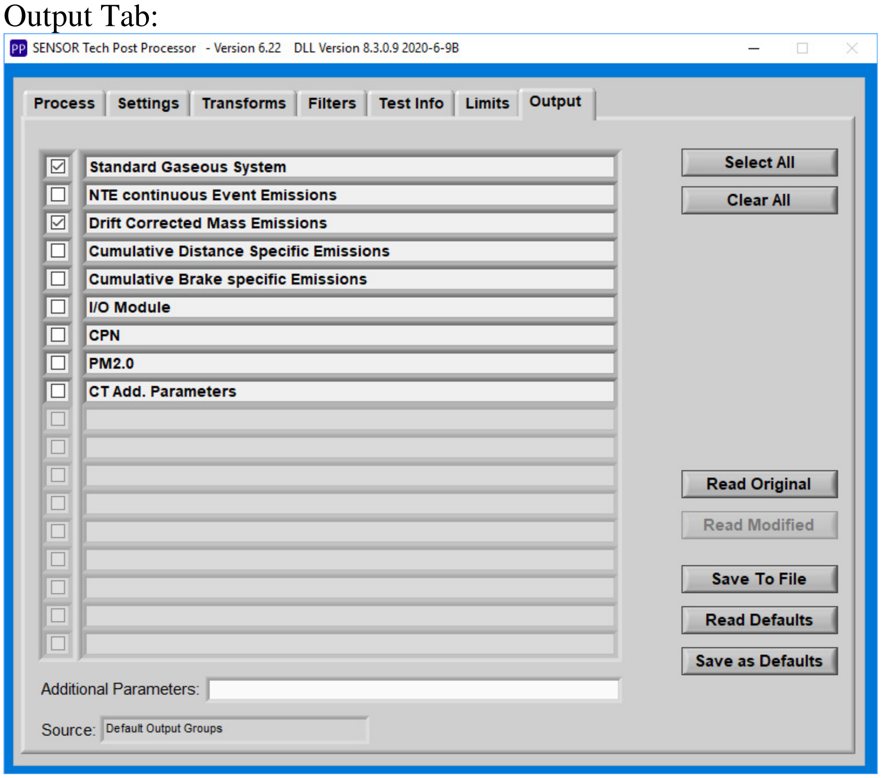
Fuel Properties Tab:



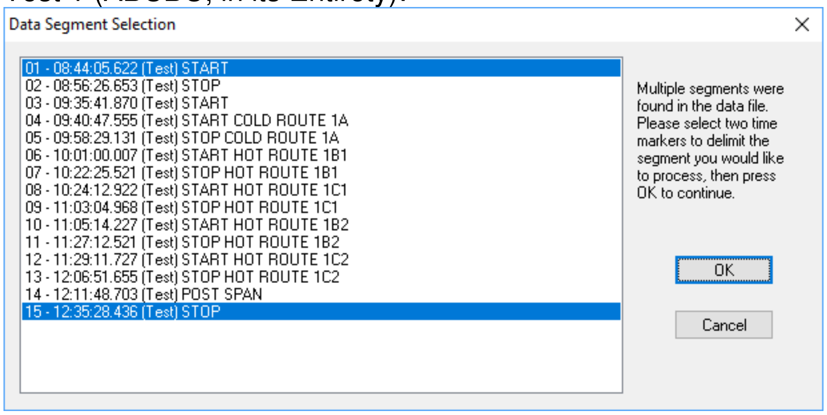
Parameter Filters Tab is used to usually filter out weather probe, ECM and/or GPS outliars. For example, wether probe temperature (iSCB_LAT) values changing by more than 10 degrees C will be filtered out, since it’s impossible to get this rate of change under normal conditions.



Output Tab:

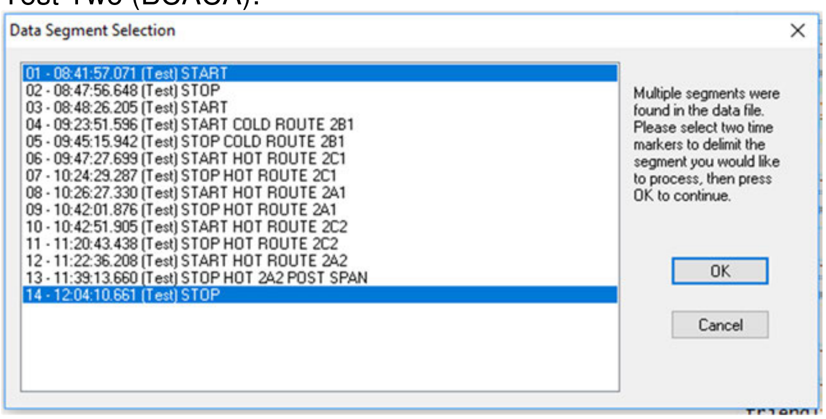


Use the following User Marks when post-processing raw or converted data files:
Test 1 (ABCBC; in its Entirety):

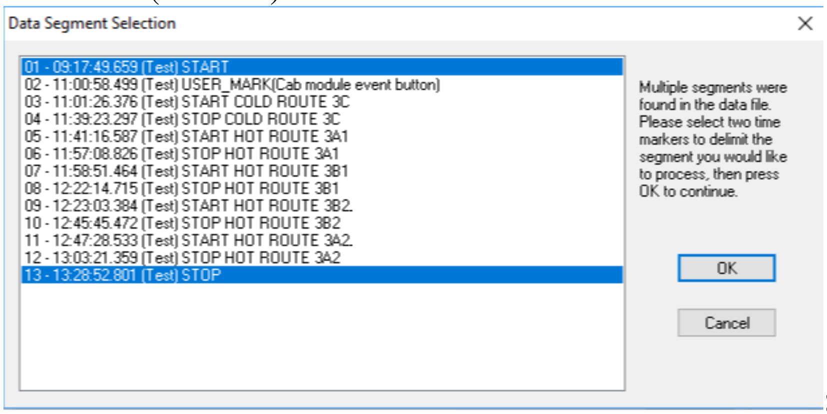


Use the following User Marks when post-processing raw or converted data files:

Test Two (BCACA):



Test Three (CABBA):



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Appendix 1D: Pictures of Test Vehicle and Installation of Instrumentation

Figure 9 - Test Vehicle

Figure 10 - Exhaust Flowmeter and License Plate

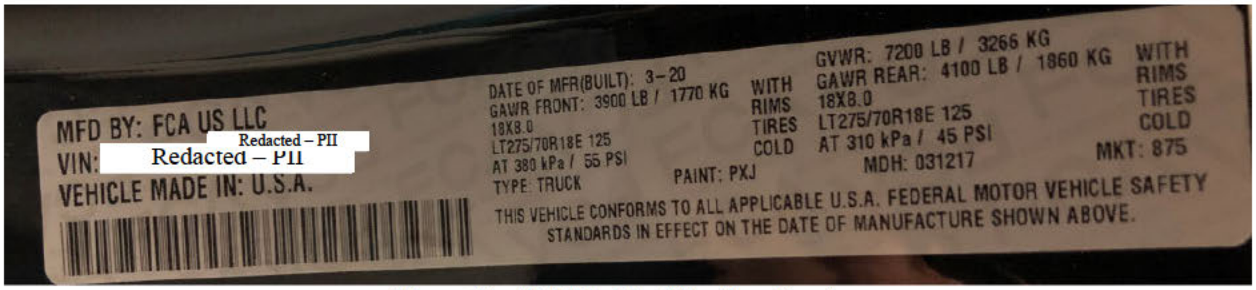


Figure 11 - Vehicle Identification Number

Emissions Tag

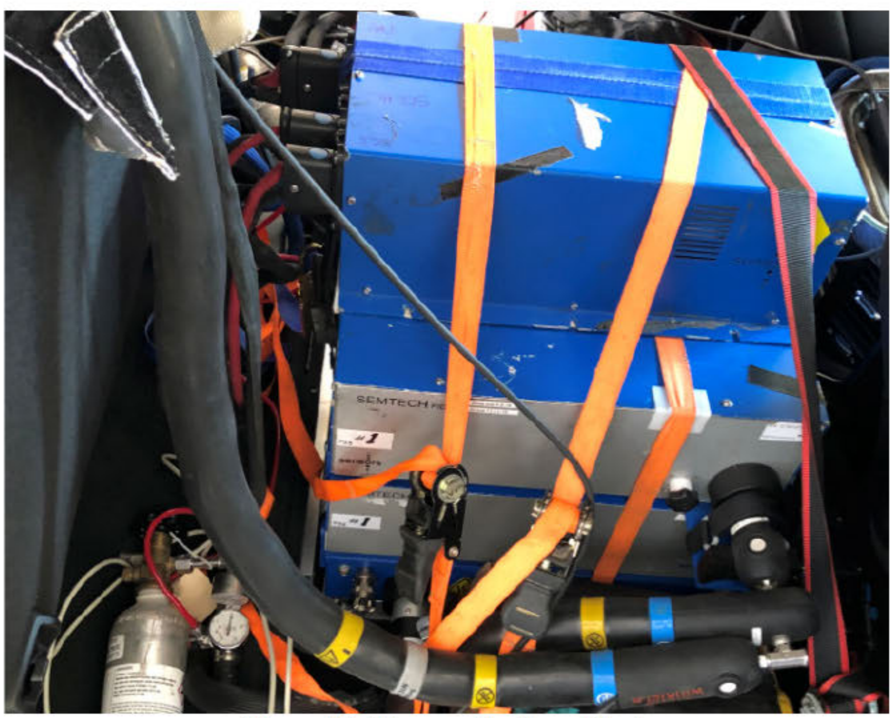


Figure 12 - Gaseous Analyzer Stack

Figure 13 - FCA Vehicle Tag, Weather Probe and GPS

2020 DURANGO TEST

Test Information

Test Date	November 16, 17, 18, 2020
Vehicle Owner	Fiat Chrysler
Test Location	Ann Arbor, MI
Type / Descr	No. VOWDD4712
Make	DURANGO
Model	WDEA75
Model Year	2020
VIN	Redacted – PII
Vehicle Emissions Tag	
Engine Family	LCRXT03.65P5
License Plate	Redacted – PII

Participants

Name	Affiliation / Title
Viorel Filip	Sensors, Inc./ TSS Supervisor
Louie Moret	Sensors, Inc./ Field Engineer
Chad Neff	Mahle/ Emissions Engineer
V Filip	Sensors, Inc. /Driver

Test Summary –

This is the summary report for FCA DURANGO vehicle (VOWDD4712) whose on-road emissions testing was completed on November 16, 17, 18, 2020, pursuant to an EPA and California ARB approved test plan.

In October, 2019, Sensors, Inc. was retained by Fiat-Chrysler as an independent third-party emissions tester pursuant to the Consent Decree dated 05/03/19 with reference to paragraph 59.b PEMS testing. Project scope included the independent testing of two FCA vehicles on three well-known EPA defined routes in and around the Ann Arbor, Michigan area. These routes (A, B, and C) include a mix of urban, rural and highway drive cycles (with route C offering wide-open throttle accelerations) which characterize vehicle emissions across all vehicle specific power bins as defined in the EPA MOVES model. These routes were repeated at least three times in random order to vary the cold start route. Final route selections were in this order: ABCBC, BCACA, and CABBA. For each of these eighteen routes, Sensors, Inc. reported tailpipe emissions for carbon monoxide, carbon dioxide, nitric oxide, nitrogen dioxide, total hydrocarbons, and non-methane hydrocarbons, vehicle exhaust flow, vehicle interface parameters, GPS and ambient temperature, humidity, and barometric pressure.

As approved by EPA and California ARB, Sensors, Inc.'s testing under Paragraph 59.b of the Consent Decree for the DURANGO vehicle utilized the above route selection, analytical methodology, and post-processor calculations to provide emissions trends during each route segment. Eighteen large output files include exhaust gas pollutants, vehicle characteristics, ambient conditions, and vehicle ECM data. This information is available for each second of test time, and where possible, includes a summary or average by route. Output data has also been

parsed into an additional fifty-four files which include vehicle interface parameters for engine load and vehicle speed in DAT format, and csv file extensions for instantaneous mass and distance-specific results as mandated by paragraph 59.g of the Consent Decree.
In this DURANGO summary report, on-road emissions results have been displayed by test day and also test route with average and standard deviation values for hot starts. Several appendices are available in this report, including:
Appendix A mapped route description and vehicle speed profile
Appendix B a correlation of SEMTECH LDV PEMS to Mahle modal and bag bench results based on *Regulation EU 2016.427, Appendix 3, Section 3.*
Appendix C screenshots for post-processing of raw data files.
Appendix D pictures of the test vehicle and installation of Sensors, Inc. instrumentation.

Sensors, Inc.'s instrumentation utilized standard laboratory and field practices that comply with known or applicable regulations including, but not limited to 40CFR1065, 40CFR86, and other Environmental Protection Agency (EPA) guidelines and requirements.

Sensors, Inc.'s instrumentation utilized standard laboratory and field practices that comply with known or applicable regulations including, but not limited to 40CFR1065, 40CFR86, and other Environmental Protection Agency (EPA) guidelines and requirements.

The nature of Sensors, Inc.'s test instrumentation is described in the analytical methods report which included SEMTECH LDV analytical methods for carbon monoxide and carbon dioxide (via non-dispersive infra-red analysis), nitric oxide, and nitrogen dioxide (via non-dispersive ultraviolet analysis), total hydrocarbons analysis (by flame ionization detector), and exhaust flow measurement. The analytical methods report also includes product performance specifications (such as concentration range, accuracy, and drift), and mass calculations as used by the SensorTECH post-processor software to generate the various report files as listed in the RAM and DURANGO Summary Reports. This analytical methods report is located after the RAM and DURANGO Summary Reports.

Equipment Used

Component	SN	Verified 1065 Compliant	Expiration Date	Initials
SEMTECH-LDV Module				
SCS Asset 1111	K15127978	YES	01-12-2021	BF
Gaseous Module	C15122161	YES	07-21-2020	BF
FID Hydrocarbon Module	C16131218	YES	07-22-2020	BF
EFM4 Exhaust Flowmeter, 3"	A19512194	YES	12-17-2020	CE
FID Fuel bottle LOT: 70001824UG	FF57245	YES	01-06-2023	BF
Weather Probe RH Sensor VAISALA	F5040022	YES	02-21-2021	MC
GPS by Garmin	1A4176211	-	-	JE
Vehicle Interface	H17500656	-	-	JE

Calibration Gases Used

Bottle	SN	Listed Concentrations	Expiration Date	Initials
Quad Span Cylinder: CO2, CO, NO, Propane LOT_700019024GK	FF55394	15.7 %, CO2, 4480 ppm CO, 1038 ppm NO, 251 ppm C3H8	10/31/2021	BF
NO2 Span Cylinder Ref# 122-401692822-1	CC277471	504.6 ppm NO2	12-31-2022	BF
Zero Nitrogen Cylinder LOT_700019298F2 Praxair 200002298242	FF64302	100% N2	11-08-22	BF

Gaseous Emission Results

A. On-Road Test Strategy

Sensors, Inc. tested each vehicle on well-known EPA defined routes A, B, and C in the Ann Arbor, Michigan area. These routes were a mixture of urban, rural, and highway surfaces, and elevations designed to adequately characterize vehicle emissions across all Vehicle Specific power (VSP) bins as defined in the EPA MOVES model. The EPA test routes (A, B, and C) and Sensors, Inc.'s test plan was approved by EPA and California ARB organizations. Sensors, Inc. understands that the EPA and CARB have had very strong agreement with results when these routes were previously used.

Pursuant to Paragraph 59.b of the Consent Decree, Sensors, Inc. implemented the following strategy:

- A mix of urban, rural and highway routes (defined as routes A, B, and C),
- Portions of select routes(s) contained multiple wide-open throttle (WOT) accelerations in order to detect when or if fuel enrichments occur,
- All routes were repeated at least three times in a manner where each route had a cold start,
- The route order was also purposely mixed, to minimize dependency,
- Each day of testing featured a twelve-hour minimum cold soak prior to testing which was conducted according to the following sequence:

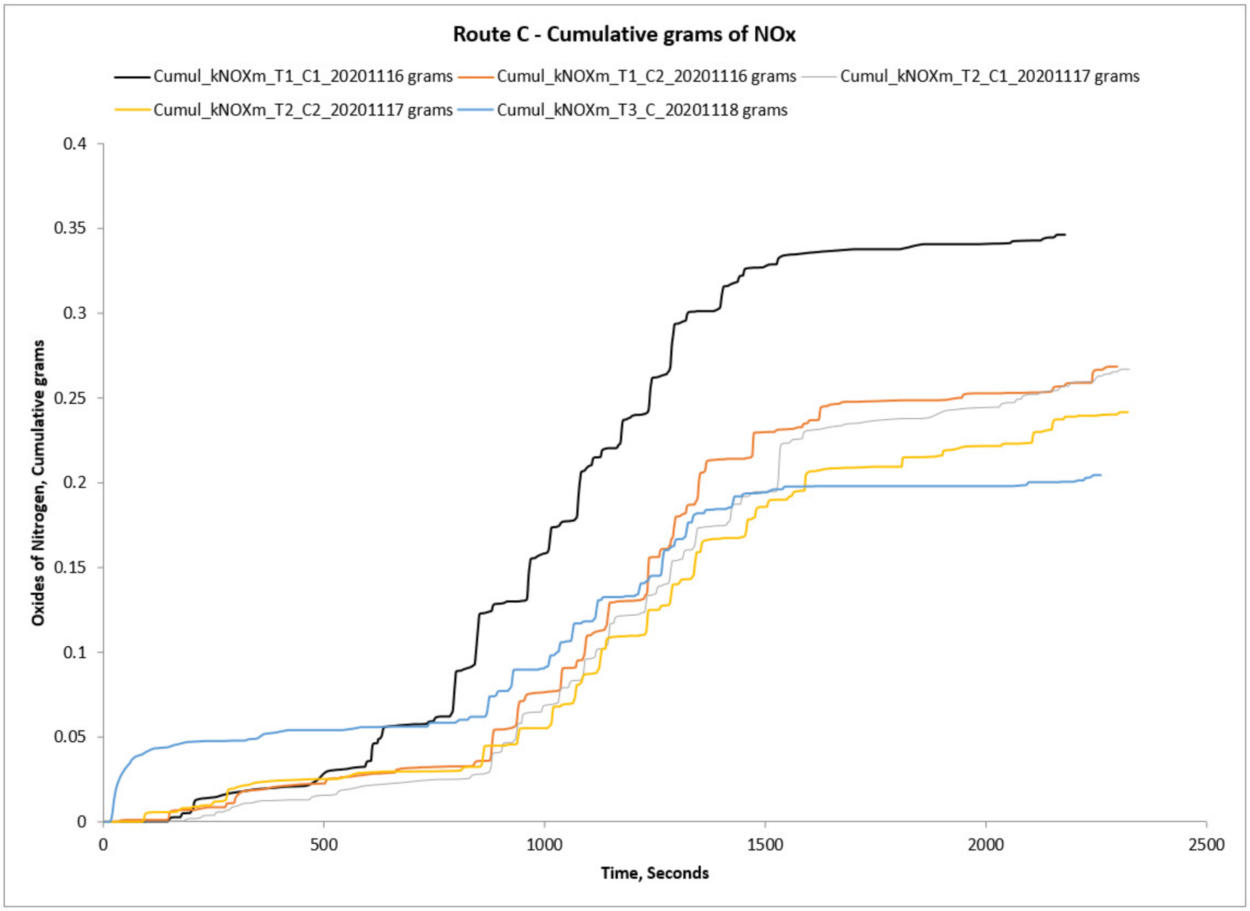
Test 1: Cold start on Route 1A, then routes 1B1, 1C1, 1B2, 1C2.
Test 2: Cold start on Route 2B, then routes 2C1, 2A1, 2C3, 2A2, (2C3) (Route 2C3 replaces 2C2 due to a highway accident closing M-14).
Test 3: Cold start on Route 3C, then routes 3A1, 3B1, 3B2, 3A2.

The test vehicle was cold-soaked at a parking lot located at a USEPA parking lot adjacent to the starting point. Each test day had one cold start and four hot starts. The added hot start routes provided sufficient data to determine if outliers existed, in which case additional testing could be performed upon request.

For each day's cold start route only, the hydrocarbon analyzer was set to range three (0-10,000 PPM); for all other routes, the hydrocarbon analyzer was set to range two (0-1,000 PPM). PEMS interlocks required the operator to put the hydrocarbon analyzer and PEMS in Standby mode before switching hydrocarbon analyzer ranges. Usually the PEMS gas analyzers were zeroed between the cold and first hot route. Other occasional zeroes were done after the completion of a route and before the next one.

A review of various test segments indicated good agreement except for:

1. elevated carbon monoxide and non-methane hydrocarbons seen in the cold start for route A as reported in section C, emissions trend by route, and
2. oxides of nitrogen cumulative gram trends during route C tests (influenced by factors such as differences in ambient temperature, humidity, and hard accelerations).



Route C - Cumulative grams of NOx
Cumul_kNOXm_T1_C1_20201116 grams
Cumul_kNOXm_T1_C2_20201116 grams
Cumul_kNOXm_T2_C1_20201117 grams
Cumul_kNOXm_T2_C2_20201117 grams
Cumul_kNOXm_T3_C_20201118 grams
Oxides of Nitrogen, Cumulative grams
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0
500
1000
1500
2000
2500
Time, Seconds

Test Records

The following table provides a list of post-processed files (pp) as well as the raw data file for each day of on-road tests. Incorporated in the name of the processed file is the vehicle tested VIN, manufacturer year, test sequence, test date, processing route ID, and revision level. For example, "3B2" means the third test day, the "B" route, and the second route occurrence.

No.	File Name	Duration (seconds)	Comment
1	Redacted – PII_MY2020_ABCBC_20201116_1A_Rev1.csv	1067	PP Route 1A cold
	_MY2020_ABCBC_20201116_1B1_Rev1.csv	1376	PP Route 1B1 (first)
	_MY2020_ABCBC_20201116_1B2_Rev1.csv	1342	PP Route 1B2 (second)
	_MY2020_ABCBC_20201116_1C1_Rev1.csv	2179	PP Route 1C1 (first)
	_MY2020_ABCBC_20201116_1C2_Rev1.csv	2297	PP Route 1C2 (second)
	_MY2020_ABCBC_20201116_ALL_Rev1.csv	NA	PP ALL
2	Redacted – PII_MY2020_BCACAC_202011172_2A2_Rev1.csv	932	PP Route 2A2 (second)
	_MY2020_BCACAC_20201117_2A1_Rev1.csv	977	PP Route 2A1 (first)
	_MY2020_BCACAC_20201117_2B_Rev1.csv	1398	PP Route 2B (cold)
	_MY2020_BCACAC_20201117_2C1_Rev1.csv	2325	PP Route 2C1 (first)
	_MY2020_BCACAC_20201117_2C3_Rev1.csv	2321	PP Route 2C3 (second)
	_MY2020_BCACAC_20201117_ALL_Rev1.csv	NA	PP ALL
3	Redacted – PII_MY2020_CABBA_20201118_3A1_Rev1.csv	915	PP Route 3A1 (first)
	_MY2020_CABBA_20201118_3A2_Rev1.csv	1080	PP Route 3A2 (second)
	_MY2020_CABBA_20201118_3B1_Rev1.csv	1348	PP Route 3B1 (first)
	_MY2020_CABBA_20201118_3B2_Rev1.csv	1367	PP Route 3B2 (second)
	_MY2020_CABBA_20201118_3C_Rev1.csv	2260	PP Route 3C (cold)
	_MY2020_CABBA_20201118_ALL_Rev1.csv	NA	PP ALL

Parsed Report Files

Pursuant to paragraph 59.g of the Consent Decree, the above post-processed data was further parsed in summary data such as instantaneous vehicle interface engine load and engine speed parameters, instantaneous distance-specific emissions parameters, and average emissions per mile values.

Name	Date modified	Size
Redacted – PII MY2020_ABCBC_20201116_1A_Rev1__Gram-mile.csv	12/3/2020 7:11 PM	1 KB
MY2020_ABCBC_20201116_1A_Rev1__Gram-sec.csv	12/3/2020 7:11 PM	59 KB
Redacted – PII MY2020_ABCBC_20201116_1A_Rev1__Load_speed.DAT	12/3/2020 7:11 PM	39 KB
MY2020_ABCBC_20201116_1B1_Rev1_Gram-mile.csv	12/3/2020 7:11 PM	1 KB
Redacted – PII MY2020_ABCBC_20201116_1B1_Rev1_Gram-sec.csv	12/3/2020 7:11 PM	76 KB
MY2020_ABCBC_20201116_1B1_Rev1_Load_speed.DAT	12/3/2020 7:11 PM	51 KB
Redacted – PII MY2020_ABCBC_20201116_1B2_Rev1_Gram-mile.csv	12/3/2020 7:11 PM	1 KB
MY2020_ABCBC_20201116_1B2_Rev1_Gram-sec.csv	12/3/2020 7:11 PM	65 KB
Redacted – PII MY2020_ABCBC_20201116_1B2_Rev1_Load_speed.DAT	12/3/2020 7:11 PM	49 KB
MY2020_ABCBC_20201116_1C1_Rev1_Gram-mile.csv	12/3/2020 7:11 PM	1 KB
Redacted – PII MY2020_ABCBC_20201116_1C1_Rev1_Gram-sec.csv	12/3/2020 7:11 PM	126 KB
MY2020_ABCBC_20201116_1C1_Rev1_Load_speed.DAT	12/3/2020 7:11 PM	80 KB
Redacted – PII MY2020_ABCBC_20201116_1C2_Rev1_Gram-mile.csv	12/3/2020 7:11 PM	1 KB
MY2020_ABCBC_20201116_1C2_Rev1_Gram-sec.csv	12/3/2020 7:11 PM	134 KB
Redacted – PII MY2020_ABCBC_20201116_1C2_Rev1_Load_speed.DAT	12/3/2020 7:11 PM	84 KB
MY2020_BCACAC_20201117_2A1_Rev1_Gram-mile.csv	12/3/2020 7:12 PM	1 KB
Redacted – PII MY2020_BCACAC_20201117_2A1_Rev1_Gram-sec.csv	12/3/2020 7:12 PM	57 KB
MY2020_BCACAC_20201117_2A1_Rev1_Load_speed.DAT	12/3/2020 7:12 PM	36 KB
Redacted – PII MY2020_BCACAC_20201117_2B_Rev1_Gram-mile.csv	12/3/2020 7:12 PM	1 KB
MY2020_BCACAC_20201117_2B_Rev1_Gram-sec.csv	12/3/2020 7:12 PM	79 KB
Redacted – PII MY2020_BCACAC_20201117_2B_Rev1_Load_speed.DAT	12/3/2020 7:12 PM	51 KB
MY2020_BCACAC_20201117_2C1_Rev1_Gram-mile.csv	12/3/2020 7:12 PM	1 KB
Redacted – PII MY2020_BCACAC_20201117_2C1_Rev1_Gram-sec.csv	12/3/2020 7:12 PM	140 KB
MY2020_BCACAC_20201117_2C1_Rev1_Load_speed.DAT	12/3/2020 7:12 PM	85 KB
Redacted – PII MY2020_BCACAC_20201117_2C3_Rev1_Gram-mile.csv	12/3/2020 7:12 PM	1 KB
MY2020_BCACAC_20201117_2C3_Rev1_Gram-sec.csv	12/3/2020 7:12 PM	134 KB
Redacted – PII MY2020_BCACAC_20201117_2C3_Rev1_Load_speed.DAT	12/3/2020 7:12 PM	85 KB
MY2020_BCACAC_202011172_A2_Rev1_Gram-mile.csv	12/3/2020 7:12 PM	1 KB
Redacted – PII MY2020_BCACAC_202011172_A2_Rev1_Gram-sec.csv	12/3/2020 7:12 PM	51 KB
MY2020_BCACAC_202011172_A2_Rev1_Load_speed.DAT	12/3/2020 7:12 PM	34 KB
Redacted – PII MY2020_CABBA_20201118_3A1_Rev1_Gram-mile.csv	12/3/2020 7:13 PM	1 KB
MY2020_CABBA_20201118_3A1_Rev1_Gram-sec.csv	12/3/2020 7:13 PM	50 KB
Redacted – PII MY2020_CABBA_20201118_3A1_Rev1_Load_speed.DAT	12/3/2020 7:13 PM	34 KB
MY2020_CABBA_20201118_3A2_Rev1_Gram-mile.csv	12/3/2020 7:13 PM	1 KB
Redacted – PII MY2020_CABBA_20201118_3A2_Rev1_Gram-sec.csv	12/3/2020 7:13 PM	58 KB
MY2020_CABBA_20201118_3A2_Rev1_Load_speed.DAT	12/3/2020 7:13 PM	39 KB
Redacted – PII MY2020_CABBA_20201118_3B1_Rev1_Gram-mile.csv	12/3/2020 7:13 PM	1 KB
MY2020_CABBA_20201118_3B1_Rev1_Gram-sec.csv	12/3/2020 7:13 PM	70 KB
Redacted – PII MY2020_CABBA_20201118_3B1_Rev1_Load_speed.DAT	12/3/2020 7:13 PM	49 KB
MY2020_CABBA_20201118_3B2_Rev1_Gram-mile.csv	12/3/2020 7:13 PM	1 KB
Redacted – PII MY2020_CABBA_20201118_3B2_Rev1_Gram-sec.csv	12/3/2020 7:13 PM	68 KB
MY2020_CABBA_20201118_3B2_Rev1_Load_speed.DAT	12/3/2020 7:13 PM	50 KB
Redacted – PII MY2020_CABBA_20201118_3C_Rev1_Gram-mile.csv	12/3/2020 7:13 PM	1 KB
MY2020_CABBA_20201118_3C_Rev1_Gram-sec.csv	12/3/2020 7:13 PM	152 KB
MY2020_CABBA_20201118_3C_Rev1_Load_speed.DAT	12/3/2020 7:13 PM	97 KB

B. On-Road Test Results by Test Day

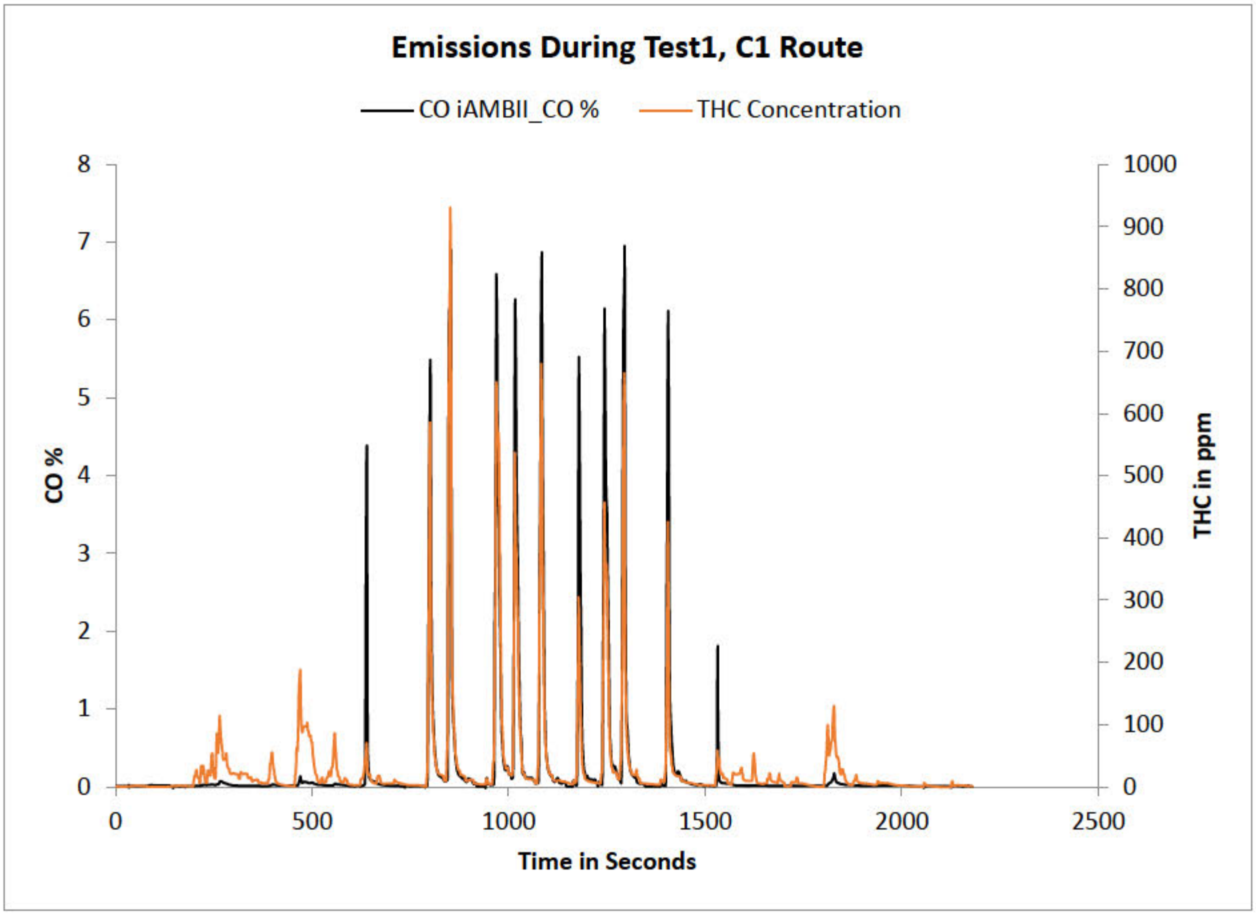
The tables below summarizes daily test results by route, and includes total and average values. During Test 1, and Test 2, Route C and its duplicate accounted for two-thirds of total mileage, and along with its multiple wide-open throttle, accounted for most of on-road, carbon monoxide and oxides of nitrogen emissions.

Test 1								
11/16/2020		COLD 1A	HOT 1B1	HOT 1C1	HOT 1B2	HOT 1C2	Total	Average
		Route A	Route B	Route C	Route B	Route C		
Distance	(mi)	7.672	10.778	30.481	10.777	30.466	90.174	
Length	(sec)	1067	1376	2179	1342	2297	8261	
Fuel Economy	mpg	22.651	25.101	21.667	25.94	22.401		23.552
CO2	(g)	3093.992	3936.34	12315.32	3809.115	12256.03	35410.8	
CO	(g)	4.799	1.17	353.044	1.49	129.024	489.527	
kNOx	(g)	0.079	0.082	0.347	0.045	0.269	0.822	
THC	(g)	0.201	0.004	0.368	0.002	0.104	0.679	
NMCH	(g)	0.197	0.004	0.361	0.002	0.102	0.666	
CO2	(g/mi)	403.273	365.223	404.029	353.441	402.28		385.6492
CO	(g/mi)	0.625	0.109	11.582	0.138	4.235		3.3378
kNOx	(g/mi)	0.01	0.008	0.011	0.004	0.009		0.0084
THC	(g/mi)	0.026	0	0.012	0	0.003		0.0082
NMCH	(g/mi)	0.026	0	0.012	0	0.003		0.0082
							Std. Dev.	Average
Ambient Temp	DegC	1.6	1.8	1.6	1.4	1.6	0.14	1.60
Ambient Press	mbar	986.8	989.2	986.8	990.0	987.9	1.42	988.12
Relative Humid.	%	62.2	62.6	61.5	59.9	61.2	1.12	61.47
Absol. Humid.	grains	18.8	19.2	18.7	17.9	18.6	0.53	18.64
AVG. kH Factor		0.8	0.8	0.8	0.8	0.8	0.00	0.76

Test 2								
11/17/2020		COLD 2B	HOT 2C1	HOT 2A1	HOT 2C3	HOT 2A2	Total	Average
		Route B	Route C	Route A	Route C	Route A		
Distance	(mi)	10.881	30.483	7.66	30.477	7.662	87.163	
Length	(sec)	1398	2325	977	2321	932	7953	
Fuel Economy	mpg	21.543	20.811	27.407	21.352	26.895		23.6016
CO2	(g)	4597.512	13130.44	2555.788	12787.26	2605.15		7135.23
CO	(g)	8.365	161.14	0.752	164.774	0.865		67.1792
kNOx	(g)	0.163	0.267	0.036	0.242	0.039		0.1494
THC	(g)	0.26	0.162	0.002	0.158	0.002		0.1168
NMCH	(g)	0.255	0.158	0.002	0.155	0.001		0.1142
CO2	(g/mi)	422.515	430.739	333.637	419.567	340.024		389.2964
CO	(g/mi)	0.769	5.286	0.098	5.406	0.113		2.3344
kNOx	(g/mi)	0.015	0.009	0.005	0.008	0.005		0.0084
THC	(g/mi)	0.024	0.005	0	0.005	0		0.0068
NMCH	(g/mi)	0.023	0.005	0	0.005	0		0.0066
							Std. Dev.	Average
Ambient Temp	DegC	0.6	0.0	-0.6	-0.4	-0.8	0.36	-0.24
Ambient Press	mbar	994.1	992.6	994.0	995.8	995.8	1.59	994.47
Relative Humid.	%	78.8	68.1	65.1	60.7	65.9	3.10	67.72
Absol. Humid.	grains	22.1	18.4	16.7	15.8	16.7	1.08	17.91
AVG. kH Factor		0.8	0.8	0.8	0.7	0.8	0.00	0.76

Test 3								
11/18/2020		COLD 3C	HOT 3A1	HOT 3B1	HOT 3B2	HOT 3A2	Total	Average
		Route C	Route A	Route B	Route B	Route A		
Distance	(mi)	30.573	7.673	10.772	10.799	7.655	67.472	
Length	(sec)	2260	915	1348	1367	1080	6970	
Fuel Economy	mpg	20.391	27.197	24.3	24.265	24.777		24.186
CO2	(g)	13402.429	2583.878	4060.027	4077.735	2830.645		5390.943
CO	(g)	200.035	0.837	1.571	1.334	0.873		40.93
kNOx	(g)	0.205	0.049	0.079	0.063	0.043		0.0878
THC	(g)	0.445	0.002	0.001	0.001	0.002		0.0902
NMCH	(g)	0.436	0.001	0.001	0.001	0.002		0.0882
CO2	(g/mi)	438.38	336.765	376.901	377.601	369.785		379.8864
CO	(g/mi)	6.543	0.109	0.146	0.124	0.114		1.4072
kNOx	(g/mi)	0.007	0.006	0.007	0.006	0.006		0.0064
THC	(g/mi)	0.015	0	0	0	0		0.003
NMCH	(g/mi)	0.014	0	0	0	0		0.0028
							Std. Dev.	Average
Ambient Temp	DegC	-5.2	-5.9	-5.9	-5.4	-4.7	0.58	-5.41
Ambient Press	mbar	1004.3	1005.7	1008.5	1008.7	1006.7	1.42	1006.79
Relative Humid.	%	73.2	77.3	79.7	77.8	73.9	2.39	76.37
Absol. Humid.	grains	13.1	13.2	13.6	13.8	13.8	0.28	13.50
AVG. kH Factor		0.7	0.7	0.7	0.7	0.7	0.00	0.74

During Test 3, the cold start on Route C accounted for 45% of distance, and 93% of carbon monoxide and hydrocarbons emissions.
Below is a chart with CO emissions on a C route showing that most of the CO and Hydrocarbons are emitted during **W**ide **O**pen **T**hrottle accelerations.



C. Emissions Trends by Route

The tables below summarize emissions by route.
Results for average and standard deviation columns are based on hot routes only.

		Route A Only						
		COLD 1A	HOT 2A1	HOT2A2	HOT 3A1	HOT 3A2	Average	Std. Dev.
Distance	**(mi)**	7.67	7.66	7.66	7.67	7.66	7.66	0.01
Length	**(sec)**	1067	977	932	915	1080	994	76
Fuel Economy	**mpg**	22.65	27.41	26.90	27.20	24.78	26.57	1.21
CO2	**(g)**	3094	2556	2605	2584	2831	2643.87	126.15
CO	**(g)**	4.799	0.752	0.865	0.837	0.873	0.83	0.06
kNOx	**(g)**	0.079	0.036	0.039	0.049	0.043	0.04	0.01
THC	**(g)**	0.201	0.002	0.002	0.002	0.002	0.00	0.00
NMCH	**(g)**	0.197	0.002	0.001	0.001	0.002	0.00	0.00
CO2	**(g/mi)**	403.27	333.64	340.02	336.77	369.79	345.05	16.69
CO	**(g/mi)**	0.625	0.098	0.113	0.109	0.114	0.11	0.01
kNOx	**(g/mi)**	0.01	0.005	0.005	0.006	0.006	0.01	0.00
THC	**(g/mi)**	0.026	0	0	0	0	0.00	0.00
NMCH	**(g/mi)**	0.026	0	0	0	0	0.00	0.00
Ambient Temp	**DegC**	1.6	-0.6	-0.8	-5.9	-4.7	-2.99	2.67
Ambient Press	**mbar**	986.8	994.0	995.8	1005.7	1006.7	1000.56	6.59
Relative Humid.	**%**	62.2	65.1	65.9	77.3	73.9	70.57	6.01
Absol. Humid.	**grains**	18.8	16.7	16.7	13.2	13.8	15.10	1.83
AVG. kH Factor		0.76	0.75	0.75	0.74	0.74	0.75	0.01

		Route B Only						
		COLD 2B	HOT 1B1	HOT 1B2	HOT 3B1	HOT 3B2	Average	Std. Dev.
Distance	**(mi)**	10.88	10.78	10.78	10.77	10.80	10.80	0.05
Length	**(sec)**	1398	1376	1342	1348	1367	1366	22
Fuel Economy	**mpg**	21.54	25.10	25.94	24.30	24.27	24.90	0.79
CO2	**(g)**	4598	3936	3809	4060	4078	3970.80	124.80
CO	**(g)**	8.365	1.17	1.49	1.571	1.334	1.39	0.18
kNOx	**(g)**	0.163	0.082	0.045	0.079	0.063	0.07	0.02
THC	**(g)**	0.26	0.004	0.002	0.001	0.001	0.00	0.00
NMCH	**(g)**	0.255	0.004	0.002	0.001	0.001	0.00	0.00
CO2	**(g/mi)**	422.52	365.22	353.44	376.90	377.60	368.29	11.41
CO	**(g/mi)**	0.769	0.109	0.138	0.146	0.124	0.13	0.02
kNOx	**(g/mi)**	0.015	0.008	0.004	0.007	0.006	0.01	0.00
THC	**(g/mi)**	0.024	0	0	0	0	0.00	0.00
NMCH	**(g/mi)**	0.023	0	0	0	0	0.00	0.00
Ambient Temp	**DegC**	0.6	1.8	1.4	-5.9	-5.4	-2.01	4.19
Ambient Press	**mbar**	994.1	989.2	990.0	1008.5	1008.7	999.08	10.97
Relative Humid.	**%**	78.8	62.6	59.9	79.7	77.8	69.97	10.19
Absol. Humid.	**grains**	22.1	19.2	17.9	13.6	13.8	16.11	2.87
AVG. kH Factor		0.78	0.76	0.76	0.74	0.74	0.75	0.01

		Route C Only						
		COLD 3C	HOT 1C1	HOT 1C2	HOT 2C1	HOT 2C2	Average	Std. Dev.
Distance	(mi)	30.57	30.48	30.47	30.48	30.48	30.50	0.04
Length	(sec)	2260	2179	2297	2325	2321	2276	60
Fuel Economy	mpg	20.39	21.67	22.40	20.81	21.35	21.56	0.66
CO2	(g)	13402	12315	12256	13130	12787	12622.26	413.85
CO	(g)	200.035	353.044	129.024	161.14	164.774	202.00	101.97
kNOx	(g)	0.205	0.347	0.269	0.267	0.242	0.28	0.05
THC	(g)	0.445	0.368	0.104	0.162	0.158	0.20	0.12
NMCH	(g)	0.436	0.361	0.102	0.158	0.155	0.19	0.11
CO2	(g/mi)	438.38	404.03	402.28	430.74	419.57	414.15	13.51
CO	(g/mi)	6.543	11.582	4.235	5.286	5.406	6.63	3.34
kNOx	(g/mi)	0.007	0.011	0.009	0.009	0.008	0.01	0.00
THC	(g/mi)	0.015	0.012	0.003	0.005	0.005	0.01	0.00
NMCH	(g/mi)	0.014	0.012	0.003	0.005	0.005	0.01	0.00
Ambient Temp	DegC	-5.2	1.6	1.6	0.0	-0.4	0.71	1.05
Ambient Press	mbar	1004.3	986.8	987.9	992.6	995.8	990.76	4.21
Relative Humid.	%	73.2	61.5	61.2	68.1	60.7	62.88	3.49
Absol. Humid.	grains	13.1	18.7	18.6	18.4	15.8	17.84	1.39
AVG. kH Factor		0.74	0.76	0.76	0.76	0.75	0.76	0.01

D. Recorded Vehicle Parameters

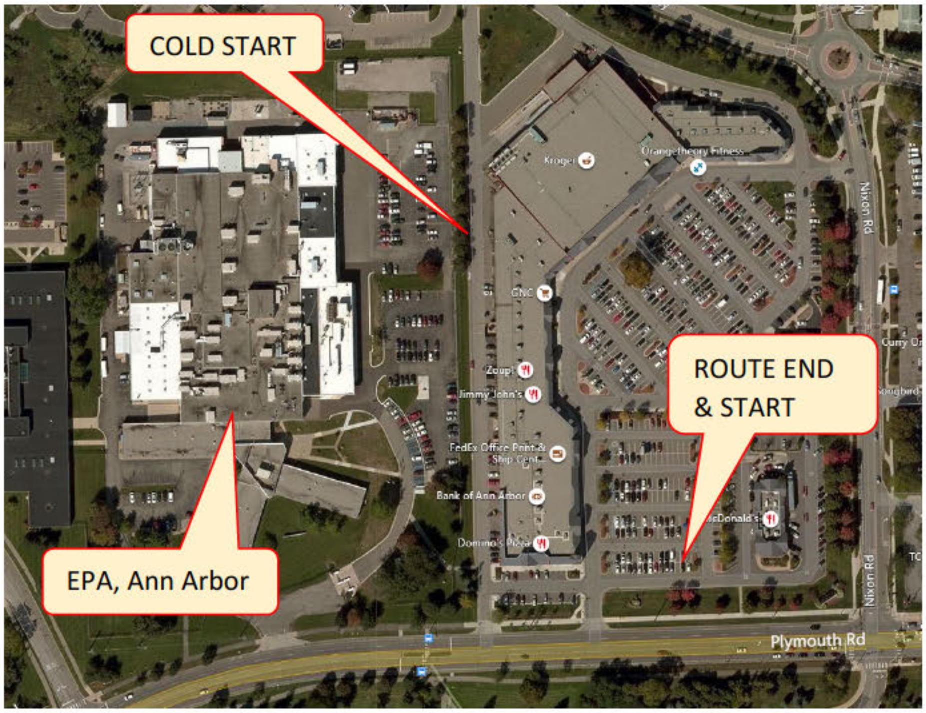
The following list includes several DURANGO vehicle interface parameters not required by the Consent Decree but requested separately by the Agencies and agreed to by FCA where available.

No. of DTCs	sMAL_FUN_IND	#
Fuel System A Status	FUEL_STAT_A	
Fuel System B Status	FUEL_STAT_B	
Load Percent	iENG_LOAD	%
Limit Adjusted iCOOL_TEM	iCOOL_TEMP	degF
Short-Term Fuel Trim 1	ST_FUELTRIM_1	%
Short-Term Fuel Trim 3	ST_FUELTRIM_3	%
Long-Term Fuel Trim 1	LT_FUELTRIM_1	%
Long-Term Fuel Trim 3	LT_FUELTRIM_3	%
Short-Term Fuel Trim 2	ST_FUELTRIM_2	%
Short-Term Fuel Trim 4	ST_FUELTRIM_4	%
Long-Term Fuel Trim 1	LT_FUELTRIM_2	%
Long-Term Fuel Trim 4	LT_FUELTRIM_4	%
Manif Press	iMAP	kPa
Engine RPM	iENG_SPEED	RPM
Vehicle Speed	iVEH_SPEED	mph
Spark Advance	SPARKADV	Deg
Intake Air Temp.	IAT	degC
Abs Throttle Postn	TP	%
O2 Sensor Location	O2_SENSOR_LOC	
Bank1 O2 Sensor-1 Volt	BK1_O2_SENSOR1_VOLT	V
Bank1 O2 Sensor-1 SHAFT	BK1_O2_SENSOR1_SHRFT	%
Bank1 O2 Sensor-2 Volt	BK1_O2_SENSOR2_VOLT	V
Bank1 O2 Sensor-2 SHAFT	BK1_O2_SENSOR2_SHRFT	%
Bank2 O2 Sensor-1 Volt	BK2_O2_SENSOR1_VOLT	V
Bank2 O2 Sensor-1 SHAFT	BK2_O2_SENSOR1_SHRFT	%
Bank2 O2 Sensor-2 Volt	BK2_O2_SENSOR2_VOLT	V
Bank2 O2 Sensor-2 SHAFT	BK2_O2_SENSOR2_SHRFT	%
OBD REQUIREMENT LEVEL	OBD_REQ_LEVEL	

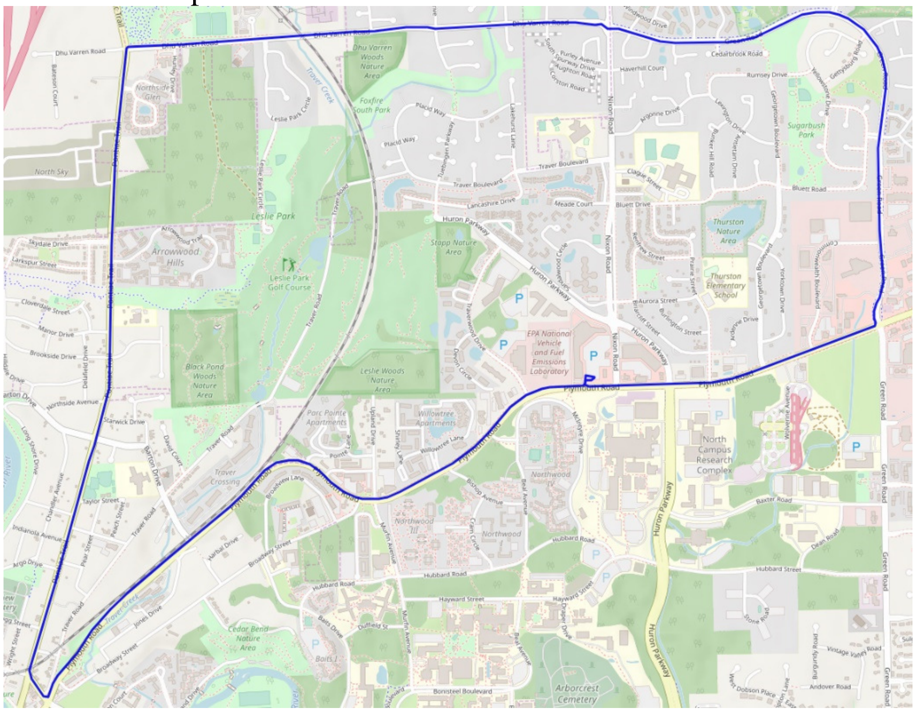
Time Since Start	RUNTM	S
MIL Dist. Traveled	MIL_DIST	km
Commanded EGR	EGR_PCT	%
EGR Error	EGR_ERR	%
Cmd. Evap. Purge	EVAP_PCT	%
Fuel Level Input	FLI	%
No. of Warm Ups	WARM_UPS	
Distance Cleared	CLR_DIST	km
Evap. System VP	EVAP_VP1	Pa
Limit Adjusted iBAR_PRESS	iBAR_PRESS	kPa
Catalyst Temp. 1-1	CATEMP11	degC
Catalyst Temp. 2-1	CATEMP21	degC
Driving Cycle Status	DRV_CYC_STAT	
Control Voltage	VPWR	V
Abs. Load Value	LOAD_ABS	%
F/A Equiv. Ratio	LAMBDA	
Rel. Throttle Postn	TP_R	%
Amb. Air Temp.	AAT	degC
Throttle Postn B	TP_B	%
Accel. Postn D	iTHROT_POS	%
Accel. Postn E	APP_E	%
Throttle Act. Ctrl.	TAC_PCT	%
Current Fuel Type	FUEL_TYPE	
Act. Eng. Pct. Torque	iPCNT_TORQUE	%
Eng. Ref. Torque	sREF_ENG_TORQUE	lb-ft
EGR Wide Temp. 1-2	EGRWTC	degC
Eng. Frictn Pct. Tq	iFRICT_TORQUE	%
Engine Fuel Rate	ENG_FUEL_RATE	g/s
Eng. Exh. Flow Rate	EXH_RATE	kg/hr
Vehicle Odometer	Odometer	hm

App. 2A. SEMTECH LDV (PEMS) Tests by Route with Vehicle Speed Profile

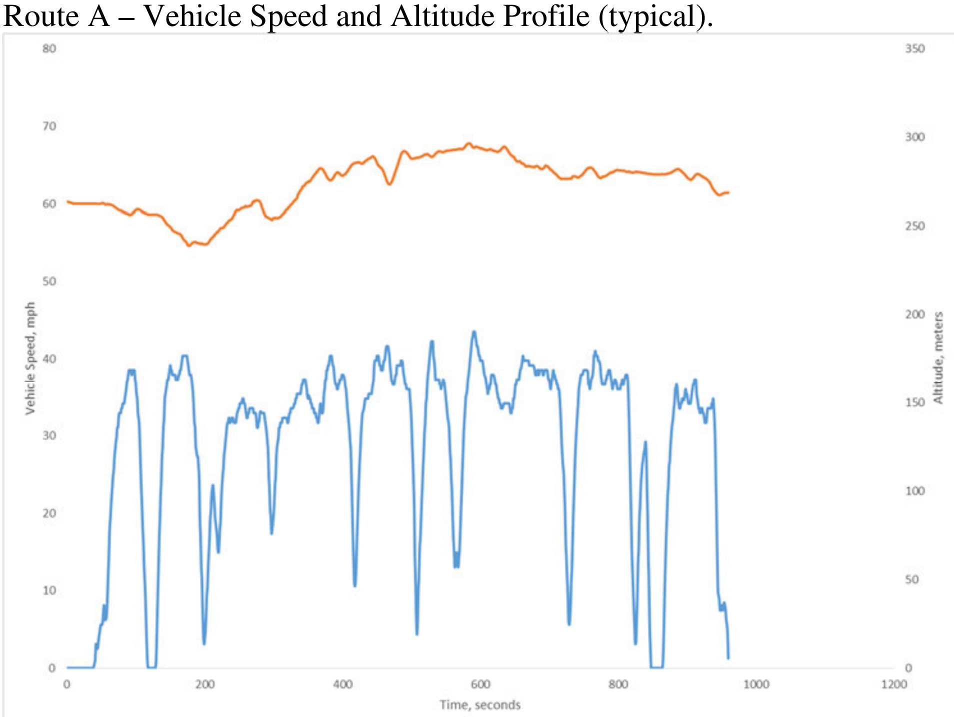
Route Description
The picture below provides the typical start location for three approved routes.



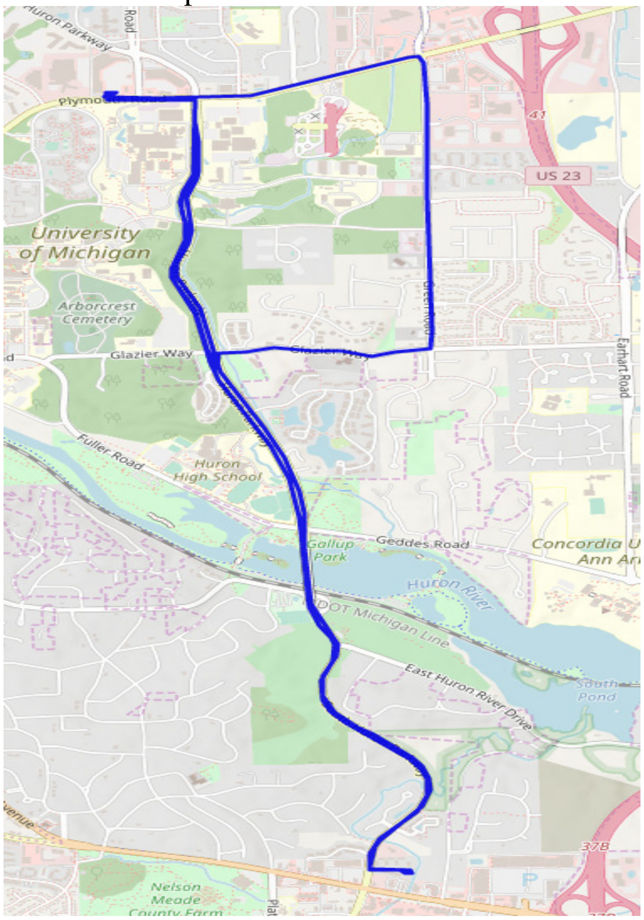
Route A -- Map



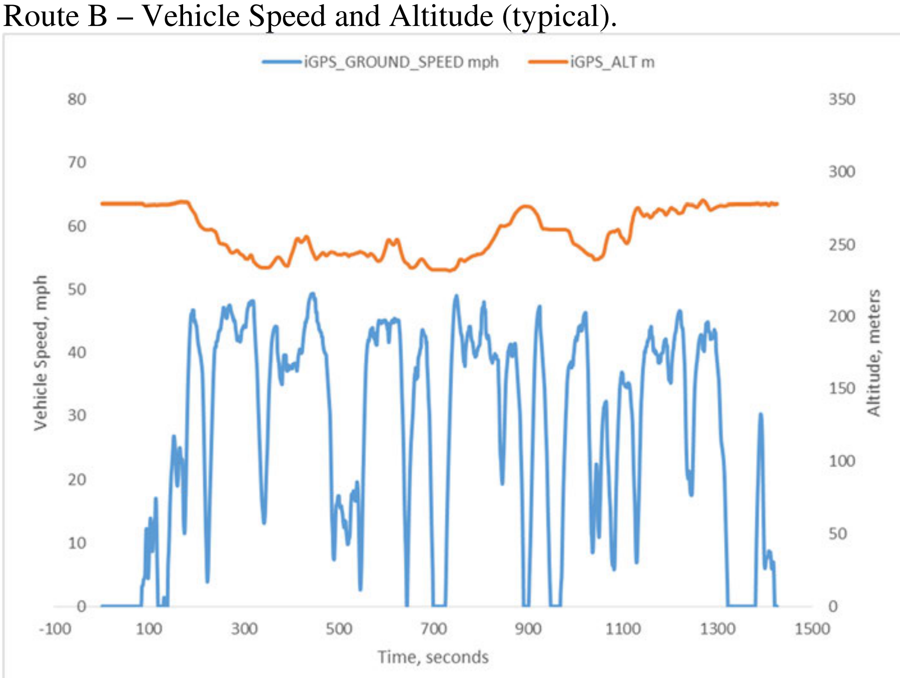
Route A – Vehicle Speed and Altitude Profile (typical).



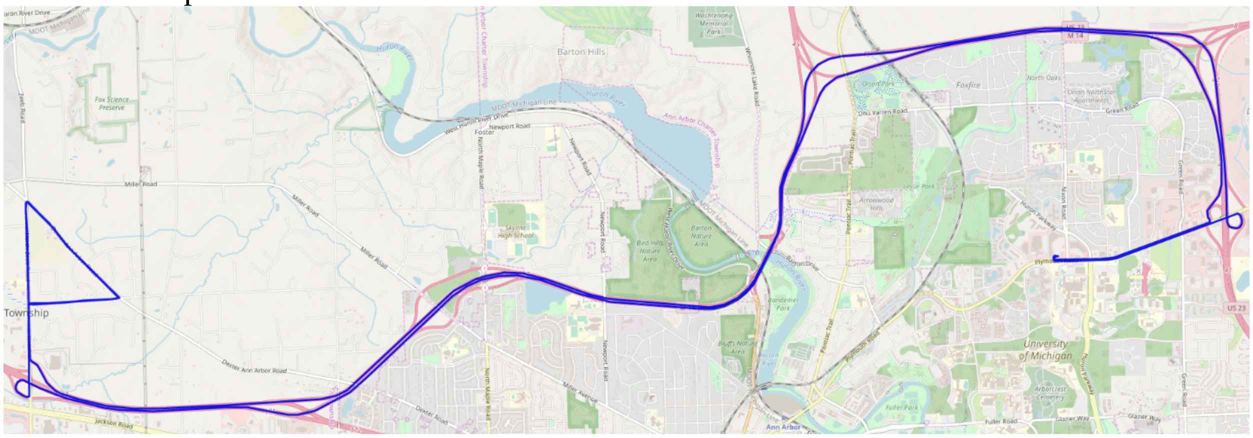
Route B – Map



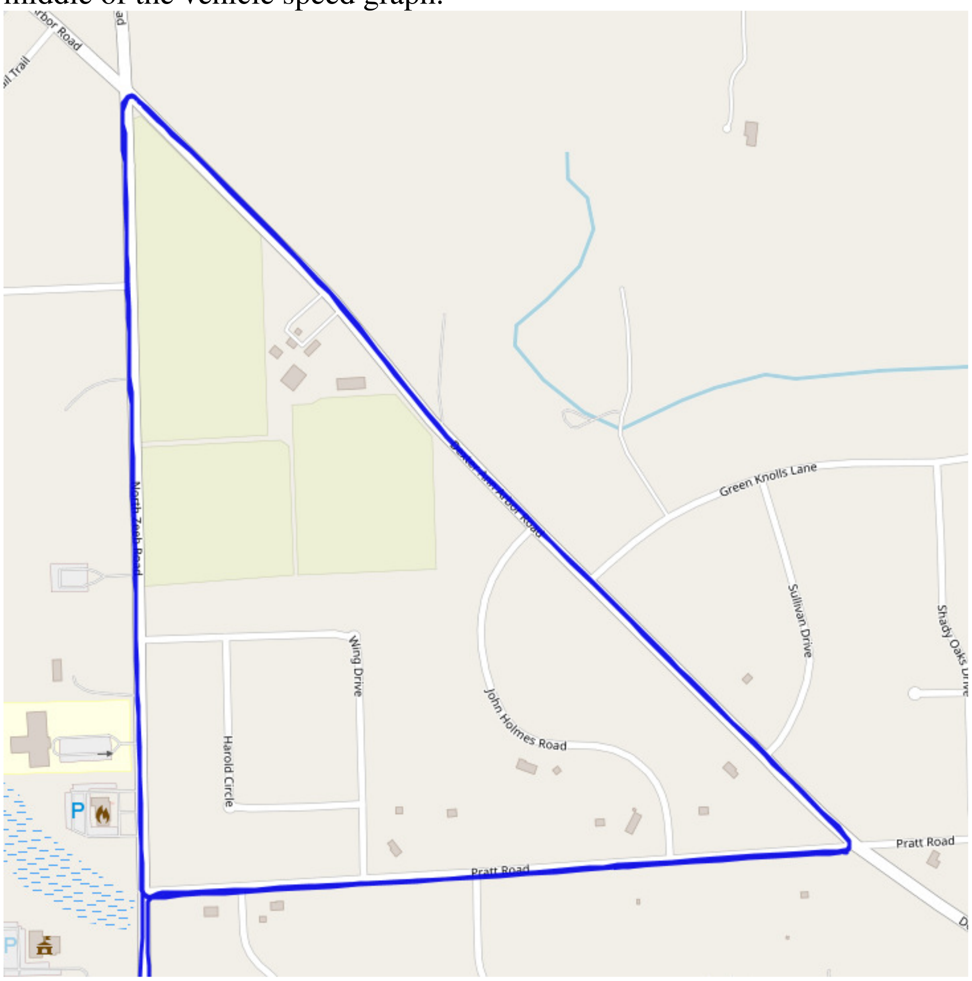
Route B – Vehicle Speed and Altitude (typical).



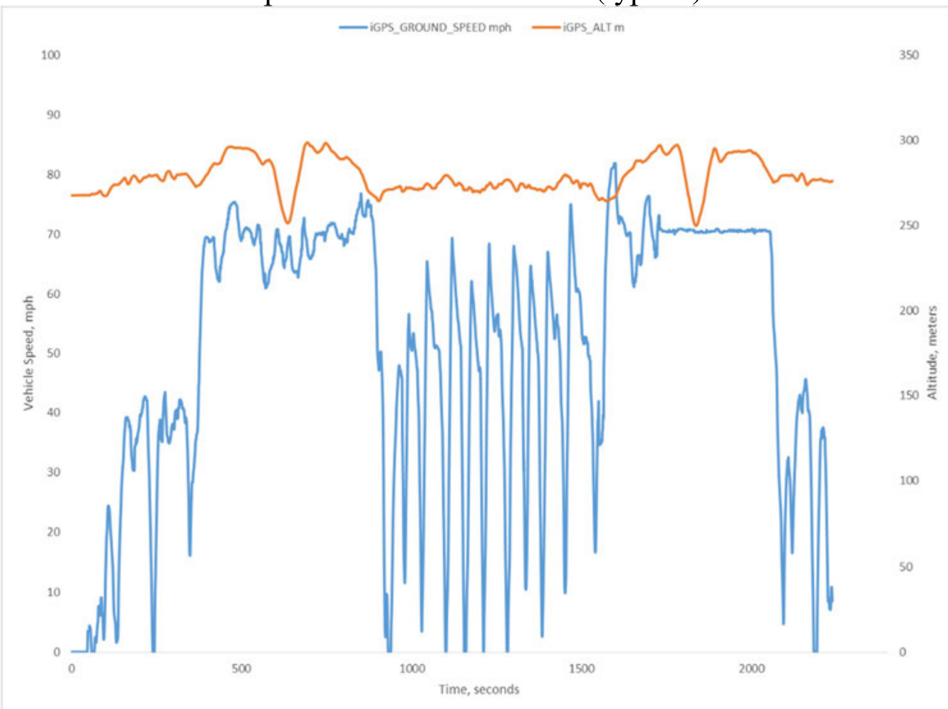
Route C – Map



Route C included one triangular loop which was driven three times. Each side of the triangle featured a segment of wide-open throttle for a total of nine wide-open throttles as recorded in the middle of the vehicle speed graph.



Route C – Vehicle Speed and Altitude Profile (typical).



Appendix 2B. Correlation of Sensors, Inc. SEMTECH LDV (PEMS) versus Mahle Dynamometer modal and bag benches

This report includes a correlation test between the SEMTECH LDV PEMS and the Mahle Dynamometer modal and bag benches. A correlation is a well-accepted quality check to confirm the performance of the PEMS during the testing period and is an excellent reference to validate road data. This correlation test is a regulatory requirement in some regions/countries such as in Europe. Since there are no standards by which to evaluate correlation tests in the United States, Sensors, Inc. utilized European Real Drive Emission standards, based *on Regulation EU 2016.427, Appendix 3, Section 3.3 Permissible Tolerances for PEMS Validation:*

Pollutant	Tolerance	Alternative
Total Hydrocarbons	+/- 15 mg/km or	15 % of the laboratory reference
Carbon Monoxide	+/- 150 mg/km or	15 % of the laboratory reference
Carbon Dioxide	+/- 10 mg/km or	10% of the laboratory reference
Oxides of Nitrogen	+/- 15 mg/km or	15% of the laboratory reference

The following tables reflect differences in gram values for the LDV PEMS as correlated to Mahle modal and bag bench analyzers. The PEMS equipment met European Union tolerances as required for a valid correlation.

DURANGO -- 2020 Test

Correlation Summary

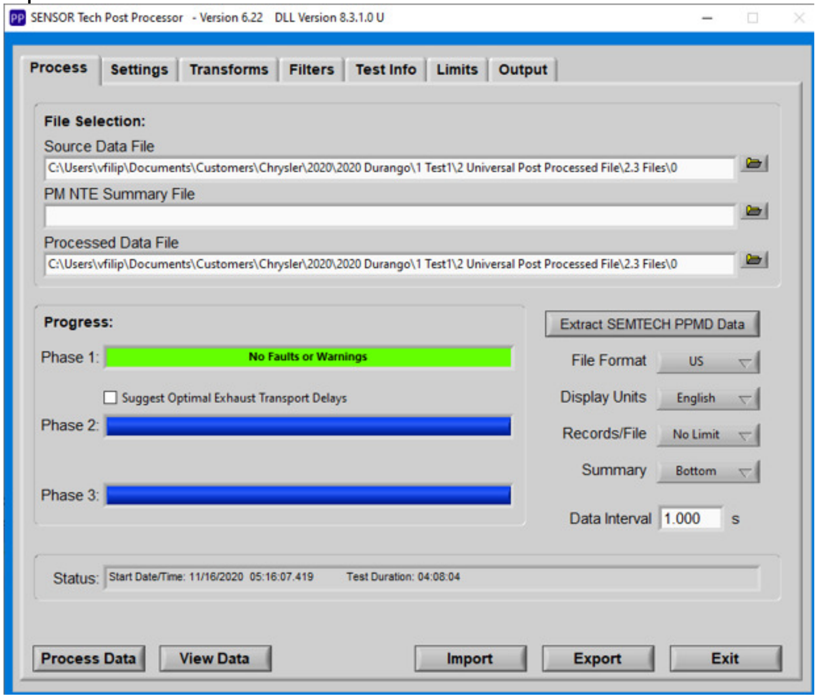
Dyno. distance :	11.05	miles
Dyno. distance :	17.68	km

	PEMS (SEMTECH LDV)			Dynamometer Bag Bench		
Overall Emissions:	grams	g/mi	g/km	grams	g/mi	g/km
CO2	4750.40	429.12	268.20	4732.71	427.53	267.20
CO	3.4690	0.3134	0.1959	2.0850	0.1883	0.1177
kNOx	0.0770	0.0070	0.0043	0.0510	0.0046	0.0029
THC[A]	0.1890	0.0171	0.0107	0.1620	0.0146	0.0091

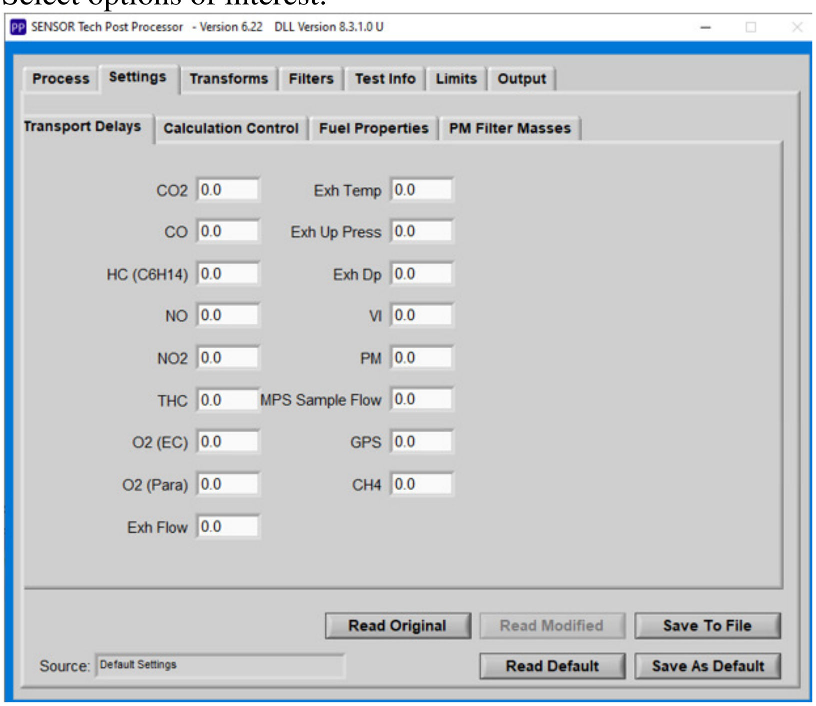
	Correlation versus EU Tolerance			Difference versus Dynmometer		
Overall Emissions:	Difference	Tolerance	Percent	% Diff	% Tolerance	Abs diff (g/km)
CO2	0.9988	10.0000	0.0999	0.4%	10.0%	0.999
CO	0.0781	0.1500	0.5209	66.4%	15.0%	0.078
kNOx	0.0015	0.0150	0.0979	51.0%	15.0%	0.001
THC[A]	0.0015	0.0150	0.1016	16.7%	15.0%	0.002

Appendix 2C: Post-processing raw data files (typical)

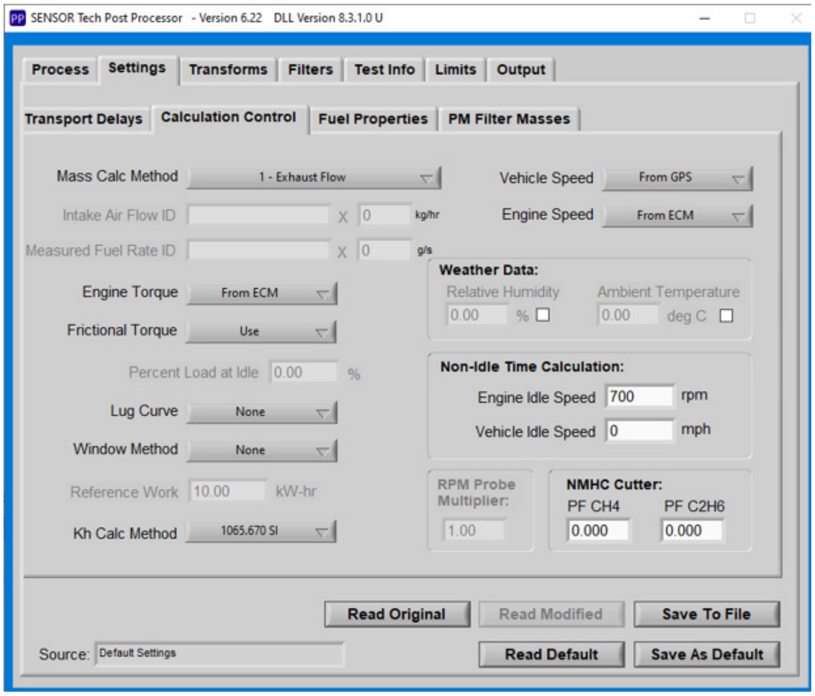
Open SENSORTech Post Processor and select the raw datafile of interest:



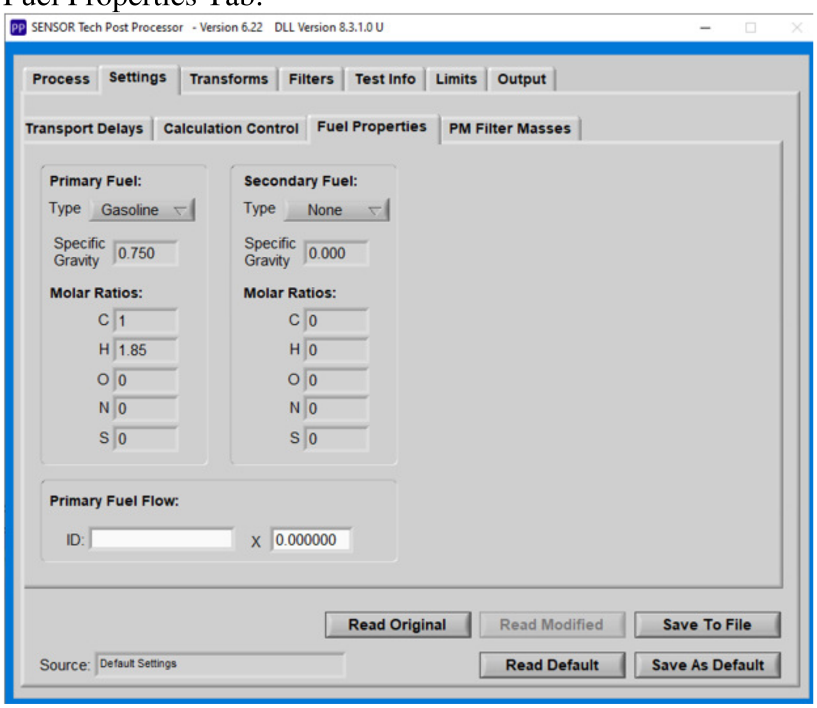
Select options of interest:



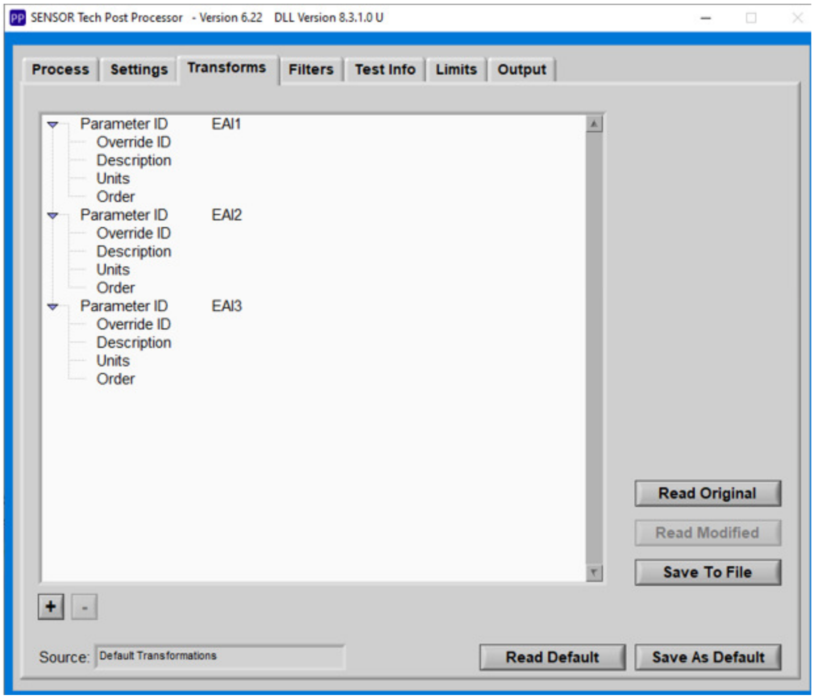
Calculation Control Tab:



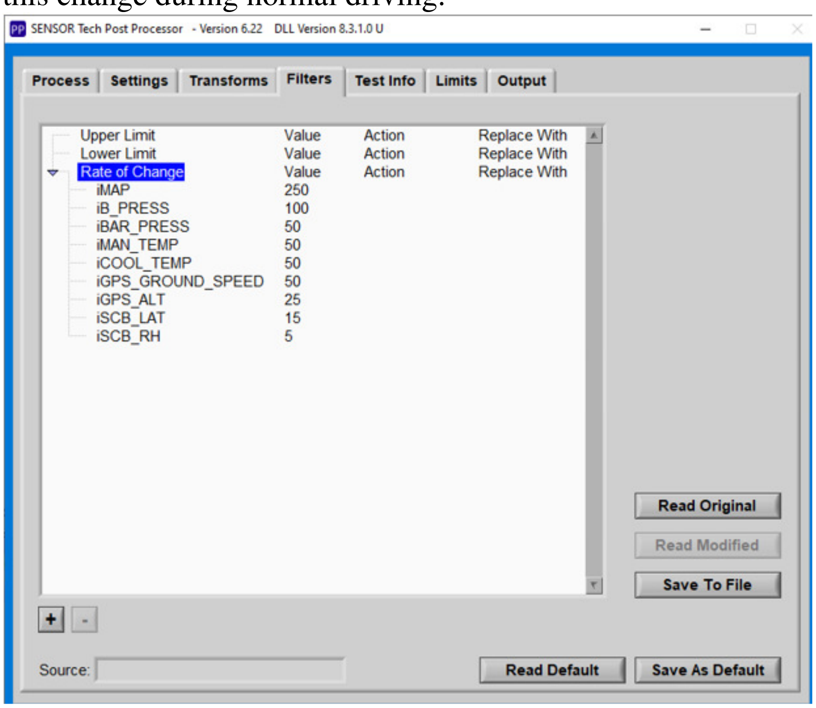
Fuel Properties Tab:



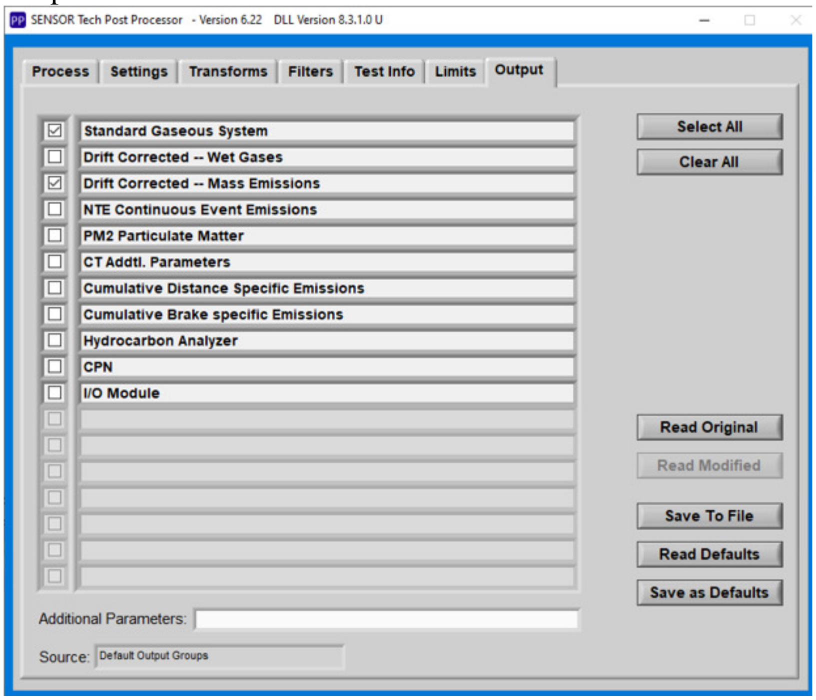
Transforms are used when post-processing DURANGO data files to provide correct scaling. No transforms were used on this test.



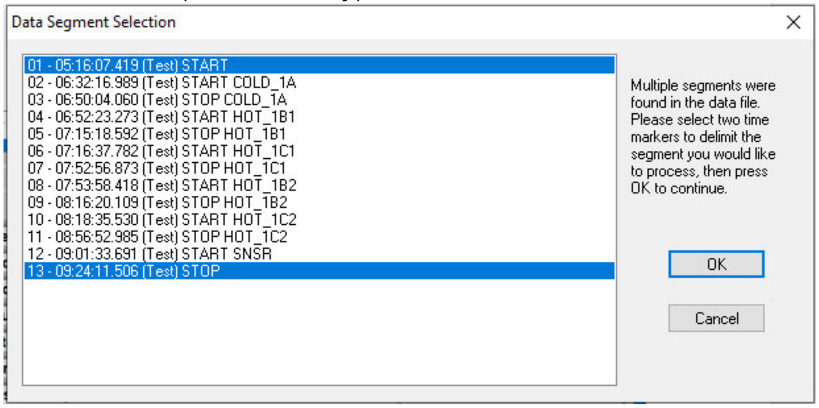
Parameter Filters Tab. This tab is used to filter out ECM or GPS outliars. For example, GPS Speeds changing by more than 50km/second will be filtered out, since will be impossoble to get this change during normal driving.



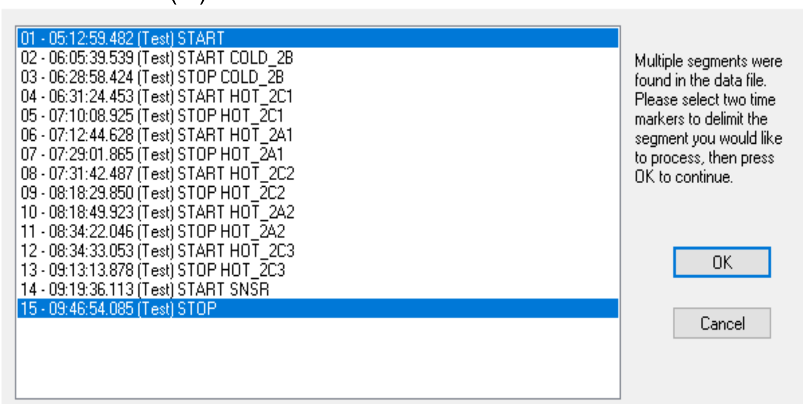
Output Tab:


SENSOR Tech Post Processor - Version 6.22 DLL Version 8.3.1.0 U
Process
Settings
Transforms
Filters
Test Info
Limits
Output
Standard Gaseous System
Drift Corrected -- Wet Gases
Drift Corrected -- Mass Emissions
NTE Continuous Event Emissions
PM2 Particulate Matter
CT Addtl. Parameters
Cumulative Distance Specific Emissions
Cumulative Brake specific Emissions
Hydrocarbon Analyzer
CPN
I/O Module
Select All
Clear All
Read Original
Read Modified
Save To File
Read Defaults
Save as Defaults
Additional Parameters:
Source:
Default Output Groups

Use the following User Marks when post-processing raw or converted data files (typical):
Test ABCBC (in its Entirety):

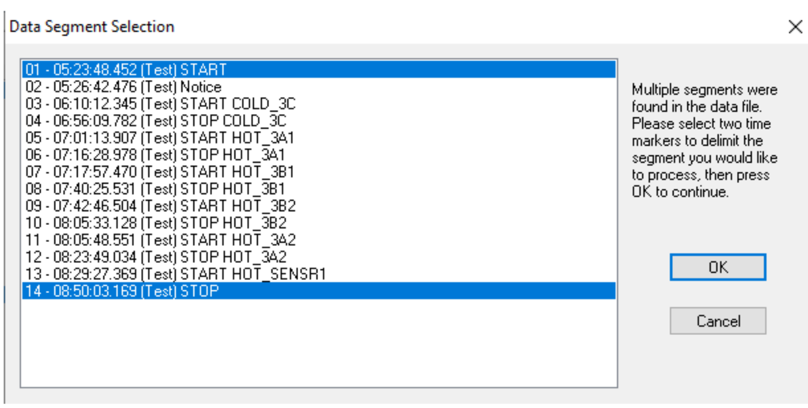


Test BCACA(C)*



* - Test HOT_2C2 heas been repeated (HOT_2C3) due to M-14 being closed due to an accident

Test CABBA

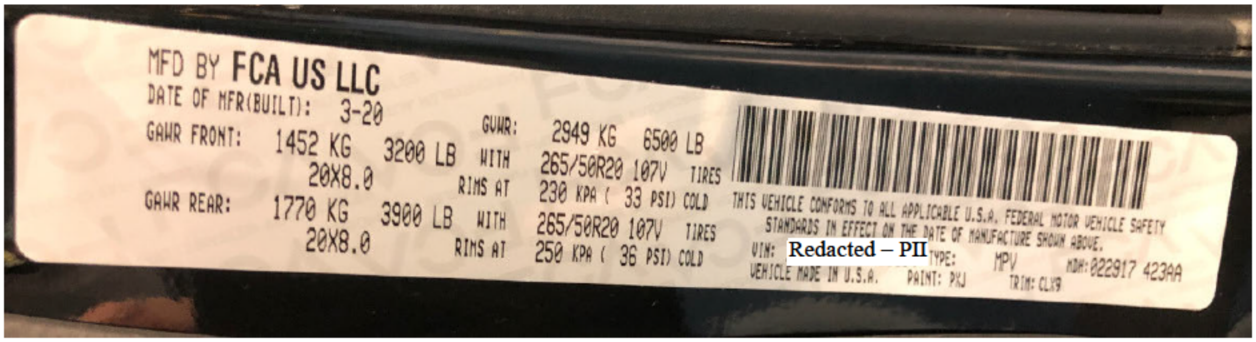


Appendix 2D: Pictures of Test Vehicle and Installation of Instrumentation

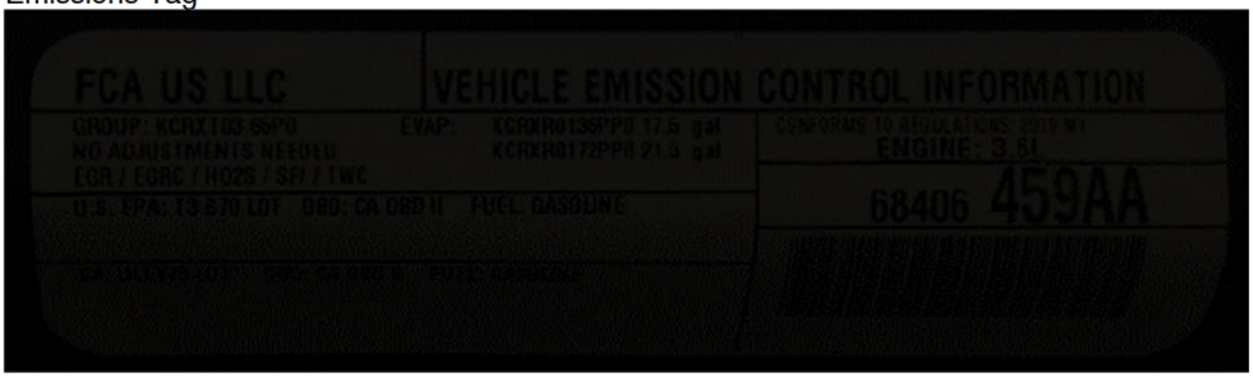
Test Vehicle

Exhaust Flowmeter and License Plate

Vehicle Identification Number



Emissions Tag



Gaseous Analyzer Stack

FCA Vehicle Tag

Correlation of Sensors, Inc. PEMS to Mahle modal and bag bench Dynamometer


Redacted – PII

Overview:

This analytical methods summary report is pursuant to paragraph 59.f of the Consent Decree. The report provides a description of Sensors, Inc.'s analytical methods and instrument specifications for gaseous analyzers and exhaust flowmeter devices. These devices were used to record vehicle emissions data during the on-road testing for FCA RAM and DURANGO vehicles which were respectively tested in November and December, 2019. In addition, Sensors, Inc. has included details regarding post-processing of recorded data as well as the calculation methodology. Additional details regarding test route description and emissions trends are available in the RAM1500 and DURANGO summary reports.

SEMTECH LDV: Analytical Methods

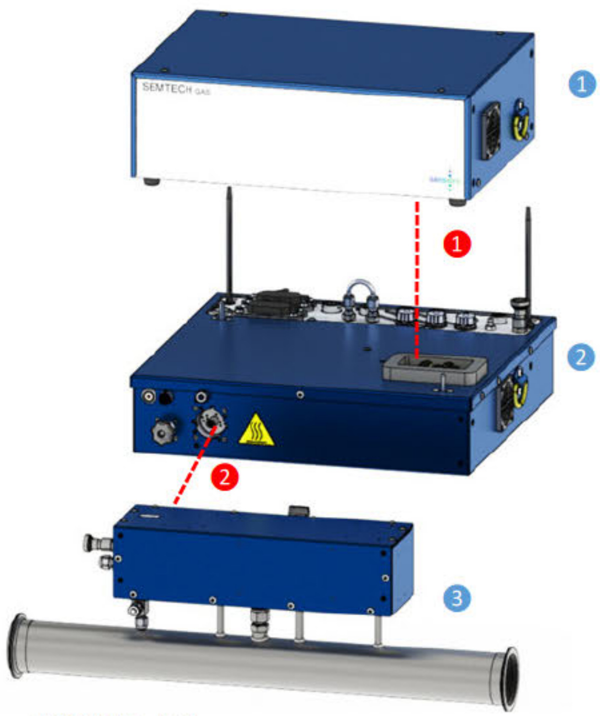
The three main modules of the SEMTECH® **L**ight **D**uty **V**ehicle PEMS analyzer consist of:

- **GAS** (**G**as **A**nalysis **S**ystem), measuring CO, CO_2, NO and NO_2.
- **SCS** (**S**ample **C**onditioning **S**ystem) containing sample conditioning system.
- **EFM** (**Ex**haust **F**low **M**eter) including sample flow tube.

The system may be mounted on a tow bar, with a quick clamp to the vehicle, or in the vehicle trunk. Externally mounted modules are covered by an aerodynamic fairing, which shields the system from elements while minimizing drag on the vehicle.

Sample lines, pneumatics, and cables are minimized with modules that mate directly by means of electrical and pneumatic connections.

The system may be configured to suit various applications (see configuration details chart).



LDV Modules:

1. SEMTECH® GAS (Gas Analysis System)
2. SEMTECH® SCS (Sample Cond. System)
3. SEMTECH® EFM (Exhaust Flow Meter)

Blind Connections:

1. SCS to GAS
2. EFM to SCS

Non-Dispersive Infrared CO and CO_2 Analyzer

The LDV employs the Sensors, Inc. Automotive Micro-Bench II (AMBII), non-dispersive infrared (NDIR) analyzer for the measurement of CO and CO_2 exhaust constituents. Prior to analysis in the NDIR analyzer, the exhaust sample is cooled and dried with a coalescing filter followed by a Nafion dryer. This removes water vapor that would otherwise cause interference in the infrared channels. This analyzer is housed in a temperature controlled enclosure for maximum stability in rapidly changing thermal environments.

The NDIR analyzer reports concentration measurements for CO and CO_2 on a continuous 5 Hz data rate to the LDV data collection software via an internal serial connection. This data rate is sufficient for accurate transient mass measurements as demonstrated during numerous correlation tests against laboratory equipment.

The CO analyzer has a range of 0 – 8%, however the range of interest for typical diesel exhaust is 1000 ppm, or 0.1%. When span calibrated at 1200 – 1500 ppm and zero calibrated prior to a test, the CO channel has an accuracy of .3% of full scale. This has been verified through extensive correlation testing with diesel engine exhaust. The analyzer can also be calibrated at the full scale range of 8% (80,000 ppm). The analyzer then has an accuracy of 2% of reading, or .3% of full scale, whichever is greater. The LDV software can display the CO concentration either in percent or ppm.

Non-Dispersive Ultraviolet NO and NO_2 Analyzer

The LDV employs the Sensors, Inc. non-dispersive ultraviolet (NDUV) NO and NO_2 analyzer for the independent measurement of NO and NO_2 exhaust gas constituents. Prior to analysis in the NDUV analyzer, the exhaust sample is cooled and dried with an ambient temperature coalescing filter followed by a Nafion dryer. This removes the heavy hydrocarbons found in diesel exhaust that would otherwise cause contamination of the optics. A small amount of the NO_2 is lost in this process but this difference is within acceptable efficiency limits for typical $NO_2 \rightarrow NO$ converters found in certification instruments.

The NDUV analyzer reports continuous concentration measurements for NO and NO_2 at a user configurable rate of up to 5 Hz to the LDV data collection software.

The performance of the NDUV NO/NO_2 analyzer compares favorably with laboratory chemiluminescent analyzers, as demonstrated in extensive correlation testing.

Electrochemical Oxygen Sensor

A replaceable oxygen sensor cartridge is installed onto a flow adapter and is located inside the gas analyzer. The exhaust sample flows through the adapter and the sensor produces a signal that is proportional to the partial pressure of oxygen in the sample gas. The signal is fed into an analog input channel of AMBII module. The AMBII embedded firmware processes the signal and monitors the status of the oxygen sensor.

FID Analyzer Specifications

A Flame Ionization Detector is used for the measurement of total hydrocarbons (THC). The FID chamber is first heated to 191°C, which takes approximately 30 minutes.
The valve is then opened to allow FID fuel and air into the chamber, and the flame is ignited automatically. The exhaust sample can then be added. The FID fuel, air, and exhaust sample are mixed together at the bottom of the detector's flame jet, and are burned on the jet's tip.
As the hydrocarbons burn, they form positively charged ions. These ions are repelled by the jet's nozzle head, which has a positive bias voltage. The carbons are then attracted to the negatively charged collector plate, where the resulting current is measured.

LDV Analyzer Specifications

Parameter	CO	CO_2	O_2 (1)	NO	NO_2
Max range	8% vol.	18 % vol.	25% vol.	0 to 3000 ppm	0 to 500 ppm
Full scale for RDE/LDV	1%	12%	25%	1500 ppm	500 ppm
Resolution	10 ppm	< 0.01% vol. CO_2	<.1% vol.	0.3 ppm	0.3 ppm
Zero drift (over 1 hour)	± 50 ppm	< ± 0.1% vol CO_2	< ± 0.1% vol.	< 4 ppm / hour with Δt <10°C and using purified N_2 as zero gas	
Span drift (over 8 hours)	< ± 2% of span value or < ± 20 ppm, whichever is greater	< ± 2% of span value or < ± 20 ppm, whichever is greater	< ± 2% of Full scale	< 4 ppm / hour with Δt <10°C and using purified N_2 as zero gas	
Sample flow rate (nominal)	3 LPM				

(1) When using optional paramagnetic O_2

Can't include any of these specs for electrochemical O2

Linearity	Accuracy	Precision	Noise
$\lvert x_{min}\, x(a_1 - 1) + a_0 \rvert < 0.5\%$ of max, slope a_1 between .99 and 1.01, Std. Error of Estimates SEE < 1% of max, Coefficient of Determination $r^2 > .998$	< ± 2% of reading or < ± 0.3% of full scale, whichever is greater	< ± 1% of full scale	< ± 1% of full scale

	Flow tube	SCS module	G.A.S. module	CAB module	Zero/Span box
Input voltage	12V supplied by base box	12 VDC	12V supplied by base box	Power over Ethernet (PoE	Power over Ethernet (PoE
Storage temperature	-10 °C to 60 °C dry				
Ambient operating temperature	-10 °C to 40 °C, up to 100% when used with a fairing *				
Dimensions (W x D x H)	14.25 x 4.125 x 3.375 in. box only 36.2 x 10.5 x 8.6 cm box only	17 x 16 x 4 in 43.2 x 40.6 x 10.2 cm	17 x 12 x 5 in 43.2 x 30.5 x 12.7 cm	4.5 x 8 x 1.75 in 11.4 x 20.3 x 4.5 cm	approx 12 x 12 x 3
Weight	8.4 lbs (w/2.5" flow tube) 3.81 kg (with 2.5" flow tube)	20.2 lbs 9.2 kg	19.6 lbs 8.9 kg	.75 lbs .3 kg	?
Power Consumption	20W typical, 50W max	80W typical, 150W max	70W typical, 150W max	25W typical, 45W max	15W typical, 15W max
Data Acquisition Rate	1 or 5 Hz selectable				
Communications	TCP over Ethernet				
Warm up time	60 minutes at 20 °C to meet performance specifications			N/A	N/A
Rise time	≤ 2.5 seconds			N/A	N/A
System Response Time	≤ 10 seconds				
Electromagnetic Interference and Susceptibili	CE Standards: IEC 61326-2002-2				

FID ANALYTICAL SPECIFICATIONS	
Parameter	THC
Supported Ranges	30000 $ppmC_1$ 10000 $ppmC_1$ 1000 $ppmC_1$ 100 $ppmC_1$
Linearity (all ranges)	$\lvert x_{min} \times (a_1 - 1) + a_0 \rvert \leq 0.5\%$ of selected range Slope a_1 between 0.99 and 1.01 Standard Error of Estimates (SEE) $\leq$ 1% of selected range Coefficient of Determination $r^2 \geq 0.998$
Accuracy	$\leq \pm$ 2% of reading or $\leq \pm$ 0.3% of full scale of selected range, whichever is greater
Repeatability	$\leq \pm$ 1% of point or < ± 1% of selected range, whichever is greater
Precision	$\leq$ 1% of selected range
Noise	$\leq$ 2% of selected range
Zero Drift	$\leq \pm$ 1 % of full scale of selected range over 1 hours
Span Drift	$\leq \pm$ 2 % of full scale of selected range over 8 hours
Rise Time (T_{10-90})	$\leq$ 2.5 seconds
System Response Time (T_{10-90})	$\leq$ 10 sec with rise time $\leq$ 2.5 seconds
Data Rate	5 Hz
Sample Flow Rate (nominal)	800 ml/min

SEMTECH EFM4

SEMTECH® **EFM** (**E**xhaust **F**low **M**eter) **4** or **5** must be used in conjunction with the SEMTECH-GAS and SCS modules for direct, independent measurement of exhaust mass flowrate.
The exhaust mass flow information is used by SEMTECH® LDV and Post Process application software to calculate exhaust mass emission for all exhaust gases.

SEMTECH® EFM4 Module

FLOW RATES				
Temp	100°C		400°C	
Nominal Tube Diameter (in.)	Min Flow (kg/hr)	Max Flow (kg/hr)	Min Flow (kg/hr)	Max Flow (kg/hr)
1	6.9	85.0	10.4	64.0
1.3	8.9	217.0	13.4	162.0
1.5	10.9	276.0	16.4	208.0
2	15.8	535.0	23.9	402.0
2.5	18.9	890.0	28.4	670.0
3	22.5	1250.0	34.0	930.0
4	30.7	2080.0	46.3	1550.0
5	38.6	3115.0	58.2	2345.0

SPECIFICATIONS									
Exhaust temperature range	-5 to 700° C								
Exhaust temperature accuracy	± 1% of reading or ± 2° C, whichever is greater								
Flow measurement linearity	$\lvert x_{min} \times (a_1 - 1) + a_0 \rvert \le$ 1% of max Slope a_1 between 0.99 and 1.01 Standard Error of Estimates (SEE) ≤ 1% of max. Coefficient of Determination $r^2 \ge 0.990$								
Flow measurement accuracy	± 2% of reading or ± 0.5% of full scale, whichever is greater								
Warm up time	< 5 minutes at 20° C ambient								
System response time ($T_0 - T_{90}$)	≤ 2.5 seconds; synchronized to match rise time of gaseous analyzers								
Data acquisition rate	5 Hz standard								
Resolution	0.1 kg/hr								
Power requirements	12 VDC								
Communications	RS 232								
Box dimensions (WxDxH)	35.8 x 11.2 x 9.1 cm 14.1 x 4.4 x 3.6 in								
Flow tube dimensions	OD X L (mm)	25 x 508	33 x 508	38 x 508	51 x 508	64 x 640	76 x 640	120 x 684	127 x 762
	OD X L (in)	1.0 x 20	1.3 x 20	1.5 x 20	2.0 x 20	2.5 x 25.2	3.0 x 25.2	4.0 x 25.2	5.0 x 30
Weight	kg (lbs)	3.4 (7.5)	3.7 (8.2)	3.8 (8.4)	4.2 (9.3)	4.8 (10.6)	5.2 (11.4)	5.8 (12.8)	6.4 (14.1)

Post-Processing of Data:

The following information is taken from 9510-202 SENSORTech Post Processor User Manual rev1.0:

1.1.1 CALCULATIONS

1.1.1.1 THE PITOT TUBE

Daniel Bernoulli's observation; as the static pressure of a flow stream decreases as its velocity increases, led to the common Bernoulli equation:

$$P_{total} - P_{static} = \frac{1}{2}\rho v^2$$

where

P_{Total} = Total pressure (also known as stagnation pressure or impact pressure) measured by the force per unit area required to reduce the flow velocity to zero.

P_{Static} = pressure in the freely flowing fluid stream

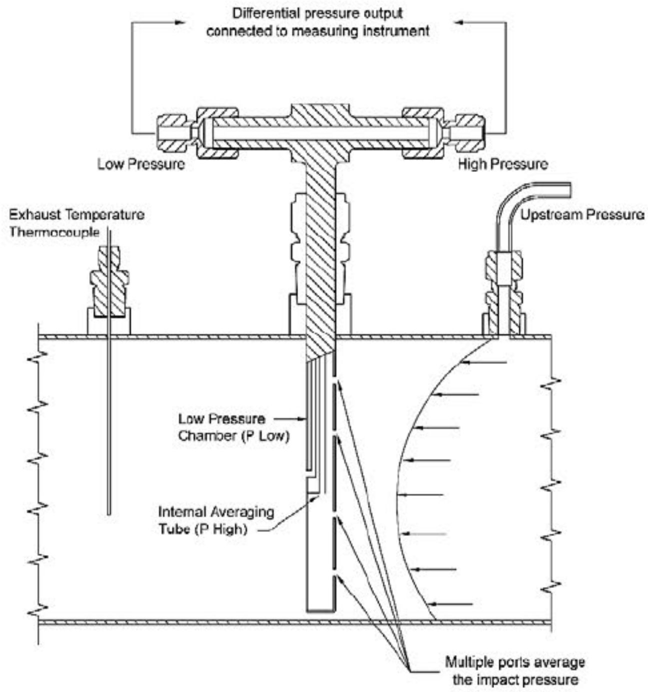
ρ = gas density

v = gas velocity

One of the most immediate applications of Bernoulli's equation was in the measurement of velocity using a pitot tube. This device determines the total pressure in a flow stream at a single point. By also measuring the static pressure, one can determine the velocity of the fluid at that point in the flow stream.

Since the volumetric flow rate is obtained by multiplying the point velocity by the cross-sectional area of the pipe or duct, it is critical that the velocity measurement be made at an insertion depth which corresponds to the average velocity. This is inherently difficult, since this position is unknown and can change depending on the inlet velocity profile.

To overcome the problem of finding the average velocity, averaging pitot tubes were introduced which provide multiple impact and static pressure ports that extend across the entire diameter of the pipe. This is the basis for SEMTECH Heated Sample Tube Assembly and shows a cross section of an averaging Pitot tube flow sensor.



Example of an Averaging Pitot tube Cross Section

1.1.2 FLOW CALCULATIONS

The governing equation for determining the mass flow rate through SEMTECH EFM is based on the Bernoulli equation and the continuity equation:

$$\dot{m} = K(RE) \times A\sqrt{\rho \times \Delta P}$$

A = the physical cross section area of the flow tube assembly
K(RE) = the discharge coefficient for the flow tube assembly, as a function of Reynolds Number
ρ = the density of the exhaust gas
ΔP = the difference between P_{High} and P_{Low}
Density of the exhaust gas is calculated using the Ideal Gas equation:

$$PV = RT$$

P = absolute pressure of the gas
V = volume of the gas
n = number of moles of gas
R = universal gas constant

T = absolute temperature of the gas

Since the number of moles is equal to the mass divided by the molar mass, this equation can be written as:

$$PV = \frac{m}{M}RT$$

Density is calculated as the mass over volume.

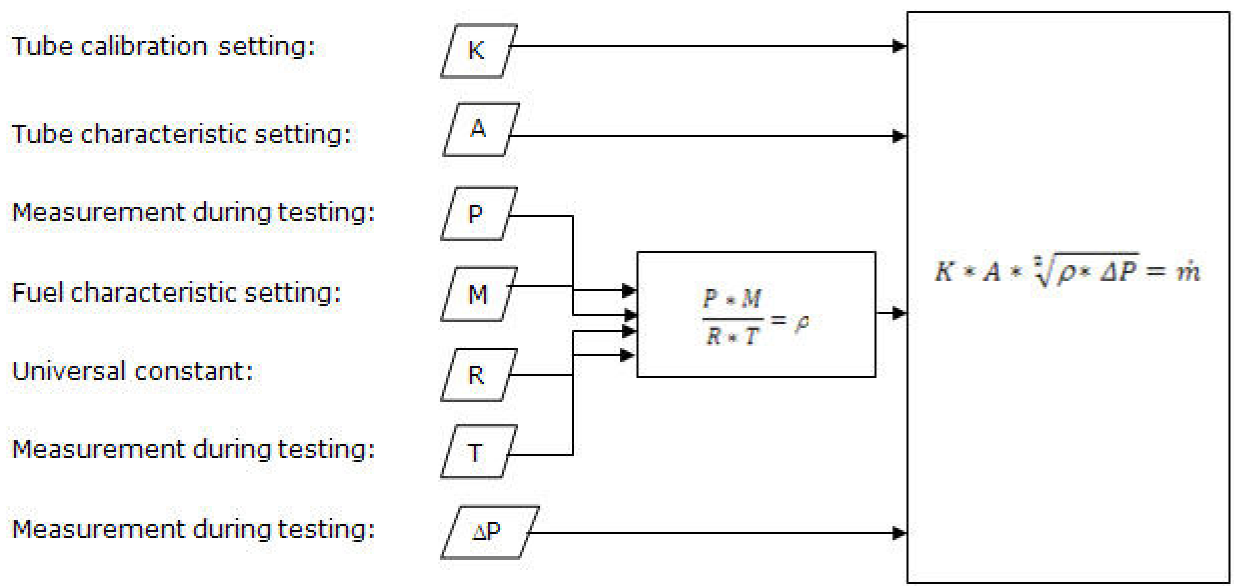
$$\rho = \frac{m}{V}$$

Replacing this density into the previous equation, and solving for ρ yields:

$$\rho = \frac{PM}{RT}$$

M, the gas molecular weight, is user definable in the Sensor TECH-EFM-HS software, under **Calibrate > Constants**, as described in the Calibrate Constants Section of this manual. Please note that the effect of uncertainty in using a constant molecular weight is small since the mass flow rate of the exhaust is proportional to the square root of this parameter.

The figure below summarizes the inputs, equations and outputs of the calculations performed by the SEMTECH EFM-HS.



Calculations Summary

The following equations carry out the calculations with the appropriate units for each parameter.

$Reynold's\ Number: K = unitless$

$Area\ of\ Tube: A = m^2$

$$Upstream\ Pressue: P = Pa = \frac{N}{m^2} = \frac{kg*m}{m^2*s^2} = \frac{kg}{m*s^2}$$

$$Gas\ Molecular\ Weight: M = \frac{kg}{mol}$$

$$Universal\ Gas\ Constant: R = \frac{J}{K * mol} = \frac{Nm}{K * mol} = \frac{\left(\frac{kg * m}{s^2}\right) * m}{K * mol} = \frac{kg * m^2}{K * mol * s^2}$$

$$Temperature: T = [K]$$

$$Differential\ Pressure: \Delta P = Pa = \frac{N}{m^2} = \frac{kg * m}{m^2 * s^2} = \frac{kg}{m * s^2}$$

$$Density: \rho = \frac{P * M}{R * T} = \frac{\left(\frac{kg}{m * s^2}\right) * \left(\frac{kg}{mol}\right)}{\left(\frac{kg * m^2}{K * mol * s^2}\right) * K} = \frac{kg}{m^3}$$

$$Mass\ Flow: \dot{m} = K * A * \sqrt[2]{\rho * \Delta P} = m^2 * \sqrt[2]{\left(\frac{kg}{m^3}\right) * \left(\frac{kg}{ms^2}\right)} = \frac{kg}{s} * \frac{3600\ s}{hr} = 3600 kg/hr$$

To convert the standard SI units to SLPM, substitute the following:

$$\rho = \frac{m}{V} = \frac{\dot{m}}{\dot{V}}$$

Solve for volumetric flow:

$$\dot{V} = \frac{\dot{m}}{\rho} = \frac{\frac{kg}{s}}{\frac{kg}{m^3}} = \frac{m^3}{s}$$

Substitute minutes for seconds and liters for m^3, and then solve for units:

$\frac{60s}{min} * \frac{L}{0.001m^3} * \frac{m^3}{s} = 60{,}000\ LPM$ or

$\frac{kg}{hr} = \frac{60{,}000\frac{l}{min}}{3600}$ = 16 2/3 LPM

However, since volumetric flow varies greatly with temperature, it is necessary to define which temperature is used for determining a standard volumetric flow, to arrive at the commonly used units of Standard Liters per Minute (SLPM).

The following density factors are therefore used:
At 20ºCelsius, for a mass flow of 1 kg/hr, the density factor is 1.204 kg/m^3, resulting in:

$$\dot{V} = \frac{\frac{kg}{hr}}{1.204\frac{kg}{m^3}} = \frac{1}{1.204}\frac{m^3}{hr} * \frac{hr}{60\ min} * \frac{L}{0.001m^3} = 13.843\ SLPM$$

At 0ºCelsius, for a mass flow of 1 kg/hr, the density factor is 1.293 kg/m^3, resulting in:

$$\dot{V} = \frac{\frac{kg}{hr}}{1.293\frac{kg}{m^3}} = \frac{1}{1.293}\frac{m^3}{hr} * \frac{hr}{60\ min} * \frac{L}{0.001m^3} = 12.890\ SLPM$$

1.1.3 FUEL SPECIFIC EMISSIONS

Fuel-specific emissions are the mass fractions of each pollutant to the fuel in the combusted air/fuel mixture. This fraction is easily computed directly from concentrations of the measured exhaust constituents. No additional measured or derived parameters are required to calculate fuel-specific emissions.
To express fuel-specific emissions in grams of pollutant per gram of fuel, the mole fraction of the pollutant to the fuel burned is computed. This is simply the ratio of the measured concentration of pollutant to the sum of the CO, HC_1, and CO_2 concentrations in the exhaust, which reflect the number of moles of fuel that is consumed per mole of exhaust. The ambient CO_2 concentration must be zero calibrated on the instrument or subtracted from the exhaust measurement. Ambient CO and HC are not subtracted from raw exhaust concentrations because it is assumed these are destroyed in the combustion process. The mass fraction of each pollutant to fuel burned is then computed by multiplying the mole fraction by the ratio of the molecular weights of the pollutant to the molecular weight of the fuel. As an example, the NO fuel specific equation is shown below:

$$NO_{fs}\left(\frac{g\_NO}{g\_fuel}\right) = \left(\frac{[NO]}{[CO] + [HC_1] + [CO_2] - [CO_2]_{ambient}}\right) \times \left(\frac{MW_{NO}}{MW_{fuel}}\right)$$

Fuel specific emissions for all other species are computed in a similar manner.

1.1.4 INSTANTANEOUS MASS EMISSIONS

There are two methods of computing time-specific mass emissions (grams/second). The first method uses fuel-specific emissions and fuel flow rate. The second method involves direct calculation from exhaust concentrations and total exhaust flow rate.

1.1.4.1 EXHAUST FLOW CALCULATION METHOD 1

Step 1: Time align raw data

The exhaust mass flow-rate must be precisely time aligned with the exhaust gas concentrations before computing mass emissions. The exhaust flow-rate measurement is typically faster than the exhaust concentrations due to the length of sample line leading to the gas analyzers.

For diesel engines, this is relatively simple because the CO_2 concentrations are directly influenced by the fuel flow-rate. Time alignment procedures are described in the previous section. Time delays for each instrument are configurable in the SENSOR Tech-PC software. They can be modified subsequent to the test using the post processor application.

Step 2: Apply dry-to-wet correction to gas concentrations

In order to compute mass emissions using exhaust flow-rate, any gas concentrations measured on a dry basis must first be converted to wet concentrations. This is because the concentrations of the other exhaust constituents will increase as the water volume is removed from the exhaust sample. The wet concentration is computed by multiplying the dry (measured) concentrations by the dry-to-wet conversion factor, Kw:

$$[\ ]_{wet} = [\ ]_{dry} \times K_w$$

The dry-to-wet correction factor is a function of the concentration of water vapor that was removed from the sample by condensation.

$$Kw = 1 - [H_2 0]_{condensed}$$

The water removed by condensation is a function of the final humidity of dried sample and the amount of water in the exhaust prior to drying.

$$[H_2 0]_{condensed} = [H_2 0]_{exhaust} - [H_2 0]_{residual}$$

The final humidity of the dried sample is a function of chiller temperature, chiller pressure, and efficiency. The amount of water in the exhaust prior to drying is a function of fuel properties, ambient humidity and stoichiometry. It is determined based on user entered molar hydrogen/carbon (H/C) ratio of the fuel, ambient humidity measurement, and exhaust constituent concentrations.

Step 3: Compute standard volumetric exhaust flow rate

The Sensors, Inc. SEMTECH EFM provides a direct mass measurement of the exhaust. This must be converted to a standard volumetric flow rate at 20°C and 1 atmosphere before computing mass emissions. This is accomplished by determining the density of the exhaust at these standard conditions based on measured constituent concentrations.

From the continuity equation, the mass flow rate is equal to actual density multiplied by the actual volumetric flow rate. It is also equal to the density at standard conditions multiplied by the standard volumetric flow rate.

$$\dot{m} = \rho V = \rho_{std} V_{std}$$

Solving for V_{std} we have:

$$V_{std} = \frac{\dot{m}}{\rho_{std}}$$

To compute the standard volumetric flow rate, the standard density of the exhaust mixture must be determined. We start by determining the molecular weight of the exhaust. This is approximated by weighting the CO_2, N_2, O_2, and water vapor by their respective wet concentrations.

$$MW_{exhaust} = \frac{1}{100} \sum [CO_2] \times 44.01 + [O_2] \times 32.0 + [N_2] \times 28.013 + [H_2O] \times 18.015$$

Once the exhaust molecular weight is determined the ideal gas constant for the exhaust is computed from the universal gas constant. The standard density of the exhaust is then computed using the ideal gas law at 20°C and 1 atmosphere. Note that the exhaust density changes with constituent concentrations, so this calculation must be performed for each data record in the test.

Step 4: Compute Instantaneous Mass Emissions

Instantaneous mass emissions (g/s) are computed by multiplying the wet gas concentrations by the standard volumetric exhaust flow-rate and the standard density for each constituent. Using CO_2 as an example,

$$CO_2\left(\frac{g}{s}\right) = \frac{[CO2]_{wet}}{100} \times V_{std} \times \rho_{CO2,std}$$

The following table (ref. 40 CFR §86.1342-94) gives the standard densities for each constituent for both English and SI units.

Constituent	Standard Density (g/ft^3)	Standard Density (g/l)
CO_2	51.81	1.830
CO	32.97	1.164
#2 Diesel HC ($CH_{1.80}$)	16.27	0.5746
#1 Diesel HC ($CH_{1.93}$)	16.42	0.5800
Gasoline HC ($CH_{1.85}$)	16.33	0.5768
NO_x (as NO_2)	54.16	1.913

By entering the molar H/C ratio for the fuel in the SENSOR Tech-PC software, the appropriate density is applied for the HC mass calculation.

Notice that the mass rate of NO_x is computed using the density of NO_2, rather than a weighted average for each species. The mass rate of HC is computed using the density for the average molar H/C ratio of the fuel.

1.1.4.2 BSFC Calculation Method II

This calculation was developed by USEPA and the Engine Manufacturers Association (EMA) during the HDIU Measurement Allowance Program. It is designated solely for in-use testing, and is designed to minimize errors related to the exhaust flow measurement. Calculation Method 2 relies on flow weighting of individual readings during a test event. This means that the flow meter only needs to be linear, and installation effects or other issues that affect span accuracy are canceled out in the calculation. In principle, any signal that is proportional to exhaust flow can be used for this method.

In addition, Method 2 uses a carbon balance method to predict the fuel consumption rate, and a brake-specific fuel consumption (BSFC) value to determine a final work term for the calculation. In the case of SEMTECH, the BSFC value can be a single value provided by the manufacturer or calculated using a manufacturer supplied table (including RPM, torque, and fuel rate), and ECM broadcast values for fuel rate.

A simplified version of this method can be expressed as:

$$M2\_mass = \frac{\sum g}{\sum \left[\frac{CO2\ fuel}{EFM\ fuel} x\ Work\right]}$$

Where:

- $M2\_work = \frac{ECM\ fuel}{BSFCi}$
- *CO2 fuel* is the fuel rate we compute based on carbon balance from emissions
- *BSFCi* has units of g/bhp-hr
- *BSFCi* can be a single value, or lookup table based on RPM, and ECM fuel rate
- *ECM fuel* is in grams

These equations simplify to:

$$M2\_mass = \frac{\sum g}{\sum \left[\frac{CO2\ fuel}{BSFCi}\right]}$$

1.1.4.3 Fuel Flow Calculation Method III

Today's heavy-duty diesel engines are typically equipped with an ECM, and typically provide fuel flow information based on the real-time pulse width of the fuel injectors. SEMTECH-ECOSTAR relies on this information in the computation of time-specific mass emissions.

With access to instantaneous, second-by-second mass fuel flow rate, transient mass emissions are easily computed by multiplying these by the instantaneous fuel-specific emissions. Using NO as an example,

$$NO\left(\frac{g}{s}\right) = NO_{fs}\left(\frac{g\_NO}{g\_fuel}\right) \times Fuelflow\left(\frac{g}{s}\right)$$

This method obviates the need for any measurement or computation of vehicle exhaust flow rate.

The fuel flow method of computing mass emissions has been well established. It is commonly used in test cell environments for steady state testing. 40 CFR §86.345-79 describes the fuel flow method for mass emissions computations for diesel engine dynamometer testing.

1.1.5 FUEL MASS FLOW RATE AND FUEL ECONOMY

The fuel mass flow rate is determined based on the method of mass emissions computation selected by the user.

1.1.5.1 Fuel Flow Calculation Method

When computing mass emissions using the fuel-flow method, the fuel flow rate used in all computations is provided by the ECM.
The SAE-J1587 heavy-duty vehicle network protocol provides volumetric fuel rate data (gallons/second) based on the fuel injector pulse width. To convert to a mass flow rate, the user is required to enter a fuel specific gravity in the SENSOR Tech-PC software TEST SETUP screen. A default specific gravity of 0.85 for diesel fuel is used if the field is left blank. If no specific gravity measurement is available, then the default value is recommended.
It is important to recognize the effect of temperature on the fuel specific gravity. Most specific gravity measurements are taken at room temperature. However, at operating temperature, the specific gravity can decrease by 2%. The engine manufacturer may have accounted for this in the calibration of the fuel injectors, so that the reported volumetric flow is corrected to standard conditions. If this information is unknown, then it is recommended to use the specific gravity at room temperature.

1.1.5.2 Exhaust Flow Calculation Method

When computing mass emissions using the exhaust flow method, the fuel flow rate is determined from the exhaust mass flow rate and the calculated air/fuel mass fraction.

$$Wf = \frac{Exhaust\ Mass\ Flowrate}{AFR + 1}$$

When selecting the exhaust flow method, the calculated fuel rate is used in the calculation of fuel-economy even if ECM data is available. The user can easily sum the ECM gal/s data and determine ECM based fuel economy manually if desired.
Fuel economy is easily computed for a test period by summing the fuel consumed and dividing by the distance traveled. These results are provided as a thirty second moving average, and for the entire test duration.

1.1.6 EXHAUST ANALYSIS

ISO 16183 provides methodologies for exhaust analysis from a wide variety of fuels, including oxygenated fuels, based on measured raw concentrations. Equations used in the SENSOR Tech-PC software differ slightly in that the SENSOR Tech-PC software accounts for actual dew point of the dried exhaust sample as it passes through the chiller. This is determined by the measured temperature of the chiller and measured efficiency.

The exhaust analysis is dependent on user selectable/definable fuel properties. The molar ratios of Carbon, hydrogen, Oxygen, Nitrogen, and Sulfur are determined by the user, along with the specific gravity. A list of pre-defined fuels with default values is available in the software.
The following computations are performed based on the ISO 16183 equations, and are available for output in the Post-Processor:

Air/fuel ratio at stoichiometry

Air/fuel ratio in the exhaust

Lambda

Exhaust water vapor concentration (% volume)

Dry-to-wet conversion factor for gas concentrations

1.1.7 NOX HUMIDITY CORRECTION FACTOR

The NO_x humidity correction factor, Kh, is applied to the instantaneous concentrations of NO, NO_2, and NO_x. The corrected values are denoted by kNO, kNO_2, and kNO_x. Mass emission results are denoted in a similar manner.
There are two methods available to the user for Kh determination, defined by 40 CFR §86.1342-94, 40 CFR §86.1370-2007, and 40 CFR §1065.670. It is up to the user to determine the suitability of these methods for a specific application.

1.1.7.1 Method 1: 40 CFR §86.1342-94 Diesel

40 CFR §86.1342-94 defines the NO_x humidity correction factor for both gasoline and diesel engines. The following are the correction factors for diesel engines in English and SI units:

$$Kh = \frac{1}{[1-0.0026(H-75)]}$$

where H is the absolute humidity in grams per pound of dry air.

$$Kh = \frac{1}{[1-0.00182(H-10.71)]}$$

where H is the absolute humidity in grams per kilogram of dry air.

1.1.7.2 Method 2: 40 CFR §86.1342-94 SI

40 CFR §86.1342-94 defines the NO_x humidity correction factor for both gasoline and diesel engines. The following are the correction factors for Otto cycle engines in English and SI units:

$$Kh = \frac{1}{[1-0.0047\,(H-75)]}$$

where H is the absolute humidity in grams per pound of dry air.

$$Kh = \frac{1}{[1-0.0329(H-10.71)]}$$

where H is the absolute humidity in grams per kilogram of dry air.

1.1.7.3 Method 3: 40 CFR §86.1370-2007 NTE

40 CFR §86.1370-2007 defines the NO_x humidity correction factor as:

if H ≥ 75 then

$$Kh = 9.953 \times X_{H_2O} + 0.832$$

else if H ≤ 50 then

$$Kh = 9.953 \times X_{H_2O} + 0.8855$$

Else

$$Kh = 1.0$$

where X_{H2O} is the molar fraction of water in dry air.

H is the absolute humidity in grains per pound of dry air.

1.1.7.4 Method 4: 40 CFR §1065.670

40 CFR §1065.670 defines the NO_x humidity correction factor as:

$$Kh = 9.953 \times X_{H_2O} + 0.832$$

where XH2O is the molar fraction of water in dry air.

1.1.7.5 Absolute Humidity Determination

For any methods Kh determination, the absolute humidity of the ambient air must be calculated. This is typically based on direct measurements of relative humidity (RH) and ambient temperature at the intake of the engine.

40 CFR §86.1342-94 defines the absolute humidity for both English and SI units as follows:

$$H = \frac{43.478\,(RH)(P_s)}{P_{baro} - P_s(RH/100)}$$

Where H is in units of grams of water per pound of dry air, RH is the relative humidity in percent, and P_s is the saturation vapor pressure in mm Hg at the engine intake air dry-bulb temperature.

$$H = \frac{6.211\,(RH)(P_s)}{P_{baro} - P_s(RH/100)}$$

Where H is in units of grams of water per kilogram of dry air, RH is the relative humidity in percent, and P_s is the saturation vapor pressure in kPa at the engine intake air dry-bulb temperature.

The saturation vapor pressure, P_s, is the water vapor pressure at the measured dew point. It has been empirically derived as a function of temperature in several forms. The following is from the ASCE Manuals and Reports on Engineering Practice No. 70, 1990 (Jensen, et al).

$$P_S(kPa) = EXP\left[\frac{16.78T_{sample} - 116.9}{T_{sample} + 237.3}\right]$$

The molar fraction of water in dry air is determined by:

$$X_{H20} = \frac{P_S}{P_{ambient}}$$

Where $P_{ambient}$ is the absolute pressure (kPa) at the location of the humidity measurement.

1.1.8 ENGINE TORQUE

The U.S. Federal Code of Regulations specifies emissions standards on a gram per brake horsepower-hour basis. Brake power is defined below, and is related to the SAE definitions of torque that are used throughout this document.

1.1.8.1 DEFINITIONS

Definition from 40 CFR §1065.1001

Brake Power: The usable power output of the engine, not including power required to fuel, lubricate, or heat the engine, circulate coolant to the engine, or to operate after-treatment devices. If the engine does not power these accessories during a test, subtract the work required to perform these functions from the total work used in brake-specific emission calculations. Subtract engine fan work from total work only for air-cooled engines.

Definitions from SAE-J1939-71

Fully Equipped Engine: A fully equipped engine is equipped with accessories necessary to perform its intended service. This includes, but is not restricted to, the basic engine, including fuel, oil, and cooling pumps, plus intake air system, exhaust system, cooling system, alternator, starter, emissions, and noise control. Accessories which are not necessary for the operation of the engine, but may be engine mounted, are not considered part of a fully equipped engine. These items include, but are not restricted to, power steering pump systems, vacuum pumps, and compressor systems for air conditioning, brakes, and suspensions.

Indicated Torque: The torque developed in the cylinders.

Friction Torque: The torque required to drive the engine alone as fully equipped.

Net Torque: The measured torque of a fully equipped engine. Net torque is calculated by subtracting friction torque from indicated torque. This SAE definition is consistent with the description of brake power in 40 CFR Part 1065 §1065.1001, which is used for calculation of brake-specific emissions. For the purposes of this document, net torque is equivalent to brake torque.

1.1.8.2 BRAKE TORQUE CALCULATION METHODS

SENSOR Tech-PC allows the user to calculate engine torque based on ECM parameters. Currently, there are three different, patented methods possible, depending on the particular ECM.

1.1.8.2.1 METHOD 1

Apply the engine torque parameter from the ECM, if available. This method applies to the SAE-J1708, SAE-J1939, and OBDII protocols. In many cases, this parameter is not available, so it is not widely used. The engine torque parameters are specified by SAE and are pre-defined in the SENSOR Tech-PC application software for the SAE- J1708 and SAE-J1939 protocols. Please note that it is up to the engine manufacturer to determine the accuracy and applicability of this parameter. SENSOR Tech-PC software will interpret this parameter as brake torque (i.e., net torque). This parameter may actually represent indicated torque depending on the manufacturer, so use caution.

For light-duty OBDII protocols, the engine torque parameter definitions vary by manufacturer and are therefore not pre-defined in the SENSOR Tech-PC software. In this case, the user would need to obtain the correct information and define this parameter using the PID Editor

Application program, supplied with the SENSOR Tech-PC software package. Sensors engineers may be able to assist customers with this task.
If this parameter is available on your ECM, and you want to use this method, select **FROM ECM** for the **ENGINE TORQUE** settings in the Post Processor, or Test Setup screen, as shown below.

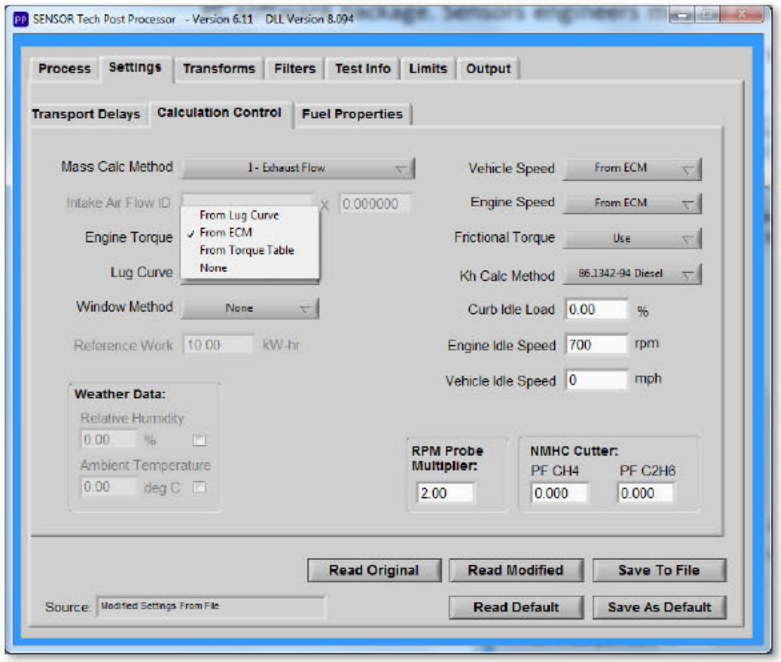


Figure 1: Post Processor engine torque source selection

1.1.8.2.2 METHOD 2

Derive engine torque using a combination of percent load and RPM parameters along with a user-input lug curve. This method is the most common when using the SAE J1708 protocol, and may also be used with the SAE-J1939 protocol. This method is specified by selecting the **FROM LUG CURVE** option in the **ENGINE TORQUE** settings.

Warning:
This method is not valid for the SAE-J1850 protocols (OBDII), since the percent load parameter definition is based on engine airflow rather than torque.

Using this method, the ECM derived torque, at any RPM is computed by:

$$ECM_{DerivedTorque} = \%Load \times Torque_{max} \tag{1}$$

Where $Torque_{max}$ is defined by the engine maximum torque curve (i.e., lug curve) as a function of RPM. The values for this curve are entered in the Sensor Tech-PC application software by the user. It is up to the user to ensure that the lug curve represents brake torque, and not indicated torque. If the lug curve represents indicated torque, be aware that your computed emissions may not be directly comparable to a brake-specific standard.

Also note that the ECM percent load parameter definition itself can vary by manufacturer, such that the ECM derived torque can represent either brake torque or indicated torque. At 100% load, there is no difference, but there can be a significant difference at idle. The best way to determine this is to observe the values at no-load conditions. If the percent load value is zero, then the ECM derived torque represents the brake torque. If the value is non-zero, then it most likely represents indicated torque.

If the tested engine reports non-zero percent load values at curb-idle conditions, then the SENSOR Tech-PC application software allows the user to adjust the percent load value so that the derived torque value represents brake torque instead of indicated torque. This adjustment is accomplished by entering the non-load torque, as a positive value, in the Post Processor application settings as shown in Figure 2. In this example, the user determined that the average curb-idle Percent Load reading was 12.5% over a range of engine RPM by running a quick test. By entering this value in the **CURB IDLE LOAD** text entry field, a corrected percent load parameter is calculated.

This correction is based on the following equation, developed at the University of West Virginia[1]:

$$\%Load_{corrected} = \left(\frac{ECM\ \%Load - \%Load_{@\ curbidle}}{100 - \%Load_{@\ curbidle}} \right) \quad (2)$$

Note that this calculation is a function of engine speed, and assumes:

- %Load at all no-load conditions is approximately constant at all engine speeds
- 100% is the maximum percent load.

To visualize this adjustment, consider the chart shown in Figure 3. In this example, the ECM %Load at no-load conditions was 14%, even though the brake torque is zero. Equation 2 adjusts the percent load so that it is zero at all no-load conditions. Note that there is no correction at 100% load, as discussed above.

1.1.8.2.3 METHOD 3

Calculate engine torque using a combination of SAE-J1939 parameters: Percent Torque, Percent Frictional Torque, and Reference Engine Torque. The parameters are defined as follows:

Percent Torque = (Total torque at the engine shaft) / (Reference Engine Torque)
Percent Frictional Torque = (Frictional torque) / (Reference Engine Torque)
Reference Engine Torque = Single fixed value defined by engine manufacturer

[1] M. Gautam, et al., 'Evaluation of Mobile Monitoring Technologies for Heavy-Duty Diesel-Powered Vehicle Emissions', West Virginia University, March 9, 2000.

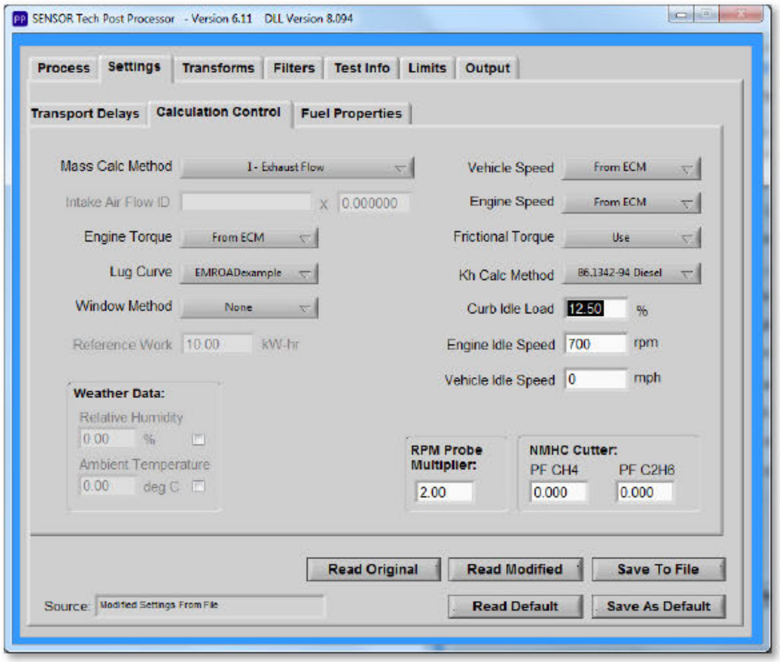


Figure 2: Post Processor Curb Idle Load correction

SENSOR Tech-PC software provides the user the option to use brake torque or indicated torque for emissions calculations. However, brake-torque will typically be used, and is required for in-use compliance testing in the U.S. To compute brake torque, SENSOR Tech-PC performs the following calculations:

Total Torque = Percent Torque x Reference Torque

Frictional Torque = Percent Frictional Torque x Reference Torque

Brake Torque (net torque) = Total Torque - Frictional Torque

To use this method, you must record data using the SAE-J1939 communications protocol, and select **FROM ECM** in the **ENGINE TORQUE** settings as shown in Figure 4. To compute brake torque as described above, you must also select **USE** for the **FRICTIONAL TORQUE** setting. By selecting **IGNORE**, the software will compute and use total torque instead of brake torque.

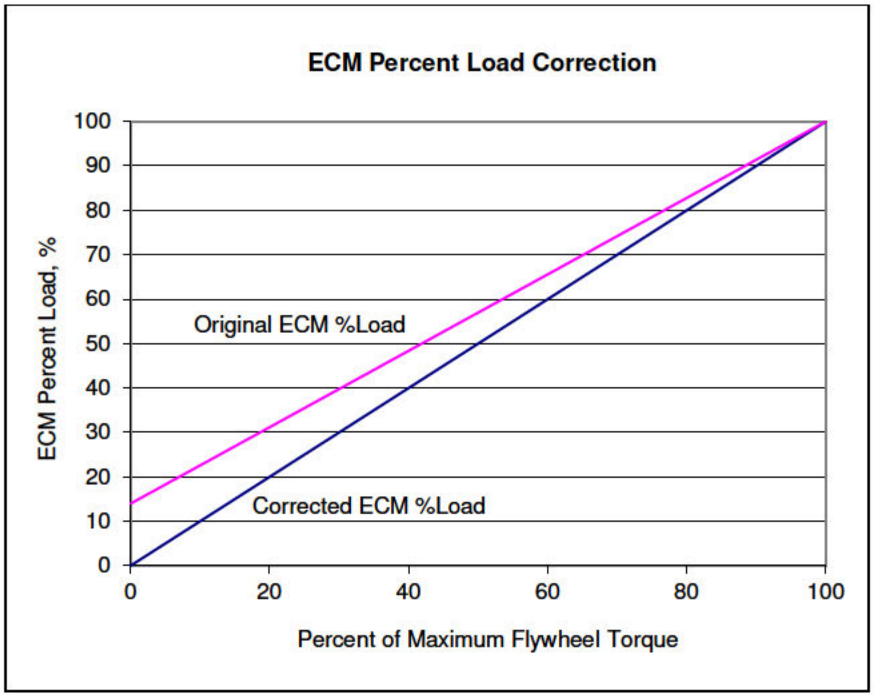


Figure 3: ECM percent load correction example

1.1.9 DISTANCE SPECIFIC EMISSIONS

With the instantaneous mass emissions computed, it is a simple task to compute distance-specific emissions. The only additional measurement is the vehicle speed. The distance-specific emissions are computed by integrating the instantaneous mass emissions over a specified time segment, and dividing by the distance traveled in that same time segment. Using NO_x as an example and assuming data is reported on a per-second basis:

$$NO_x\left(\frac{g}{mi}\right) = \frac{\sum NO_x mass}{\sum miles\ travelled} \ and\ NO_x\left(\frac{g}{km}\right) = \frac{\sum NO_x mass}{\sum kilometers\ travelled}$$

The SENSOR Tech-PC software allows the user to define custom time segments within a test to integrate the mass results. Markers are placed in the file at desired points during the test using the live data screen. The user can also add these markers to the test using an optional hand-held push button, or other digital input trigger mechanism.

The live data screen displays the resulting integrated emissions over the defined intervals. The Post-Processor application program also integrates over the defined intervals using different settings, if desired.

1.1.10 BRAKE SPECIFIC EMISSIONS

To compute brake-specific emissions, it is necessary to either directly measure or compute engine torque based on ECM data and the engine lug curve (maximum torque curve). Engine torque, however derived, is converted to engine horsepower using engine RPM. Work (bhp-hr or kW-hr) is computed for each second of the test, and then summed over the desired interval. Brake-specific emissions are reported as the sum of the grams of pollutant emitted over the interval divided by the total work.

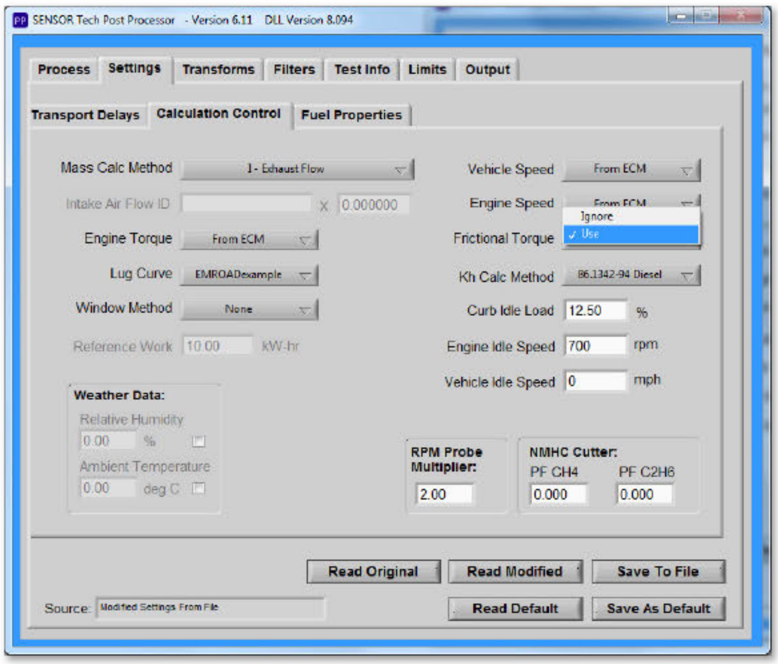


Figure 4: Post Processor setting to correct for frictional torque

Again, using NO_x as an example, and assuming the data collection rate is reported on a per-second basis:

$$NO_x(g/hp-h) = \frac{\sum NO_x mass}{\sum work} = \frac{\sum NO_x\ mass}{\sum bhp\ \times 1s(\frac{h}{3600s})}$$

And

$$NO_x\left(\frac{g}{kW}-h\right) = \frac{\sum NO_x\ mass}{\sum kW\ \times 1s(\frac{h}{3600s})}$$

The instantaneous engine power is typically computed based on a measurement of engine torque and engine speed. To compute horsepower,

$$hp = \frac{torque\ (lb\ ft) \times RPM}{5252}$$

where torque is typically measured at the flywheel, and referred to as brake torque. The power is then called brake-horsepower. On chassis dynamometers, torque and power are measured at the wheel. It may be necessary to apply a correction factor to convert wheel horsepower to brake horsepower, depending on the application.
For SI units, power is in units of kilowatts, and torque is in units of Newton-meters.

$$kW = \frac{torque\ (Nm) \times RPM}{9550}$$