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 2021 RAM 1500 Non-BSG, 5.7L gasoline (RAM) and 2021 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 13, 14, 15, 2021
Vehicle Owner	Fiat Chrysler
Test Location	Ann Arbor, MI
Type / Descr	No. V1DT60145
Make	RAM1500
Model	Rebel
Model Year	2021
VIN	Redacted - PII
Vehicle Emissions Tag	Redacted - PII
Engine Family	MCRXT06.75P0
License Plate	Redacted - PII

Participants

Name	Affiliation / Title
Vio 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, Non-BSG, 5.7L gasoline (V1DT60145) who's on-road emissions testing was completed on July 13, 14 and 15th, 2021, 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 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	02-20-2022	VF
Gaseous Module	C15122161	YES	07-28-2021	VF
FID Hydrocarbon Module	C16131218	YES	07-28-2021	VF
EFM4 Exhaust Flowmeter, 2.5"	B15121215	YES	09-10-2021	JG
FID Fuel bottle LOT: 70001824UG	FF62640	YES	01-06-2023	VF
Weather Probe RH Sensor VAISALA	L3920007	YES	02-24-2022	AM
GPS by Garmin	1A4203093	-	-	JE
Vehicle Interface	H17500656	-	-	JE

Calibration Gases Used

Bottle	SN	Listed Concentrations	Expiration Date	Initials
Quad Span Cylinder: CO2, CO, NO, Propane LOT_700018296GD	FF55413	15.7 %, CO2, 4481 ppm CO, 1009 ppm NO, 260 ppm C3H8	10/31/2021	VF
NO2 Span Cylinder LOT# 70086026201	EX0014317	263 ppm NO2	09-22-2021	VF
Zero Nitrogen Cylinder LOT_700018284K4	FF59526	N2	10-24-2022	VF

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

* - 1A route took longer due to vehicle being blocked at cold starting point

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	Redacted - PII MY2021_ABCBC_20210713_Rev2_1A.csv MY2021_ABCBC_20210713_Rev2_1B1.csv MY2021_ABCBC_20210713_Rev2_1C1.csv MY2021_ABCBC_20210713_Rev2_1B2.csv MY2021_ABCBC_20210713_Rev2_1C2.csv	1418 1473 2763 1402 2283	pp Route 1A pp Route 1B1 pp Route 1C1 pp Route 1B2 pp Route 1C2
2	Redacted - PII MY2021_BCACA_20210714_REV1_2A1.csv MY2021_BCACA_20210714_REV1_2A2.csv MY2021_BCACA_20210714_REV1_2B.csv MY2021_BCACA_20210714_REV1_2C1.csv MY2021_BCACA_20210714_REV1_2C2.csv	1032 985 1558 2204 2326	pp Route 2A1 pp Route 2A2 pp Route 2B pp Route 2C1 pp Route 2C2
3	Redacted - PII MY2021_CABBA_20210715_REV1_3A1.csv MY2021_CABBA_20210715_REV1_3A2.csv MY2021_CABBA_20210715_REV1_3B1.csv MY2021_CABBA_20210715_REV1_3B2.csv MY2021_CABBA_20210715_REV1_3C.csv	961 923 1410 1400 2538	pp Route 3A1 pp Route 3A2 pp Route 3B1 pp Route 3B2 pp Route 3C

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 MY2021_ABCBC_20210713_Rev2_1A_Gram-mile.csv	8/19/2021 1:57 PM	1 KB
MY2021_ABCBC_20210713_Rev2_1A_Gram-sec.csv	8/19/2021 1:57 PM	69 KB
MY2021_ABCBC_20210713_Rev2_1A_Load_speed.DAT	8/19/2021 1:57 PM	49 KB
MY2021_ABCBC_20210713_Rev2_1B1_Gram-mile.csv	8/19/2021 1:57 PM	1 KB
MY2021_ABCBC_20210713_Rev2_1B1_Gram-sec.csv	8/19/2021 1:57 PM	81 KB
MY2021_ABCBC_20210713_Rev2_1B1_Load_speed.DAT	8/19/2021 1:57 PM	52 KB
MY2021_ABCBC_20210713_Rev2_1B2_Gram-mile.csv	8/19/2021 1:57 PM	1 KB
MY2021_ABCBC_20210713_Rev2_1B2_Gram-sec.csv	8/19/2021 1:57 PM	82 KB
MY2021_ABCBC_20210713_Rev2_1B2_Load_speed.DAT	8/19/2021 1:57 PM	50 KB
MY2021_ABCBC_20210713_Rev2_1C1_Gram-mile.csv	8/19/2021 1:57 PM	1 KB
MY2021_ABCBC_20210713_Rev2_1C1_Gram-sec.csv	8/19/2021 1:57 PM	156 KB
MY2021_ABCBC_20210713_Rev2_1C1_Load_speed.DAT	8/19/2021 1:57 PM	98 KB
MY2021_ABCBC_20210713_Rev2_1C2_Gram-mile.csv	8/19/2021 1:57 PM	1 KB
MY2021_ABCBC_20210713_Rev2_1C2_Gram-sec.csv	8/19/2021 1:57 PM	130 KB
MY2021_ABCBC_20210713_Rev2_1C2_Load_speed.DAT	8/19/2021 1:57 PM	82 KB
MY2021_BCACA_20210714_REV1_2A1_Gram-mile.csv	8/19/2021 1:55 PM	1 KB
MY2021_BCACA_20210714_REV1_2A1_Gram-sec.csv	8/19/2021 1:55 PM	49 KB
MY2021_BCACA_20210714_REV1_2A1_Load_speed.DAT	8/19/2021 1:55 PM	37 KB
MY2021_BCACA_20210714_REV1_2A2_Gram-mile.csv	8/19/2021 1:55 PM	1 KB
MY2021_BCACA_20210714_REV1_2A2_Gram-sec.csv	8/19/2021 1:55 PM	55 KB
MY2021_BCACA_20210714_REV1_2A2_Load_speed.DAT	8/19/2021 1:55 PM	35 KB
MY2021_BCACA_20210714_REV1_2B_Gram-mile.csv	8/19/2021 1:55 PM	1 KB
MY2021_BCACA_20210714_REV1_2B_Gram-sec.csv	8/19/2021 1:55 PM	95 KB
MY2021_BCACA_20210714_REV1_2B_Load_speed.DAT	8/19/2021 1:55 PM	55 KB
MY2021_BCACA_20210714_REV1_2C1_Gram-mile.csv	8/19/2021 1:55 PM	1 KB
MY2021_BCACA_20210714_REV1_2C1_Gram-sec.csv	8/19/2021 1:55 PM	135 KB
MY2021_BCACA_20210714_REV1_2C1_Load_speed.DAT	8/19/2021 1:55 PM	79 KB
MY2021_BCACA_20210714_REV1_2C2_Gram-mile.csv	8/19/2021 1:55 PM	1 KB
MY2021_BCACA_20210714_REV1_2C2_Gram-sec.csv	8/19/2021 1:55 PM	136 KB
MY2021_BCACA_20210714_REV1_2C2_Load_speed.DAT	8/19/2021 1:55 PM	83 KB
MY2021_ABCBC_20210715_REV1_3A1_Gram-mile.csv	8/19/2021 1:53 PM	1 KB
MY2021_ABCBC_20210715_REV1_3A1_Gram-sec.csv	8/19/2021 1:53 PM	58 KB
MY2021_ABCBC_20210715_REV1_3A1_Load_speed.DAT	8/19/2021 1:53 PM	35 KB
MY2021_ABCBC_20210715_REV1_3A2_Gram-mile.csv	8/19/2021 1:53 PM	1 KB
MY2021_ABCBC_20210715_REV1_3A2_Gram-sec.csv	8/19/2021 1:53 PM	55 KB
MY2021_ABCBC_20210715_REV1_3A2_Load_speed.DAT	8/19/2021 1:53 PM	33 KB
MY2021_ABCBC_20210715_REV1_3B1_Gram-mile.csv	8/19/2021 1:53 PM	1 KB
MY2021_ABCBC_20210715_REV1_3B1_Gram-sec.csv	8/19/2021 1:53 PM	80 KB
MY2021_ABCBC_20210715_REV1_3B1_Load_speed.DAT	8/19/2021 1:53 PM	50 KB
MY2021_ABCBC_20210715_REV1_3B2_Gram-mile.csv	8/19/2021 1:53 PM	1 KB
MY2021_ABCBC_20210715_REV1_3B2_Gram-sec.csv	8/19/2021 1:53 PM	84 KB
MY2021_ABCBC_20210715_REV1_3B2_Load_speed.DAT	8/19/2021 1:53 PM	50 KB
MY2021_ABCBC_20210715_REV1_3C1_Gram-mile.csv	8/19/2021 1:53 PM	1 KB
MY2021_ABCBC_20210715_REV1_3C1_Gram-sec.csv	8/19/2021 1:53 PM	153 KB
MY2021_ABCBC_20210715_REV1_3C1_Load_speed.DAT	8/19/2021 1:53 PM	90 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								
7/13/2021		COLD 1A	HOT 1B1	HOT 1C1	HOT 1B2	HOT 1C2	Total	Average
		Route A	Route B	Route C	Route B	Route C		
Distance	(mi)	7.753	10.836	30.507	10.769	30.593	90.458	
Length	(sec)	1418	1473	2763	1402	2283	9339	
Fuel Economy	mpg	12.619	16.221	15.769	16.519	16.547		15.535
CO2	(g)	5549.582	6046.777	17010.31	5894.141	16231.47		10146.46
CO	(g)	6.196	2.012	307.598	1.607	308.752		125.233
kNOx	(g)	0.177	0.229	0.496	0.288	0.253		0.2886
THC	(g)	0.758	0.024	0.835	0.031	0.555		0.4406
NMCH	(g)	0.742	0.024	0.818	0.03	0.544		0.4316
CO2	(g/mi)	715.774	558.003	557.585	547.3	530.562		581.8448
CO	(g/mi)	0.799	0.186	10.083	0.149	10.092		4.2618
kNOx	(g/mi)	0.023	0.021	0.016	0.027	0.008		0.019
THC	(g/mi)	0.098	0.002	0.027	0.003	0.018		0.0296
NMCH	(g/mi)	0.096	0.002	0.027	0.003	0.018		0.0292
							Std. Dev.	Average
Ambient Temp	Deg C	23.642	24.08	23.96	23.777	26.011	0.974402	24.294
Ambient Press.	mbar	990.972	992.657	989.434	991.909	988.874	1.603013	990.7692
Relative Humid.	%	88.255	87.655	91.786	96.614	80.915	5.776157	89.045
Absol. Humidity	grains	116.125	118.283	123.39	128.446	122.801	4.802966	121.809
AVG kh Factor		1.183	1.193	1.215	1.237	1.212	0.020952	1.208

Test 2								
7/14/2021		COLD 2B	HOT 2C1	HOT 2A1	HOT 2C2	HOT 2A2	Total	Average
		Route B	Route C	Route A	Route C	Route A		
Distance	(mi)	10.938	30.516	7.642	30.484	7.683	87.263	
Length	(sec)	1558	2204	1032	2326	985	8105	
Fuel Economy	mpg	14.29	16.832	16.503	16.515	17.906		16.4092
CO2	(g)	6923.818	15887.57	4199.656	16255.4	3894.847		9432.257
CO	(g)	7.132	342.497	1.289	306.256	1.124		131.6596
kNOx	(g)	0.538	0.413	0.138	0.223	0.171		0.2966
THC	(g)	0.741	0.691	0.002	0.586	0.013		0.4066
NMCH	(g)	0.727	0.677	0.002	0.575	0.013		0.3988
CO2	(g/mi)	633	520.633	549.541	533.249	506.911		548.6668
CO	(g/mi)	0.652	11.224	0.169	10.047	0.146		4.4476
kNOx	(g/mi)	0.049	0.014	0.018	0.007	0.022		0.022
THC	(g/mi)	0.068	0.023	0	0.019	0.002		0.0224
NMCH	(g/mi)	0.066	0.022	0	0.019	0.002		0.0218
							Std. Dev.	Average
Ambient Temp	Deg C	28.162	28.431	28.808	29.992	30.809	1.121434	29.2404
Ambient Press.	mbar	995.943	993.085	993.913	992.818	993.263	1.261848	993.8044
Relative Humid.	%	65.624	62.432	58.931	54.146	48.588	6.746448	57.9442
Absol. Humidity	grains	112.169	108.617	104.778	102.934	96.676	5.875326	105.0348
AVG kh Factor		1.166	1.151	1.134	1.126	1.099	0.02547	1.1352

Test 3								
7/15/2021		COLD 3C	HOT 3A1	HOT 3B1	HOT 3B2	HOT 3A2	Total	Average
		Route C	Route A	Route B	Route B	Route A		
Distance	(mi)	30.628	7.64	10.758	10.771	7.622	67.419	
Length	(sec)	2538	961	1410	1400	923	7232	
Fuel Economy	mpg	15.327	17.501	16.636	16.861	17.905		16.846
CO2	(g)	17501.293	3944.105	5840.6	5769.21	3846.251		7380.292
CO	(g)	339.375	1.048	2.216	1.421	0.984		69.0088
kNOx	(g)	0.954	0.167	0.21	0.309	0.164		0.3608
THC	(g)	1.247	0.015	0.024	0.022	0.011		0.2638
NMCH	(g)	1.222	0.015	0.024	0.022	0.011		0.2588
CO2	(g/mi)	571.411	516.24	542.927	535.617	504.61		534.161
CO	(g/mi)	11.08	0.137	0.206	0.132	0.129		2.3368
kNOx	(g/mi)	0.031	0.022	0.02	0.029	0.022		0.0248
THC	(g/mi)	0.041	0.002	0.002	0.002	0.001		0.0096
NMCH	(g/mi)	0.04	0.002	0.002	0.002	0.001		0.0094
							Std. Dev.	Average
Ambient Temp	Deg C	27.735	27.61	27.835	29.019	29.428	0.836312	28.3254
Ambient Press.	mbar	987.77	988.06	989.99	990.05	987.13	1.34055	988.5982
Relative Humid.	%	68.561	67.357	67.536	63.656	59.238	3.850683	65.2696
Absol. Humidity	grains	115.313	112.419	114.021	114.962	109.702	2.294267	113.2834
AVG kh Factor		1.18	1.167	1.174	1.178	1.156	0.009747	1.171

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						
		COLD 1A	HOT 2A1	HOT2A2	HOT 3A1	HOT 3A2	Average	Std. Dev.
Distance	(mi)	7.753	7.642	7.683	7.64	7.622	7.64675	0.025786
Length	(sec)	1418	1032	985	961	923	975.25	45.63898
Fuel Econ	mpg	12.619	16.503	17.906	17.501	17.905	17.45375	0.661895
CO2	(g)	5549.582	4199.656	3894.847	3944.105	3846.251	3971.215	157.4466
CO	(g)	6.196	1.289	1.124	1.048	0.984	1.11125	0.131594
kNOx	(g)	0.177	0.138	0.171	0.167	0.164	0.16	0.014944
THC	(g)	0.758	0.002	0.013	0.015	0.011	0.01025	0.005737
NMCH	(g)	0.742	0.002	0.013	0.015	0.011	0.01025	0.005737
CO2	(g/mi)	715.774	549.541	506.911	516.24	504.61	519.3255	20.76184
CO	(g/mi)	0.799	0.169	0.146	0.137	0.129	0.14525	0.017289
kNOx	(g/mi)	0.023	0.018	0.022	0.022	0.022	0.021	0.002
THC	(g/mi)	0.098	0	0.002	0.002	0.001	0.00125	0.000957
NMCH	(g/mi)	0.096	0	0.002	0.002	0.001	0.00125	0.000957

		ROUTE B						
		COLD 2B	HOT 1B1	HOT 1B2	HOT 3B1	HOT 3A2	Average	Std. Dev.
Distance	(mi)	10.938	10.836	10.769	0	10.771	8.094	5.39609
Length	(sec)	1558	1473	1402	1410	1400	1421.25	34.76948
Fuel Econ	mpg	14.29	16.221	16.519	0	16.861	12.40025	8.270968
CO2	(g)	6923.818	6046.777	5894.141	0	5769.21	4427.532	2953.87
CO	(g)	7.132	2.012	1.607	0	1.421	1.26	0.875487
kNOx	(g)	0.538	0.229	0.288	0	0.309	0.2065	0.141771
THC	(g)	0.741	0.024	0.031	0	0.022	0.01925	0.013401
NMCH	(g)	0.727	0.024	0.03	0	0.022	0.019	0.013115
CO2	(g/mi)	633	558.003	547.3	0	535.617	410.23	273.6394
CO	(g/mi)	0.652	0.186	0.149	0	0.132	0.11675	0.081032
kNOx	(g/mi)	0.049	0.021	0.027	0	0.029	0.01925	0.013276
THC	(g/mi)	0.068	0.002	0.003	0	0.002	0.00175	0.001258
NMCH	(g/mi)	0.066	0.002	0.003	0	0.002	0.00175	0.001258

		ROUTE C						
		COLD 3C	HOT 1C1	HOT 1C2	HOT 2C1	HOT 2C2	Average	Std. Dev.
Distance	(mi)	30.628	30.507	30.593	30.516	30.484	30.525	0.047293
Length	(sec)	2538	2763	2283	2204	2326	2394	251.1348
Fuel Econ	mpg	15.327	15.769	16.547	16.832	16.515	16.41575	0.454102
CO2	(g)	17501.29	17010.31	16231.47	15887.57	16255.4	16346.19	473.567
CO	(g)	339.375	307.598	308.752	342.497	306.256	316.2758	17.51056
kNOx	(g)	0.954	0.496	0.253	0.413	0.223	0.34625	0.130086
THC	(g)	1.247	0.835	0.555	0.691	0.586	0.66675	0.126366
NMCH	(g)	1.222	0.818	0.544	0.677	0.575	0.6535	0.123511
CO2	(g/mi)	571.411	557.585	530.562	520.633	533.249	535.5073	15.68678
CO	(g/mi)	11.08	10.083	10.092	11.224	10.047	10.3615	0.575329
kNOx	(g/mi)	0.031	0.016	0.008	0.014	0.007	0.01125	0.004425
THC	(g/mi)	0.041	0.027	0.018	0.023	0.019	0.02175	0.004113
NMCH	(g/mi)	0.04	0.027	0.018	0.022	0.019	0.0215	0.004041

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	#		Engine Fuel Rate	ENG_FUEL_RATE	g/s
Load Percent	iENG_LOAD	%		Eng. Exh. Flow Rate	EXH_RATE	kg/hr
Coolant Temp.	ECT	degC		Fuel System A Status	FUEL_STAT_A	
Manifold Pressure	MAP	kPa		Fuel System B Status	FUEL_STAT_B	
Engine RPM	iENG_SPEED	RPM		Short-Term Fuel Trim 1	ST_FUELTRIM_1	%
Vehicle Speed	iVEH_SPEED	mph		Short-Term Fuel Trim 3	ST_FUELTRIM_3	%
Spark Advance	SPARKADV	Deg		Long-Term Fuel Trim 1	LT_FUELTRIM_1	%
Intake Air Temp.	IAT	degC		Long-Term Fuel Trim 3	LT_FUELTRIM_3	%
Abs Throttle Postn	TP	%		Short-Term Fuel Trim 2	ST_FUELTRIM_2	%
Time Since Start	RUNTM	S		Short-Term Fuel Trim 4	ST_FUELTRIM_4	%
MIL Dist. Traveled	MIL_DIST	km		Long-Term Fuel Trim 1	LT_FUELTRIM_2	%
Cmd. Evap. Purge	EVAP_PCT	%		Long-Term Fuel Trim 4	LT_FUELTRIM_4	%
Fuel Level Input	FLI	%		O2 Sensor Location	O2_SENSOR_LOC	
No. of Warm Ups	WARM_UPS			Bank1 O2 Sensor-1 Volt	BK1_O2_SENSOR1_VOLT	V
Distance Cleared	CLR_DIST	km		Bank1 O2 Sensor-1 SHAFT	BK1_O2_SENSOR1_SHRFT	%
Evap. System VP	EVAP_VP1	Pa		Bank1 O2 Sensor-2 Volt	BK1_O2_SENSOR2_VOLT	V
Limit Adjusted iBAR_PRESS	iBAR_PRESS	kPa		Bank1 O2 Sensor-2 SHAFT	BK1_O2_SENSOR2_SHRFT	%
Catalyst Temp. 1-1	CATEMP11	degC		Bank2 O2 Sensor-1 Volt	BK2_O2_SENSOR1_VOLT	V
Catalyst Temp. 2-1	CATEMP21	degC		Bank2 O2 Sensor-1 SHAFT	BK2_O2_SENSOR1_SHRFT	%
Control Voltage	VPWR	V		Bank2 O2 Sensor-2 Volt	BK2_O2_SENSOR2_VOLT	V
Abs. Load Value	LOAD_ABS	%		Bank2 O2 Sensor-2 SHAFT	BK2_O2_SENSOR2_SHRFT	%
F/A Equiv. Ratio	LAMBDA			OBD REQUIREMENT LEVEL	OBD_REQ_LEVEL	
Rel. Throttle Postn	TP_R	%		Driving Cycle Status	DRV_CYC_STAT	
Amb. Air Temp.	AAT	degC		Current Fuel Type	FUEL_TYPE	
Throttle Postn B	TP_B	%		Vehicle Odometer	Odometer	hm
Accel. Postn D	APP_D	%				
Accel. Postn E	APP_E	%				
Throttle Act. Ctrl.	TAC_PCT	%				
Act. Eng. Pct. Torque	iPCNT_TORQUE	%				
Eng. Ref. Torque	sREF_ENG_TORQUE	lb-ft				

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.

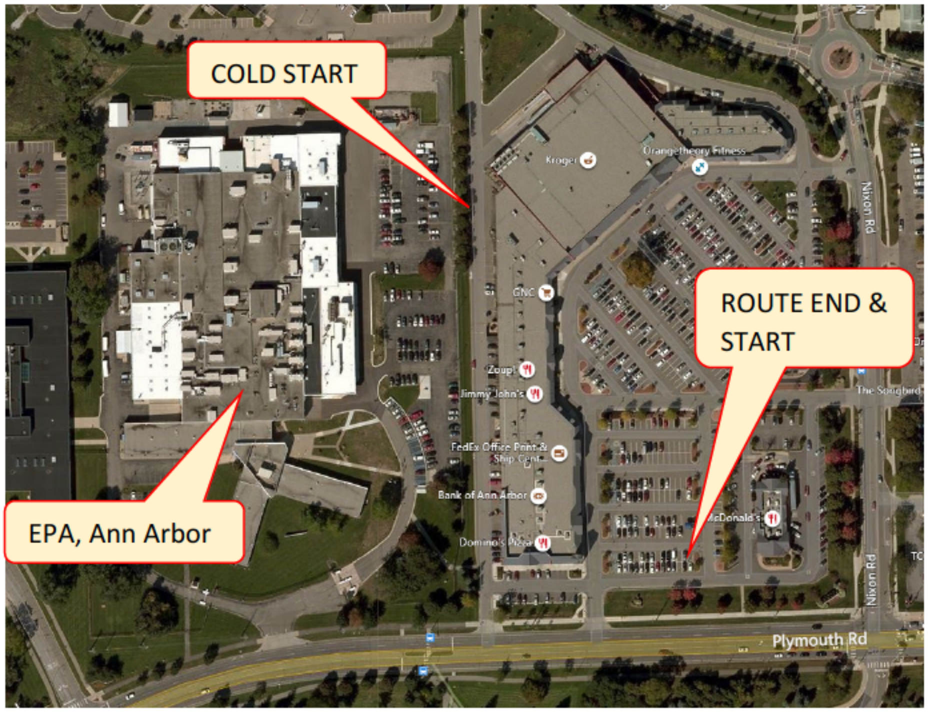


Figure 1 - Routes A, B and C Start and Stop for all routes at 2675 Plymouth Rd. Ann Arbor

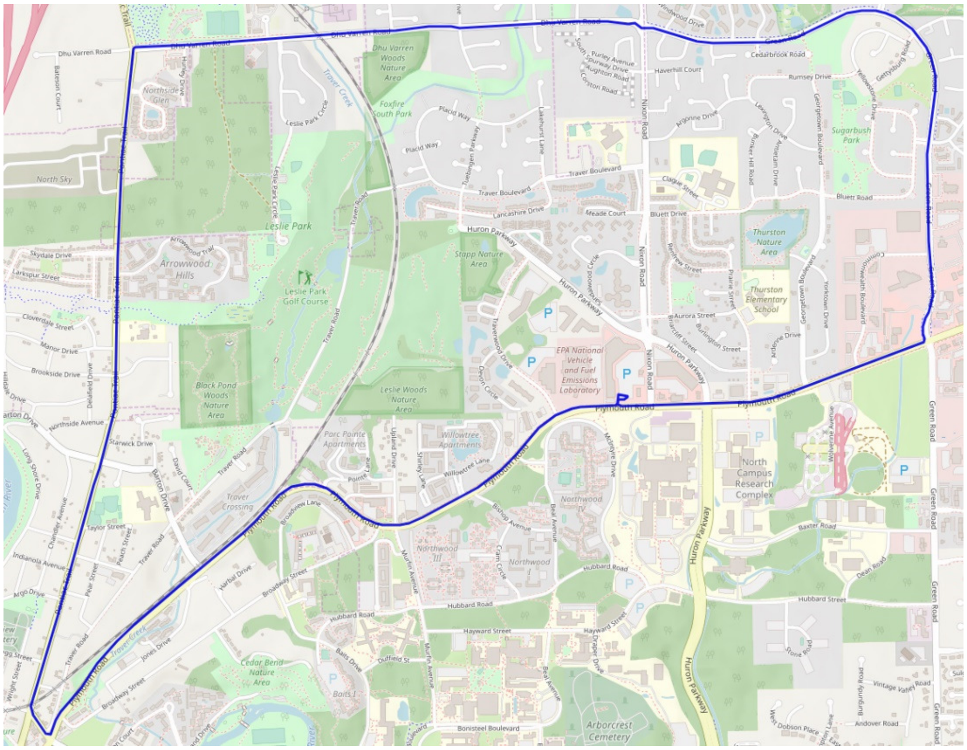


Figure 2 - Route A -- Map

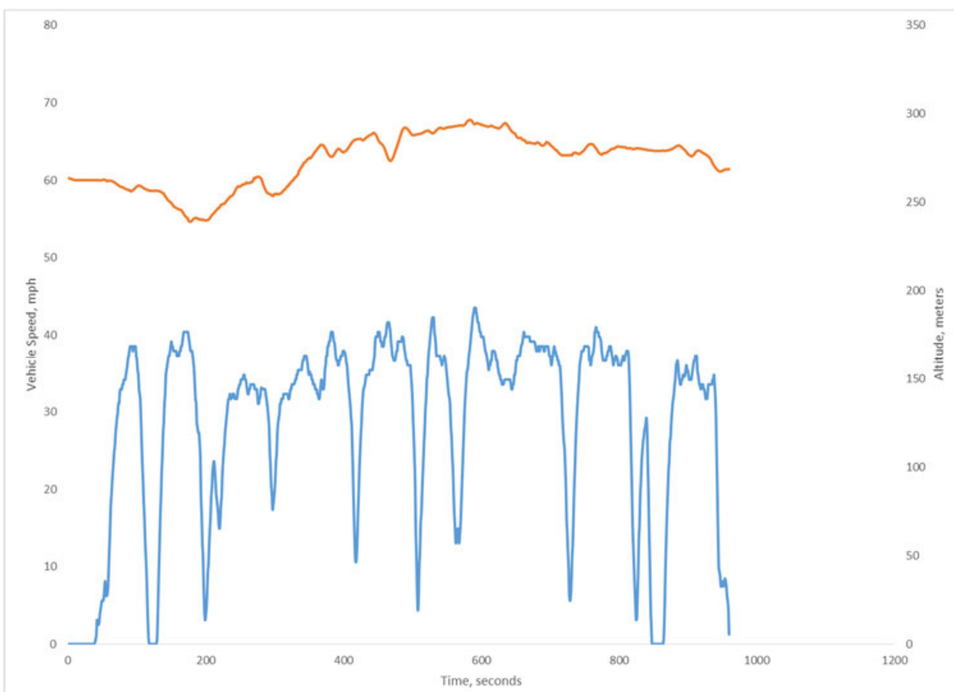


Figure 3 - Route A – Vehicle Speed and Altitude Profile

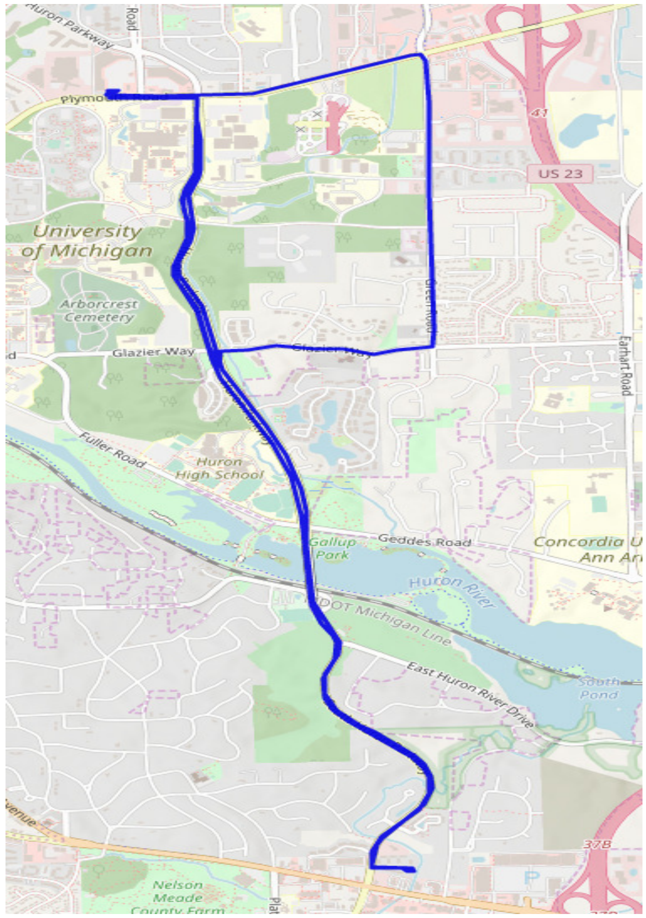


Figure 4 - Route B – Map

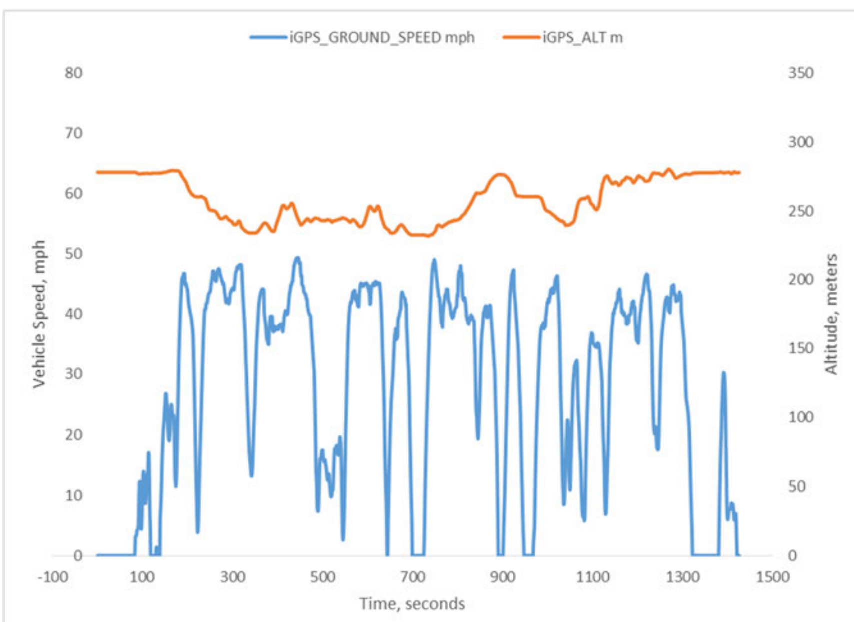


Figure 5 - Route B – Vehicle Speed and Altitude

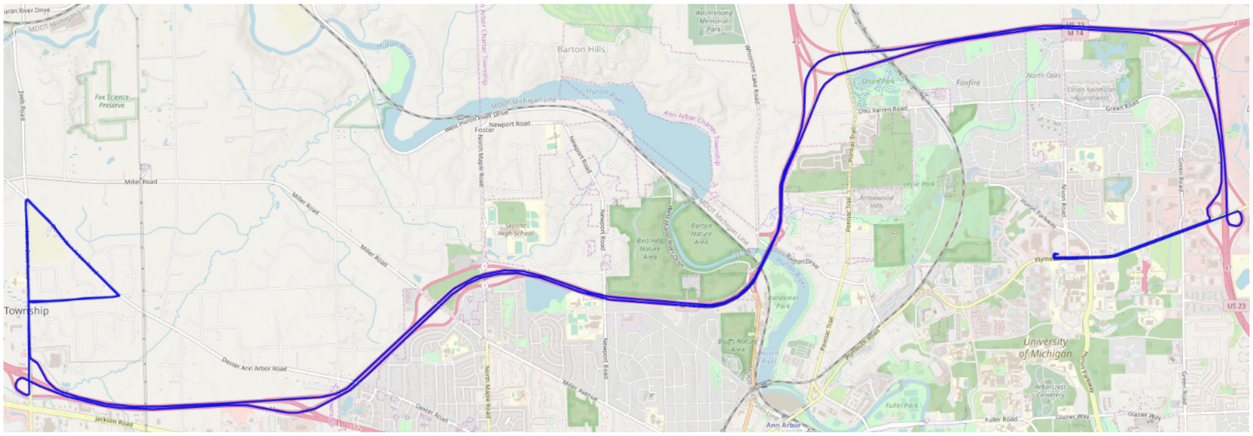


Figure 6 - Route C – Map

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.

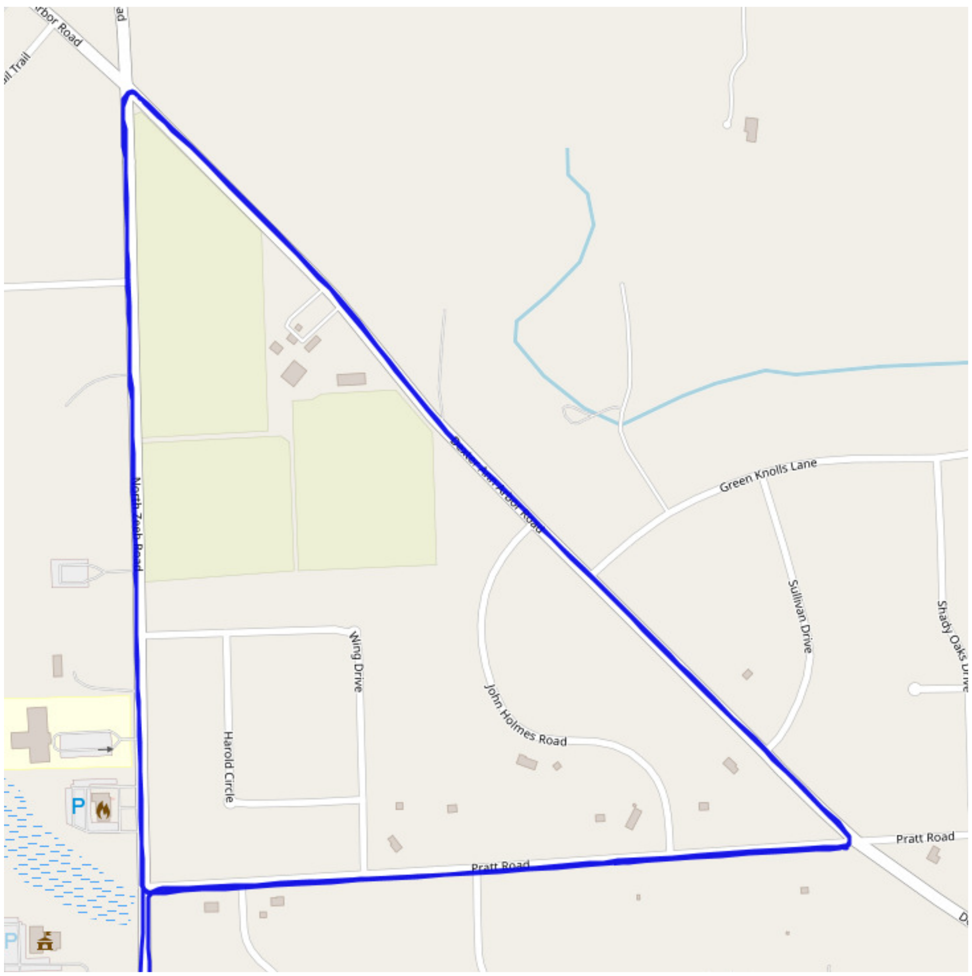


Figure 7 - Wide Open Throttle Loop

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 -- 2021 Test

Correlation Summary

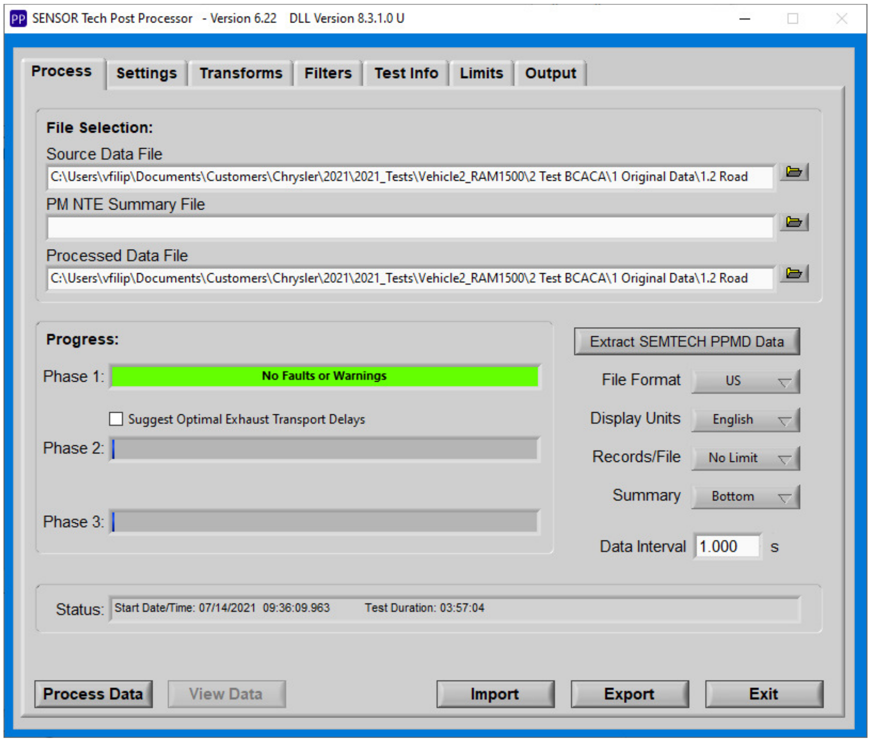
Dyno. distance :	11.05	miles
Dyno. distance :	17.68	km

	PEMS (SEMTECH LDV)			Dynamometer Bag Bench		
Overall Emissions:	grams	g/mi	g/km	grams	g/mi	g/km
CO2	6145.823	555.178	346.986	5868.000	530.081	331.301
CO	8.784	0.793	0.496	7.717	0.697	0.436
kNOx	0.185	0.017	0.010	0.149	0.013	0.008
THCA	0.458	0.041	0.026	0.423	0.038	0.024

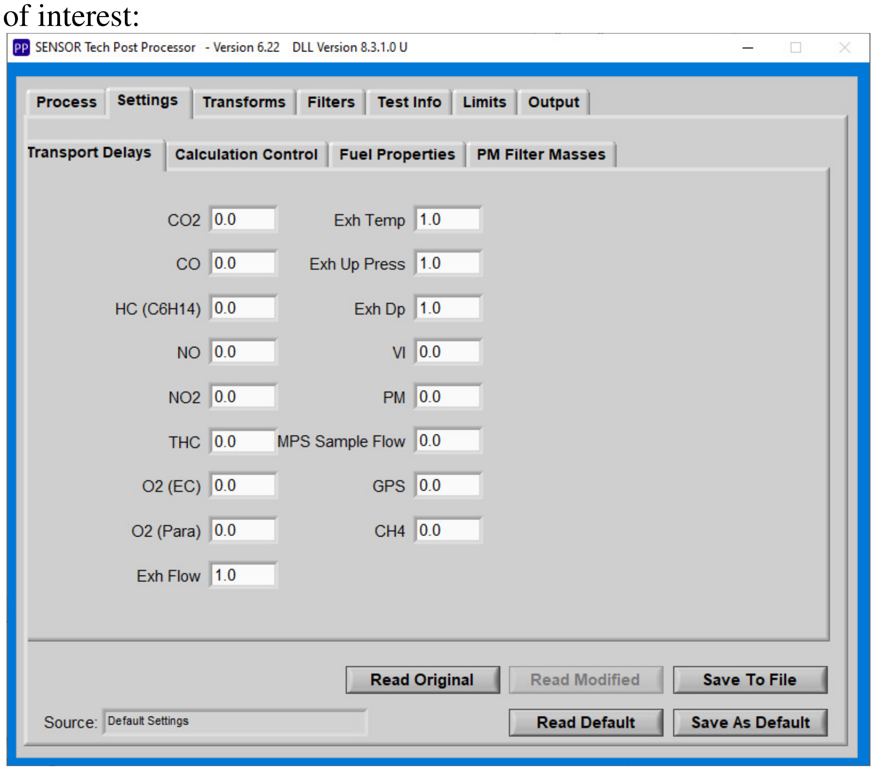
	Correlation versus EU Tolerance			Difference versus Dynmometer		
Overall Emissions:	Difference	Tolerance	Percent	% Diff	% Tolerance	Abs diff (g/km)
CO2	15.686	10.000	1.569	4.7%	10.0%	15.686
CO	0.060	0.150	0.402	13.8%	15.0%	0.060
kNOx	0.002	0.015	0.136	24.2%	15.0%	0.002
THCA	0.002	0.015	0.132	8.3%	15.0%	0.002

Appendix 1C: Post-processing raw data files.

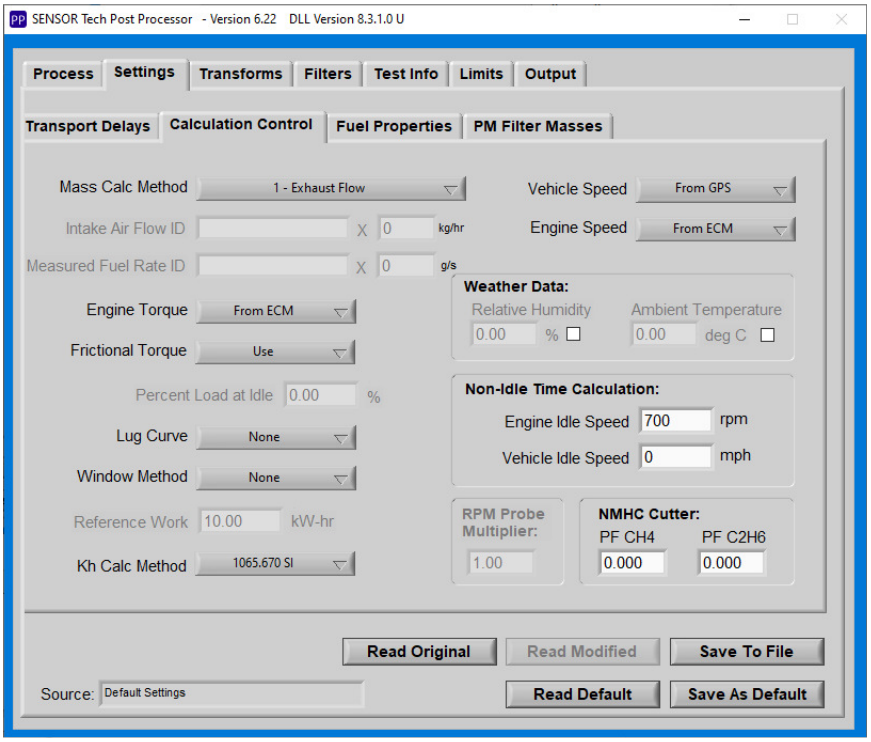
Open SENSORTech Post Processor and select the raw datafile of interest:



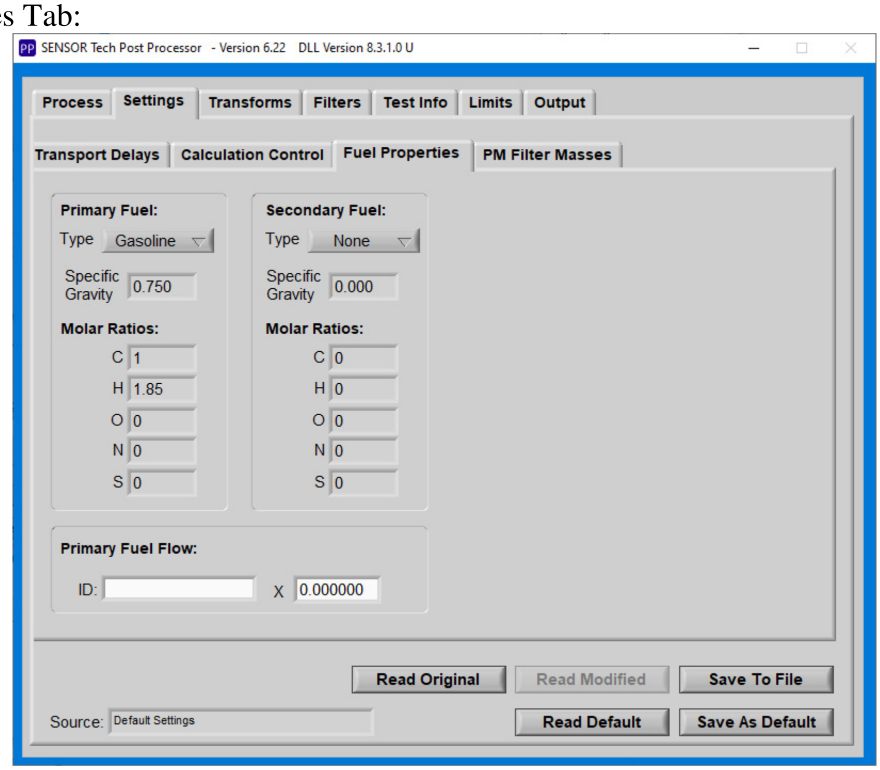
Select options of interest:



Calculation Control Tab:

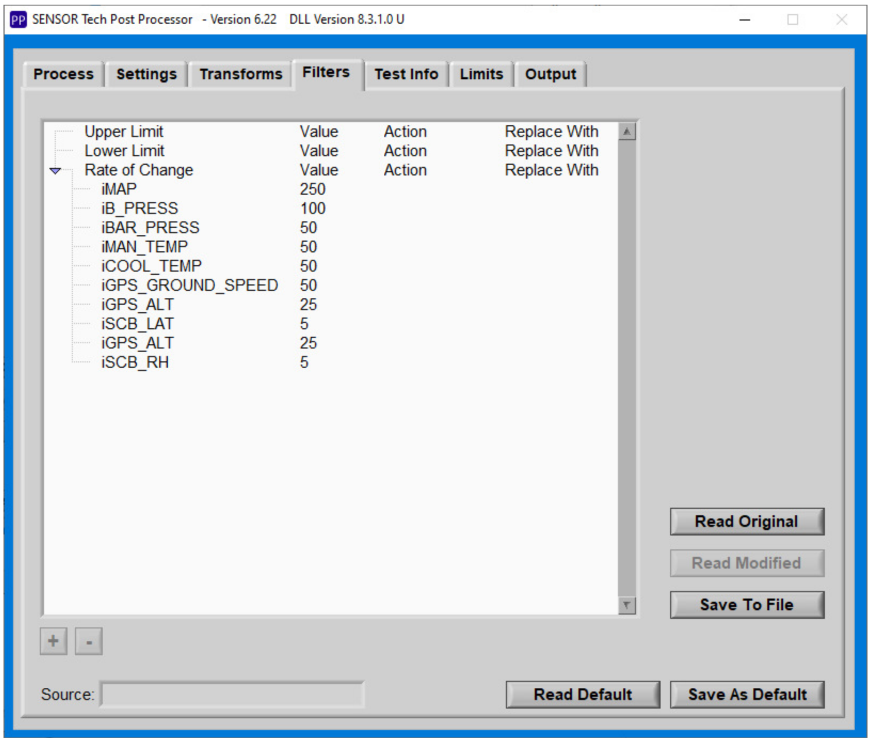


Fuel Properties Tab:

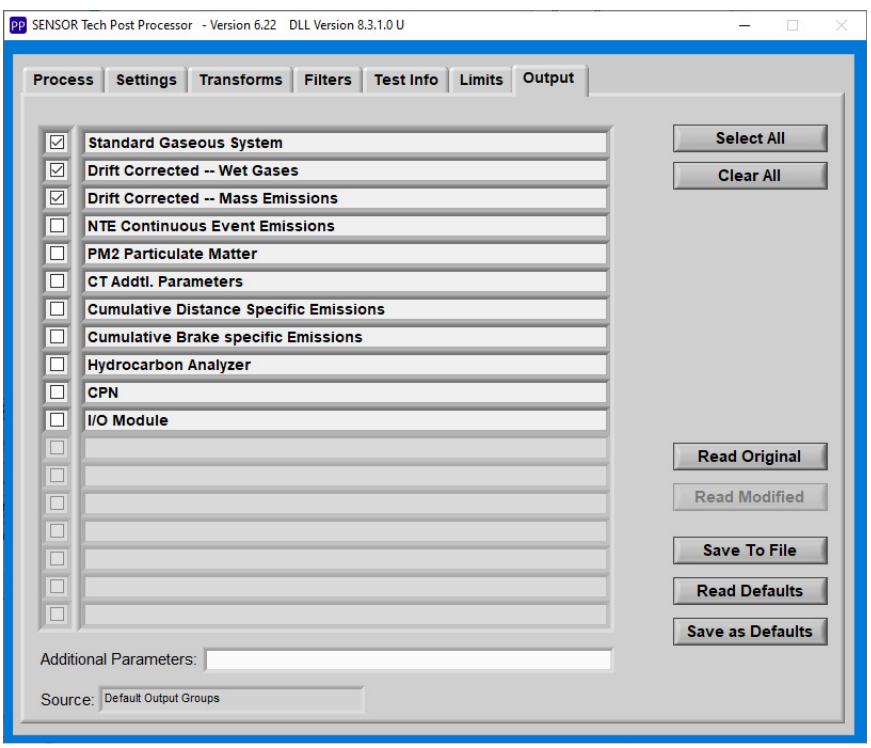


Parameter Filters Tab is used to usually filter out weather probe, ECM and/or GPS outliars. For example, wether probe temperature (iSCB_LAT) values changing by more than 10 degrees C will be filtered out, since it's impossible to get this rate of change under normal conditions.

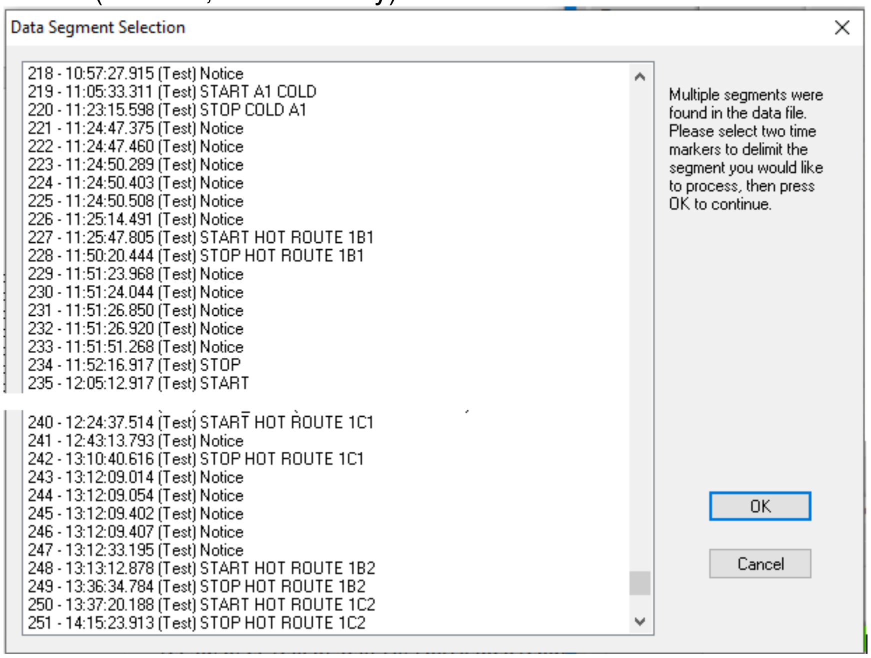
Limits Tab:



Output Tab:

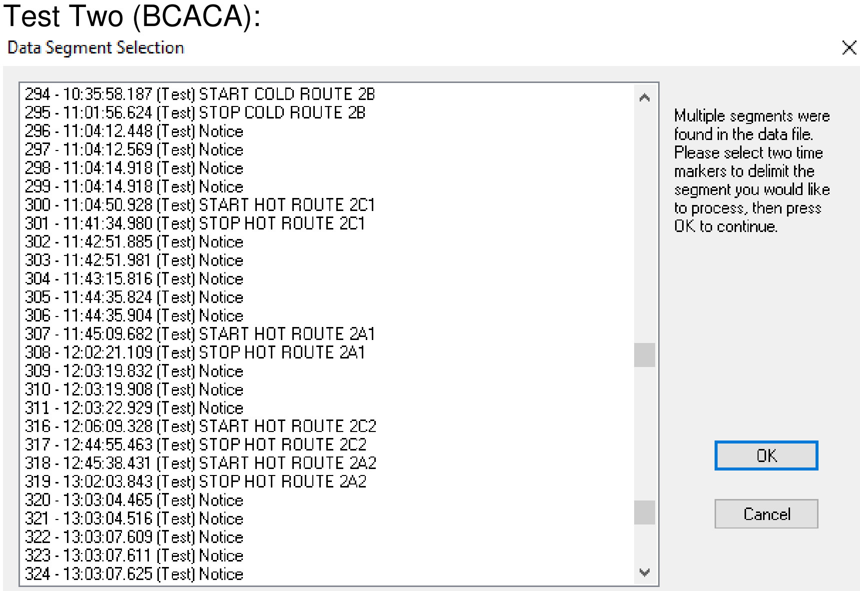


Use the following User Marks when post-processing raw or converted data files:
Test 1 (ABCBC; in its Entirety):

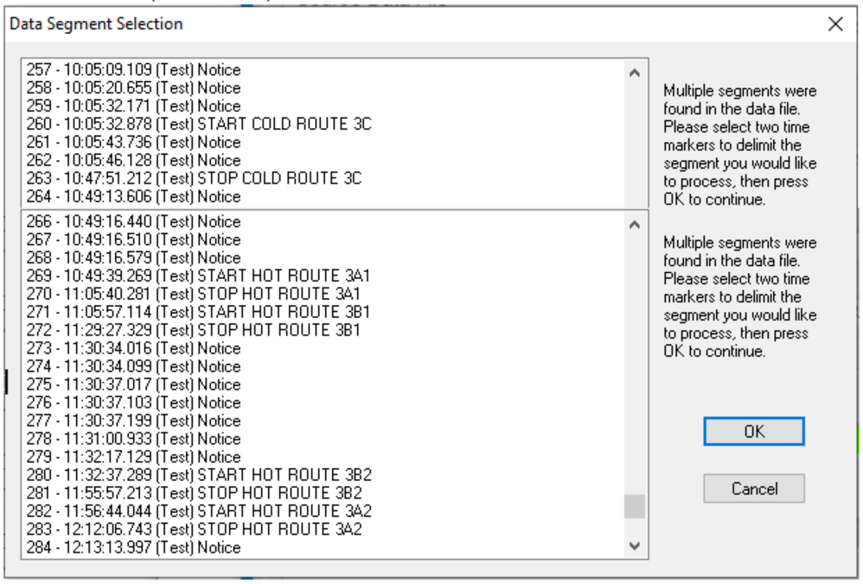


Use the following User Marks when post-processing raw or converted data files:

Test Two (BCACA):



Test Three (CABBA):



:

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

Figure 9 - Test Vehicle

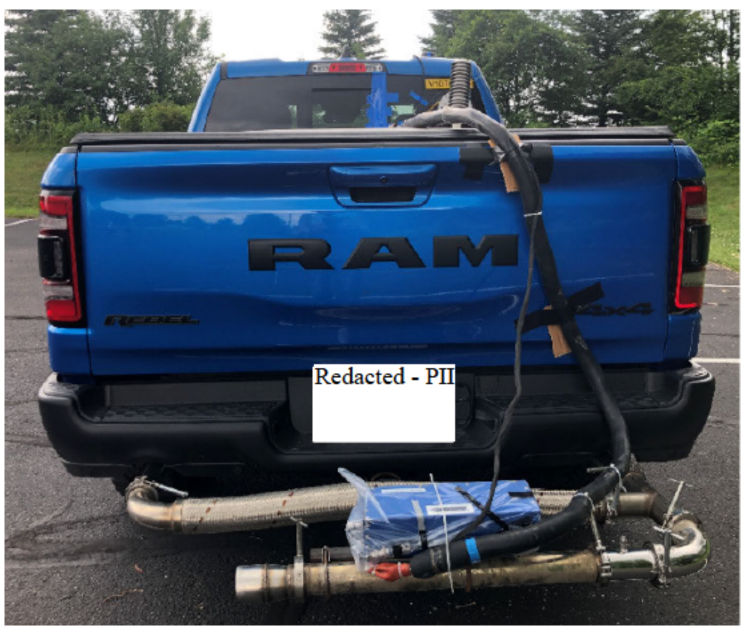


Figure 10 - Exhaust Flowmeter and License Plate

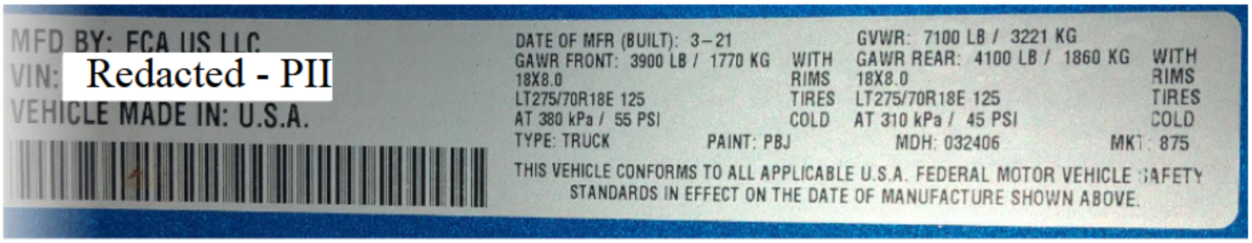


Figure 11 - Vehicle Identification Number

Emissions Tag

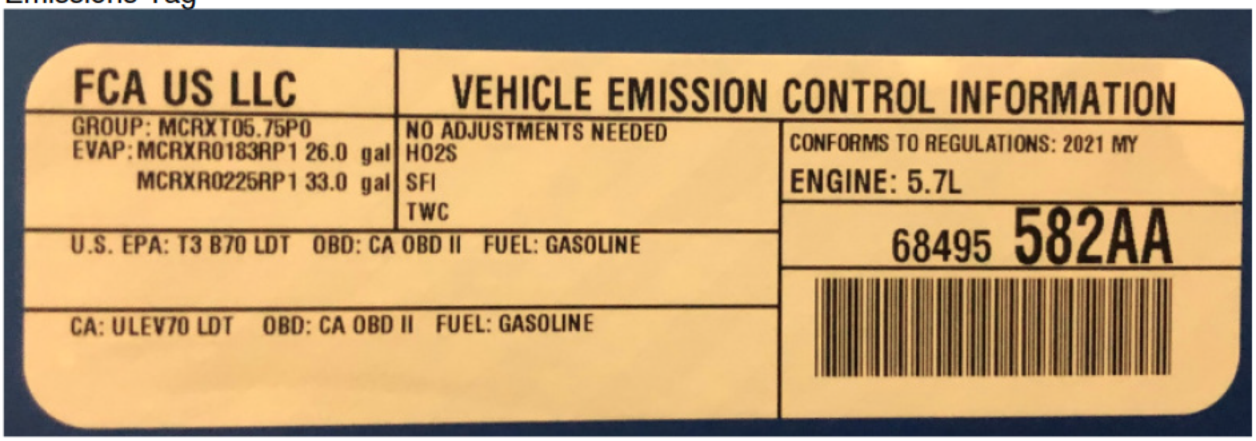


Figure 12 - Gaseous Analyzer Stack

Figure 13 - FCA Vehicle Tag, Weather Probe and GPS

2021 DURANGO TEST

Test Information

Test Date	March 18,19,20, 2021
Vehicle Owner	Fiat Chrysler
Test Location	Ann Arbor, MI
Type / Descr	No. V1WDD3575
Make	DURANGO
Model	
Model Year	2021
VIN	Redacted - PII
Vehicle Emissions Tag	
Engine Family	MCRXT03.65P5
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 (V1WDD3575) whose on-road emissions testing was completed on March 18, 19, 20, 2021, 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	02-20-2022	VF
Gaseous Module	C15122161	YES	03-22-2021	VF
FID Hydrocarbon Module	C16131218	YES	03-22-2021	VF
EFM4 Exhaust Flowmeter, 2.5"	B15121215	YES	09-10-2021	JG
FID Fuel bottle LOT: 70001824UG	FF62640	YES	01-06-2023	VF
Weather Probe RH Sensor VAISALA	L3920007	YES	02-24-2022	AM
GPS by Garmin	1A4227390	-	-	JE
Vehicle Interface	H17500656	-	-	JE

Calibration Gases Used

Bottle	SN	Listed Concentrations	Expiration Date	Initials
Quad Span Cylinder: CO2, CO, NO, Propane LOT_700018296GD	FF55413	15.7 %, CO2, 4481 ppm CO, 1009 ppm NO, 260 ppm C3H8	10/31/2021	VF
NO2 Span Cylinder LOT# 70086026201	EX0014320	264 ppm NO2	09-22-2021	VF
Zero Nitrogen Cylinder LOT_700018284K4	FF62616	20.7% Oxygen, Bal N2	10-24-2022	VF

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:

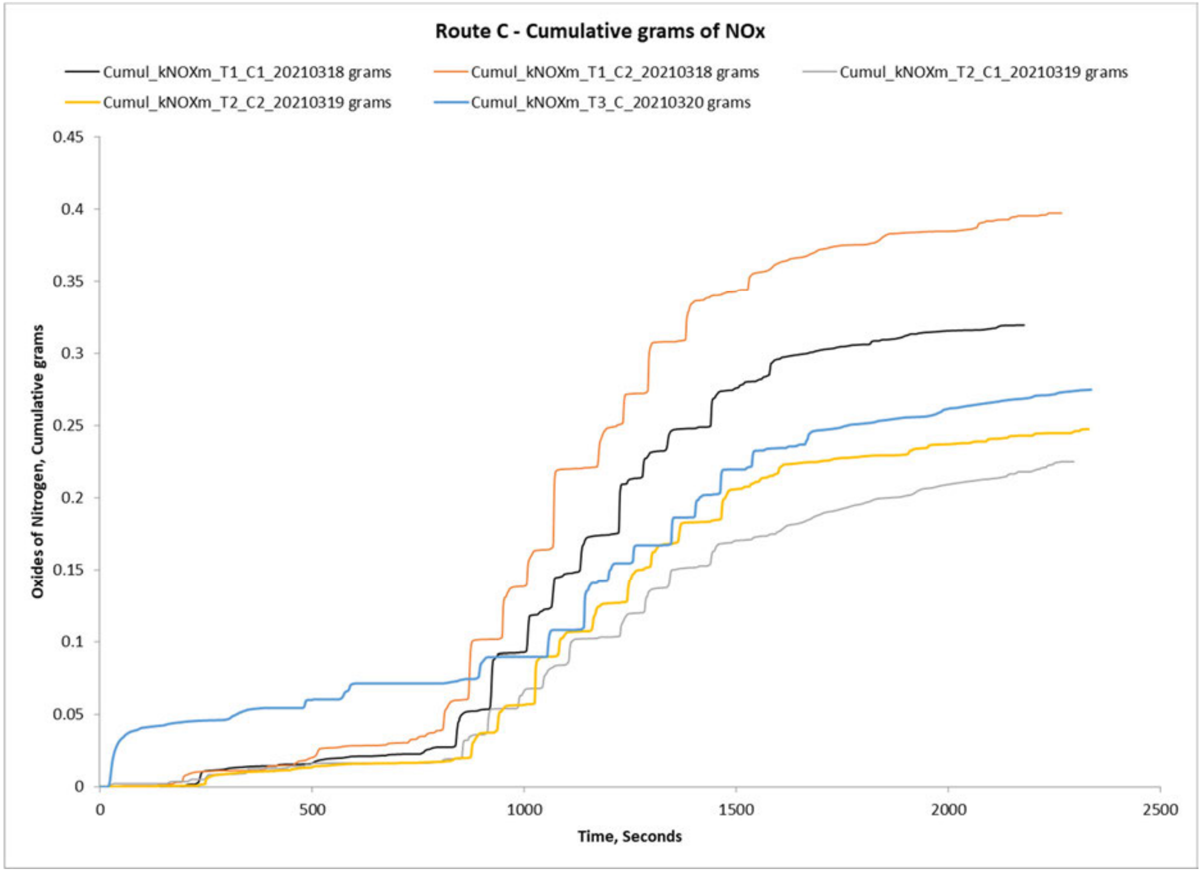
Test 1: Cold start on Route 1A, then routes 1B1, 1C1, 1B2, 1C2.
Test 2: Cold start on Route 2B, then routes 2C1, 2A1, 2C3, 2A2, (2C3) (Route 2C3 replaces 2C2 due to a highway accident closing M-14).
Test 3: Cold start on Route 3C, then routes 3A1, 3B1, 3B2, 3A2.

The test vehicle was cold-soaked at 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.

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_20210318 grams
Cumul_kNOXm_T1_C2_20210318 grams
Cumul_kNOXm_T2_C1_20210319 grams
Cumul_kNOXm_T2_C2_20210319 grams
Cumul_kNOXm_T3_C_20210320 grams
Oxides of Nitrogen, Cumulative grams
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
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 MY2021_ABCBC_20210318_1A_REV2.csv	1121	PP Route 1A cold
	MY2021_ABCBC_20210318_1B1_REV2.csv	1501	PP Route 1B1 (first)
	MY2021_ABCBC_20210318_1B2_REV2.csv	1317	PP Route 1B2 (second)
	MY2021_ABCBC_20210318_1C1_REV2.csv	2293	PP Route 1C1 (first)
	MY2021_ABCBC_20210318_1C2_REV2.csv	2277	PP Route 1C2 (second)
2	Redacted - PII MY2021_BCACA_20210319_2A1_REV2.csv	982	PP Route 2A2 (second)
	MY2021_BCACA_20210319_2A2_REV2.csv	911	PP Route 2A1 (first)
	MY2021_BCACA_20210319_2B_REV2.csv	1513	PP Route 2B (cold)
	MY2021_BCACA_20210319_2C1_REV2.csv	2392	PP Route 2C1 (first)
	MY2021_BCACA_20210319_2C2_REV2.csv	2333	PP Route 2C2 (second)
3	Redacted - PII MY2021_CABBA_20210320_3A1_REV3.csv	873	PP Route 3A1 (first)
	MY2021_CABBA_20210320_3A2_REV3.csv	948	PP Route 3A2 (second)
	MY2021_CABBA_20210320_3B1_REV3.csv	1367	PP Route 3B1 (first)
	MY2021_CABBA_20210320_3B2_REV3.csv	1463	PP Route 3B2 (second)
	MY2021_CABBA_20210320_3C_REV3.csv	2393	PP Route 3C (cold)

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 MY2021_ABCBC_20210318_1A_REV2_Gram-mile.csv	4/5/2021 11:14 AM	1 KB
MY2021_ABCBC_20210318_1A_REV2_Gram-sec.csv	4/5/2021 11:12 AM	59 KB
MY2021_ABCBC_20210318_1A_REV2_Load_speed.DAT	4/5/2021 11:12 AM	40 KB
MY2021_ABCBC_20210318_1B1_REV2_Gram-mile.csv	4/5/2021 11:20 AM	1 KB
MY2021_ABCBC_20210318_1B1_REV2_Gram-sec.csv	4/5/2021 11:12 AM	75 KB
MY2021_ABCBC_20210318_1B1_REV2_Load_speed.DAT	4/5/2021 11:12 AM	53 KB
MY2021_ABCBC_20210318_1B2_REV2_Gram-mile.csv	4/5/2021 11:15 AM	1 KB
MY2021_ABCBC_20210318_1B2_REV2_Gram-sec.csv	4/5/2021 11:12 AM	65 KB
MY2021_ABCBC_20210318_1B2_REV2_Load_speed.DAT	4/5/2021 11:12 AM	47 KB
MY2021_ABCBC_20210318_1C1_REV2_Gram-mile.csv	4/5/2021 11:16 AM	1 KB
MY2021_ABCBC_20210318_1C1_REV2_Gram-sec.csv	4/5/2021 11:12 AM	131 KB
MY2021_ABCBC_20210318_1C1_REV2_Load_speed.DAT	4/5/2021 11:12 AM	82 KB
MY2021_ABCBC_20210318_1C2_REV2_Gram-mile.csv	4/5/2021 11:16 AM	1 KB
MY2021_ABCBC_20210318_1C2_REV2_Gram-sec.csv	4/5/2021 11:12 AM	133 KB
MY2021_ABCBC_20210318_1C2_REV2_Load_speed.DAT	4/5/2021 11:12 AM	81 KB
MY2021_BCACA_20210319_2A1_REV2_Gram-mile.csv	4/5/2021 11:36 AM	1 KB
MY2021_BCACA_20210319_2A1_REV2_Gram-sec.csv	4/5/2021 11:35 AM	50 KB
MY2021_BCACA_20210319_2A1_REV2_Load_speed.DAT	4/5/2021 11:35 AM	35 KB
MY2021_BCACA_20210319_2A2_REV2_Gram-mile.csv	4/5/2021 11:37 AM	1 KB
MY2021_BCACA_20210319_2A2_REV2_Gram-sec.csv	4/5/2021 11:35 AM	46 KB
MY2021_BCACA_20210319_2A2_REV2_Load_speed.DAT	4/5/2021 11:35 AM	33 KB
MY2021_BCACA_20210319_2B_REV2_Gram-mile.csv	4/5/2021 11:37 AM	1 KB
MY2021_BCACA_20210319_2B_REV2_Gram-sec.csv	4/5/2021 11:35 AM	80 KB
MY2021_BCACA_20210319_2B_REV2_Load_speed.DAT	4/5/2021 11:35 AM	54 KB
MY2021_BCACA_20210319_2C1_REV2_Gram-mile.csv	4/5/2021 11:38 AM	1 KB
MY2021_BCACA_20210319_2C1_REV2_Gram-sec.csv	4/5/2021 11:35 AM	133 KB
MY2021_BCACA_20210319_2C1_REV2_Load_speed.DAT	4/5/2021 11:35 AM	85 KB
MY2021_BCACA_20210319_2C2_REV2_Gram-mile.csv	4/5/2021 11:38 AM	1 KB
MY2021_BCACA_20210319_2C2_REV2_Gram-sec.csv	4/5/2021 11:35 AM	131 KB
MY2021_BCACA_20210319_2C2_REV2_Load_speed.DAT	4/5/2021 11:35 AM	83 KB
MY2021_CABBA_20210320_3A1_REV3_Gram-mile.csv	4/5/2021 11:42 AM	1 KB
MY2021_CABBA_20210320_3A1_REV3_Gram-sec.csv	4/5/2021 11:42 AM	44 KB
MY2021_CABBA_20210320_3A1_REV3_Load_speed.DAT	4/5/2021 11:42 AM	32 KB
MY2021_CABBA_20210320_3A2_REV3_Gram-mile.csv	4/5/2021 11:43 AM	1 KB
MY2021_CABBA_20210320_3A2_REV3_Gram-sec.csv	4/5/2021 11:42 AM	48 KB
MY2021_CABBA_20210320_3A2_REV3_Load_speed.DAT	4/5/2021 11:42 AM	34 KB
MY2021_CABBA_20210320_3B1_REV3_Gram-mile.csv	4/5/2021 11:43 AM	1 KB
MY2021_CABBA_20210320_3B1_REV3_Gram-sec.csv	4/5/2021 11:42 AM	69 KB
MY2021_CABBA_20210320_3B1_REV3_Load_speed.DAT	4/5/2021 11:42 AM	48 KB
MY2021_CABBA_20210320_3B2_REV3_Gram-mile.csv	4/5/2021 11:44 AM	1 KB
MY2021_CABBA_20210320_3B2_REV3_Gram-sec.csv	4/5/2021 11:42 AM	72 KB
MY2021_CABBA_20210320_3B2_REV3_Load_speed.DAT	4/5/2021 11:42 AM	51 KB
MY2021_CABBA_20210320_3C_REV3_Gram-mile.csv	4/5/2021 11:44 AM	1 KB
MY2021_CABBA_20210320_3C_REV3_Gram-sec.csv	4/5/2021 11:42 AM	138 KB
MY2021_CABBA_20210320_3C_REV3_Load_speed.DAT	4/5/2021 11:42 AM	85 KB

B. On-Road Test Results by Test Day

The tables below summarize 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								
3/18/2021		COLD 1A	HOT 1B1	HOT 1C1	HOT 1B2	HOT 1C2	Total	Average
		Route A	Route B	Route C	Route B	Route C		
Distance	(mi)	7.754	10.79	30.495	10.784	30.486	90.309	
Length	(sec)	1121	1501	2293	1317	2277	8509	
Fuel Economy	mpg	18.177	22.216	22.154	22.7	21.676		21.3846
CO2	(g)	3884.659	4443.651	12352.91	4340.95	12711.44		7546.723
CO	(g)	8.752	1.267	141.675	2.358	95.02		49.8144
kNOx	(g)	0.074	0.055	0.323	0.046	0.398		0.1792
THC	(g)	1.026	0.015	1.353	0.006	0.782		0.6364
NMCH	(g)	1.006	0.015	1.326	0.006	0.766		0.6238
CO2	(g/mi)	500.99	411.834	405.077	402.554	416.958		427.4826
CO	(g/mi)	1.129	0.117	4.646	0.219	3.117		1.8456
kNOx	(g/mi)	0.01	0.005	0.011	0.004	0.013		0.0086
THC	(g/mi)	0.132	0.001	0.044	0.001	0.026		0.0408
NMCH	(g/mi)	0.13	0.001	0.043	0.001	0.025		0.04
							Std. Dev.	Average
Ambient Temp	Deg C	2.727	2.482	1.714	1.889	2.587	0.449472	2.2798
Ambient Press.	mbar	984.737	986.651	984.25	987.404	984.838	1.369676	985.576
Relative Humid.	%	77.927	80.824	88.704	87.73	82.814	4.572051	83.5998
Absol. Humidity	grains	25.731	26.168	27.271	27.225	27.062	0.698986	26.6914
AVG kh Factor		0.792	0.794	0.799	0.799	0.798	0.003209	0.7964

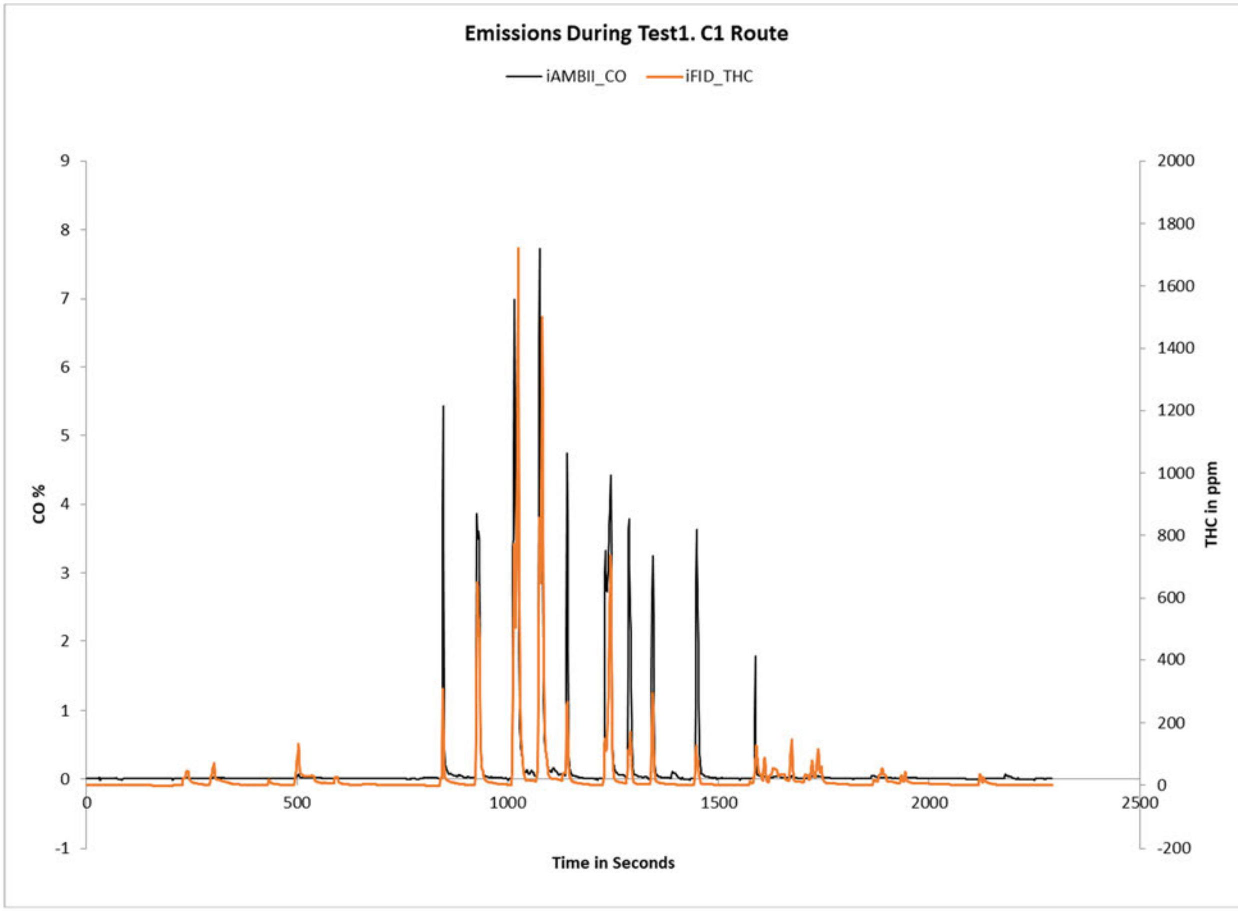
Test 2

3/19/2021		COLD 2B	HOT 2C1	HOT 2A1	HOT 2C2	HOT 2A2	Total	Average
		Route B	Route C	Route A	Route C	Route A		
Distance	(mi)	10.925	30.511	7.679	30.511	7.687	87.313	
Length	(sec)	1513	2392	982	2333	911	8131	
Fuel Economy	mpg	18.164	21.141	22.211	22.845	23.27		21.5262
CO2	(g)	5493.945	13088.66	3165.957	12100.49	3026.94		7375.199
CO	(g)	9.767	84.591	1.851	87.128	1.015		36.8704
kNOx	(g)	0.074	0.229	0.068	0.248	0.027		0.1292
THC	(g)	1.103	0.622	0.011	0.636	0.015		0.4774
NMCH	(g)	1.081	0.61	0.011	0.623	0.015		0.468
CO2	(g/mi)	502.874	428.976	412.278	396.598	393.796		426.9044
CO	(g/mi)	0.894	2.772	0.241	2.856	0.132		1.379
kNOx	(g/mi)	0.007	0.007	0.009	0.008	0.003		0.0068
THC	(g/mi)	0.101	0.02	0.001	0.021	0.002		0.029
NMCH	(g/mi)	0.099	0.02	0.001	0.02	0.002		0.0284
							Std. Dev.	Average
Ambient Temp	Deg C	-3.552	-3.306	-2.587	-1.41	-0.607	1.256977	-2.2924
Ambient Press.	mbar	1003.799	1002.279	1003.816	1003.556	1004.779	0.896212	1003.646
Relative Humid.	%	59.245	59.175	56.763	50.736	43.729	6.671716	53.9296
Absol. Humidity	grains	12.093	12.321	12.454	12.131	11.088	0.539722	12.0174
AVG kh Factor		0.733	0.734	0.735	0.733	0.729	0.00228	0.7328

Test 3

3/20/2021		COLD 3C	HOT 3A1	HOT 3B1	HOT 3B2	HOT 3A2	Total	Average
		Route C	Route A	Route B	Route B	Route A		
Distance	(mi)	30.597	7.663	10.795	10.783	7.662	67.5	
Length	(sec)	2393	873	1367	1463	948	7044	
Fuel Economy	mpg	20.365	28.116	26.726	25.377	28.311		25.779
CO2	(g)	13555.94	2825.319	4186.728	4403.929	2805.623		5555.508
CO	(g)	88.657	0.845	1.464	1.655	0.764		18.677
kNOx	(g)	0.28	0.077	0.088	0.081	0.086		0.1224
THC	(g)	1.74	0	0.004	0.002	0.002		0.3496
NMCH	(g)	1.706	0	0.004	0.002	0.002		0.3428
CO2	(g/mi)	443.055	368.688	387.848	408.432	366.17		394.8386
CO	(g/mi)	2.898	0.11	0.136	0.153	0.1		0.6794
kNOx	(g/mi)	0.009	0.01	0.008	0.008	0.011		0.0092
THC	(g/mi)	0.057	0	0	0	0		0.0114
NMCH	(g/mi)	0.056	0	0	0	0		0.0112
							Std. Dev.	Average
Ambient Temp	Deg C	-6.217	-1.913	-3.652	-2.625	-1.298	1.929623	-3.141
Ambient Press.	mbar	1005.66	1008.56	1010.59	1010.60	1008.50	2.028145	1008.781
Relative Humid.	%	79.016	65.823	75.863	72.045	61.576	7.150498	70.8646
Absol. Humidity	grains	13.252	15.113	15.268	15.666	14.795	0.930257	14.8188
AVG kh Factor		0.738	0.746	0.747	0.749	0.745	0.004183	0.745

During Test 3, the cold start on Route C accounted for 45% of distance, and 95% of carbon monoxide and 99% of 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.



B. 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						
		COLD 1A	HOT 2A1	HOT2A2	HOT 3A1	HOT 3A2	Average	Std. Dev.
Distance	(mi)	7.754	7.679	7.687	7.663	7.662	7.67275	0.012285
Length	(sec)	1121	982	911	873	948	928.5	47.00709
Fuel Econ	mpg	18.177	22.211	23.27	28.116	28.311	25.477	3.190271
CO2	(g)	3884.659	3165.957	3026.94	2825.319	2805.623	2955.96	172.0515
CO	(g)	8.752	1.851	1.015	0.845	0.764	1.11875	0.499246
kNOx	(g)	0.074	0.068	0.027	0.077	0.086	0.0645	0.026058
THC	(g)	1.026	0.011	0.015	0	0.002	0.007	0.007165
NMCH	(g)	1.006	0.011	0.015	0	0.002	0.007	0.007165
CO2	(g/mi)	500.99	412.278	393.796	368.688	366.17	385.233	21.92329
CO	(g/mi)	1.129	0.241	0.132	0.11	0.1	0.14575	0.064892
kNOx	(g/mi)	0.01	0.009	0.003	0.01	0.011	0.00825	0.003594
THC	(g/mi)	0.132	0.001	0.002	0	0	0.00075	0.000957
NMCH	(g/mi)	0.13	0.001	0.002	0	0	0.00075	0.000957

		ROUTE B						
		COLD 2B	HOT 1B1	HOT 1B2	HOT 3B1	HOT 3A2	Average	Std. Dev.
Distance	(mi)	10.925	10.79	10.784	10.795	10.783	10.788	0.005598
Length	(sec)	1513	1501	1317	1367	1463	1412	84.7978
Fuel Econ	mpg	18.164	22.216	22.7	26.726	25.377	24.25475	2.155634
CO2	(g)	5493.945	4443.651	4340.95	4186.728	4403.929	4343.815	112.9387
CO	(g)	9.767	1.267	2.358	1.464	1.655	1.686	0.475181
kNOx	(g)	0.074	0.055	0.046	0.088	0.081	0.0675	0.020174
THC	(g)	1.103	0.015	0.006	0.004	0.002	0.00675	0.005737
NMCH	(g)	1.081	0.015	0.006	0.004	0.002	0.00675	0.005737
CO2	(g/mi)	502.874	411.834	402.554	387.848	408.432	402.667	10.59693
CO	(g/mi)	0.894	0.117	0.219	0.136	0.153	0.15625	0.044342
kNOx	(g/mi)	0.007	0.005	0.004	0.008	0.008	0.00625	0.002062
THC	(g/mi)	0.101	0.001	0.001	0	0	0.0005	0.000577
NMCH	(g/mi)	0.099	0.001	0.001	0	0	0.0005	0.000577

		ROUTE C						
		COLD 3C	HOT 1C1	HOT 1C2	HOT 2C1	HOT 2C2	Average	Std. Dev.
Distance	(mi)	30.597	30.495	30.486	30.511	30.511	30.50075	0.012393
Length	(sec)	2393	2293	2277	2392	2333	2323.75	51.23394
Fuel Econ	mpg	20.365	22.154	21.676	21.141	22.845	21.954	0.723909
CO2	(g)	13555.94	12352.91	12711.44	13088.66	12100.49	12563.38	430.6583
CO	(g)	88.657	141.675	95.02	84.591	87.128	102.1035	26.75215
kNOx	(g)	0.28	0.323	0.398	0.229	0.248	0.2995	0.077195
THC	(g)	1.74	1.353	0.782	0.622	0.636	0.84825	0.34419
NMCH	(g)	1.706	1.326	0.766	0.61	0.623	0.83125	0.33732
CO2	(g/mi)	443.055	405.077	416.958	428.976	396.598	411.9023	14.1171
CO	(g/mi)	2.898	4.646	3.117	2.772	2.856	3.34775	0.877877
kNOx	(g/mi)	0.009	0.011	0.013	0.007	0.008	0.00975	0.002754
THC	(g/mi)	0.057	0.044	0.026	0.02	0.021	0.02775	0.011147
NMCH	(g/mi)	0.056	0.043	0.025	0.02	0.02	0.027	0.010924

D. Recorded Vehicle Parameters

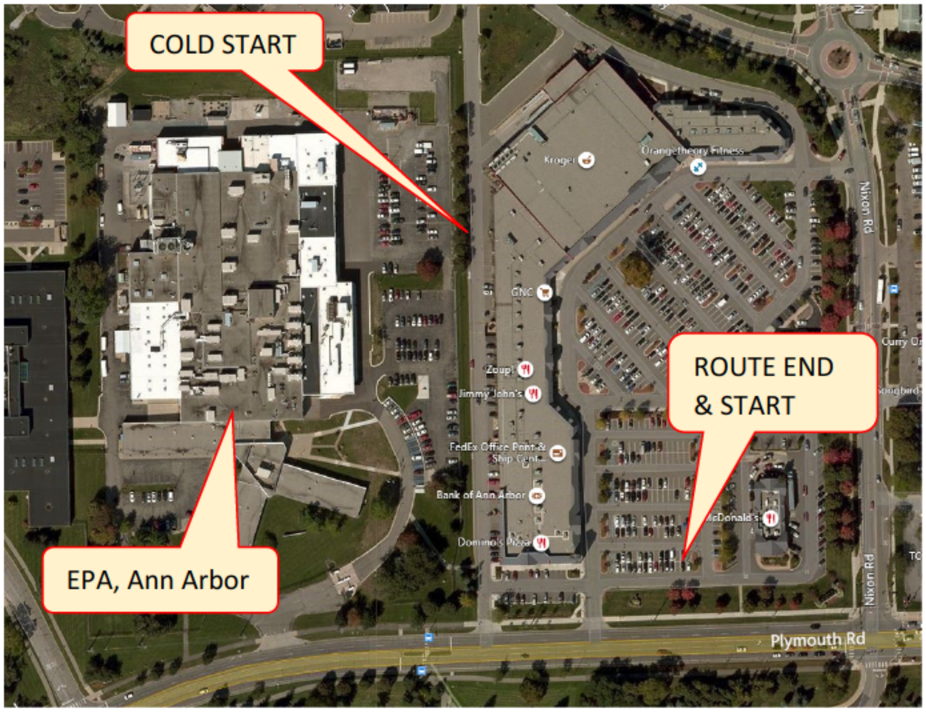
The following list includes several DURANGO vehicle interface parameters not required by the Consent Decree but requested separately by the Agencies and agreed to by FCA where available.

No. of DTCs	sMAL_FUN_IND	#		Engine Fuel Rate	iFUEL_RATE2	gal/s
Load Percent	iENG_LOAD	%		Act. Eng. Pct. Torque	iPCNT_TORQUE	%
Coolant Temp.	ECT	degC		Eng. Ref. Torque	sREF_ENG_TORQUE	lb-ft
Manifold Pressure	MAP	kPa		Engine Fuel Rate	ENG_FUEL_RATE	g/s
Engine RPM	iENG_SPEED	RPM		Eng. Exh. Flow Rate	EXH_RATE	kg/hr
Vehicle Speed	iVEH_SPEED	mph		Eng. Frictn Pct. Tq	iFRICT_TORQUE	%
Spark Advance	SPARKADV	Deg		Fuel System A Status	FUEL_STAT_A	
Intake Air Temp.	IAT	degC		Fuel System B Status	FUEL_STAT_B	
Abs Throttle Postn	TP	%		Short-Term Fuel Trim 1	ST_FUELTRIM_1	%
Time Since Start	RUNTM	S		Short-Term Fuel Trim 3	ST_FUELTRIM_3	%
MIL Dist. Traveled	MIL_DIST	km		Long-Term Fuel Trim 1	LT_FUELTRIM_1	%
Commanded EGR	EGR_PCT	%		Long-Term Fuel Trim 3	LT_FUELTRIM_3	%
EGR Error	EGR_ERR	%		Short-Term Fuel Trim 2	ST_FUELTRIM_2	%
Cmd. Evap. Purge	EVAP_PCT	%		Short-Term Fuel Trim 4	ST_FUELTRIM_4	%
Fuel Level Input	FLI	%		Long-Term Fuel Trim 1	LT_FUELTRIM_2	%
No. of Warm Ups	WARM_UPS			Long-Term Fuel Trim 4	LT_FUELTRIM_4	%
Distance Cleared	CLR_DIST	km		O2 Sensor Location	O2_SENSOR_LOC	
Evap. System VP	EVAP_VP1	Pa		Bank1 O2 Sensor-1 Volt	BK1_O2_SENSOR1_VOLT	V
Limit Adjusted iBAR_PRESS	iBAR_PRESS	kPa		Bank1 O2 Sensor-1 SHAFT	BK1_O2_SENSOR1_SHRFT	%
Catalyst Temp. 1-1	CATEMP11	degC		Bank1 O2 Sensor-2 Volt	BK1_O2_SENSOR2_VOLT	V
Catalyst Temp. 2-1	CATEMP21	degC		Bank1 O2 Sensor-2 SHAFT	BK1_O2_SENSOR2_SHRFT	%
Control Voltage	VPWR	V		Bank2 O2 Sensor-1 Volt	BK2_O2_SENSOR1_VOLT	V
Abs. Load Value	LOAD_ABS	%		Bank2 O2 Sensor-1 SHAFT	BK2_O2_SENSOR1_SHRFT	%
F/A Equiv. Ratio	LAMBDA			Bank2 O2 Sensor-2 Volt	BK2_O2_SENSOR2_VOLT	V
Rel. Throttle Postn	TP_R	%		Bank2 O2 Sensor-2 SHAFT	BK2_O2_SENSOR2_SHRFT	%
Amb. Air Temp.	AAT	degC		OBD REQUIREMENT LEVEL	OBD_REQ_LEVEL	
Throttle Postn B	TP_B	%		Driving Cycle Status	DRV_CYC_STAT	
Accel. Postn D	APP_D	%		Current Fuel Type	FUEL_TYPE	
Accel. Postn E	APP_E	%		EGR Wide Temp. 1-2	EGRWTC	degC
Throttle Act. Ctrl.	TAC_PCT	%		Vehicle Odometer	Odometer	hm

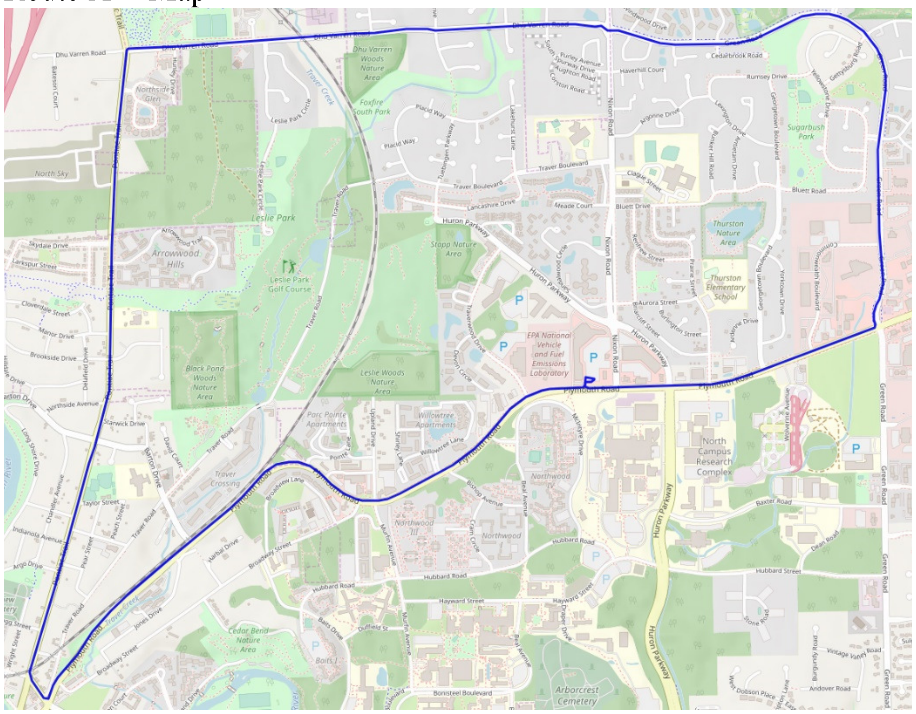
App. 2A. SEMTECH LDV (PEMS) Tests by Route with Vehicle Speed Profile

Route Description

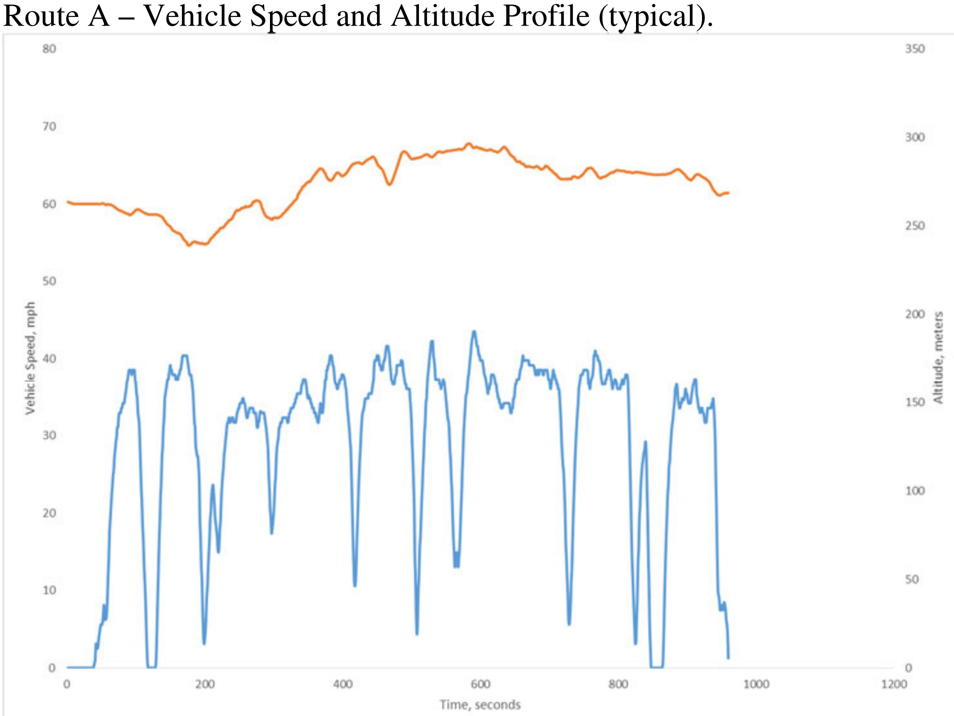
Picture below provides the typical start location for the three approved routes.



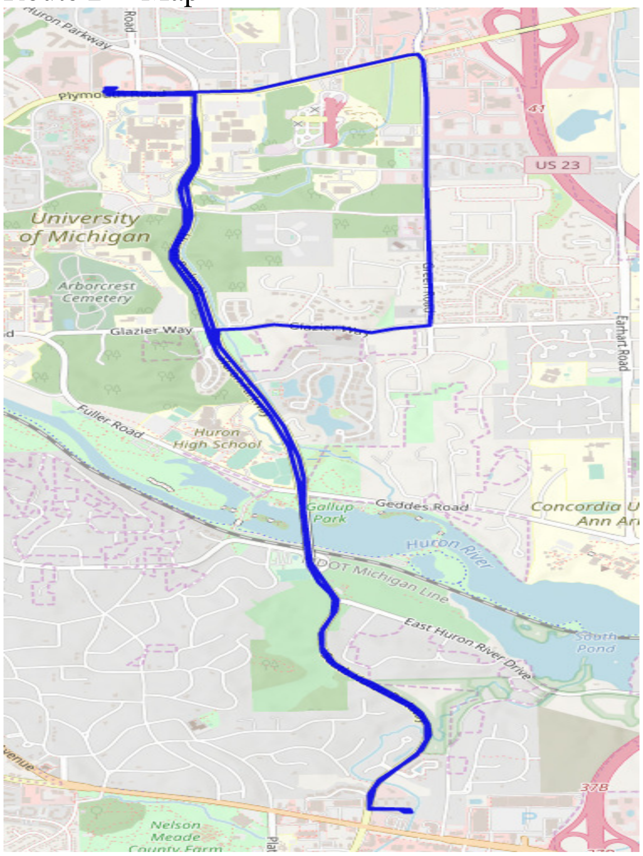
Route A -- Map



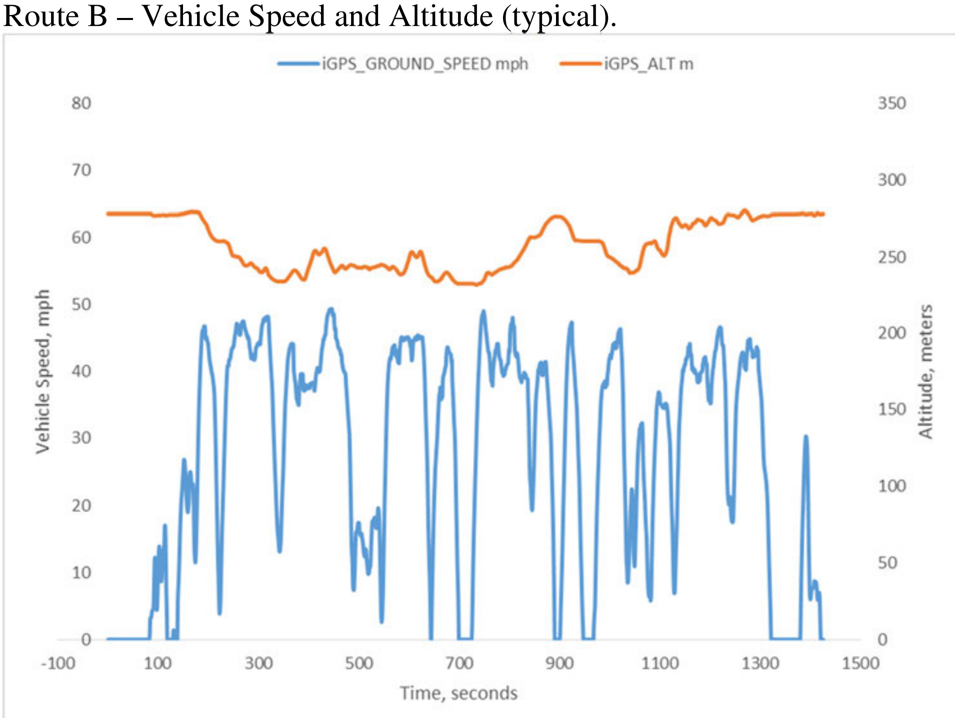
Route A – Vehicle Speed and Altitude Profile (typical).



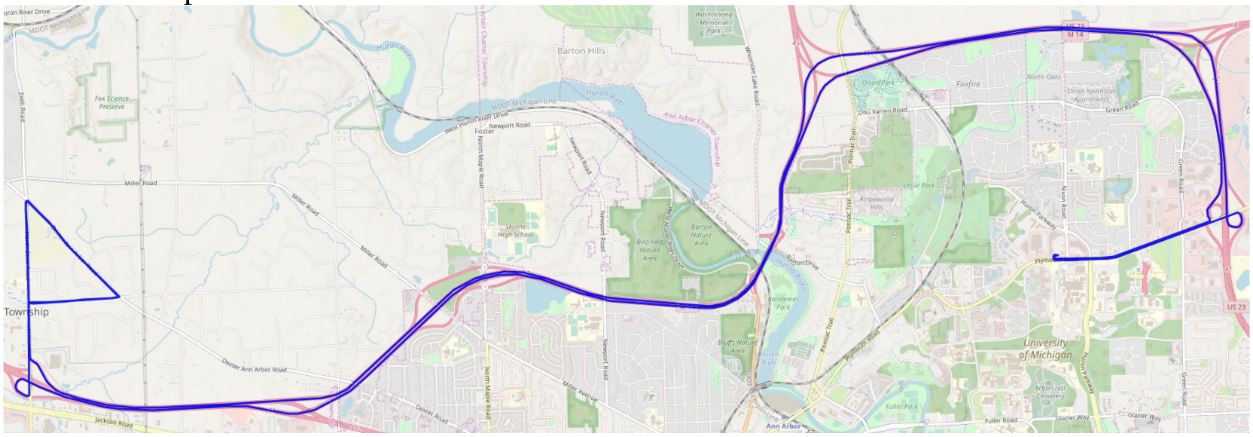
Route B – Map



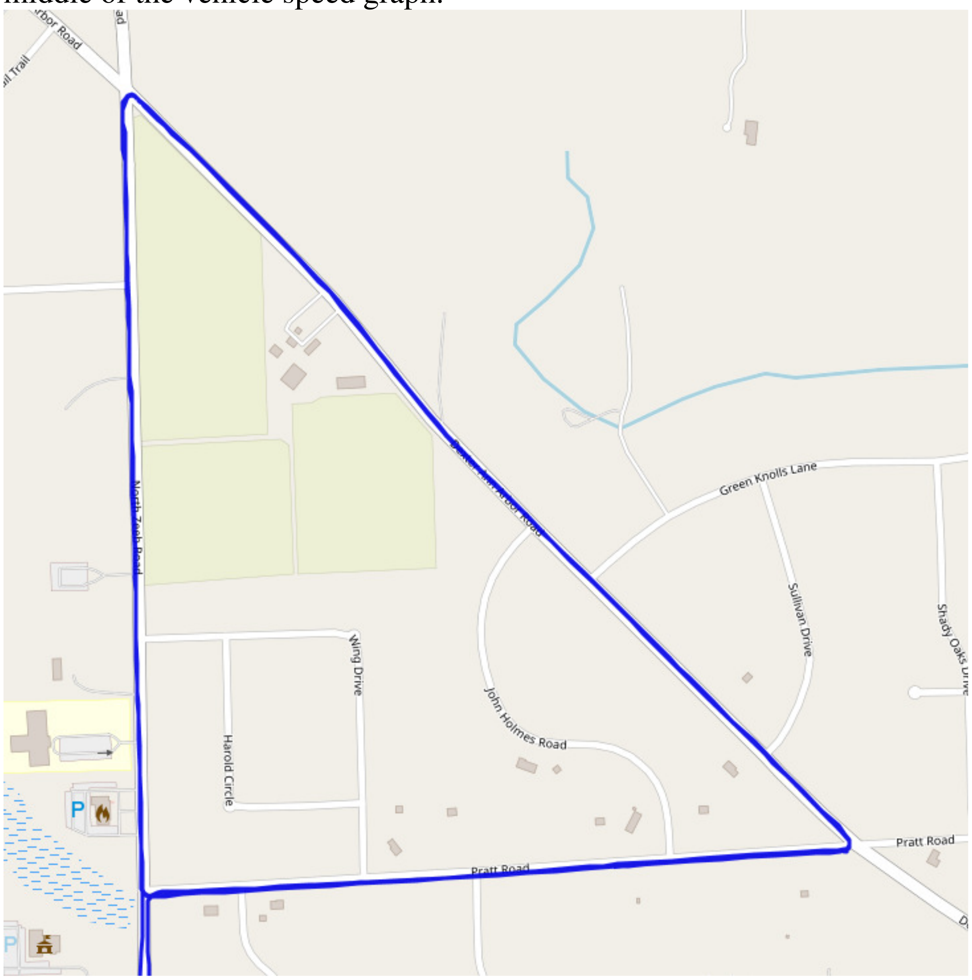
Route B – Vehicle Speed and Altitude (typical).



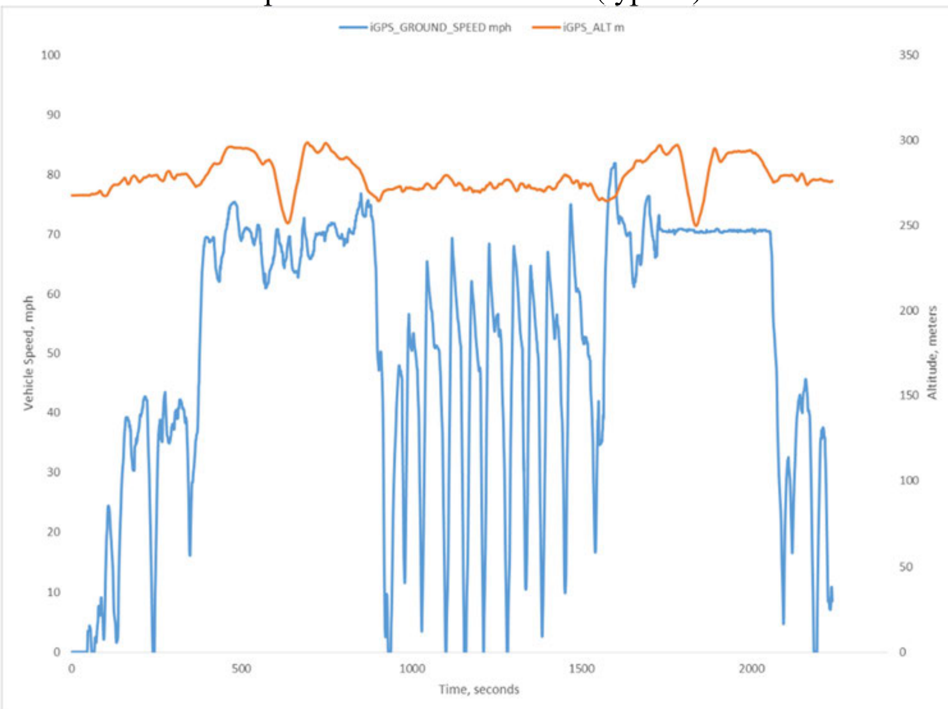
Route C – Map



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.

Correlation Summary

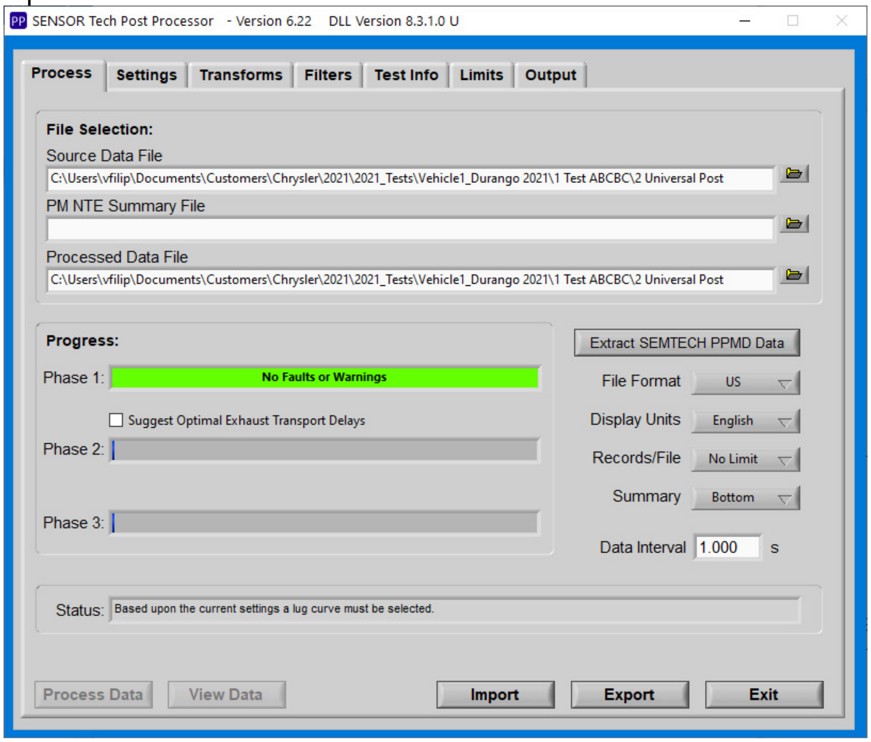
Dyno. distance :	11.07	miles
Dyno. distance :	17.712	km

	PEMS (SEMTECH LDV)			Dynamometer Bag Bench		
Overall Emissions:	grams	g/mi	g/km	grams	g/mi	g/km
CO2	4739.98	428.18	267.61	4494.70	406.03	253.77
CO	3.0360	0.2743	0.1714	1.6180	0.1462	0.0914
kNOx	0.1640	0.0148	0.0093	0.0810	0.0073	0.0046
THC[A]	0.1890	0.0171	0.0107	0.1550	0.0140	0.0088

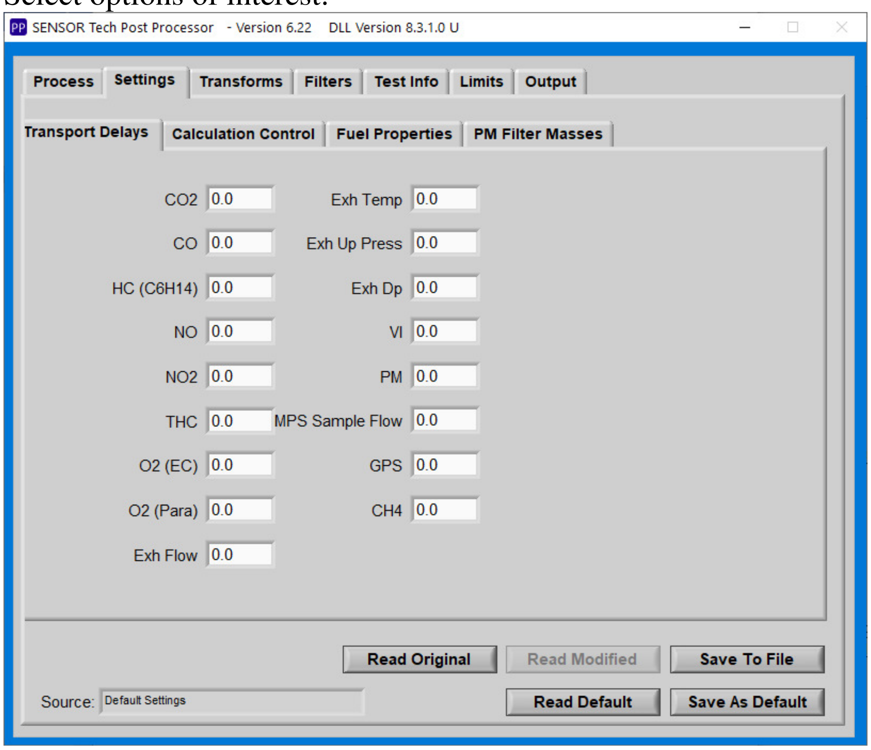
	Correlation versus EU Tolerance			Difference versus Dynmometer		
Overall Emissions:	Difference	Tolerance	Percent	% Diff	% Tolerance	Abs diff (g/km)
CO2	13.8482	10.0000	1.3848	5.5%	10.0%	13.848
CO	0.0801	0.1500	0.5337	87.6%	15.0%	0.080
kNOx	0.0047	0.0150	0.3124	102.5%	15.0%	0.005
THC[A]	0.0019	0.0150	0.1280	21.9%	15.0%	0.002

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

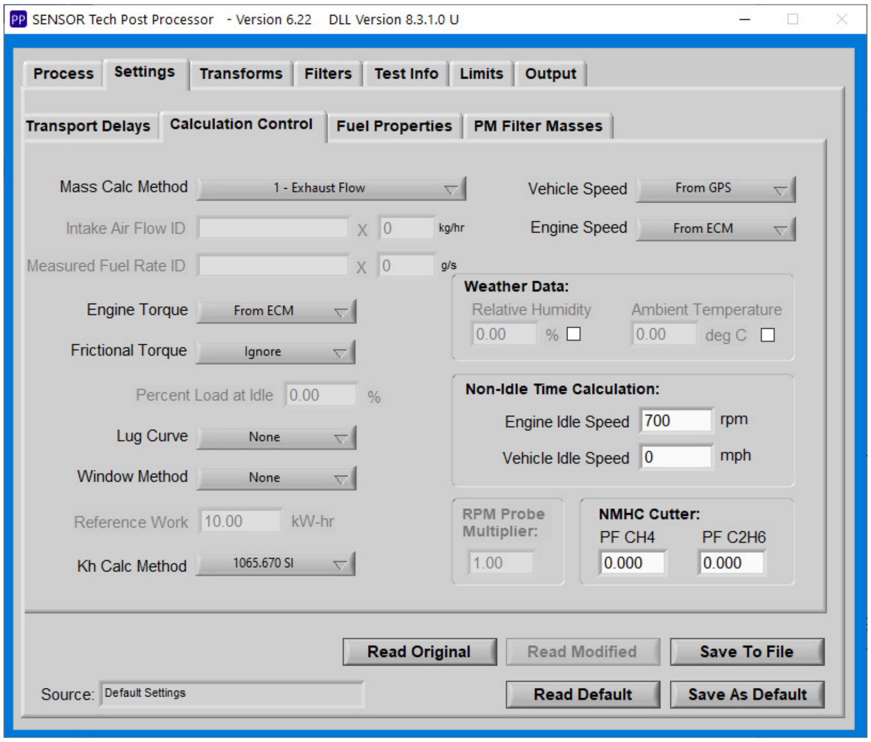
Open SENSORTech Post Processor and select the raw datafile of interest:



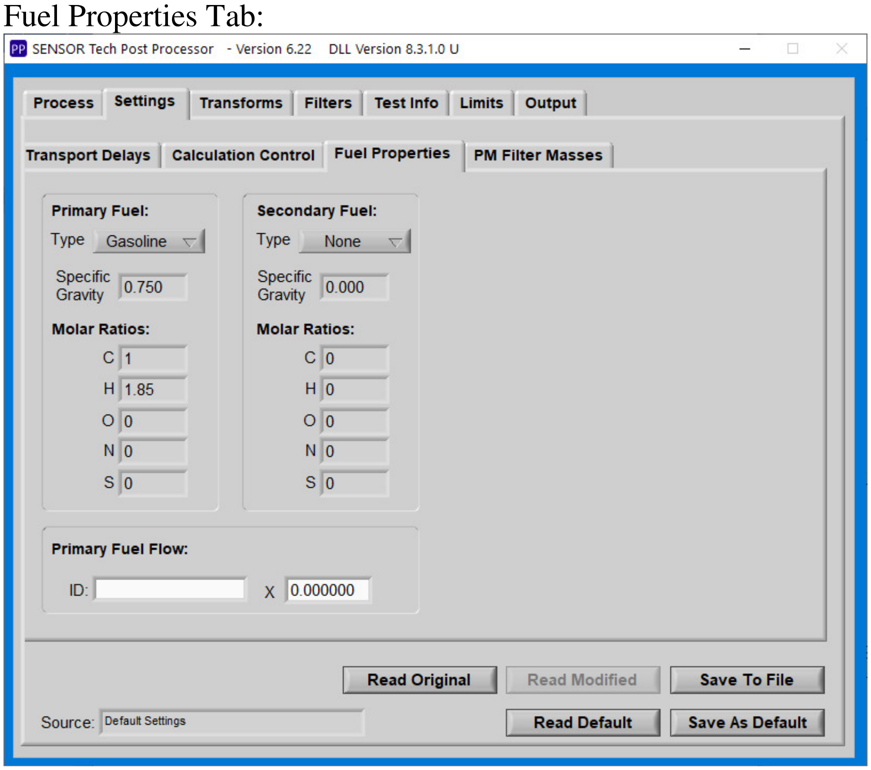
Select options of interest:



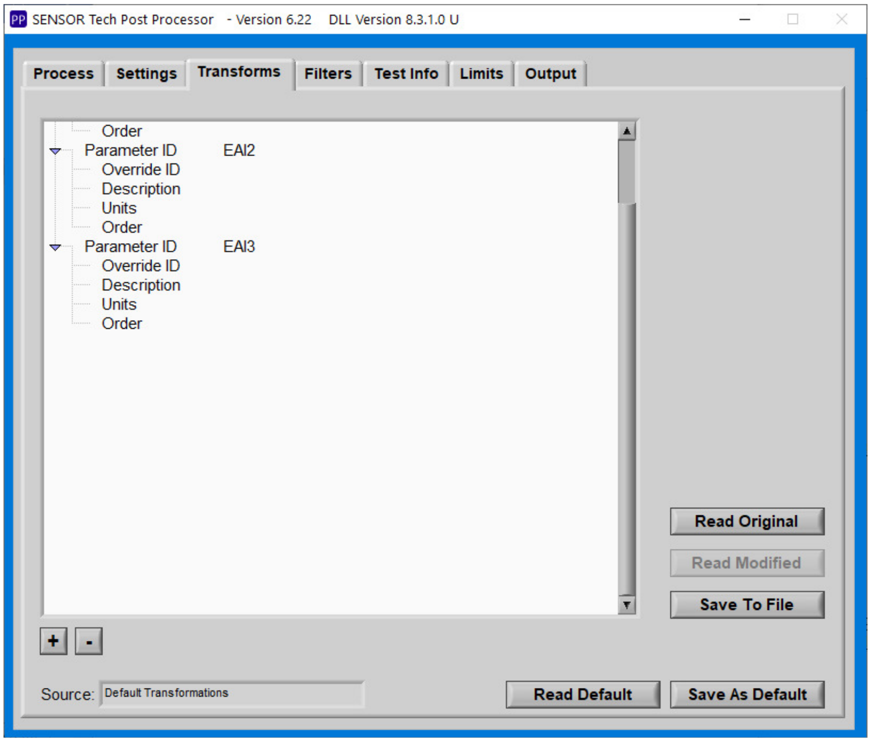
Calculation Control Tab:



Fuel Properties Tab:

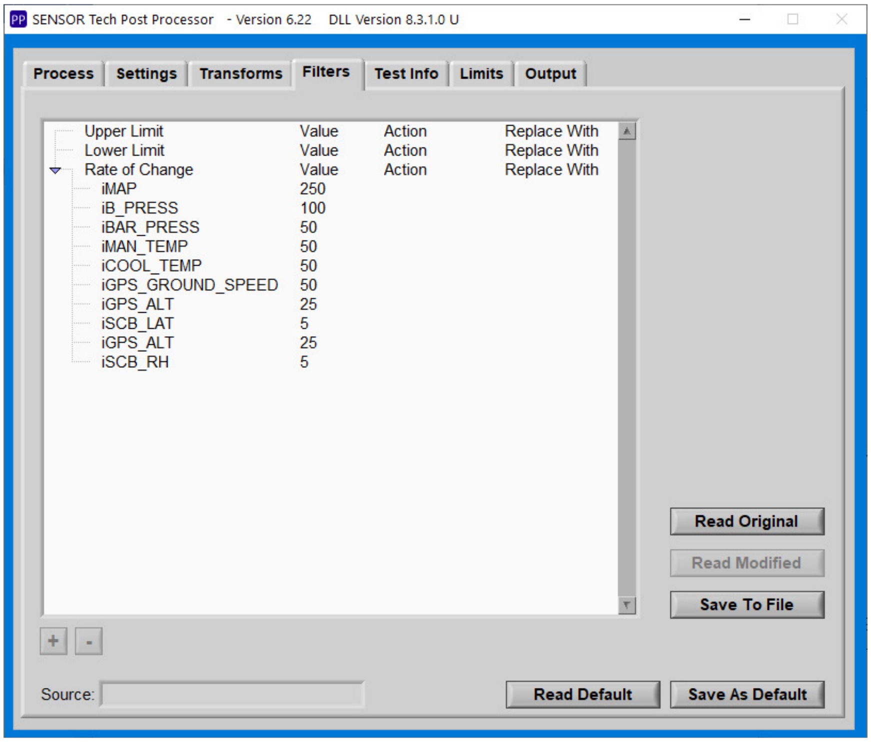


Transforms are used when post-processing DURANGO data files to provide correct scaling. No transforms were used on this test.

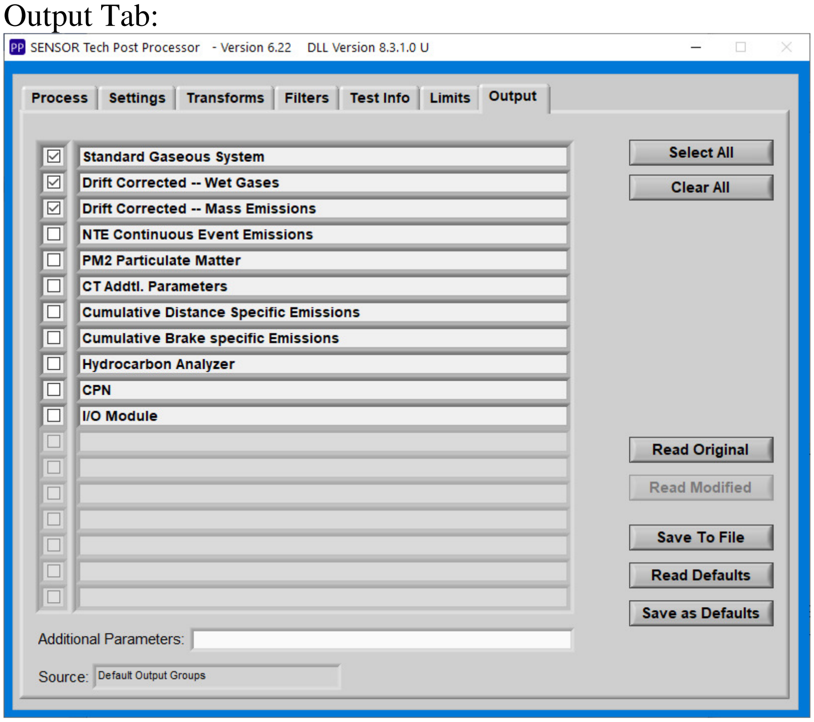


Parameter Filters Tab. This tab is used to filter out ECM or GPS outliars. For example, GPS Speeds changing by more than 50km/second will be filtered out, since will be impossible to get this change during normal driving.

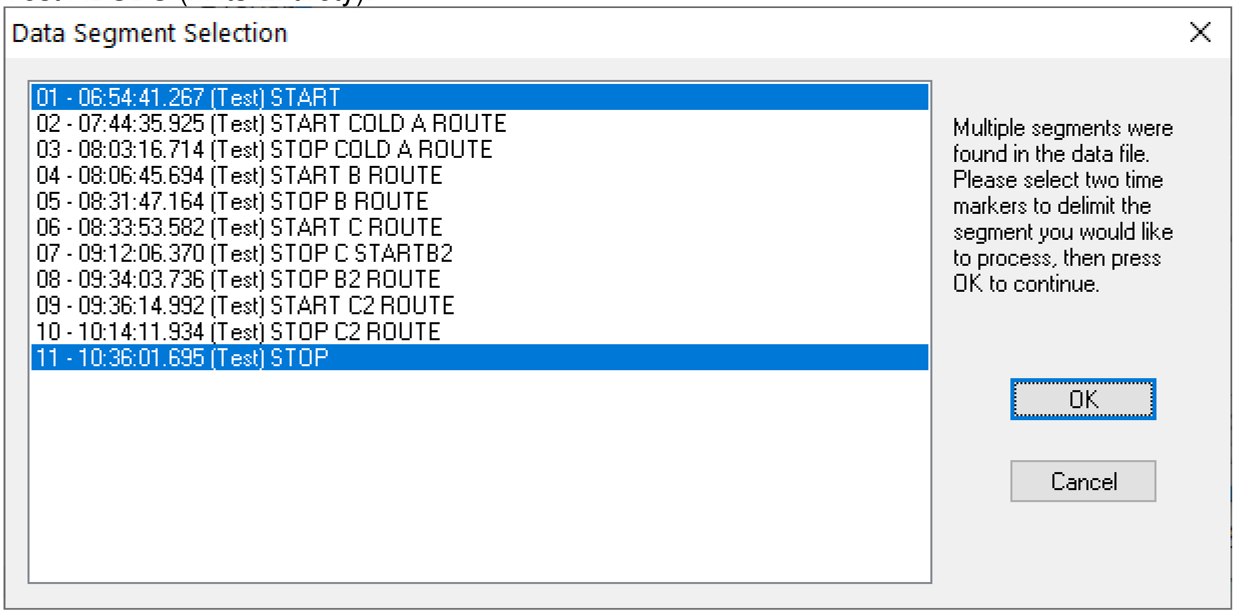
Limits Tab:



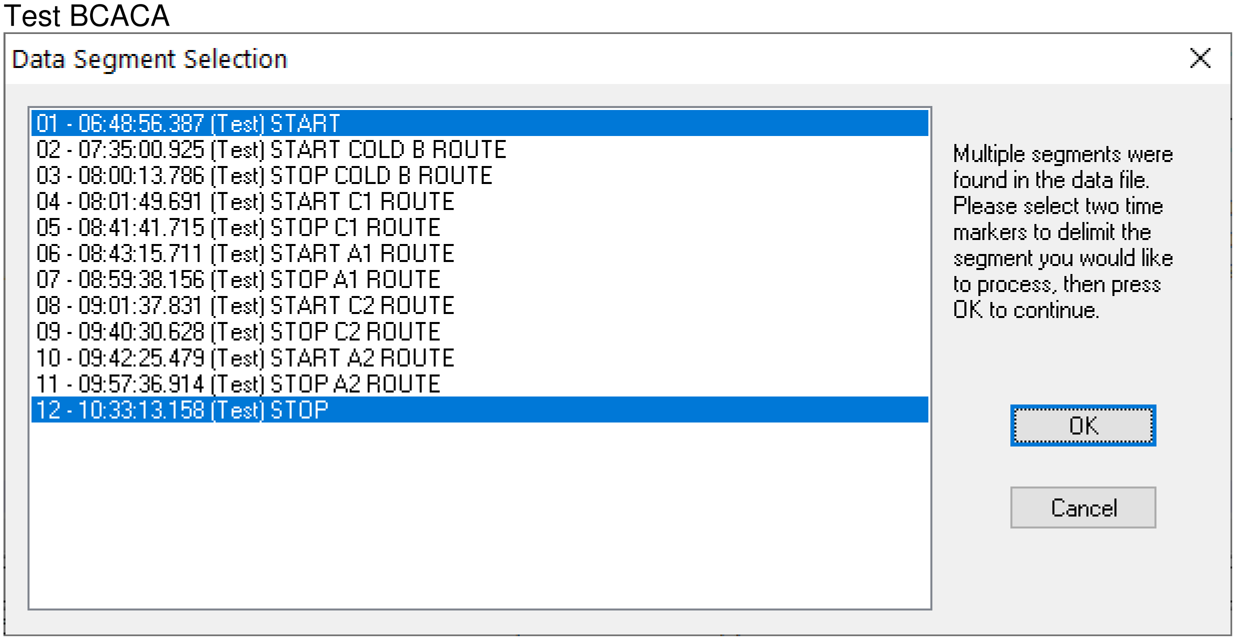
Output Tab:



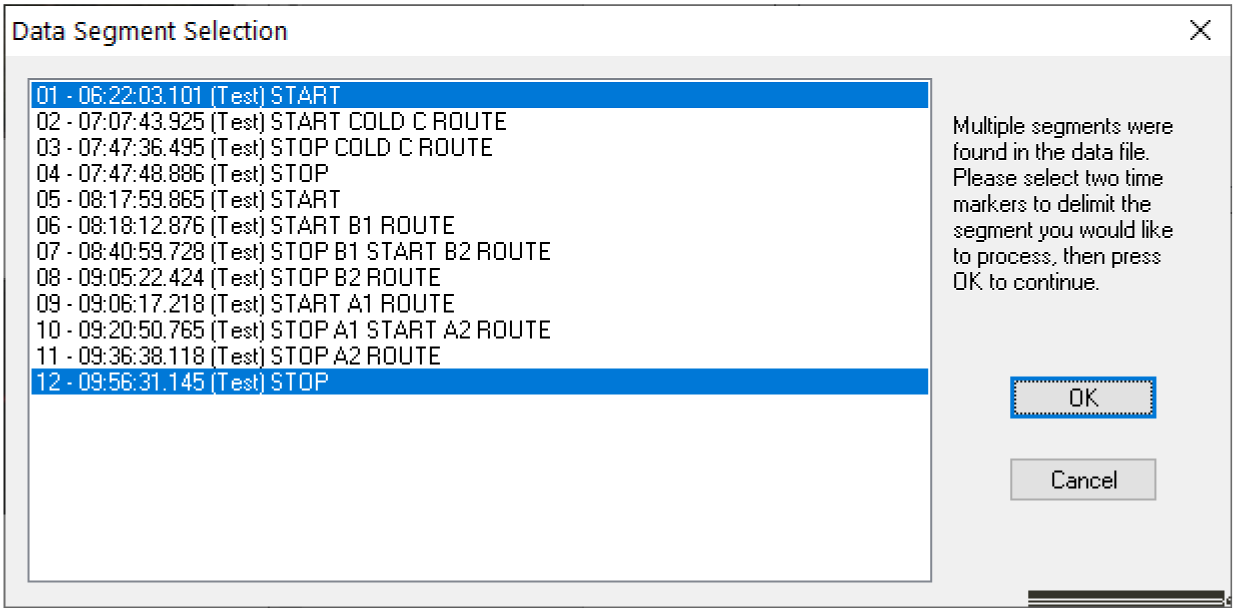
Use the following User Marks when post-processing raw or converted data files (typical):
Test ABCBC (in its Entirety):



Test BCACA



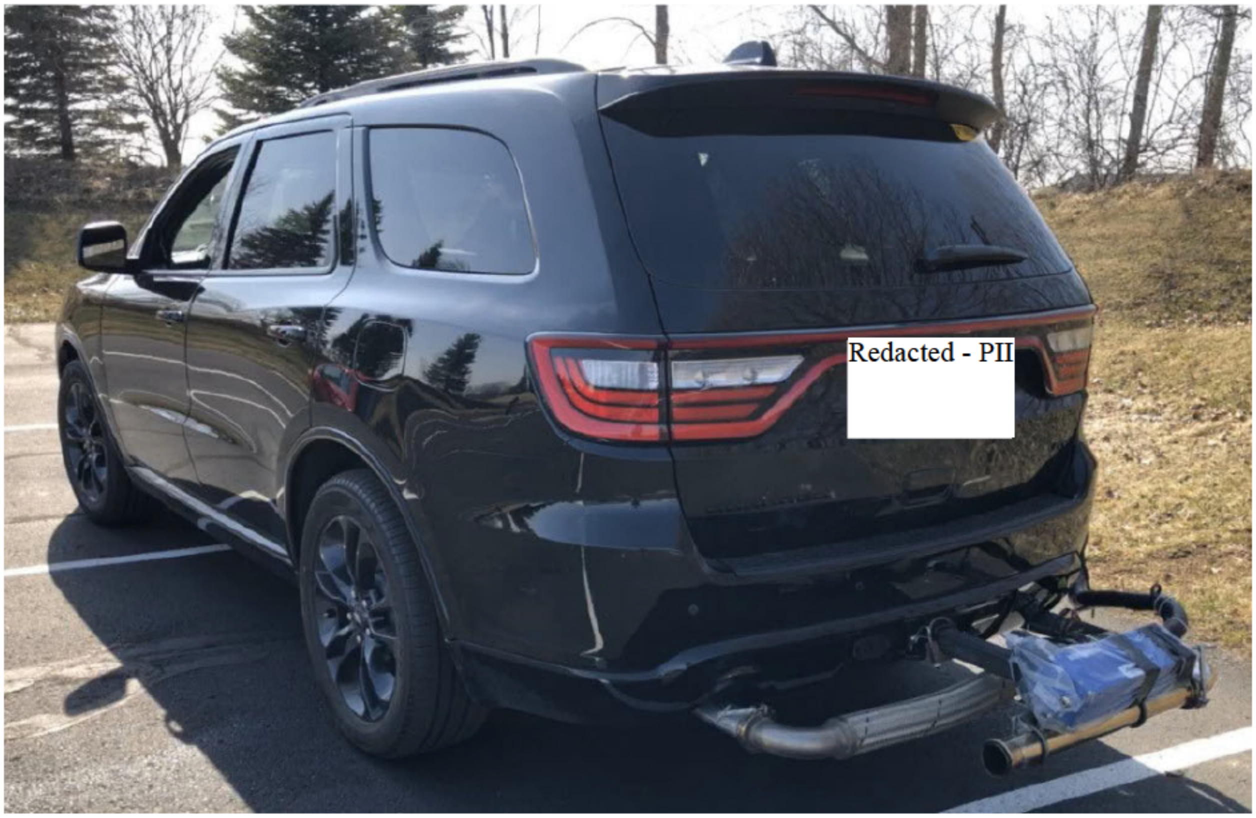
Test CABBA



Data Segment Selection
01 - 06:22:03.101 (Test) START
02 - 07:07:43.925 (Test) START COLD C ROUTE
03 - 07:47:36.495 (Test) STOP COLD C ROUTE
04 - 07:47:48.886 (Test) STOP
05 - 08:17:59.865 (Test) START
06 - 08:18:12.876 (Test) START B1 ROUTE
07 - 08:40:59.728 (Test) STOP B1 START B2 ROUTE
08 - 09:05:22.424 (Test) STOP B2 ROUTE
09 - 09:06:17.218 (Test) START A1 ROUTE
10 - 09:20:50.765 (Test) STOP A1 START A2 ROUTE
11 - 09:36:38.118 (Test) STOP A2 ROUTE
12 - 09:56:31.145 (Test) STOP
Multiple segments were found in the data file. Please select two time markers to delimit the segment you would like to process, then press OK to continue.
OK
Cancel

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

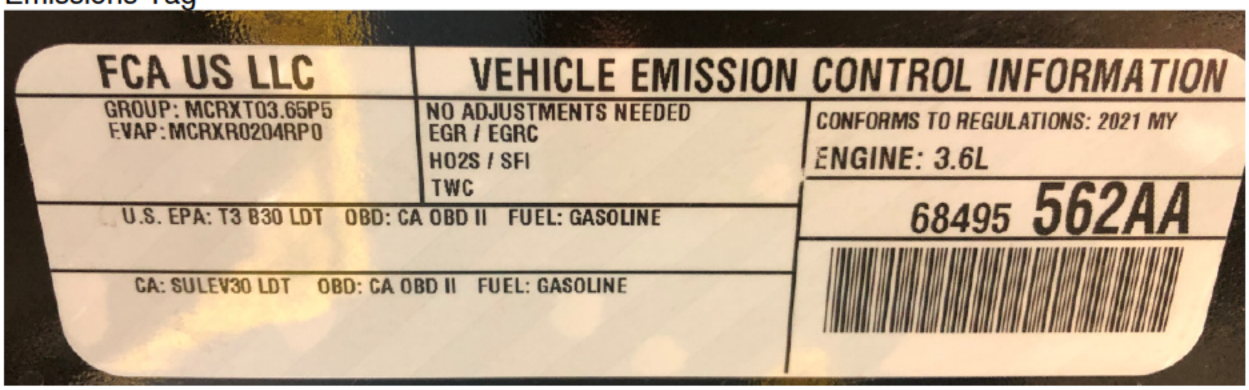
Test Vehicle



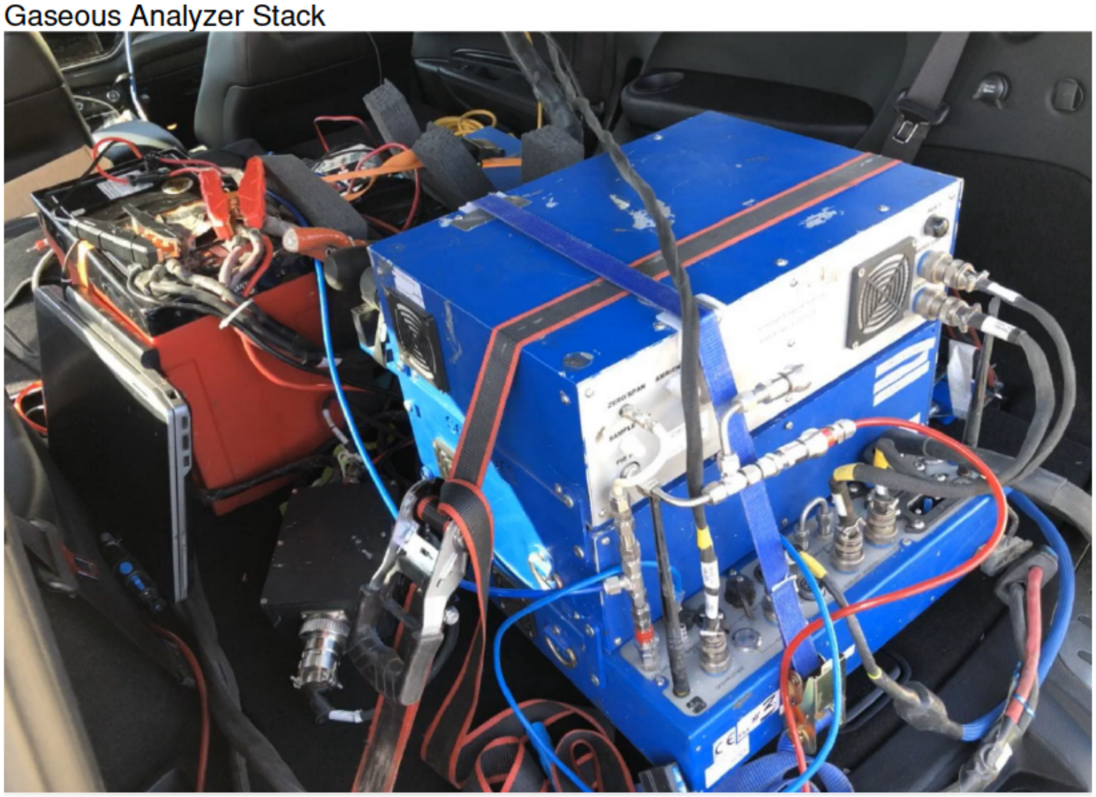
Exhaust Flowmeter and License Plate

Vehicle Identification Number

Emissions Tag

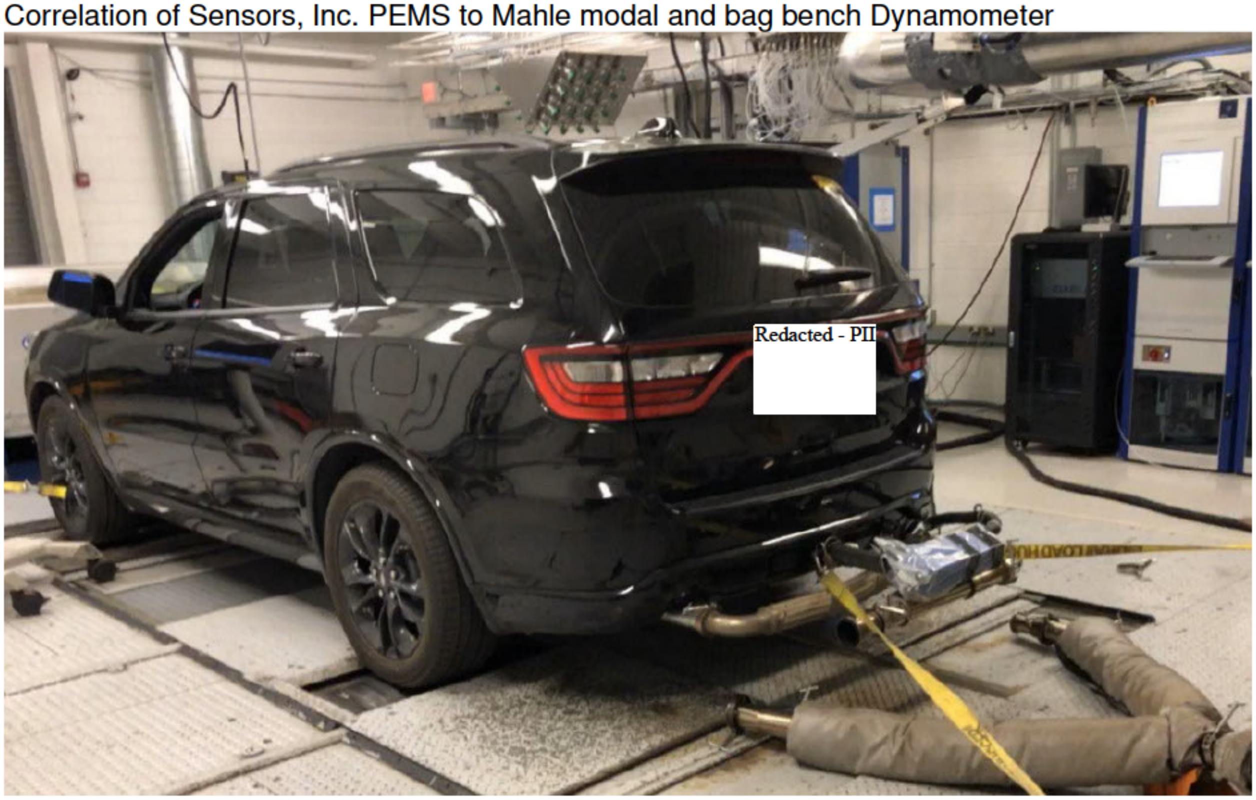


Gaseous Analyzer Stack



FCA Vehicle Tag

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



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.

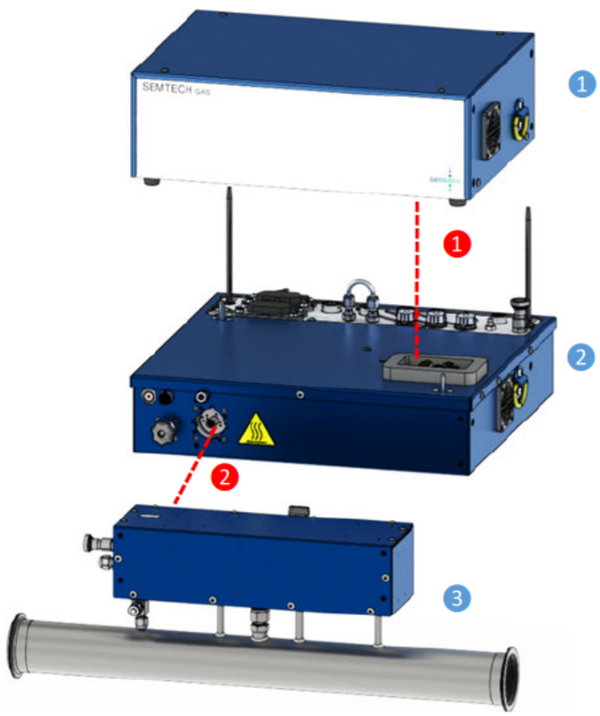
SEMTECH LDV: Analytical Methods

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** (**E**xhaust **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

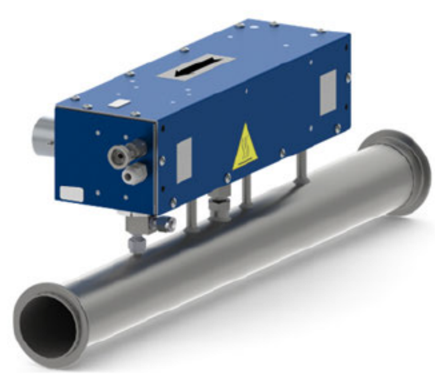
Linearity	Accuracy	Precision	Noise
$\mid x_{min}\, x(a_1 - 1) + a_0 \mid < 0.5\%$ of max, slope a_1 between .99 and 1.01, Std. Error of Estimates SEE < 1% of max, Coefficient of Determination $r^2 > .998$	< ± 2% of reading or < ± 0.3% of full scale, whichever is greater	< ± 1% of full scale	< ± 1% of 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) ≤ 1% of selected range Coefficient of Determination $r^2 \geq 0.998$
Accuracy	≤ ± 2% of reading or ≤ ± 0.3% of full scale of selected range, whichever is greater
Repeatability	≤ ± 1% of point or < ± 1% of selected range, whichever is greater
Precision	≤ 1% of selected range
Noise	≤ 2% of selected range
Zero Drift	≤ ± 1 % of full scale of selected range over 1 hours
Span Drift	≤ ± 2 % of full scale of selected range over 8 hours
Rise Time (T_{10-90})	≤ 2.5 seconds
System Response Time (T_{10-90})	≤ 10 sec with rise time ≤ 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	$\lvert x_{min} \times (a_1 - 1) + a_0 \rvert \leq$ 1% of max Slope a_1 between 0.99 and 1.01 Standard Error of Estimates (SEE) ≤ 1% of max. Coefficient of Determination $r^2 \geq 0.990$								
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

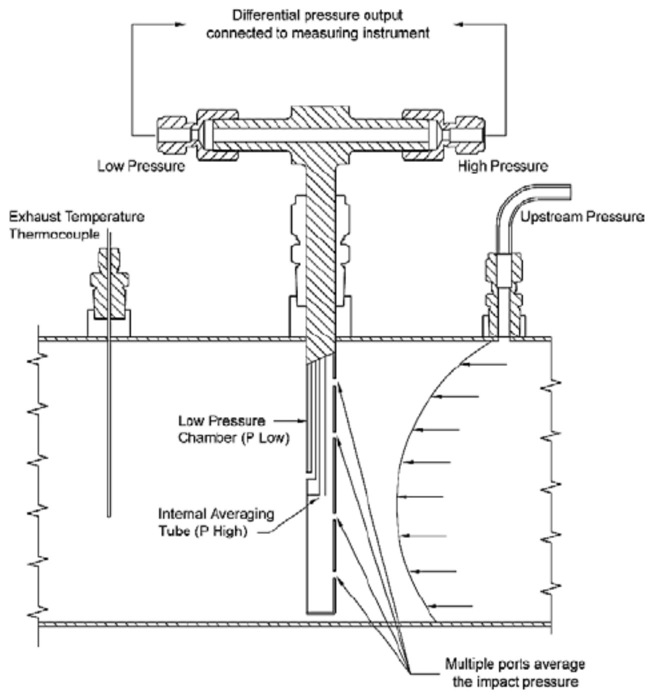
ρ = gas density

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.

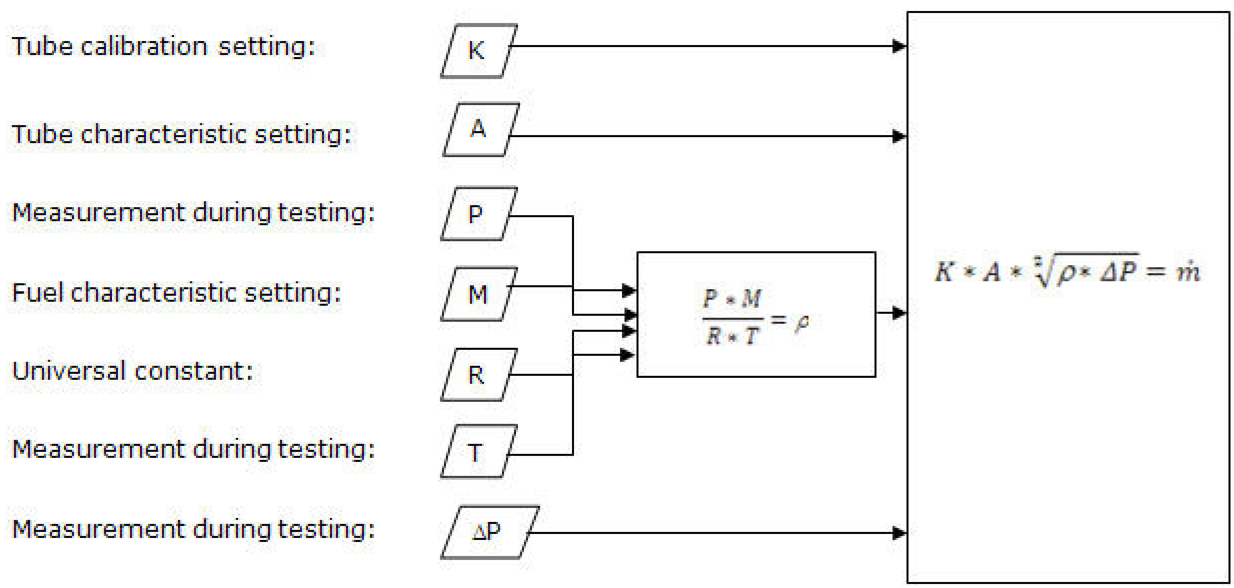
$$\rho = \frac{m}{V}$$

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.

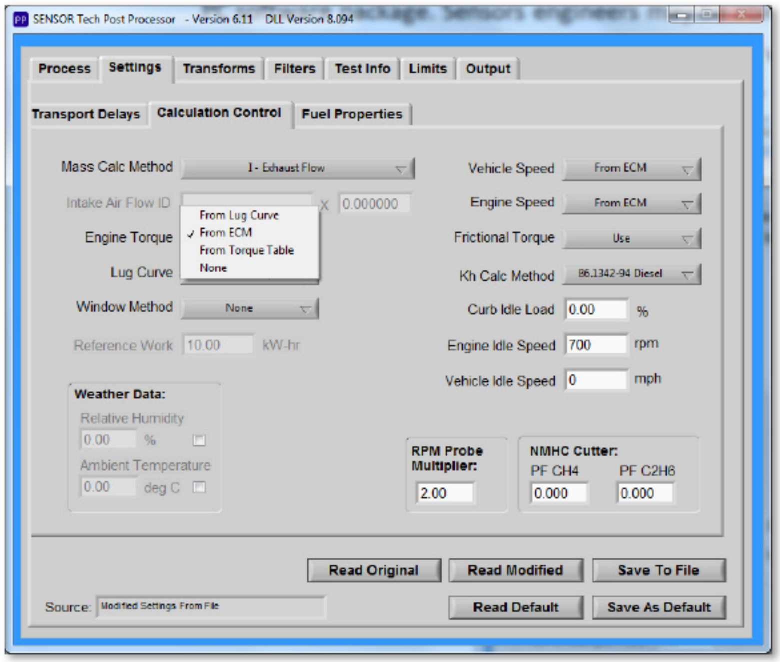


Figure 1: Post Processor engine torque source selection

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:

$$ECM_{DerivedTorque} = \%Load \times Torque_{max} \quad (1)$$

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.

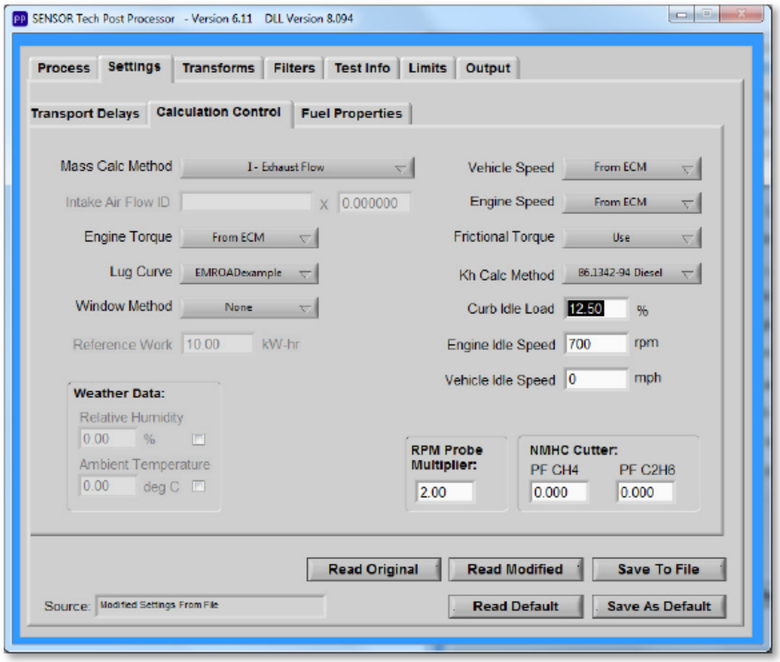


Figure 2: Post Processor Curb Idle Load correction

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.

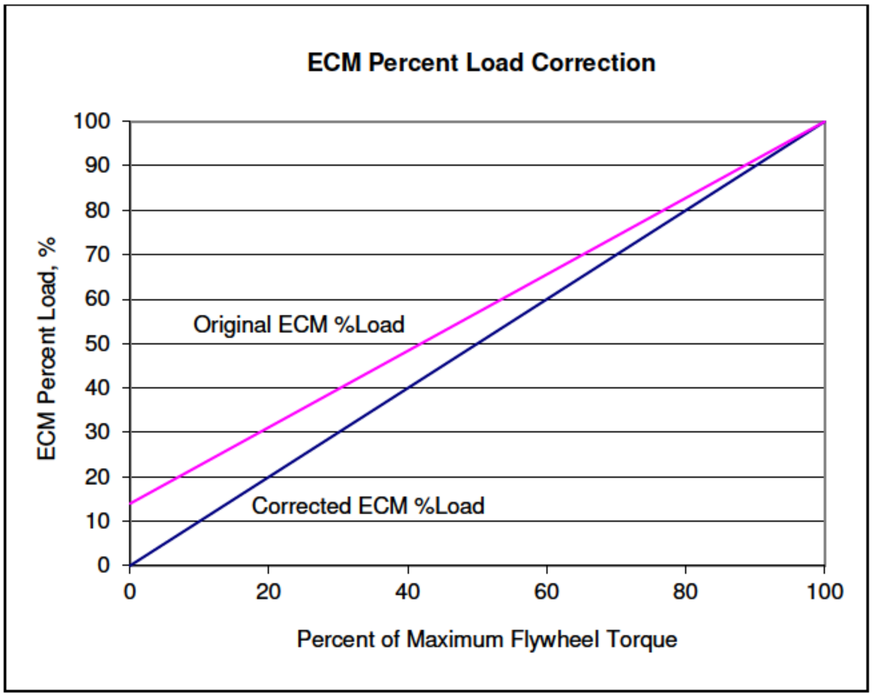


Figure 3: ECM percent load correction example

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:

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

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.

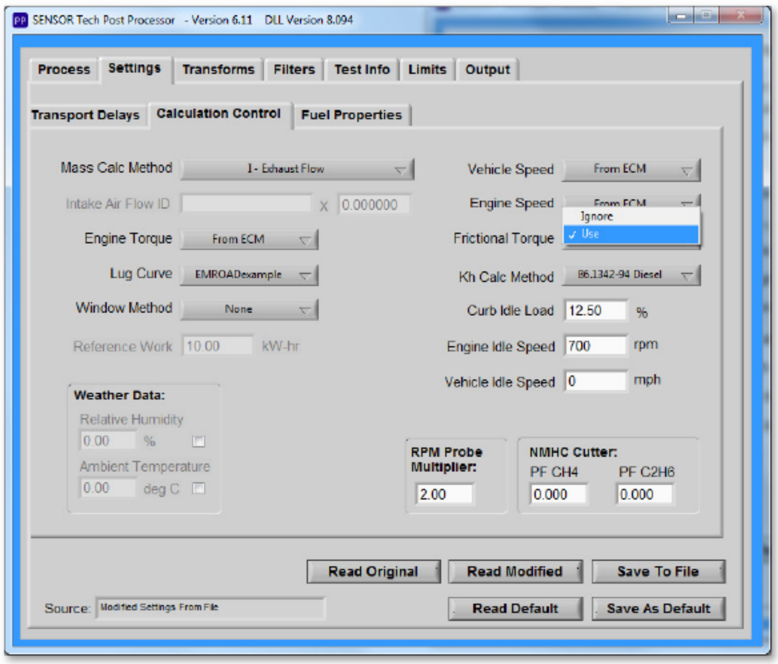


Figure 4: Post Processor setting to correct for frictional torque

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.

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