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 RAM and JEEP 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 JEEP 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 JEEP Summary Reports. This analytical methods report is located after the RAM and JEEP Summary Reports.

Test Information

Test Date	November 25,26, and 27th, 2019
Vehicle Owner	Fiat Chrysler
Test Location	Ann Arbor, MI
Type / Descr	No. V9DT15415
Make	RAM
Model	Laramie
Model Year	2019
VIN	Redacted – PII
Vehicle Emissions Tag	Redacted – PII
Engine Family	KCRXT05.75P1
License Plate	Redacted – PII Redacted – PII

Participants

Name	Affiliation / Title
Viorel Filip	Sensors, Inc./ TSS Supervisor
Chris Darby	Sensors, Inc./Senior Applications Engineer
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 RAM1500 Laramie (V9DT15415) whose on-road emissions testing was completed on November 25, 26, and 27th 2019, 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 JEEP 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 n DAT format, and csv file extensions for instantaneous mass and distance-specific results as mandated by paragraph 59.g of the Consent Decree.

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

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

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

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 JEEP Summary Reports. This analytical methods report is located after the RAM and JEEP Summary Reports.

Equipment Used

Component	SN	Verified 1065 Compliant	Expiration Date	Initials
SEMTECH-LDV Module				
SCS Asset 1111	K15127978	YES	12-11-19	BF
Gaseous Module	C15122161	YES	12-11-19	BF
FID Hydrocarbon Module	C16131218	YES	12-11-19	BF
EFM4 Exhaust Flowmeter	B15121215	YES	01-06-20	CE
FID Fuel bottle LOT: 70001801204	CK1047900	YES	02-01-21	BF
Weather Probe RH Sensor VAISALA	H2720004	YES	04-02-20	MC
GPS by Garmin	1A44269958	-	-	JE
Vehicle Interface	D16131267	-	-	JE

Calibration Gases Used

Bottle	SN	Listed Concentrations	Expiration Date	Initials
Quad Span Cylinder: CO2, CO, NO, Propane LOT_700019024GK	FF62631	15.7 %, CO2, 4536 ppm CO, 1013 ppm NO, 258 ppm C3H8	01-29-22	BF
Quad Span Cylinder: CO2, CO, NO, Propane	X04NI87T15AC033	7.028% CO2, 5.020% CO, 2076 ppm C3H8	01-24-27	BF
NO2 Span Cylinder LOT 70001734060	EA0004949	244 ppm NO2	12-06-19	BF
Zero Nitrogen Cylinder LOT_700019298F2 Praxair 200002298242	FF55357	100% N2	11-08-22	BF

Gaseous Emission Results

A. On-Road Test Strategy

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

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

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

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

The test vehicle was cold-soaked at a parking lot approximately 0.9 miles from the original starting point. So, overnight parking for the RAM added 0.9 miles to cold starts on route B and route C. Each test day had one cold start and four hot starts. The added hot start routes provided sufficient data to determine if outliers existed, in which case additional testing could be performed upon request.

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

Wide open throttle during Route C segments accounted for the majority of the carbon monoxide emissions.

During Test 2, commercial gasoline was purchased between the third and fourth routes (between route A1 and route C2). Recording was paused during this time.

Test Records

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

No.	File Name	Duration (seconds)	Comment
1	RAM_20191127_ABCBC_T1_rev1.csv	na	Test_1 Datafile
	pp-RAM_20191127_ABCBC_M1-M9_1ALL_rev1.csv	8,489	Pp Test_1 results
	pp-RAM_20191127_ABCBC_M2-M3_1A_rev1.csv	960	pp Route 1A cold start
	pp-RAM_20191127_ABCBC_M4-M5_1B1_rev1.csv	1,552	pp Route 1B1 (first)
	pp-RAM_20191127_ABCBC_M5-M6_1C1_rev1.csv	2,272	pp Route 1C1 (first)
	pp-RAM_20191127_ABCBC_M6-M7_1B2_rev1.csv	1,426	pp Route 1B2 (second)
	pp-RAM_20191127_ABCBC_M7-M8_1C2_rev1.csv	2,279	pp Route 1C2 (second)
2	RAM_20191126_BCACA_T2_rev1.csv	na	Test_2 Datafile
	pp-RAM_20191126_BCACA_M1-M12_2ALL_rev1.csv	8,174	pp Test_2 results
	pp-RAM_20191126_BCACA_M2-M3_2B_rev1.csv	1,517	pp Route 2B cold start
	pp-RAM_20191126_BCACA_M4-M5_2C1_rev1.csv	2,288	pp Route 2C1 (first)
	pp-RAM_20191126_BCACA_M6_M7_2A1_rev1.csv	1,104	pp Route 2A1 (first)
	pp-RAM_20191126_BCACA_M8-M9_2C2_rev1.csv	2,137	pp Route 2C2 (second)
	pp-RAM_20191126_BCACA_M10_M11_2A2_rev1.csv	1,128	pp Route 2A2 (second)
3	RAM_20191125_CABBA_T3_rev1.csv	na	Test_3 Datafile
	pp-RAM_20191125_CABBA_M1-M12_3ALL_rev1.csv	6,694	pp Test_3 results
	pp-RAM_20191125_CABBA_M2-M3_3C_rev1.csv	2,237	pp Route 3C cold start
	pp-RAM_20191125_CABBA_M4-M5_3A1_rev1.csv	831	pp Route 3A1 (first)
	pp-RAM_20191125_CABBA_M6_M7_3B1_rev1.csv	1,314	pp Route 3B1 (first)
	pp-RAM_20191125_CABBA_M8-M9_3B2_rev1.csv	1,392	pp Route 3B2 (second)
	pp-RAM_20191125_CABBA_M10_M11_3A2_rev1.csv	920	pp Route 3A2 (second)

Parsed Report Files

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

RAM_ Redacted – PII _MY19_ABCBC_1ALL_20191127_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1ALL_20191127_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1ALL_20191127_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_ABCBC_1A_20191127_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1A_20191127_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1A_20191127_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_ABCBC_1B1_20191127_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1B1_20191127_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1B1_20191127_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_ABCBC_1B2_20191127_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1B2_20191127_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1B2_20191127_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_ABCBC_1C1_20191127_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1C1_20191127_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1C1_20191127_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_ABCBC_1C2_20191127_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1C2_20191127_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_ABCBC_1C2_20191127_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_BCACA_2A1_20191126_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2A1_20191126_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2A1_20191126_Load_Speed_rev1.DAT
RAM_ Redacted – PII 0_MY19_BCACA_2A2_20191126_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2A2_20191126_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2A2_20191126_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_BCACA_2ALL_20191126_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2ALL_20191126_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2ALL_20191126_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_BCACA_2B_20191126_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2B_20191126_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2B_20191126_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_BCACA_2C1_20191126_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2C1_20191126_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2C1_20191126_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_BCACA_2C2_20191126_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_BCACA_2C2_20191126_Gram-sec_rev1.csv
RAM_Re Redacted – PII _MY19_BCACA_2C2_20191126_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_CABBA_3A1_20191125_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3A1_20191125_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3A1_20191125_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_CABBA_3A2_20191125_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3A2_20191125_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3A2_20191125_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_CABBA_3ALL_20191125_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3ALL_20191125_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3ALL_20191125_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_CABBA_3B1_20191125_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3B1_20191125_Gram-sec_rev1.csv
RAM_Red Redacted – PII Red_MY19_CABBA_3B1_20191125_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_CABBA_3B2_20191125_Gram-mile_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3B2_20191125_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3B2_20191125_Load_Speed_rev1.DAT
RAM_ Redacted – PII _MY19_CABBA_3C_20191125_Gram-mile_rev1.csv
RAM_ Redacted – PII Red_MY19_CABBA_3C_20191125_Gram-sec_rev1.csv
RAM_ Redacted – PII _MY19_CABBA_3C_20191125_Load_Speed_rev1.DAT

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.

Test 1

		COLD 1A	HOT 1B1	HOT 1C1	HOT 1B2	HOT 1C2	Total	Average
		Route A	Route B	Route C	Route B	Route C		
Distance	mi	7.63	10.78	30.47	10.78	30.48	90.13	
Duration	sec	960	1,552	2,272	1,426	2,279	8,489	
Fuel Economy	mpg	18.84	19.96	19.08	20.20	19.20		19.33
CO2	g	3,670	4,914	14,259	4,867	13,885	41,596	
CO	g	6.040	1.389	186.302	1.488	366.213	561.432	
kNOx	g	0.270	0.472	2.139	0.520	1.621	5.022	
THC	g	0.373	0.049	0.655	0.022	0.965	2.064	
NMCH	g	0.366	0.048	0.642	0.021	0.945	2.022	
CO2	g/mi	481.26	456.02	467.95	451.48	455.54		461.49
CO	g/mi	0.792	0.129	6.114	0.138	12.014		6.229
kNOx	g/mi	0.035	0.044	0.070	0.048	0.053		0.056
THC	g/mi	0.049	0.005	0.022	0.002	0.032		0.023
NMHC	g/mi	0.048	0.004	0.021	0.002	0.031		0.022
Ambient Temp	DegC	12.0	12.9	11.1	10.4	10.3		11.1
Ambient Press	mbar	962.4	964.4	962.7	966.1	964.1		963.9
Relative Humid.	%	87.7	77.4	70.0	61.4	60.6		70.9
Absol. Humidity	grains	56.5	52.4	42.3	35.3	34.4		43.3
Avg. Kh Factor		0.93	0.91	0.86	0.83	0.83		0.87

Test 2

		COLD 2B	HOT 2C1	HOT 2A1	HOT 2C2	HOT 2A2	Total	Average
		Route B	Route C	Route A	Route C	Route A		
Distance	mi	11.61	30.50	7.69	30.52	7.66	87.98	
Duration	sec	1,517	2,288	1,104	2,137	1,128	8,174	
Fuel Economy	mpg	18.10	20.11	22.06	20.50	21.23		20.20
CO2	g	5,823	13,480	3,175	13,058	3,282	38,818	
CO	g	11.847	209.055	0.767	304.928	0.809	527.406	
kNOx	g	0.462	1.213	0.323	1.561	0.502	4.061	
THC	g	0.588	0.781	0.025	0.947	0.029	2.37	
NMCH	g	0.576	0.766	0.025	0.928	0.028	2.323	
CO2	g/mi	501.391	441.937	412.817	427.923	428.643		441.22
CO	g/mi	1.020	6.854	0.100	9.992	0.106		5.995
kNOx	g/mi	0.040	0.040	0.042	0.051	0.066		0.046
THC	g/mi	0.051	0.026	0.003	0.031	0.004		0.027
NMHC	g/mi	0.050	0.025	0.003	0.030	0.004		0.026
Ambient Temp	DegC	12.2	12.4	12.1	11.8	11.3		11.8
Ambient Press	mbar	982.5	979.5	980.1	979.3	980.2		980.2
Relative Humid.	%	47.3	46.5	47.3	50.5	55.0		49.9
Absol. Humidity	grains	29.9	29.9	29.9	31.3	32.9		30.6
Avg. Kh Factor		0.81	0.81	0.81	0.82	0.82		0.81

During Test 3, the cold start on Route C accounted for 46% of the total distance, and 90.6% of hydrocarbons emissions, and 98.6% of carbon monoxide emissions.

Test 3

		COLD 3C	HOT 3A1	HOT 3B1	HOT 3B2	HOT 3A2	Total	Average
		Route C	Route A	Route B	Route B	Route A		
Distance	mi	31.323	7.649	10.764	10.759	7.646	68.141	
Duration	sec	2,237	831	1,314	1,392	920	6,694	
Fuel Economy	mpg	17.651	20.62	20.05	19.824	22.279		19.10
CO2	g	15,641	3,380	4,894	4,948	3,128	31,990	
CO	g	332.924	1.280	1.579	1.169	0.823	337.775	
kNOx	g	1.701	0.252	0.338	0.399	0.295	2.985	
THC	g	1.509	0.040	0.045	0.041	0.030	1.665	
NMCH	g	1.479	0.039	0.044	0.040	0.029	1.631	
CO2	g/mi	499.339	441.851	454.651	459.873	409.129		469.47
CO	g/mi	10.629	0.167	0.147	0.109	0.108		4.957
kNOx	g/mi	0.054	0.033	0.031	0.037	0.039		0.044
THC	g/mi	0.048	0.005	0.004	0.004	0.004		0.024
NMHC	g/mi	0.047	0.005	0.004	0.004	0.004		0.024
Ambient Temp	DegC	7.0	7.6	7.4	7.7	7.8		7.3
Ambient Press	mbar	973.9	975.0	977.3	977.4	975.2		975.4
Relative Humid.	%	83.0	79.2	80.1	78.3	77.2		80.8
Absol. Humidity	grains	37.5	37.3	36.9	36.8	36.7		37.1
Avg. Kh Factor		0.8	0.8	0.8	0.8	0.8		0.8

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			Hot	
		COLD 1A	HOT 2A1	HOT 2A2	HOT 3A1	HOT 3A2	Average	Std. Dev.
Distance	mi	7.63	7.69	7.66	7.65	7.65	7.66	0.02
Duration	sec	960	1,104	1,128	831	920	996	144
Fuel Econ.	mpg	18.84	22.06	21.23	20.62	22.28	21.55	0.77
CO2	g	3670	3175	3282	3380	3128	3241	112
CO	g	6.040	0.767	0.809	1.280	0.823	0.920	0.241
kNOx	g	0.270	0.323	0.502	0.252	0.295	0.343	0.110
THC	g	0.373	0.025	0.029	0.040	0.030	0.031	0.006
NMCH	g	0.366	0.025	0.028	0.039	0.029	0.030	0.006
CO2	g/mi	481.26	412.82	428.64	441.85	409.13	423.11	15.09
CO	g/mi	0.792	0.100	0.106	0.167	0.108	0.120	0.031
kNOx	g/mi	0.035	0.042	0.066	0.033	0.039	0.045	0.014
THC	g/mi	0.049	0.003	0.004	0.005	0.004	0.004	0.001
NMHC	g/mi	0.048	0.003	0.004	0.005	0.004	0.004	0.001
Ambient Temp	DegC	12.0	12.1	11.3	7.6	7.8	9.7	2.3
Ambient Press	mbar	962.4	980.1	980.2	975.0	975.2	977.6	2.9
Relative Humid.	%	87.7	47.3	55.0	79.2	77.2	64.7	15.9
Absol. Humidity	grains	56.5	29.9	32.9	37.3	36.7	34.2	3.5
Avg. Kh Factor		0.93	0.81	0.82	0.84	0.84	0.83	0.015

				Route B			Hot	
		COLD 2B	HOT 1B1	HOT 1B2	HOT 3B1	HOT 3B2	Average	Std. Dev.
Distance	mi	11.61	10.78	10.78	10.76	10.76	10.77	0.01
Duration	sec	1517	1552	1426	1314	1392	1421	99
Fuel Econ.	mpg	18.10	19.96	20.20	20.05	19.82	20.01	0.16
CO2	g	5823	4914	4867	4894	4948	4906	34
CO	g	11.847	1.389	1.488	1.579	1.169	1.406	0.176
kNOx	g	0.462	0.472	0.520	0.338	0.399	0.432	0.080
THC	g	0.588	0.049	0.022	0.045	0.041	0.039	0.012
NMCH	g	0.576	0.048	0.021	0.044	0.040	0.038	0.012
CO2	g/mi	501.39	456.02	451.48	454.65	459.87	455.51	3.48
CO	g/mi	1.020	0.129	0.138	0.147	0.109	0.131	0.016
kNOx	g/mi	0.040	0.044	0.048	0.031	0.037	0.040	0.008
THC	g/mi	0.051	0.005	0.002	0.004	0.004	0.004	0.001
NMHC	g/mi	0.050	0.004	0.002	0.004	0.004	0.004	0.001
Ambient Temp	DegC	12.2	12.9	10.4	7.4	7.7	9.6	2.6
Ambient Press	mbar	982.5	964.4	966.1	977.3	977.4	971.3	7.0
Relative Humid.	%	47.3	77.4	61.4	80.1	78.3	74.3	8.6
Absol. Humidity	grains	29.9	52.4	35.3	36.9	36.8	40.4	8.1
Avg. Kh Factor		0.81	0.91	0.83	0.84	0.84	0.86	0.035

				Route C			Hot	
		COLD 3C	**HOT 1C1**	**HOT 1C2**	**HOT 2C1**	**HOT 2C2**	**Average**	**Std. Dev.**
Distance	mi	31.32	30.47	30.48	30.50	30.52	30.49	0.02
Duration	sec	2,237	2,272	2,279	2,288	2,137	2,244	72
Fuel Econ.	mpg	17.65	19.08	19.20	20.11	20.50	19.72	0.69
CO2	g	15,641	14,259	13,885	13,480	13,058	13,671	518
CO	g	332.92	186.30	366.21	209.06	304.93	266.62	83.97
kNOx	g	1.701	2.139	1.621	1.213	1.561	1.634	0.382
THC	g	1.509	0.655	0.965	0.781	0.947	0.837	0.147
NMCH	g	1.479	0.642	0.945	0.766	0.928	0.820	0.144
CO2	g/mi	499.34	467.95	455.54	441.94	427.92	448.34	17.26
CO	g/mi	10.629	6.114	12.014	6.854	9.992	8.744	2.753
kNOx	g/mi	0.054	0.070	0.053	0.040	0.051	0.054	0.012
THC	g/mi	0.048	0.022	0.032	0.026	0.031	0.028	0.005
NMHC	g/mi	0.047	0.021	0.031	0.025	0.030	0.027	0.005
Ambient Temp	DegC	7.0	11.1	10.3	12.4	11.8	11.4	0.9
Ambient Press	mbar	973.9	962.7	964.1	979.5	979.3	971.4	9.2
Relative Humid.	%	83.0	70.0	60.6	46.5	50.5	56.9	10.5
Absol. Humidity	grains	37.5	42.3	34.4	29.9	31.3	34.5	5.6
Avg. Kh Factor		0.84	0.86	0.83	0.81	0.82	0.83	0.024

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.

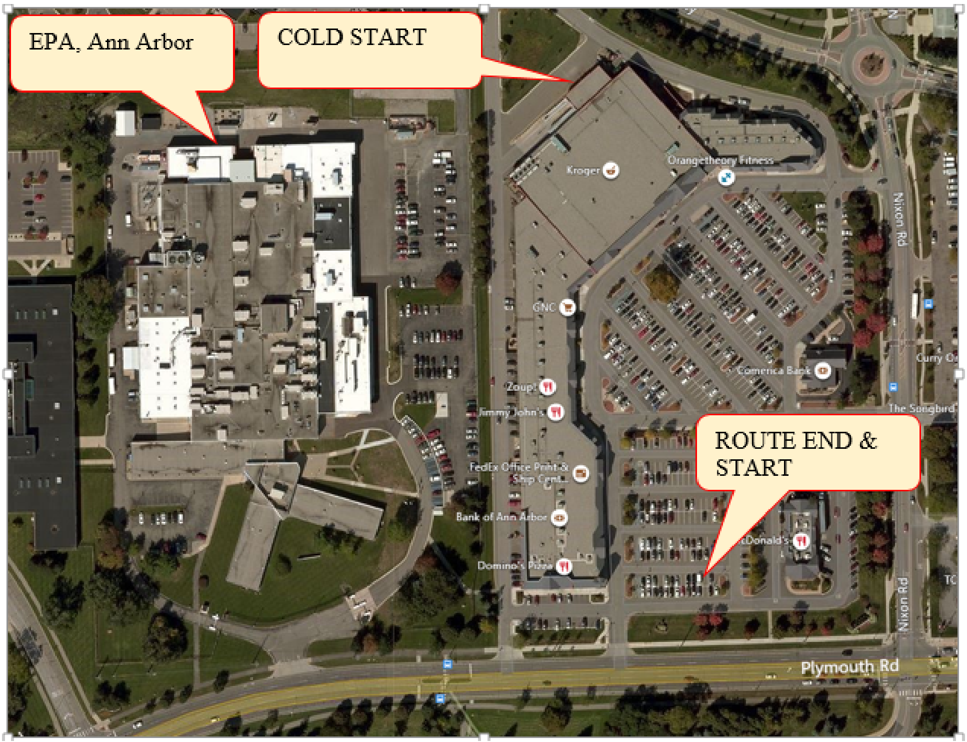
RAM1500 Vehicle Interface Parameters

Description	Parameter	Units
No. of DTCs	DTC_CNT	#
Fuel System A Status	FUEL_STAT_A	
Fuel System B Status	FUEL_STAT_B	
Load Percent	iENG_LOAD	%
Coolant Temp.	iCOOL_TEMP	degF
Short-Term Fuel Trim 1	ST_FUELTRIM_1	%
Long-Term Fuel Trim 1	LT_FUELTRIM_1	%
Short-Term Fuel Trim 2	ST_FUELTRIM_2	%
Long-Term Fuel Trim 1	LT_FUELTRIM_2	%
Manifold Pressure	iMAP	kPa
Engine RPM	iENG_SPEED	RPM
Vehicle Speed	iVEH_SPEED	mph
Spark Advance	SPARKADV	Deg
Intake Air Temp.	iMAN_TEMP	degF
Abs Throttle Postn	TP	%
O2 Sensor Location	O2_SENSOR_LOC	
Bank1 O2 Sensor-1 Volt	BK1_O2_SENSOR1_VOLT	V
Bank1 O2 Sensor-1 SHAFT	BK1_O2_SENSOR1_SHRFT	%
Bank1 O2 Sensor-2 Volt	BK1_O2_SENSOR2_VOLT	V
Bank1 O2 Sensor-2 SHAFT	BK1_O2_SENSOR2_SHRFT	%
Bank2 O2 Sensor-1 Volt	BK2_O2_SENSOR1_VOLT	V
Bank2 O2 Sensor-1 SHAFT	BK2_O2_SENSOR1_SHRFT	%
Bank2 O2 Sensor-2 Volt	BK2_O2_SENSOR2_VOLT	V
Bank2 O2 Sensor-2 SHAFT	BK2_O2_SENSOR2_SHRFT	%
OBD REQUIREMENT LEVEL	OBD_REQ_LEVEL	
Time Since Start	RUNTM	S
MIL Dist. Traveled	MIL_DIST	km
Cmd. Evap. Purge	EVAP_PCT	%
Fuel Level Input	FLI	%
No. of Warm Ups	WARM_UPS	
Distance Cleared	CLR_DIST	km
Evap. System VP	EVAP_VP1	Pa
Baro. Pressure	BARO	kPa
Catalyst Temp. 1-1	CATEMP11	degC
Catalyst Temp. 2-1	CATEMP21	degC
Driving Cycle Status	DRV_CYC_STAT	
Control Voltage	VPWR	V
Abs. Load Value	LOAD_ABS	%
F/A Equiv. Ratio	LAMBDA	
Rel. Throttle Postn	TP_R	%
Amb. Air Temp.	AAT	degC
Throttle Postn B	TP_B	%
Accel. Postn D	APP_D	%
Accel. Postn E	APP_E	%
Throttle Act. Ctrl.	TAC_PCT	%
Current Fuel Type	FUEL_TYPE	
Battery Pack Charge	BAT_PWR	%
Vehicle Speed	imVEH_SPEED	km/h

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

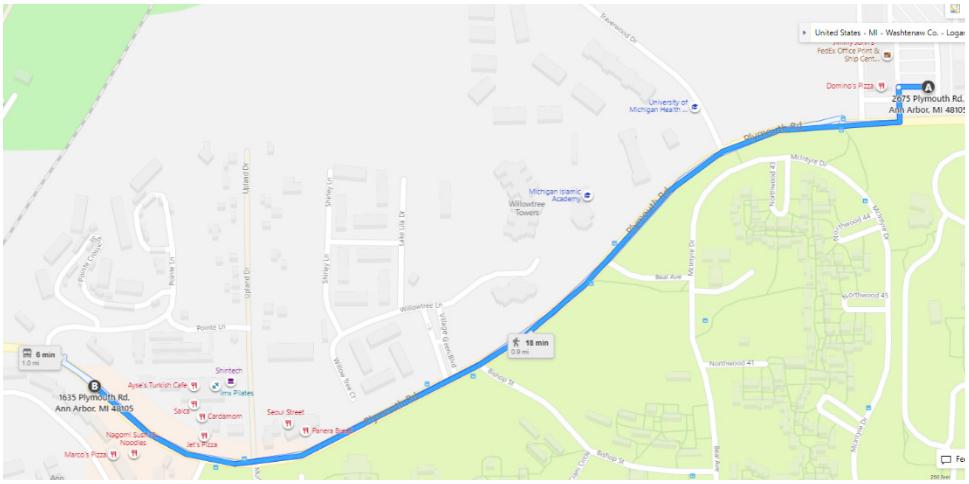
Route Description

The picture below indicates the planned start and termination of daily testing.

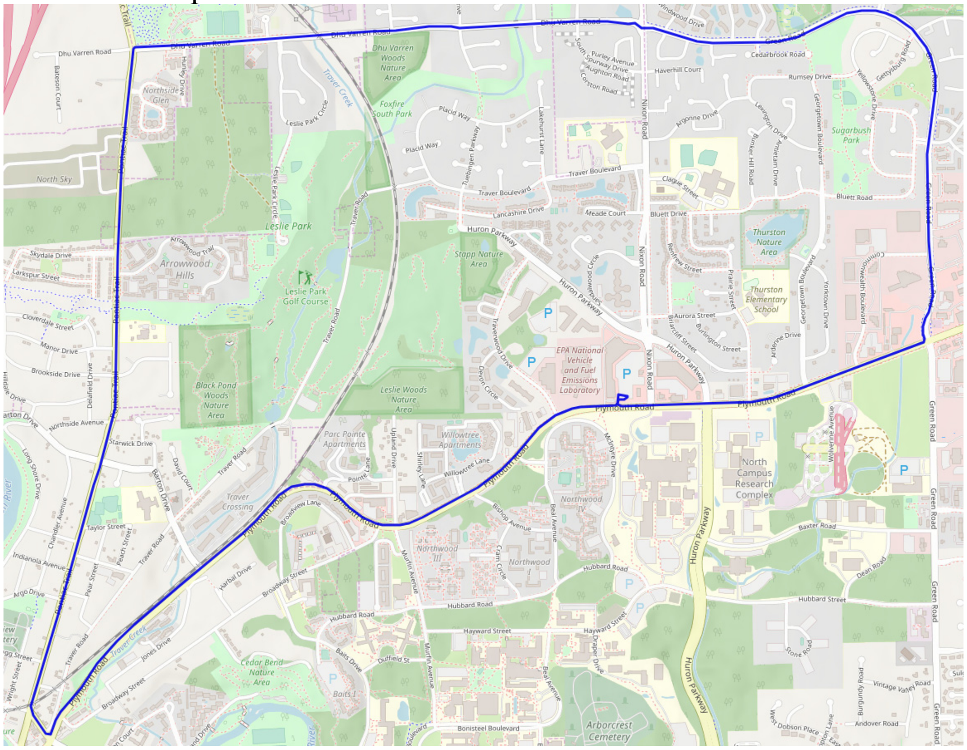


While based upon approved routes, the RAM 1500 Laramie was parked overnight for cold start testing approximately 0.9 miles distant from the suggested starting point which would add an equivalent distance and some time to routes B and C.

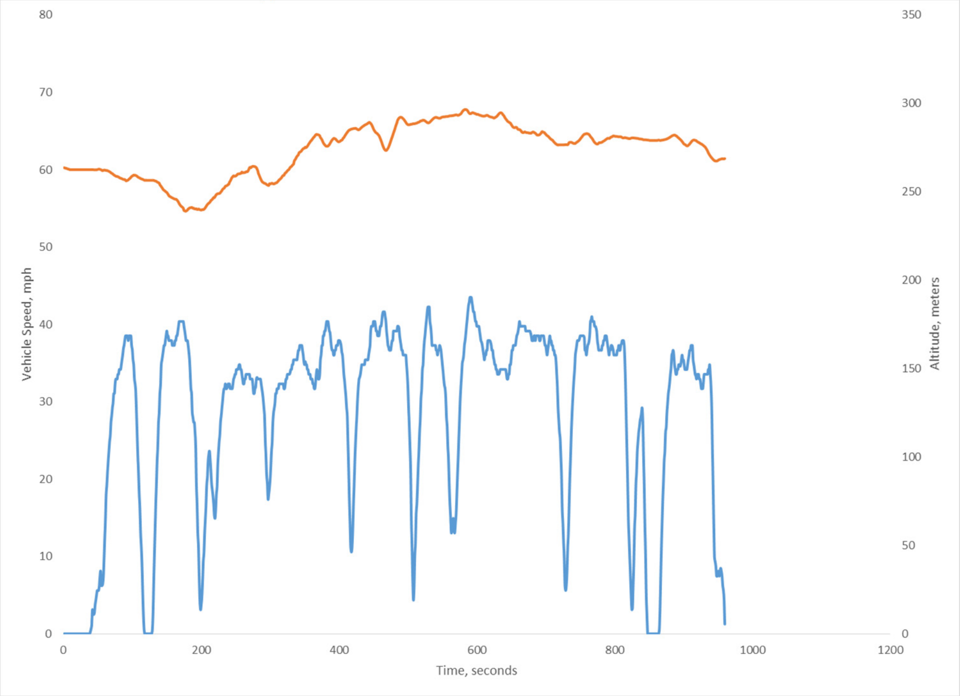
Figure 1 - Routes A, B and C Cold Start at 1635 Plymouth Rd, Ann Arbor.
Start and Stop for all hot routes at 2675 Plymouth Rd. Ann Arbor



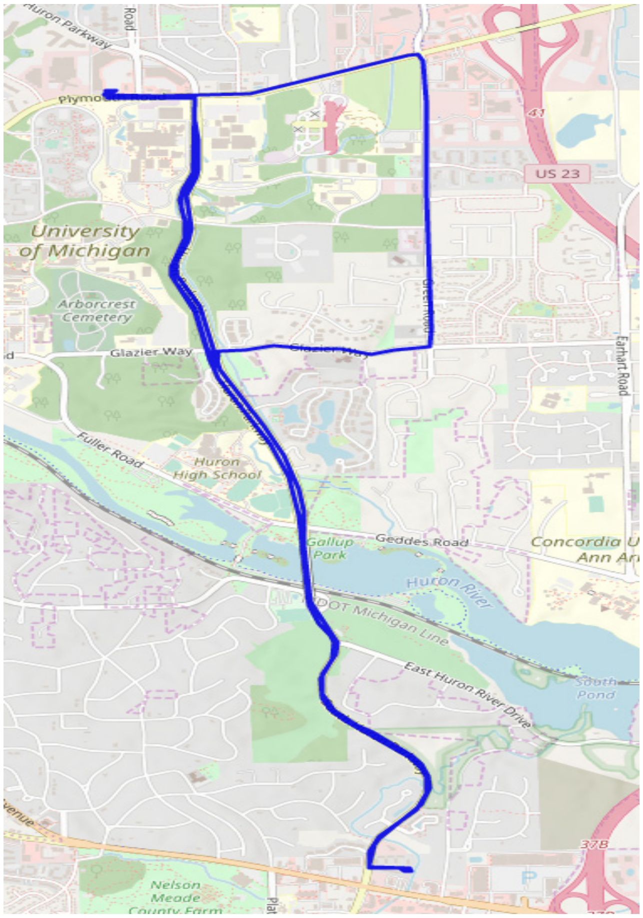
Route A -- Map



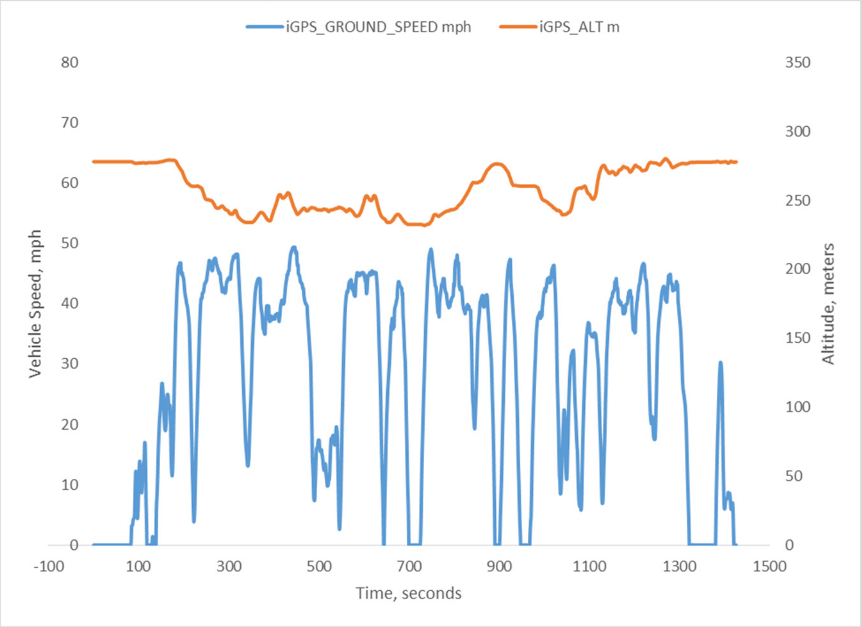
Route A – Vehicle Speed and Altitude Profile:



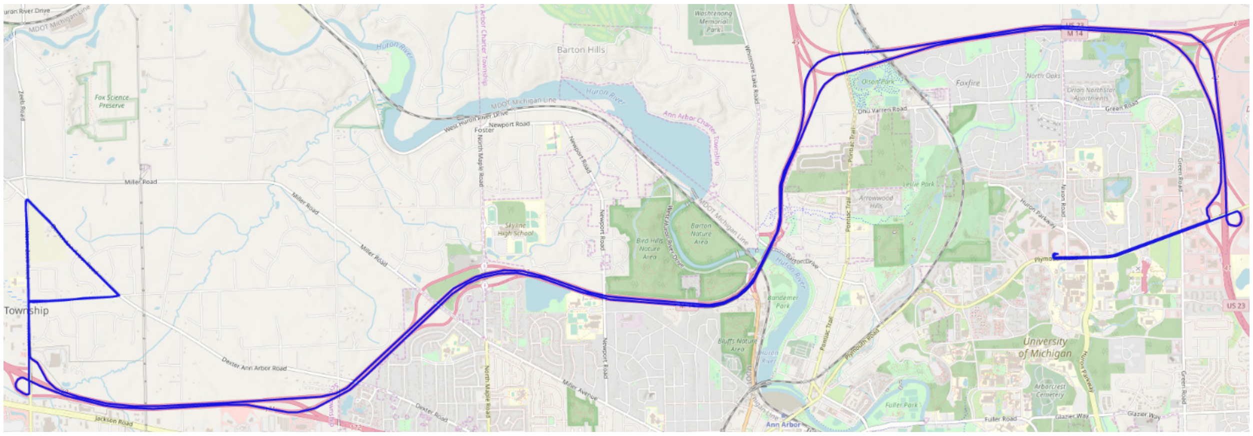
Route B – Map



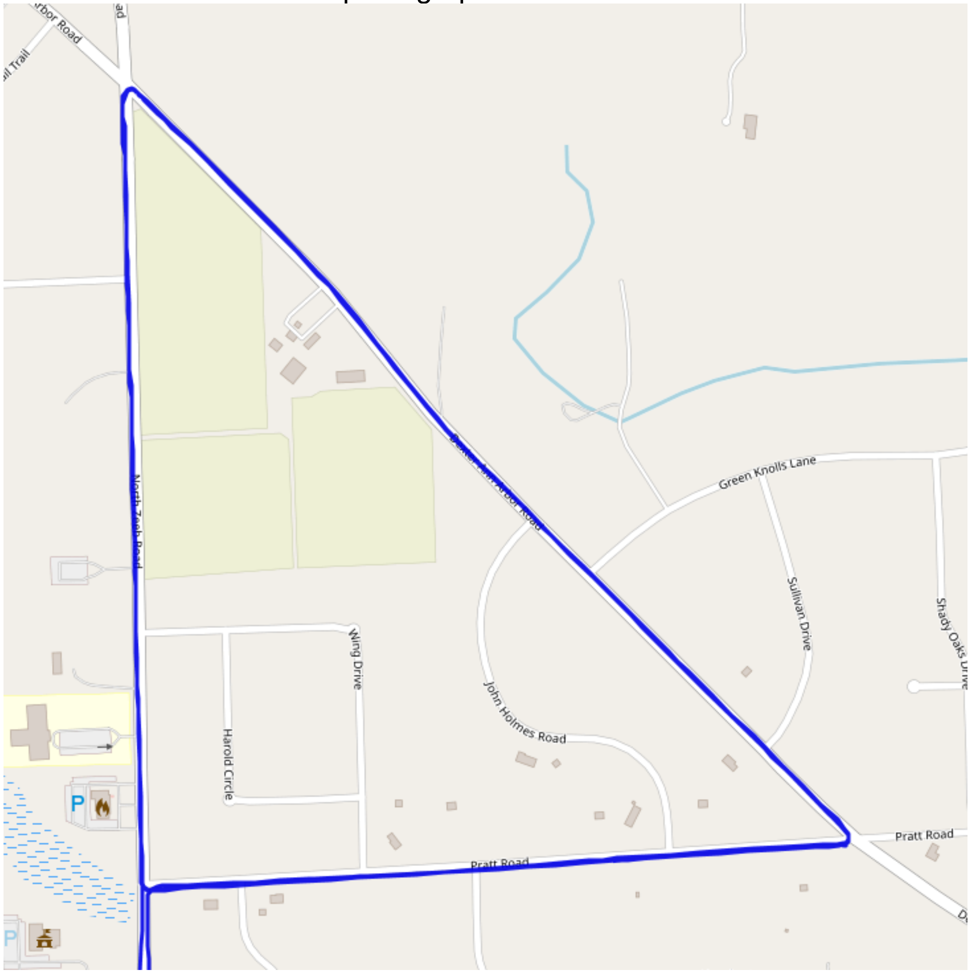
Route B – Vehicle Speed and Altitude



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

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.

Correlation Summary

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

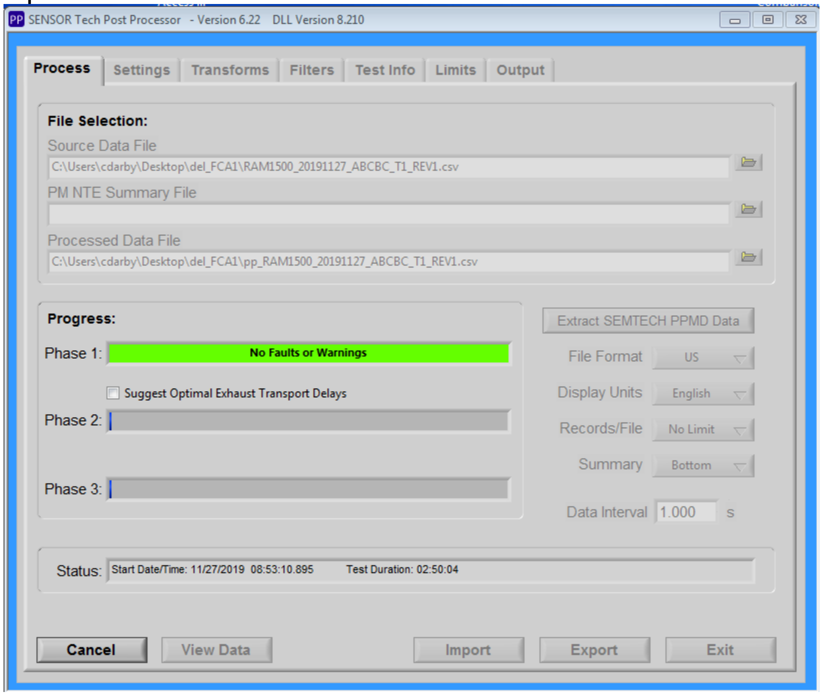
	PEMS (SEMTECH LDV)			Dynamometer Bag Bench		
Overall Emissions:	**grams**	**g/mi**	**g/km**	**grams**	**g/mi**	**g/km**
CO2	5150	466.04	291.28	5002	452.67	282.92
CO	6.3320	0.5730	0.3581	5.5990	0.5067	0.3167
kNOx	0.4790	0.0433	0.0271	0.4410	0.0399	0.0249
THC^{A}	0.8796	0.0796	0.0498	0.8990	0.0814	0.0508

	Correlation versus EU Tolerance			Difference versus Dynmometer		
Overall Emissions:	**Difference**	**Tolerance**	**Percent**	**% Diff**	**% Tolerance**	**Abs diff (g/km)**
CO2	8.3568	10	83.6%	3.0%	10%	8.357
CO	0.0415	0.15	27.6%	13.1%	15%	0.041
kNOx	0.0021	0.015	14.3%	8.6%	15%	0.002
THC^{A}	-0.0011	0.015	-7.3%	-2.2%	15%	0.001

Note: A) The PEMS hydrocarbon analyzer was railed for twelve seconds during the cold start segment of FTP75 Phase One. This report increased the original value for hydrocarbon analyzer emissions by a factor of four.

Appendix 1C: Post-processing raw data files.

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



Source Data File: C:\Users\cdarby\Desktop\del_FCA1\RAM1500_20191127_ABCBC_T1_REV1.csv

PM NTE Summary File:

Processed Data File: C:\Users\cdarby\Desktop\del_FCA1\pp_RAM1500_20191127_ABCBC_T1_REV1.csv

Phase 1: No Faults or Warnings

☐ Suggest Optimal Exhaust Transport Delays

Phase 2:

Phase 3:

File Format: US

Display Units: English

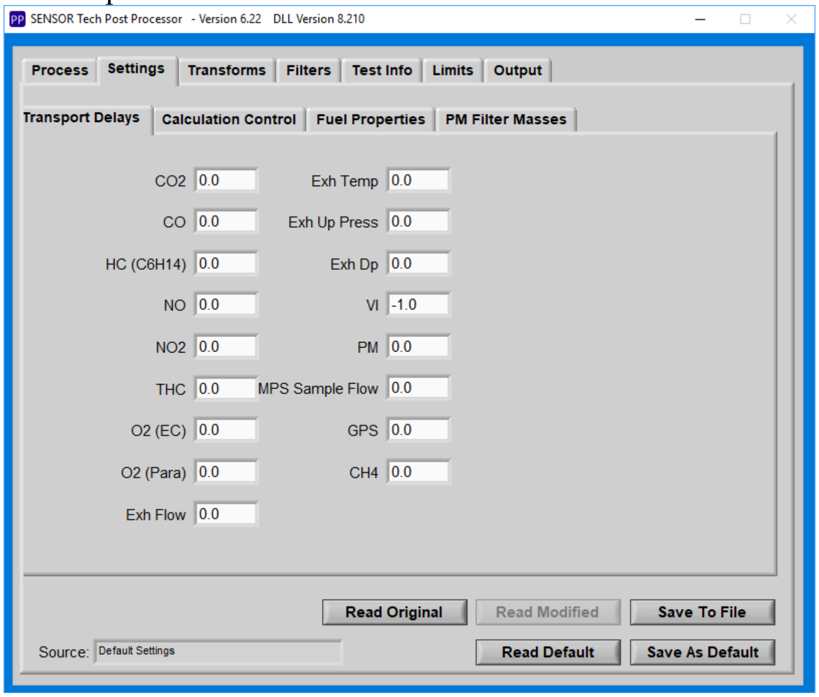
Records/File: No Limit

Summary: Bottom

Data Interval: 1.000 s

Status: Start Date/Time: 11/27/2019 08:53:10.895 Test Duration: 02:50:04

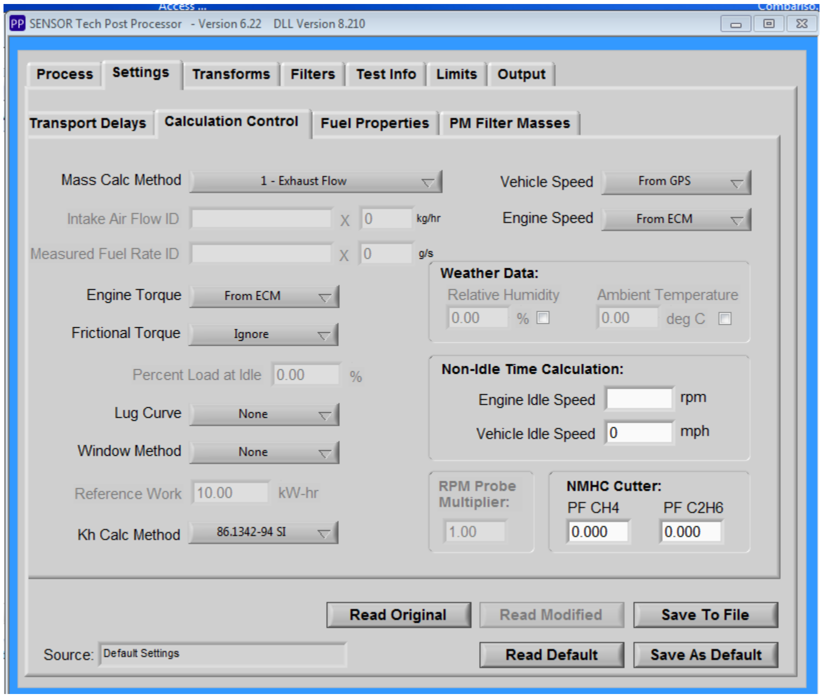
Select options of interest:



CO2 0.0
CO 0.0
HC (C6H14) 0.0
NO 0.0
NO2 0.0
THC 0.0
O2 (EC) 0.0
O2 (Para) 0.0
Exh Flow 0.0
Exh Temp 0.0
Exh Up Press 0.0
Exh Dp 0.0
VI -1.0
PM 0.0
MPS Sample Flow 0.0
GPS 0.0
CH4 0.0

Source: Default Settings

Calculation Control Tab:



Mass Calc Method: 1 - Exhaust Flow
Intake Air Flow ID: X 0 kg/hr
Measured Fuel Rate ID: X 0 g/s
Engine Torque: From ECM
Frictional Torque: Ignore
Percent Load at Idle: 0.00 %
Lug Curve: None
Window Method: None
Reference Work: 10.00 kW-hr
Kh Calc Method: 86.1342-94 SI
Vehicle Speed: From GPS
Engine Speed: From ECM

Weather Data:
Relative Humidity: 0.00 % ☐
Ambient Temperature: 0.00 deg C ☐

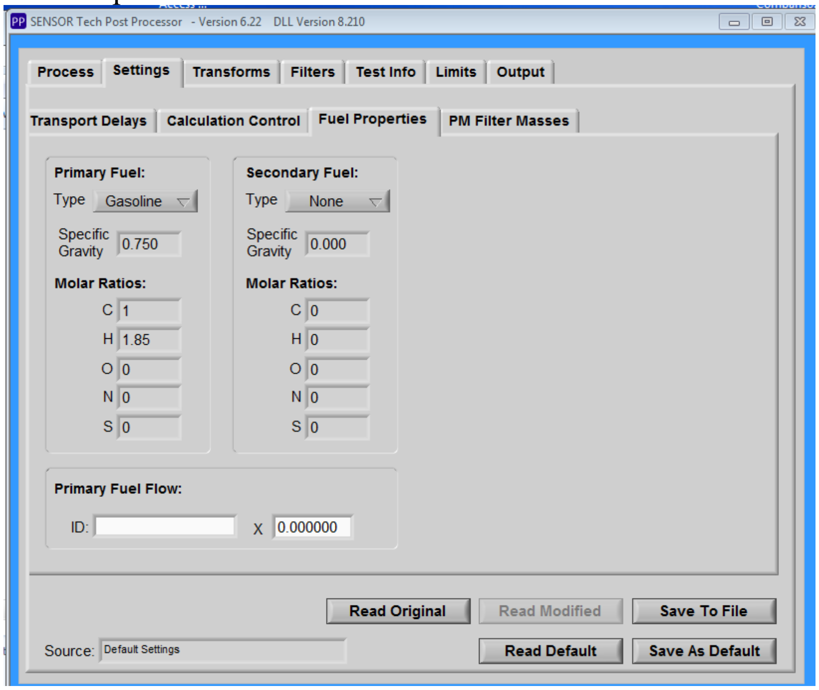
Non-Idle Time Calculation:
Engine Idle Speed: rpm
Vehicle Idle Speed: 0 mph

RPM Probe Multiplier: 1.00

NMHC Cutter:
PF CH4: 0.000
PF C2H6: 0.000

Source: Default Settings

Fuel Properties Tab:

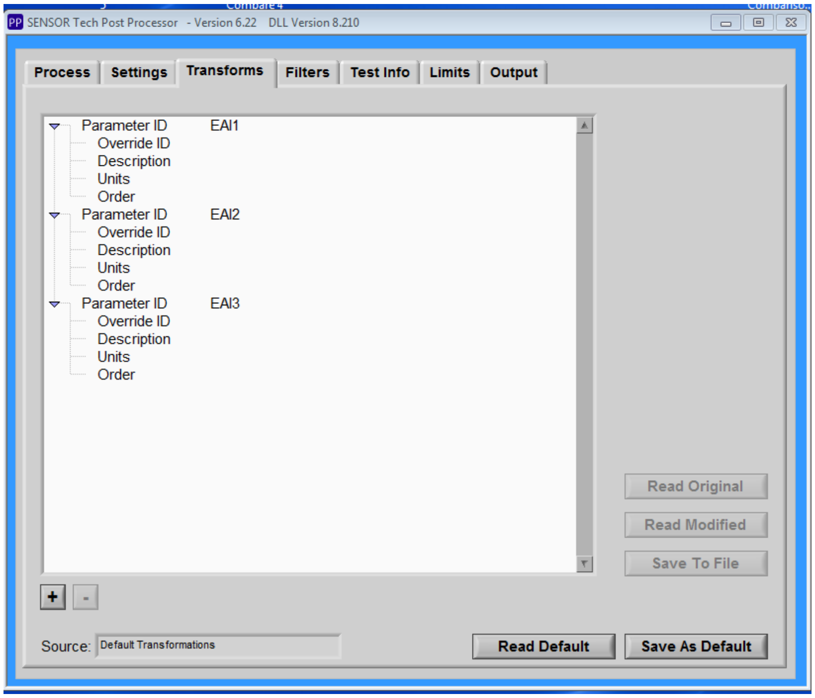


	Primary Fuel:	**Secondary Fuel:**
Type	Gasoline	None
Specific Gravity	0.750	0.000
Molar Ratios:		
C	1	0
H	1.85	0
O	0	0
N	0	0
S	0	0

Primary Fuel Flow:
ID: X 0.000000

Source: Default Settings

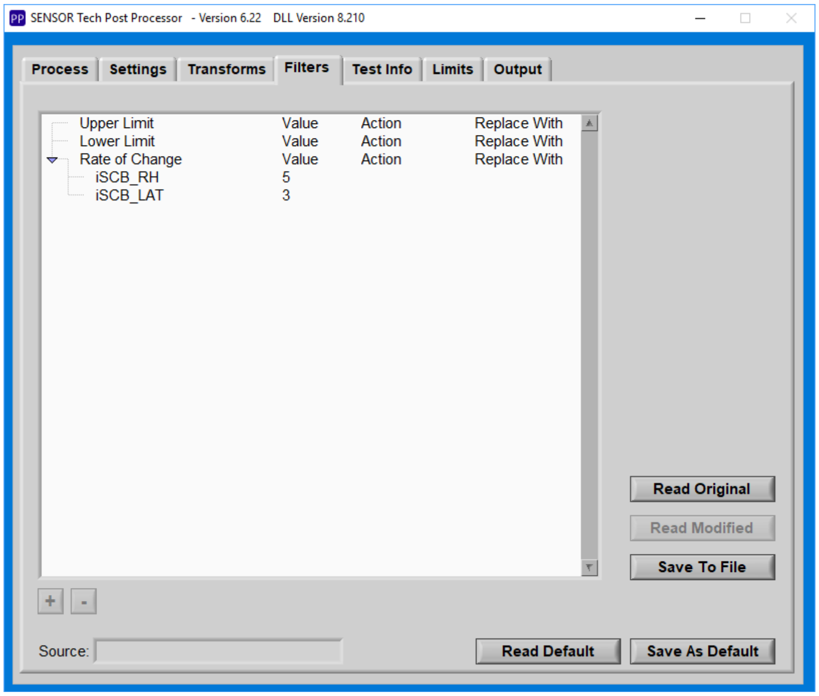
Transforms are not used when post-processing RAM data files (unlike JEEP data files which are corrected for two parameters: ENG_FUEL_RATE, and EXH_RATE).



```
Parameter ID      EAI1
    Override ID
    Description
    Units
    Order
Parameter ID      EAI2
    Override ID
    Description
    Units
    Order
Parameter ID      EAI3
    Override ID
    Description
    Units
    Order
```

Source: Default Transformations

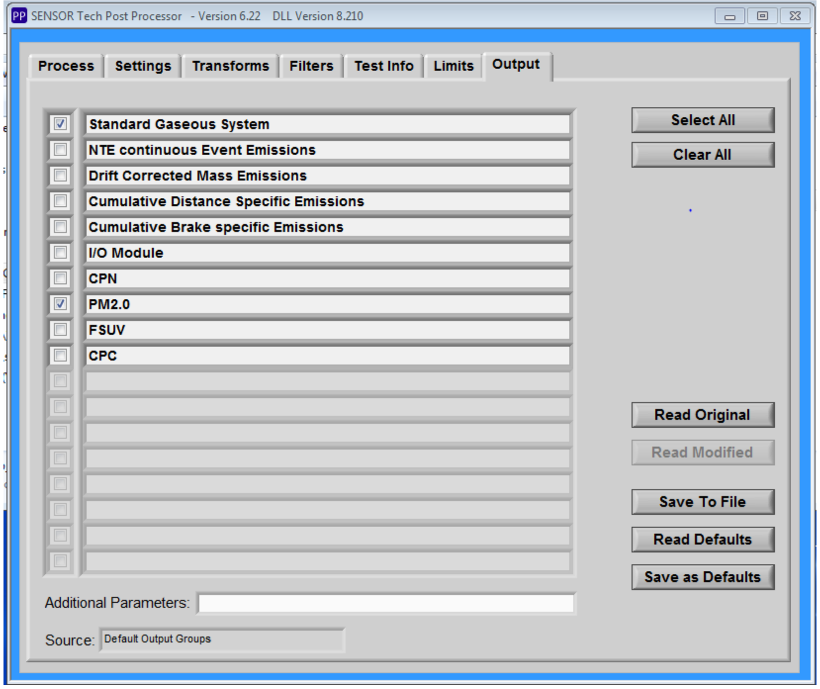
Parameter Filters Tab:



```
Upper Limit           Value    Action    Replace With
Lower Limit           Value    Action    Replace With
Rate of Change        Value    Action    Replace With
    iSCB_RH           5
    iSCB_LAT          3
```

Source:

Output Tab:

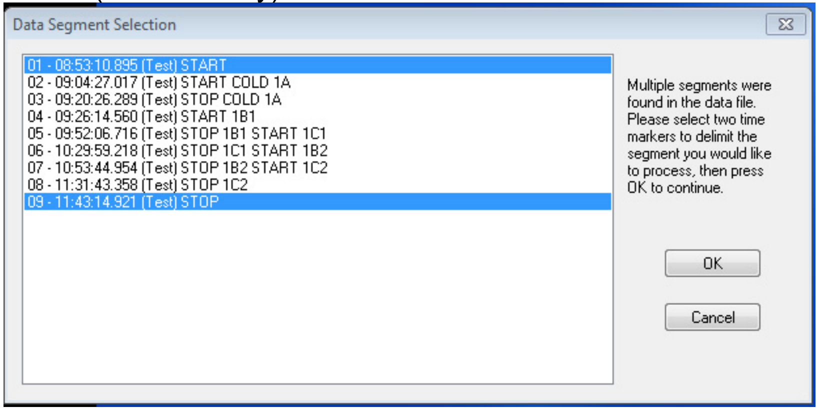


☑ Standard Gaseous System
☐ NTE continuous Event Emissions
☐ Drift Corrected Mass Emissions
☐ Cumulative Distance Specific Emissions
☐ Cumulative Brake specific Emissions
☐ I/O Module
☐ CPN
☑ PM2.0
☐ FSUV
☐ CPC

Additional Parameters:

Source: Default Output Groups

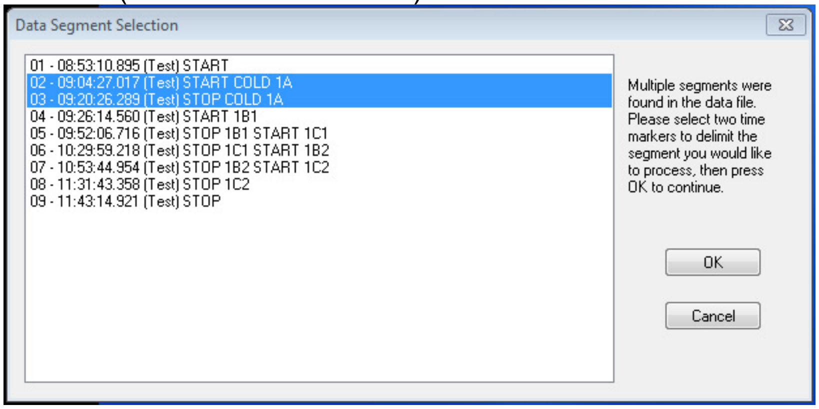
Use the following User Marks when post-processing raw or converted data files:
Test 1 (in its Entirety):



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

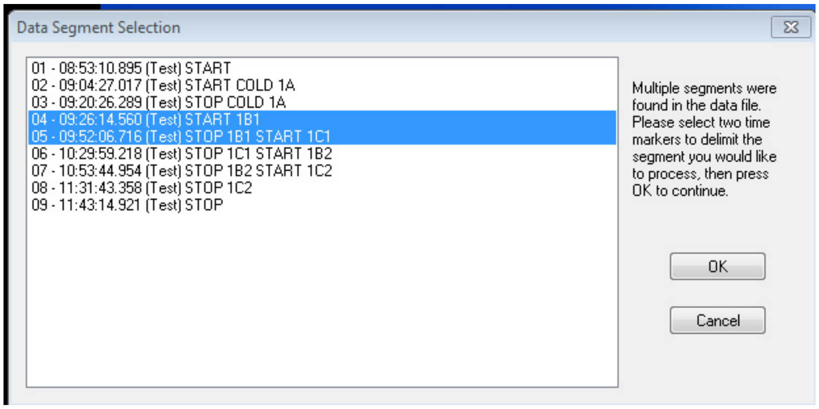
Route A (Cold Start in this case):



01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

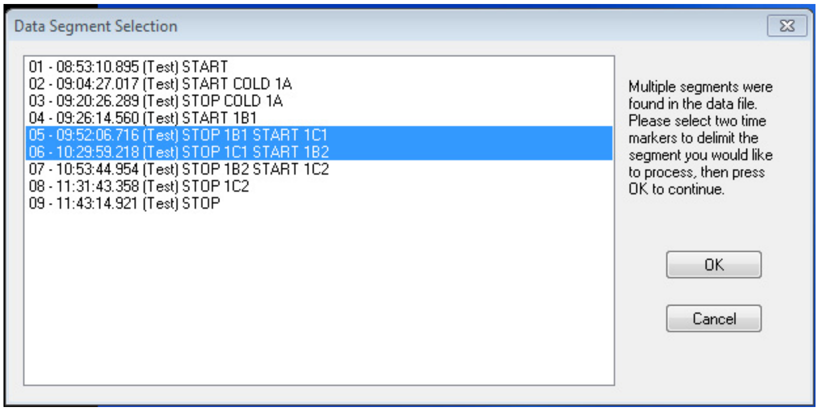
Route B1



01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

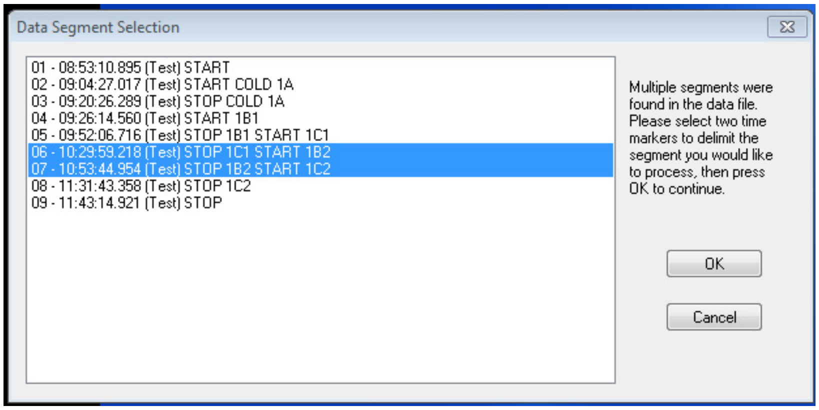
Route C1



01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

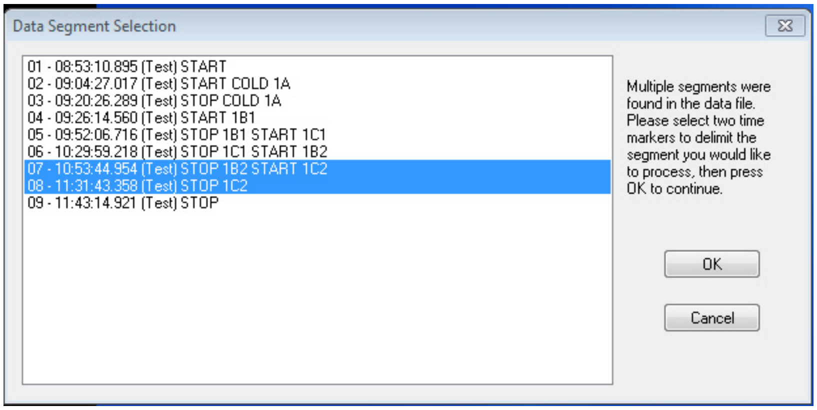
Route B2



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

Route C2

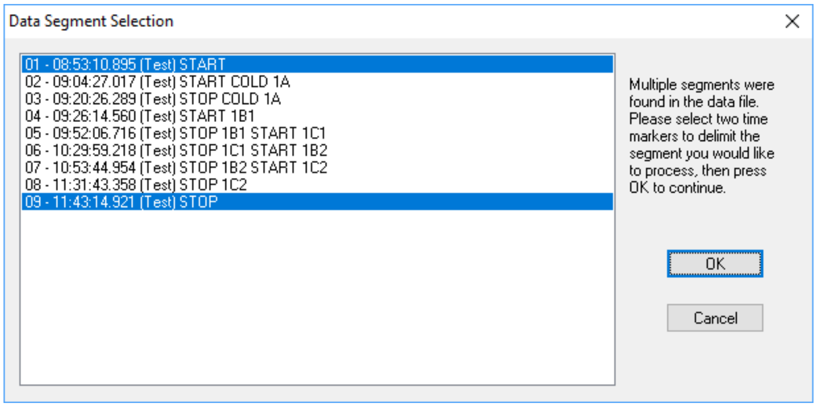


```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

For other Days of Testing:
Use the following User Marks when post-processing raw or converted data files:

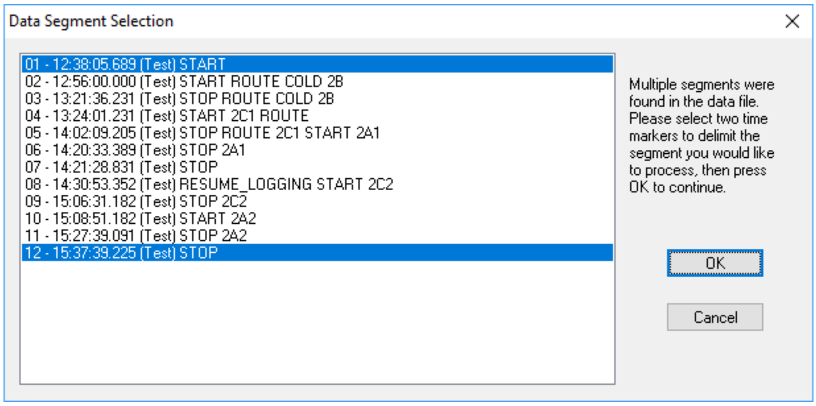
Test Two:



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

Test Three:



```
01 - 12:38:05.689 (Test) START
02 - 12:56:00.000 (Test) START ROUTE COLD 2B
03 - 13:21:36.231 (Test) STOP ROUTE COLD 2B
04 - 13:24:01.231 (Test) START 2C1 ROUTE
05 - 14:02:09.205 (Test) STOP ROUTE 2C1 START 2A1
06 - 14:20:33.389 (Test) STOP 2A1
07 - 14:21:28.831 (Test) STOP
08 - 14:30:53.352 (Test) RESUME_LOGGING START 2C2
09 - 15:06:31.182 (Test) STOP 2C2
10 - 15:08:51.182 (Test) START 2A2
11 - 15:27:39.091 (Test) STOP 2A2
12 - 15:37:39.225 (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.

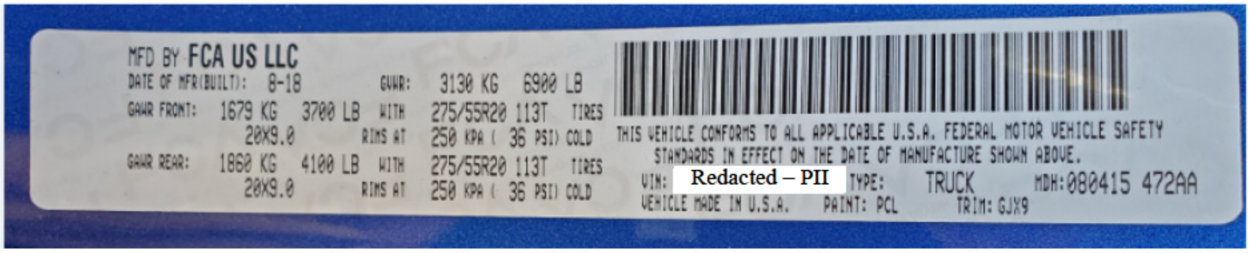
:

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

Test Vehicle

Exhaust Flowmeter and License Plate:

Vehicle Identification Number



MFD BY FCA US LLC
DATE OF MFR(BUILT): 8-18 GVWR: 3130 KG 6900 LB
GAWR FRONT: 1679 KG 3700 LB WITH 275/55R20 113T TIRES
20X9.0 RIMS AT 250 KPA (36 PSI) COLD
GAWR REAR: 1860 KG 4100 LB WITH 275/55R20 113T TIRES
20X9.0 RIMS AT 250 KPA (36 PSI) COLD

THIS VEHICLE CONFORMS TO ALL APPLICABLE U.S.A. FEDERAL MOTOR VEHICLE SAFETY STANDARDS IN EFFECT ON THE DATE OF MANUFACTURE SHOWN ABOVE.
VIN: Redacted – PII TYPE: TRUCK MDH:080415 472AA
VEHICLE MADE IN U.S.A. PAINT: PCL TRIM: GJX9

Emissions Tag

FCA US LLC

VEHICLE EMISSION CONTROL INFORMATION

GROUP: KCRXT05.75P1
NO ADJUSTMENTS NEEDED
HO2S / SFI / TWC

EVAP: KCRXR0183RP0 23.0,26.0 gal
KCRXR0225RP0 33.0 gal

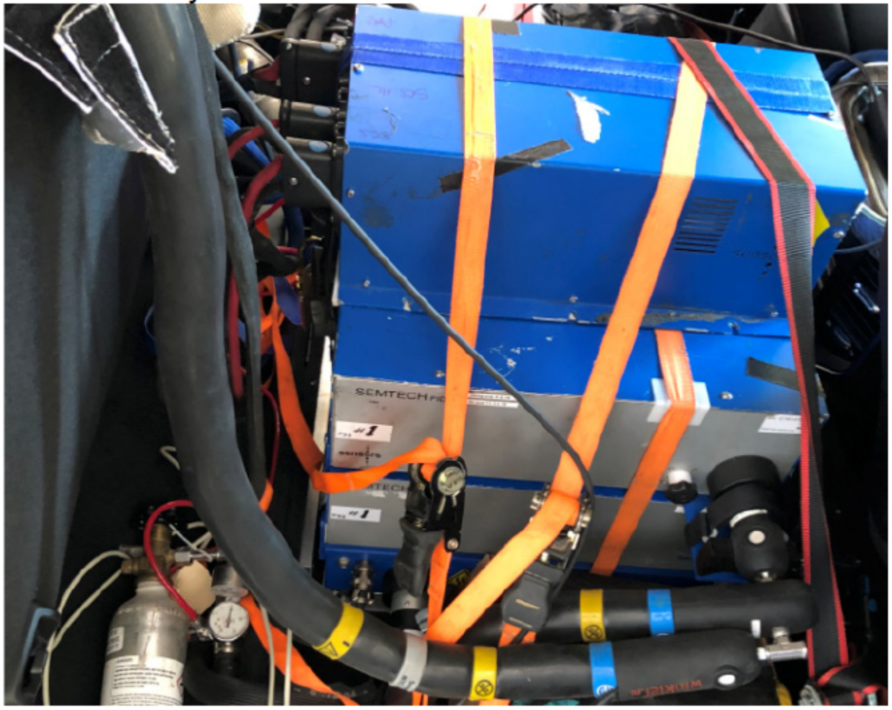
CONFORMS TO REGULATIONS: 2019 MY
ENGINE: 5.7L

U.S. EPA: T3 B70 LDT OBD: CA OBD II FUEL: GASOLINE

68406 472AA

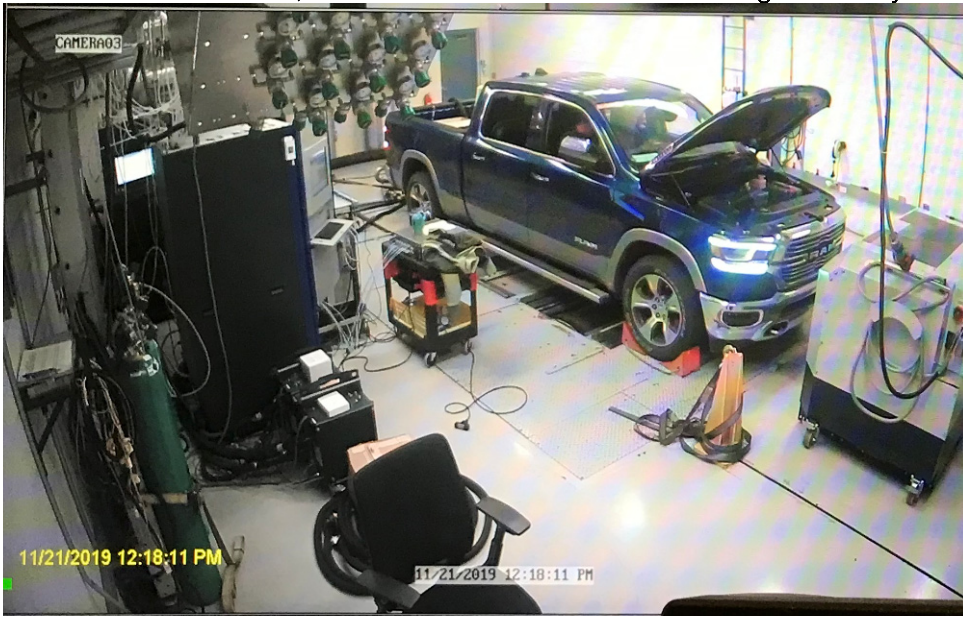
CA: ULEV70 LDT OBD: CA OBD II FUEL: GASOLINE

Gaseous Analyzer Stack



FCA Vehicle Tag

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



Test Information

Test Date	December 3,4, and 5th, 2019
Vehicle Owner	Fiat Chrysler
Test Location	Ann Arbor, MI
Type / Descr	No. V9JLJ1947
Make	JEEP Wrangler
Model	4DR 4WD Rubicon
Model Year	2019
VIN	Redacted – PII
Vehicle Emissions Tag	Redacted – PII
Engine Family	KCRXT03.65P0
License Plate	Redacted – PII Redacted – PII

Participants

Name	**Affiliation / Title**
Viorel Filip	Sensors, Inc./ TSS Supervisor
Chris Darby	Sensors, Inc./Senior Applications Engineer
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 JEEP vehicle (V9JLJ1947) whose on-road emissions testing was completed on December 3, 4, and 5th, 2019, 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 JEEP 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 JEEP 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 JEEP Summary Reports. This analytical methods report is located after the RAM and JEEP Summary Reports.

Equipment Used

Component	SN	Verified 1065 Compliant	Expiration Date	Initials
SEMTECH-LDV Module				
SCS Asset 1111	K15127978	YES	12-11-19	BF
Gaseous Module	C15122161	YES	12-11-19	BF
FID Hydrocarbon module	C16131218	YES	12-11-19	BF
EFM4 Exhaust Flowmeter	B15121215	YES	01-06-20	CE
FID Fuel bottle LOT: 70001801204	CK1047900	YES	02-01-21	BF
Weather Probe RH Sensor VAISALA	H2720004	YES	04-02-20	MC
EFM4 Exhaust Flowmeter	A19512194	YES	10-03-20	KS
GPS by Garmin	1A44269958	-	-	JE
Vehicle Interface	D16131267	-	-	JE

Calibration Gases Used

Bottle	SN	Listed Concentrations	Expiration Date	Initials
Quad Span Cylinder: CO2, CO, NO, Propane LOT 700019024GK	FF62631	15.7 %, CO2, 4536 ppm CO, 1013 ppm NO, 258 ppm C3H8	01-29-22	BF
Quad Span Cylinder: CO2, CO, NO, Propane	X04NI87T15AC033	7.028% CO2, 5.020% CO, 2076 ppm C3H8	01-24-27	BF
NO2 Span Cylinder LOT _70001734060	EA0004949	244 ppm NO2	12-06-19	BF
Zero Nitrogen Cylinder LOT_700019298F2 Praxair 200002298242	FF55357	100% N2	11-08-22	BF

Gaseous Emission Results

A. On-Road Test Strategy

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

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

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

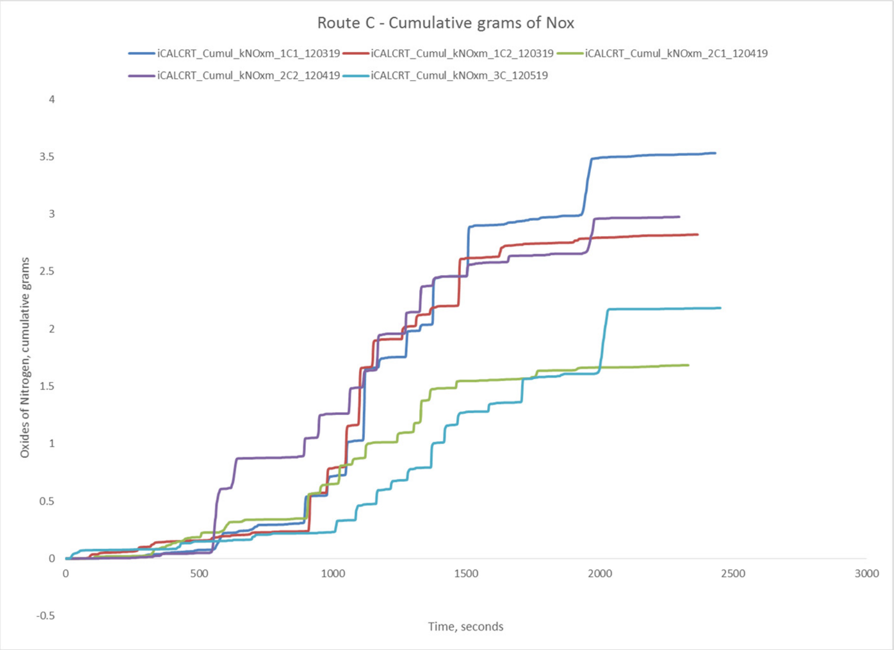
Test 1: Cold start on Route 1A, then routes 1B1, 1C1, 1B2, 1C2.
Test 2: Cold start on Route 2B, then routes 2C1, 2A1, 2C2, 2A2
Test 3: Cold start on Route 3C, then routes 3A1, 3B1, 3B2, 3A2

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

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

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

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



Route C - Cumulative grams of Nox
iCALCRT_Cumul_kNOxm_1C1_120319
iCALCRT_Cumul_kNOxm_1C2_120319
iCALCRT_Cumul_kNOxm_2C1_120419
iCALCRT_Cumul_kNOxm_2C2_120419
iCALCRT_Cumul_kNOxm_3C_120519
Oxides of Nitrogen, cumulative grams
4
3.5
3
2.5
2
1.5
1
0.5
0
-0.5
0
500
1000
1500
2000
2500
3000
Time, seconds

Test Records

The following table provides of 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	JEEP_20191203_ABCBC_T1_rev1.csv	na	Test_1 Datafile
	pp-JEEP _20191203_ABCBC_M1-M11_1ALL_rev1.csv	9,759	Pp Test_1 results
	pp-JEEP_20191203_ABCBC_M4-M5_1A_rev1.csv	1,026	pp Route 1A cold
	pp-JEEP_20191203_ABCBC_M6-M7_1B1_rev1.csv	1,312	pp Route 1B (first)
	pp-JEEP_20191203_ABCBC_M7-M8_1C1_rev1.csv	2,433	pp Route 1C (first)
	pp-JEEP_20191203_ABCBC_M8-M9_1B2_rev1.csv	1,350	pp Route 1B (second)
	pp-JEEP_20191203_ABCBC_M9-M10_1C2_rev1.csv	2,367	pp Route 1C (second)
2	JEEP_20191204_BCACA_T2_rev1.csv	na	Test_2 Datafile
	pp-JEEP _20191204_BCACA_M1-M14_2ALL_rev1.csv	10,818	pp Test_2 results
	pp-JEEP_20191204_BCACA_M5-M6_2B_rev1.csv	1,428	pp Route 2B cold
	pp-JEEP_20191204_BCACA_M7-M8_2C1_rev1.csv	2,322	pp Route 2C(first)
	pp-JEEP_20191204_BCACA_M8_M9_2A1_rev1.csv	960	pp Route 2A(first)
	pp-JEEP_20191204_BCACA_M9-M10_2C2_rev1.csv	2,298	pp Route 2C (second)
	pp-JEEP_20191204_BCACA_M10_M11_2A2_rev1.csv	934	pp Route 2A (second)
3	JEEP_20191205_CABBA_T3_rev1.csv	na	Test_3 Datafile
	pp-JEEP _20191205_CABBA_M1-M14_3ALL_rev1.csv	11,248	pp Test_3 results
	pp-JEEP_20191205_CABBA_M7-M8_3C_rev1.csv	2,453	pp Route 3C cold
	pp-JEEP_20191205_CABBA_M9-M10_3A1_rev1.csv	1,007	pp Route 3A (first)
	pp-JEEP_20191205_CABBA_M10_M11_3B1_rev1.csv	1,446	pp Route 3B (first)
	pp-JEEP_20191205_CABBA_M11-M12_3B2_rev1.csv	1,613	pp Route 3B (second)
	pp-JEEP_20191205_CABBA_M12_M13_3A2_rev1.csv	984	pp Route 3A (second)

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.

Redacted – PII _MY19_ABCBC_1ALL_20191203_Gram-mile_rev1.csv
Redacted – PII _MY19_ABCBC_1ALL_20191203_Gram-sec_rev1.csv
Redacted – PII _MY19_ABCBC_1ALL_20191203_Load_Speed_rev1.DAT
Redacted – PII _MY19_ABCBC_1A_20191203_Gram-mile_rev1.csv
Redacted – PII _MY19_ABCBC_1A_20191203_Gram-sec_rev1.csv
Redacted – PII _MY19_ABCBC_1A_20191203_Load_Speed_rev1.DAT
Redacted – PII _MY19_ABCBC_1B1_20191203_Gram-mile_rev1.csv^{R}
Redacted – PII _MY19_ABCBC_1B1_20191203_Gram-sec_rev1.csv
Redacted – PII _MY19_ABCBC_1B1_20191203_Load_Speed_rev1.DAT
Redacted – PII _MY19_ABCBC_1B2_20191203_Gram-mile_rev1.csv
Redacted – PII _MY19_ABCBC_1B2_20191203_Gram-sec_rev1.csv
Redacted – PII _MY19_ABCBC_1B2_20191203_Load_Speed_rev1.DAT
Redacted – PII _MY19_ABCBC_1C1_20191203_Gram-mile_rev1.csv
Redacted – PII _MY19_ABCBC_1C1_20191203_Gram-sec_rev1.csv
Redacted – PII _MY19_ABCBC_1C1_20191203_Load_Speed_rev1.DAT
Redacted – PII _MY19_ABCBC_1C2_20191203_Gram-mile_rev1.csv
Redacted – PII _MY19_ABCBC_1C2_20191203_Gram-sec_rev1.csv
Redacted – PII _MY19_ABCBC_1C2_20191203_Load_Speed_rev1.DAT
Redacted – PII _MY19_BCACA_2A1_20191204_Gram-mile_rev1.csv
Redacted – PII _MY19_BCACA_2A1_20191204_Gram-sec_rev1.csv
Redacted – PII _MY19_BCACA_2A1_20191204_Load_Speed_rev1.DAT
Redacted – PII _MY19_BCACA_2A2_20191204_Gram-mile.csv
Redacted – PII _MY19_BCACA_2A2_20191204_Gram-sec_rev1.csv
Redacted – PII _MY19_BCACA_2A2_20191204_Load_Speed_rev1.DAT
Redacted – PII _MY19_BCACA_2ALL_20191204_Gram-mile.csv
Redacted – PII _MY19_BCACA_2ALL_20191204_Gram-sec_rev1.csv^{R}
Redacted – PII _MY19_BCACA_2ALL_20191204_Load_Speed_rev1.DAT
Redacted – PII _MY19_BCACA_2B_20191204_Gram-mile.csv
Redacted – PII _MY19_BCACA_2B_20191204_Gram-sec_rev1.csv
Redacted – PII _MY19_BCACA_2B_20191204_Load_Speed_rev1.DAT
Redacted – PII _MY19_BCACA_2C1_20191204_Gram-mile.csv
Redacted – PII _MY19_BCACA_2C1_20191204_Gram-sec_rev1.csv
Redacted – PII _MY19_BCACA_2C1_20191204_Load_Speed_rev1.DAT
Redacted – PII _MY19_BCACA_2C2_20191204_Gram-mile.csv
Redacted – PII _MY19_BCACA_2C2_20191204_Gram-sec_rev1.csv
Redacted – PII _MY19_BCACA_2C2_20191204_Load_Speed_rev1.DAT
Redacted – PII _MY19_CABBA_3A1_20191205_Gram-mile.csv
Redacted – PII _MY19_CABBA_3A1_20191205_Gram-sec_rev1.csv
Redacted – PII _MY19_CABBA_3A1_20191205_Load_Speed_rev1.DAT
Redacted – PII _MY19_CABBA_3A2_20191205_Gram-mile.csv
Redacted – PII _MY19_CABBA_3A2_20191205_Gram-sec_rev1.csv^{R}
Redacted – PII _MY19_CABBA_3A2_20191205_Load_Speed_rev1.DAT
Redacted – PII _MY19_CABBA_3ALL_20191205_Gram-mile.csv
Redacted – PII _MY19_CABBA_3ALL_20191205_Gram-sec_rev1.csv
Redacted – PII _MY19_CABBA_3ALL_20191205_Load_Speed_rev1.DAT^{R}
Redacted – PII _MY19_CABBA_3B1_20191205_Gram-mile.csv
Redacted – PII _MY19_CABBA_3B1_20191205_Gram-sec_rev1.csv
Redacted – PII _MY19_CABBA_3B1_20191205_Load_Speed_rev1.DAT
Redacted – PII _MY19_CABBA_3B2_20191205_Gram-mile.csv
Redacted – PII _MY19_CABBA_3B2_20191205_Gram-sec_rev1.csv
Redacted – PII _MY19_CABBA_3B2_20191205_Load_Speed_rev1.DAT
Redacted – PII _MY19_CABBA_3C_20191205_Gram-mile.csv
Redacted – PII _MY19_CABBA_3C_20191205_Gram-sec_rev1.csv
Redacted – PII _MY19_CABBA_3C_20191205_Load_Speed_rev1.DAT

B. On-Road Test Results by Test Day

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

Test 1

		COLD 1A	HOT 1B1	HOT 1C1	HOT 1B2	HOT 1C2	Total	Average
		Route A	Route B	Route C	Route B	Route C		
Distance	mi	7.86	10.77	30.46	10.76	30.45	90.30	
Duration	sec	1026	1312	2433	1350	2367	8,488	
Fuel Economy	mpg	17.92	20.67	17.07	20.89	17.82		18.18
CO2	g	3,993	4,762	15,968	4,707	15,286	44,717	
CO	g	8.179	2.453	218.202	2.517	208.092	439.44	
kNOx	g	0.113	0.121	3.505	0.134	2.792	6.665	
THC	g	1.761	0.075	1.421	0.059	0.978	4.294	
NMCH	g	1.726	0.074	1.392	0.058	0.958	4.208	
CO2	g/mi	507.90	442.23	524.20	437.61	502.06		495.22
CO	g/mi	1.04	0.228	7.163	0.234	6.835		4.867
kNOx	g/mi	0.014	0.011	0.115	0.012	0.092		0.074
THC	g/mi	0.224	0.007	0.047	0.005	0.032		0.048
NMHC	g/mi	0.22	0.007	0.046	0.005	0.031		0.047
Ambient Temp	DegC	-0.7	-0.4	-0.2	0.0	-0.1		-0.3
Ambient Press	mbar	974.7	976.4	973.5	975.7	972.5		974.1
Relative Humid.	%	92.43	88.69	84.06	82.61	80.45		85.00
Absol. Humidity	grains	24.02	23.58	22.72	22.54	21.91		22.79
Avg. Kh Factor		0.79	0.78	0.78	0.78	0.78		0.78

Test 2

		COLD 2B	HOT 2C1	HOT 2A1	HOT 2C2	HOT 2A2	Total	Average
		Route B	Route C	Route A	Route C	Route A		
Distance	mi	11.02	30.47	7.66	30.48	7.66	87.29	
Duration	sec	1428	2332	960	2298	934	7,952	
Fuel Economy	mpg	17.72	17.50	22.98	18.23	23.24		18.58
CO2	g	5,666	15,526	3,045	15,025	3,013	42,274	
CO	g	8.335	237.17	1.105	161.053	0.869	408.53	
kNOx	g	0.147	1.684	0.066	2.974	0.074	4.945	
THC	g	1.738	1.405	0.023	0.906	0.011	4.083	
NMCH	g	1.703	1.377	0.022	0.888	0.011	4.001	
CO2	g/mi	514.06	509.51	397.74	492.98	393.41		484.32
CO	g/mi	0.756	7.783	0.144	5.284	0.113		4.680
kNOx	g/mi	0.013	0.055	0.009	0.098	0.01		0.057
THC	g/mi	0.158	0.046	0.003	0.03	0.001		0.047
NMHC	g/mi	0.155	0.045	0.003	0.029	0.001		0.046
Ambient Temp	DegC	1.9	2.0	1.9	2.2	2.2		1.9
Ambient Press	mbar	969.1	967.5	968.3	967.7	968.0		968.0
Relative Humid.	%	78.16	73.95	73.50	72.18	71.88		74.89
Absol. Humidity	grains	24.64	23.53	23.24	23.41	23.21		23.66
Avg. Kh Factor		0.79	0.78	0.78	0.78	0.78		0.78

During Test 3, the cold start on Route C accounted for 45% of distance, and 98% of carbon monoxide and hydrocarbons emissions, and 85% of oxides of nitrogen.

Test 3

		COLD 3C	HOT 3A1	HOT 3B1	HOT 3B2	HOT 3A2	Total	Average
		Route C	Route A	Route B	Route B	Route A		
Distance	mi	30.73	7.66	10.77	10.77	7.66	67.60	
Duration	sec	2453	1007	1446	1613	984	7,503	
Fuel Economy	mpg	16.72	21.96	21.10	21.08	23.17		19.10
CO2	g	16,294	3,184	4,658	4,661	3,019	31,817	
CO	g	294.27	1.037	1.616	1.668	0.931	299.52	
kNOx	g	2.191	0.084	0.114	0.116	0.087	2.592	
THC	g	3.405	0.02	0.028	0.022	0.004	3.479	
NMCH	g	3.337	0.02	0.027	0.022	0.004	3.410	
CO2	g/mi	530.20	415.61	432.51	432.90	393.94		470.70
CO	g/mi	9.575	0.135	0.15	0.155	0.121		4.431
kNOx	g/mi	0.071	0.011	0.011	0.011	0.011		0.038
THC	g/mi	0.111	0.003	0.003	0.002	0.001		0.051
NMHC	g/mi	0.109	0.003	0.003	0.002	0.001		0.050
Ambient Temp	DegC	1.5	1.4	1.9	1.9	1.6		1.5
Ambient Press	mbar	983.5	984.7	986.8	986.1	983.9		983.1
Relative Humid.	%	61.84	61.79	60.29	60.28	61.48		62.37
Absol. Humidity	grains	18.71	18.49	18.66	18.63	18.64		18.76
Avg. Kh Factor		0.76	0.76	0.76	0.76	0.8		0.76

C. Emissions Trends by Route

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

				Route A			Hot	
		COLD 1A	HOT 2A1	HOT 2A2	HOT 3A1	HOT 3A2	Average	Std. Dev.
Distance	mi	7.86	7.66	7.66	7.66	7.66	7.66	0.00
Duration	sec	1,026	960	934	1,007	984	971	31
Fuel Econ.	mpg	17.92	22.98	23.24	21.96	23.17	22.84	0.59
CO2	g	3993	3045	3013	3184	3019	3065	80
CO	g	8.179	1.105	0.869	1.037	0.931	0.986	0.106
kNOx	g	0.113	0.066	0.074	0.084	0.087	0.078	0.010
THC	g	1.761	0.023	0.011	0.020	0.004	0.015	0.009
NMCH	g	1.726	0.022	0.011	0.020	0.004	0.014	0.008
CO2	g/mi	507.90	397.74	393.41	415.61	393.94	400.17	10.47
CO	g/mi	1.040	0.144	0.113	0.135	0.121	0.128	0.014
kNOx	g/mi	0.014	0.009	0.010	0.011	0.011	0.010	0.001
THC	g/mi	0.224	0.003	0.001	0.003	0.001	0.002	0.001
NMHC	g/mi	0.220	0.003	0.001	0.003	0.001	0.002	0.001
Ambient Temp	DegC	-0.7	1.9	2.2	1.4	1.6	1.8	0.4
Ambient Press	mbar	974.7	968.3	968.0	984.7	983.9	976.2	9.3
Relative Humid.	%	92.4	73.5	71.9	61.8	61.5	67.2	6.4
Absol. Humidity	grains	24.0	23.2	23.2	18.5	18.6	20.9	2.7
Avg. Kh Factor		0.79	0.78	0.78	0.76	0.76	0.77	0.012

				Route B			Hot	
		COLD 2B	HOT 1B1	HOT 1B2	HOT 3B1	HOT 3B2	Average	Std. Dev.
Distance	mi	11.02	10.77	10.76	10.77	10.77	10.77	0.01
Duration	sec	1428	1312	1350	1446	1613	1430	134
Fuel Econ.	mpg	17.72	20.67	20.89	21.10	21.08	20.93	0.20
CO2	g	5666	4762	4707	4658	4661	4697	49
CO	g	8.335	2.453	2.517	1.616	1.668	2.064	0.488
kNOx	g	0.147	0.121	0.134	0.114	0.116	0.121	0.009
THC	g	1.738	0.075	0.059	0.028	0.022	0.046	0.025
NMCH	g	1.703	0.074	0.058	0.027	0.022	0.045	0.025
CO2	g/mi	514.06	442.23	437.61	432.51	432.90	436.31	4.58
CO	g/mi	0.756	0.228	0.234	0.150	0.155	0.192	0.045
kNOx	g/mi	0.013	0.011	0.012	0.011	0.011	0.011	0.001
THC	g/mi	0.158	0.007	0.005	0.003	0.002	0.004	0.002
NMHC	g/mi	0.155	0.007	0.005	0.003	0.002	0.004	0.002
Ambient Temp	DegC	1.9	-0.4	0.0	1.9	1.9	0.8	1.2
Ambient Press	mbar	969.1	976.4	975.7	986.8	986.1	981.2	6.0
Relative Humid.	%	78.2	88.7	82.6	60.3	60.3	73.0	14.9
Absol. Humidity	grains	24.6	23.6	22.5	18.7	18.6	20.9	2.6
Avg. Kh Factor		0.79	0.78	0.78	0.76	0.76	0.77	0.011

				Route C			Hot	
		COLD 3C	HOT 1C1	HOT 1C2	HOT 2C1	HOT 2C2	Average	Std. Dev.
Distance	mi	30.73	30.46	30.45	30.47	30.48	30.47	0.01
Duration	sec	2,453	2,433	2,367	2,332	2,298	2,358	58
Fuel Econ.	mpg	16.72	17.07	17.82	17.50	18.23	17.65	0.49
CO2	g	16,294	15,968	15,286	15,526	15,025	15,451	401
CO	g	294.27	218.20	208.09	237.17	161.05	206.13	32.38
kNOx	g	2.191	3.505	2.792	1.684	2.974	2.739	0.765
THC	g	3.405	1.421	0.978	1.405	0.906	1.178	0.274
NMCH	g	3.337	1.392	0.958	1.377	0.888	1.154	0.268
CO2	g/mi	530.20	524.20	502.06	509.51	492.98	507.19	13.20
CO	g/mi	9.575	7.163	6.835	7.783	5.284	6.766	1.063
kNOx	g/mi	0.071	0.115	0.092	0.055	0.098	0.090	0.025
THC	g/mi	0.111	0.047	0.032	0.046	0.030	0.039	0.009
NMHC	g/mi	0.109	0.046	0.031	0.045	0.029	0.038	0.009
Ambient Temp	DegC	1.5	-0.2	-0.1	2.0	2.2	1.0	1.3
Ambient Press	mbar	983.5	973.5	972.5	967.5	967.7	970.3	3.1
Relative Humid.	%	61.8	84.1	80.4	74.0	72.2	77.7	5.6
Absol. Humidity	grains	18.7	22.7	21.9	23.5	23.4	22.9	0.7
Avg. Kh Factor		0.76	0.78	0.78	0.78	0.78	0.78	0.003

D. Recorded Vehicle Parameters

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

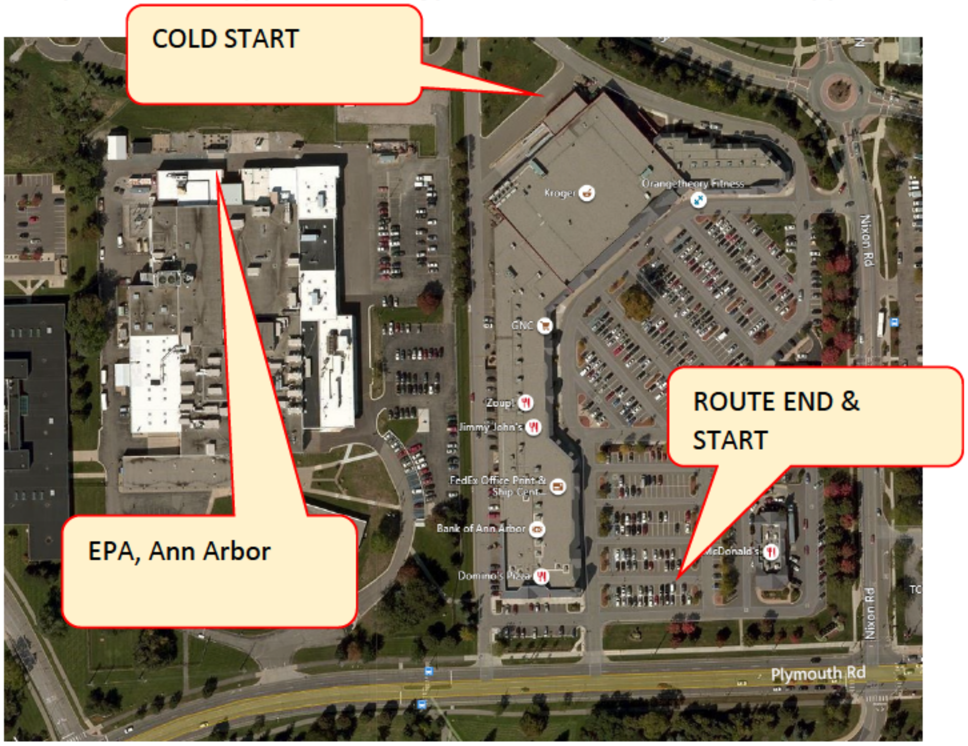
Wrangler Vehicle Interface Parameters

Description	VI Parameter	Units
No. of DTCs	DTC_CNT	#
Fuel System A Status	FUEL_STAT_A	
Fuel System B Status	FUEL_STAT_B	
Load Percent	iENG_LOAD	%
Coolant Temp.	iCOOL_TEMP	degF
Short-Term Fuel Trim 1	ST_FUELTRIM_1	%
Short-Term Fuel Trim 3	ST_FUELTRIM_3	%
Long-Term Fuel Trim 1	LT_FUELTRIM_1	%
Short-Term Fuel Trim 2	ST_FUELTRIM_2	%
Long-Term Fuel Trim 1	LT_FUELTRIM_2	%
Fuel Pressure	FP1	kPa
Manifold Pressure	iMAP	kPa
Engine RPM	iENG_SPEED	RPM
Vehicle Speed	iVEH_SPEED	mph
Spark Advance	SPARKADV	Deg
Intake Air Temp.	iMAN_TEMP	degF
Abs Throttle Postn	TP	%
O2 Sensor Location	O2_SENSOR_LOC	
Bank1 O2 Sensor-1 Volt	BK1_O2_SENSOR1_VOLT	V
Bank1 O2 Sensor-1 SHAFT	BK1_O2_SENSOR1_SHRFT	%
Bank1 O2 Sensor-2 Volt	BK1_O2_SENSOR2_VOLT	V
Bank1 O2 Sensor-2 SHAFT	BK1_O2_SENSOR2_SHRFT	%
Bank2 O2 Sensor-1 Volt	BK2_O2_SENSOR1_VOLT	V
Bank2 O2 Sensor-1 SHAFT	BK2_O2_SENSOR1_SHRFT	%
Bank2 O2 Sensor-2 Volt	BK2_O2_SENSOR2_VOLT	V
Bank2 O2 Sensor-2 SHAFT	BK2_O2_SENSOR2_SHRFT	%
OBD REQUIREMENT LEVEL	OBD_REQ_LEVEL	
Time Since Start	RUNTM	S
MIL Dist. Traveled	MIL_DIST	km
Commanded EGR	EGR_PCT	%
EGR Error	EGR_ERR	%
Cmd. Evap. Purge	EVAP_PCT	%
Fuel Level Input	FLI	%
No. of Warm Ups	WARM_UPS	
Distance Cleared	CLR_DIST	km
Evap. System VP	EVAP_VP1	Pa
Baro. Pressure	BARO	kPa
Catalyst Temp. 1-1	CATEMP11	degC
Catalyst Temp. 2-1	CATEMP21	degC
Driving Cycle Status	DRV_CYC_STAT	
Control Voltage	VPWR	V
Abs. Load Value	LOAD_ABS	%
F/A Equiv. Ratio	LAMBDA	
Rel. Throttle Postn	TP_R	%
Amb. Air Temp.	AAT	degC
Throttle Postn B	TP_B	%
Accel. Postn D	APP_D	%
Accel. Postn E	APP_E	%
Throttle Act. Ctrl.	TAC_PCT	%
Current Fuel Type	FUEL_TYPE	
Act. Eng. Pct. Torque	iPCNT_TORQUE	%
Eng. Ref. Torque	sREF_ENG_TORQUE	lb-ft
EGR Wide Temp. 1-2	EGRWTC	degC
Eng. Frictn Pct. Tq	iFRICT_TORQUE	%
Engine Fuel Rate	ENG_FUEL_RATE	g/s
Engine Exhaust Flow	EXH_RATE	kg/hr
Vehicle Odometer	Odometer	hm
Vehicle Odometer	Odometer	hm

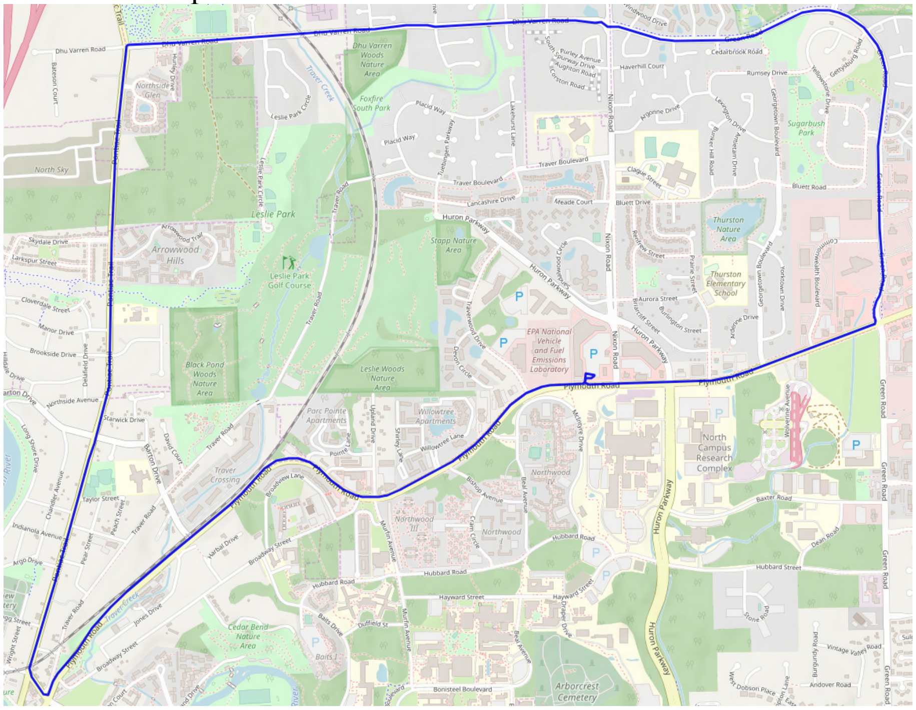
App. 2A. SEMTECH LDV (PEMS) Tests by Route with Vehicle Speed Profile

Route Description

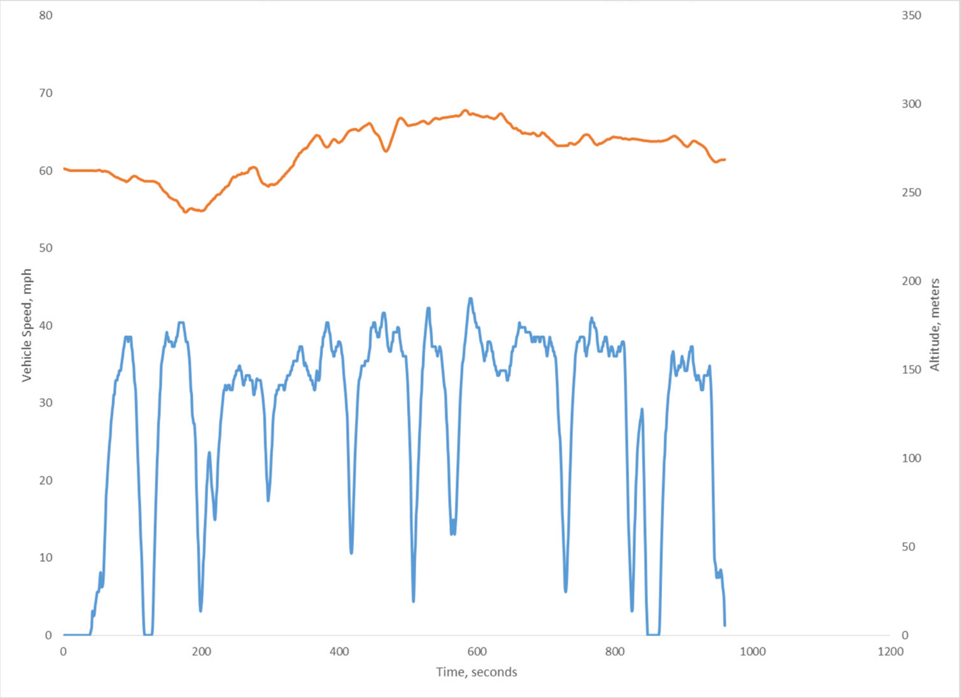
The picture below provides the typical start location for three approved routes.



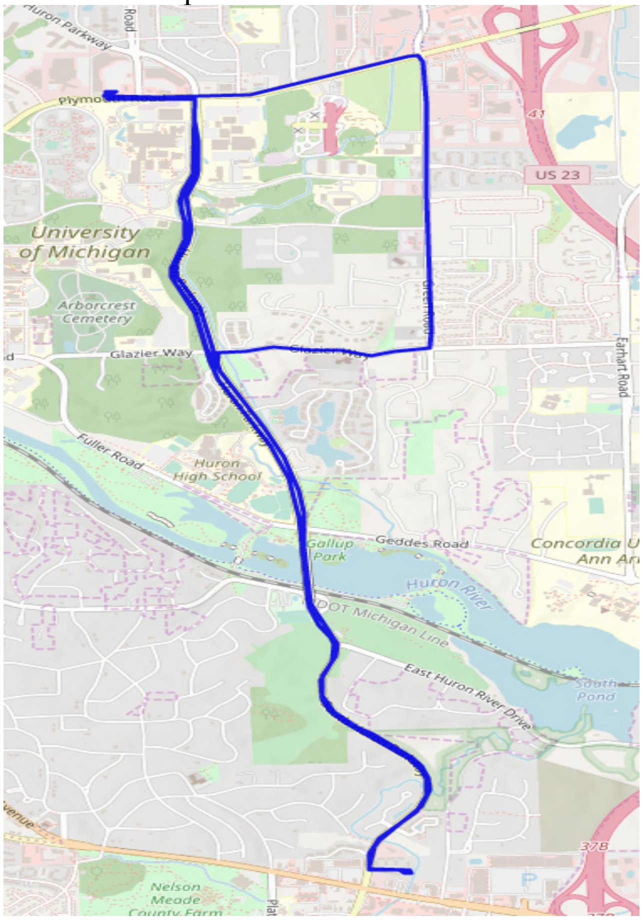
Route A -- Map



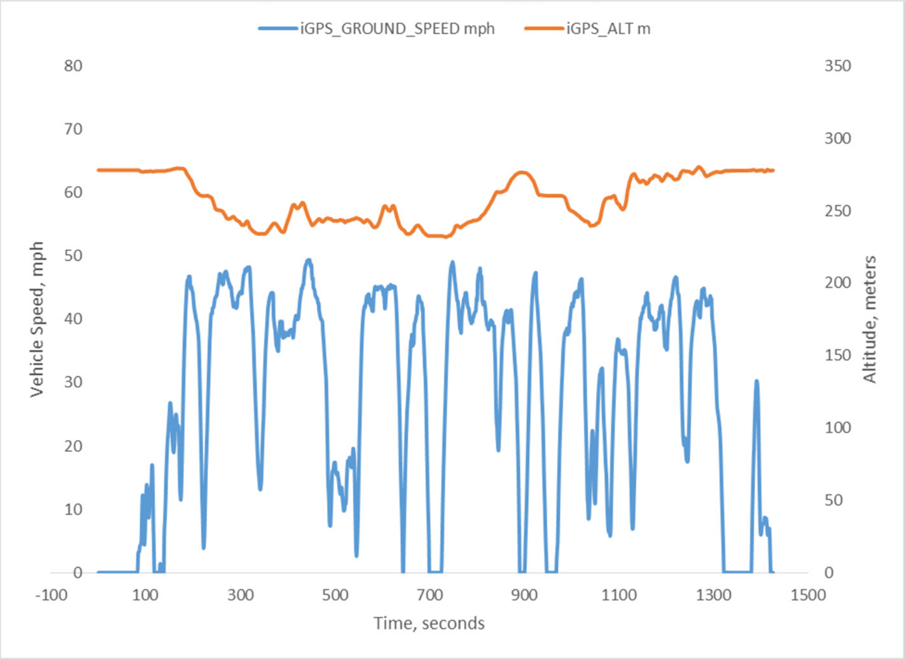
Route A – Vehicle Speed and Altitude Profile (typical).



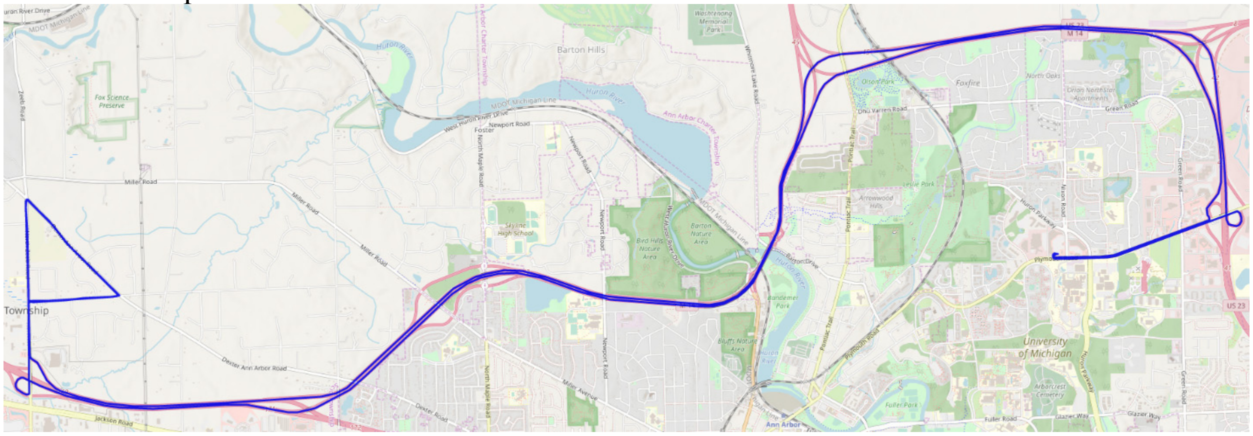
Route B – Map



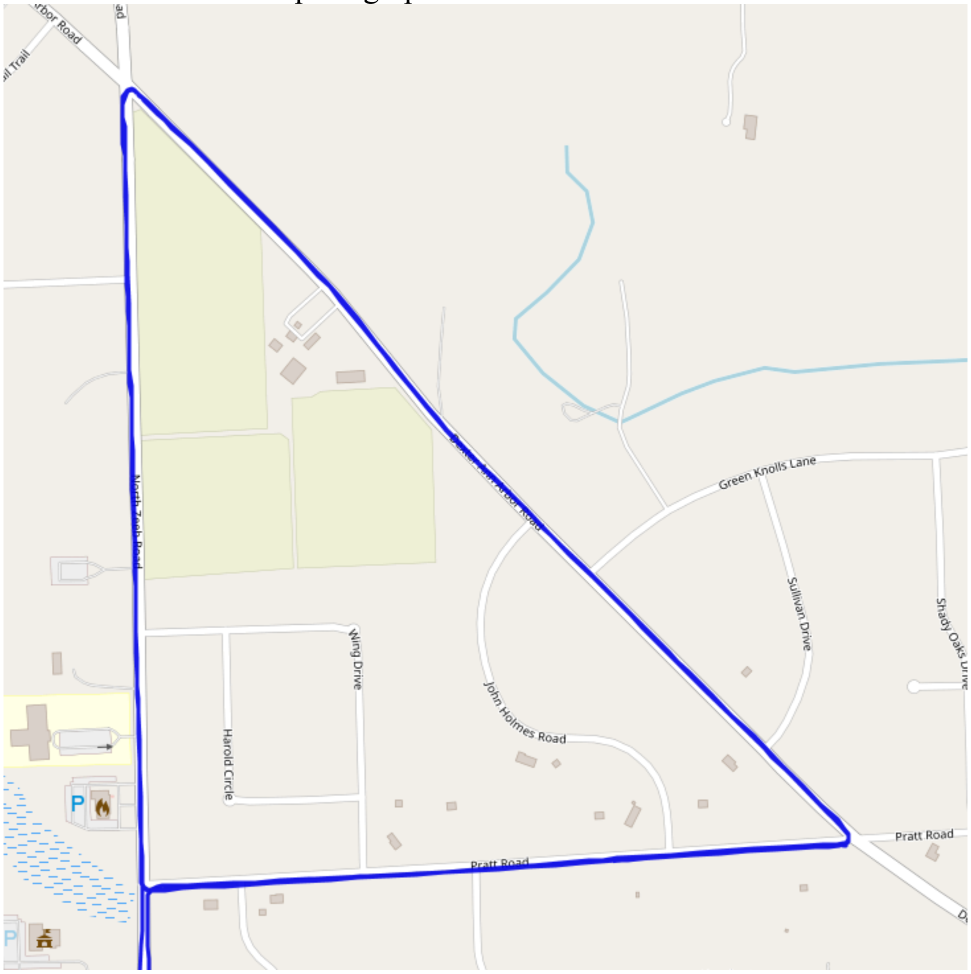
Route B – Vehicle Speed and Altitude (typical).



Route C – Map



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



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

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

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

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

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

Correlation Summary

Dyno. distance : 11.05
Dyno. distance : 17.68

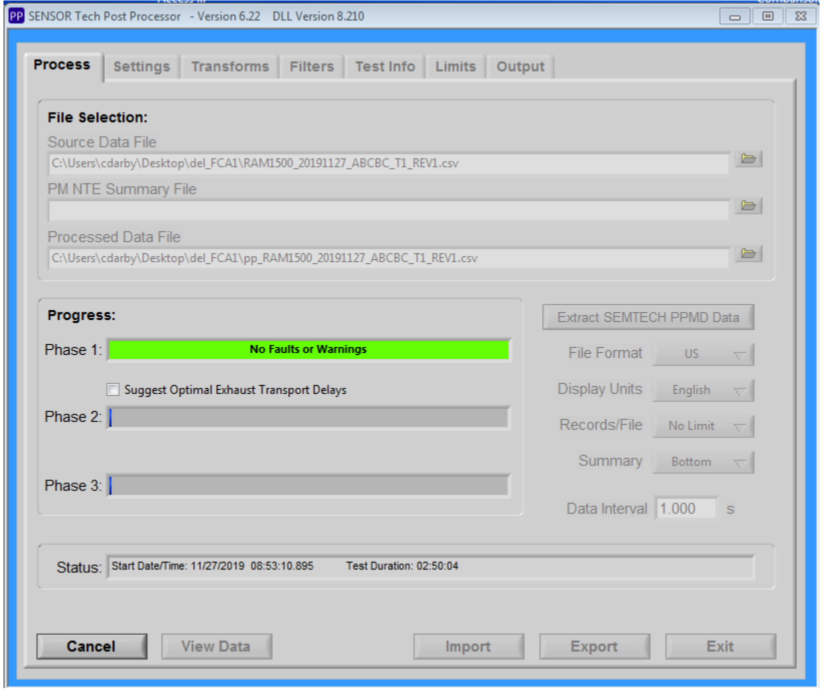
	PEMS (SEMTECH LDV)			Dynamometer Bag Bench		
Overall Emissions:	**grams**	**g/mi**	**g/km**	**grams**	**g/mi**	**g/km**
CO2	4544.59	411.28	257.05	4486	405.96	253.73
CO	2.9540	0.2673	0.1671	2.3630	0.2138	0.1337
kNOx	0.2954	0.0267	0.0167	0.2670	0.0242	0.0151
THC[A]	0.3220	0.0291	0.0182	0.2640	0.0239	0.0149

	Correlation versus EU Tolerance			Difference versus Dynmometer		
Overall Emissions:	**Difference**	**Tolerance**	**Percent**	**% Diff**	**% Tolerance**	**Abs Diff (g/km)**
CO2 (g)	3.321	10	33.2%	1.3%	10%	3.321
CO (g)	0.0334	0.15	22.3%	25.0%	15%	0.033
kNOx (g)	0.0016	0.015	10.7%	10.6%	15%	0.002
THC[A]	0.0033	0.015	21.9%	22.0%	15%	0.003

Note: A) The PEMS hydrocarbon analyzer was railed for twelve seconds during the cold start segment of FTP75 Phase One. This report increased the original value for hydrocarbon analyzer emissions by a factor of four.

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

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



Source Data File: C:\Users\cdarby\Desktop\del_FCA1\RAM1500_20191127_ABCBC_T1_REV1.csv

PM NTE Summary File:

Processed Data File: C:\Users\cdarby\Desktop\del_FCA1\pp_RAM1500_20191127_ABCBC_T1_REV1.csv

Phase 1: No Faults or Warnings

☐ Suggest Optimal Exhaust Transport Delays

Phase 2:

Phase 3:

File Format: US

Display Units: English

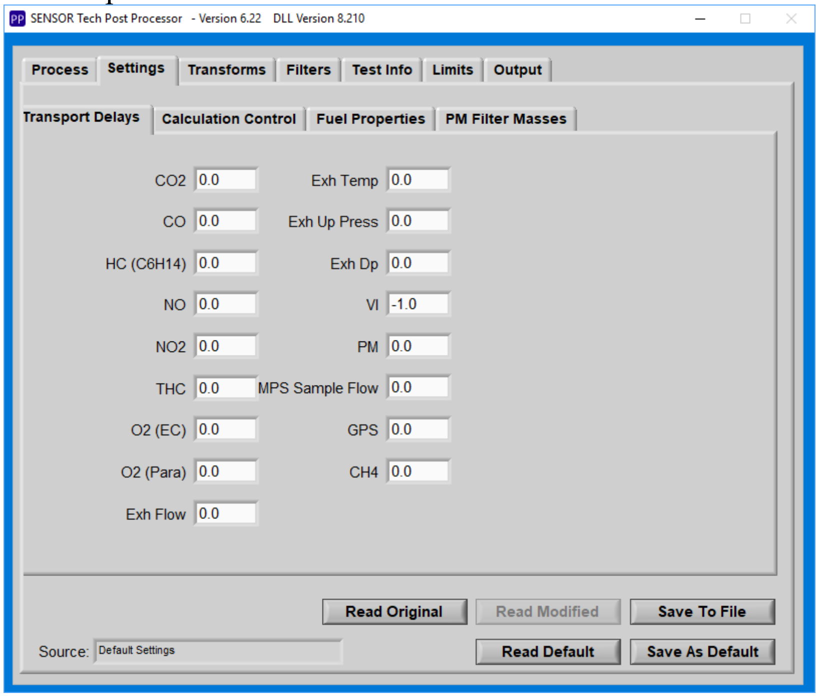
Records/File: No Limit

Summary: Bottom

Data Interval: 1.000 s

Status: Start Date/Time: 11/27/2019 08:53:10.895 Test Duration: 02:50:04

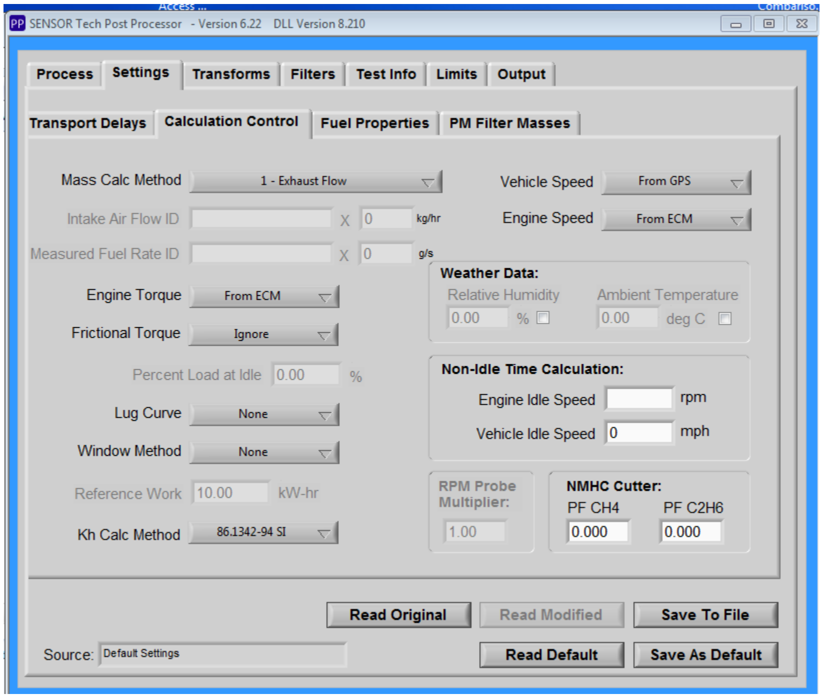
Select options of interest:



CO2 0.0
CO 0.0
HC (C6H14) 0.0
NO 0.0
NO2 0.0
THC 0.0
O2 (EC) 0.0
O2 (Para) 0.0
Exh Flow 0.0
Exh Temp 0.0
Exh Up Press 0.0
Exh Dp 0.0
VI -1.0
PM 0.0
MPS Sample Flow 0.0
GPS 0.0
CH4 0.0

Source: Default Settings

Calculation Control Tab:



Mass Calc Method: 1 - Exhaust Flow
Intake Air Flow ID: X 0 kg/hr
Measured Fuel Rate ID: X 0 g/s
Engine Torque: From ECM
Frictional Torque: Ignore
Percent Load at Idle: 0.00 %
Lug Curve: None
Window Method: None
Reference Work: 10.00 kW-hr
Kh Calc Method: 86.1342-94 SI
Vehicle Speed: From GPS
Engine Speed: From ECM

Weather Data:
Relative Humidity: 0.00 % ☐
Ambient Temperature: 0.00 deg C ☐

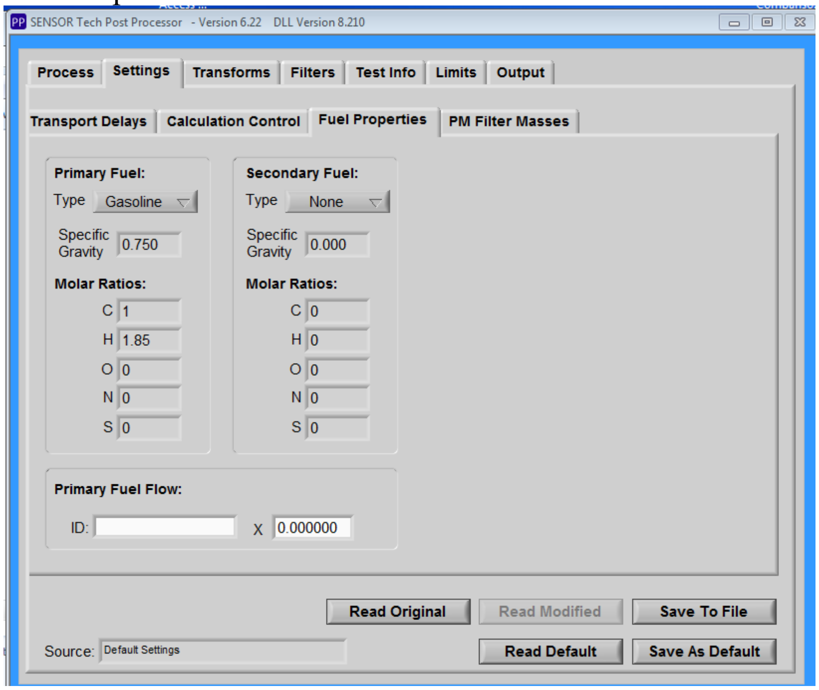
Non-Idle Time Calculation:
Engine Idle Speed: rpm
Vehicle Idle Speed: 0 mph

RPM Probe Multiplier: 1.00

NMHC Cutter:
PF CH4: 0.000
PF C2H6: 0.000

Source: Default Settings

Fuel Properties Tab:



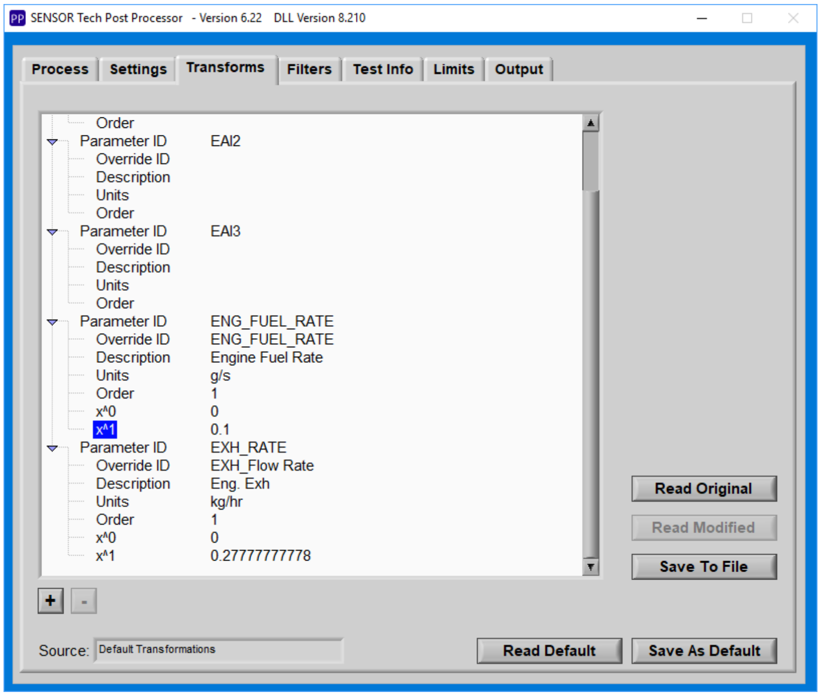
Primary Fuel:
Type: Gasoline
Specific Gravity: 0.750
Molar Ratios:
C 1
H 1.85
O 0
N 0
S 0

Secondary Fuel:
Type: None
Specific Gravity: 0.000
Molar Ratios:
C 0
H 0
O 0
N 0
S 0

Primary Fuel Flow:
ID: X 0.000000

Source: Default Settings

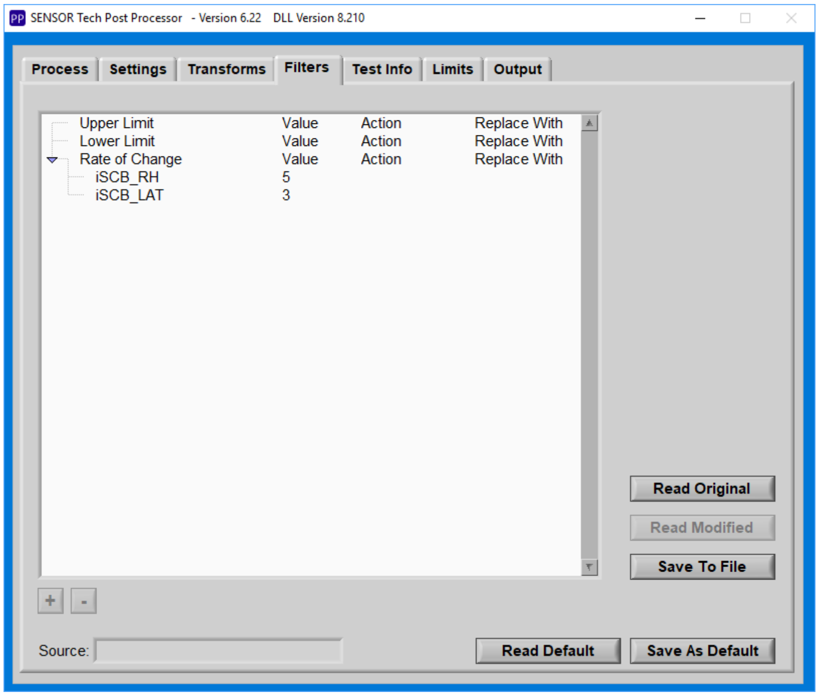
Transforms are used when post-processing JEEP data files to provide correct scaling for two parameters: ENG_FUEL_RATE, and EXH_RATE.



Order	
Parameter ID	EAI2
Override ID	
Description	
Units	
Order	
Parameter ID	EAI3
Override ID	
Description	
Units	
Order	
Parameter ID	ENG_FUEL_RATE
Override ID	ENG_FUEL_RATE
Description	Engine Fuel Rate
Units	g/s
Order	1
x^0	0
x^1	0.1
Parameter ID	EXH_RATE
Override ID	EXH_Flow Rate
Description	Eng. Exh
Units	kg/hr
Order	1
x^0	0
x^1	0.27777777778

Source: Default Transformations

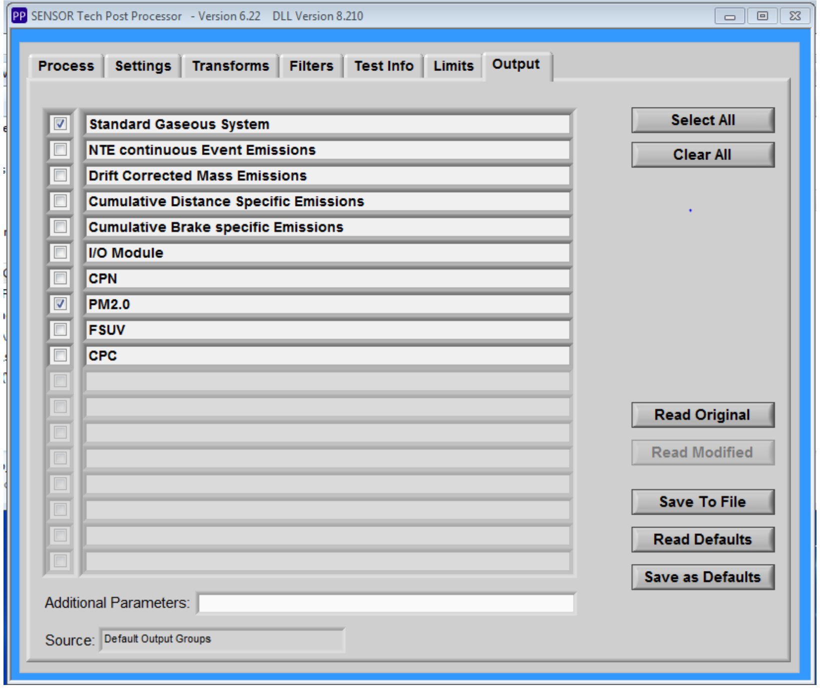
Parameter Filters Tab:



Upper Limit	Value	Action	Replace With
Lower Limit	Value	Action	Replace With
Rate of Change	Value	Action	Replace With
iSCB_RH	5		
iSCB_LAT	3		

Source:

Output Tab:

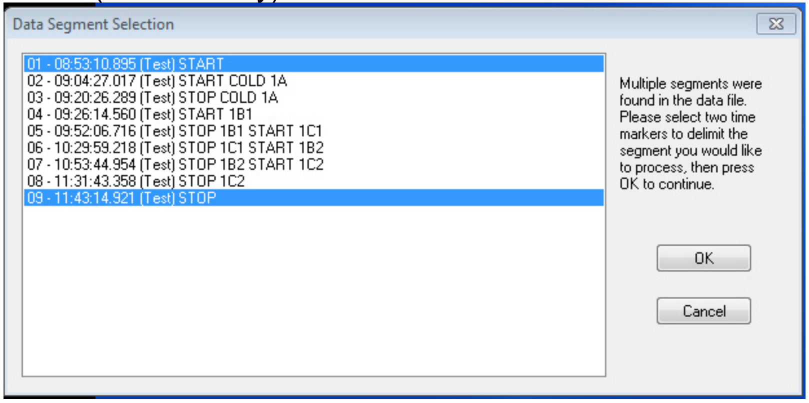


☑ Standard Gaseous System
☐ NTE continuous Event Emissions
☐ Drift Corrected Mass Emissions
☐ Cumulative Distance Specific Emissions
☐ Cumulative Brake specific Emissions
☐ I/O Module
☐ CPN
☑ PM2.0
☐ FSUV
☐ CPC

Additional Parameters:

Source: Default Output Groups

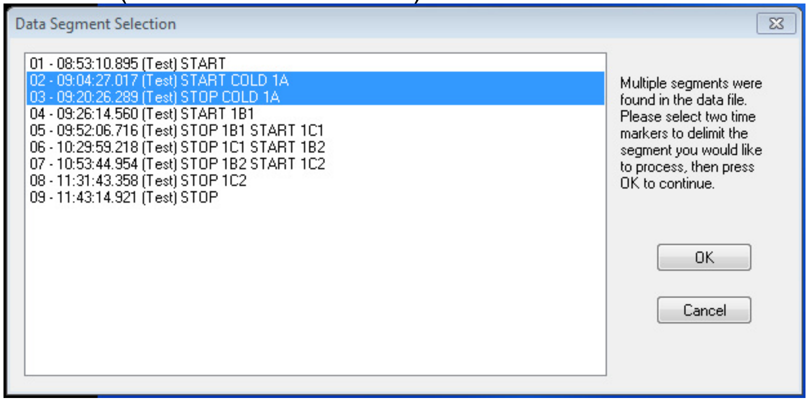
Use the following User Marks when post-processing raw or converted data files (typical):
Test 1 (in its Entirety):



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

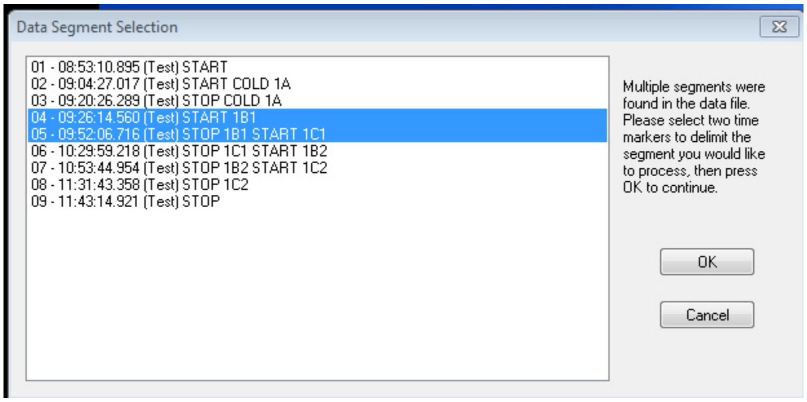
Route A (Cold Start in this case):



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

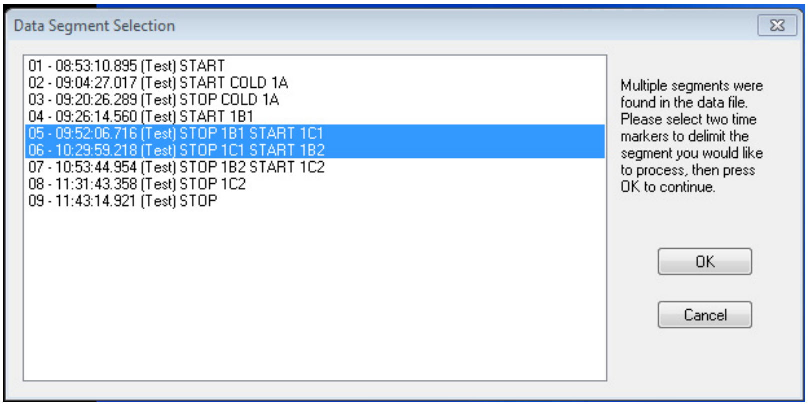
Route B1



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

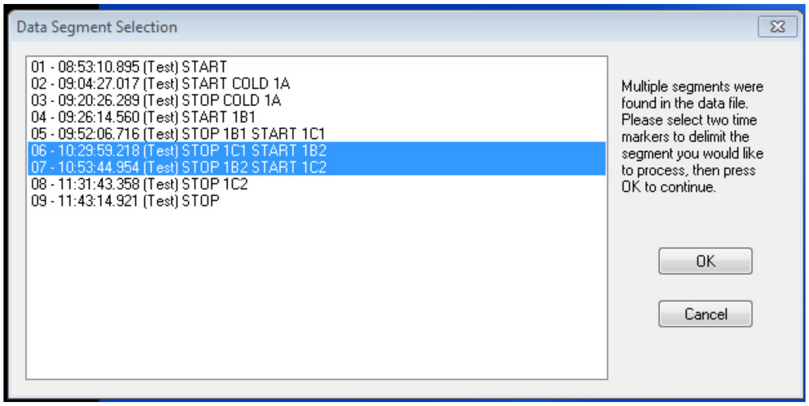
Route C1



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

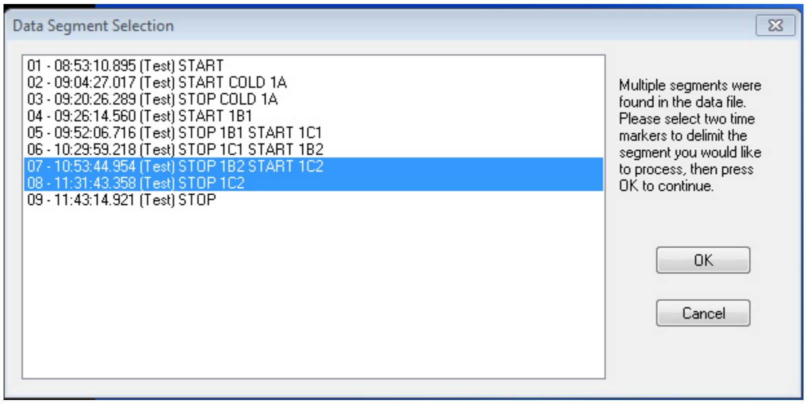
Route B2



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

Route C2

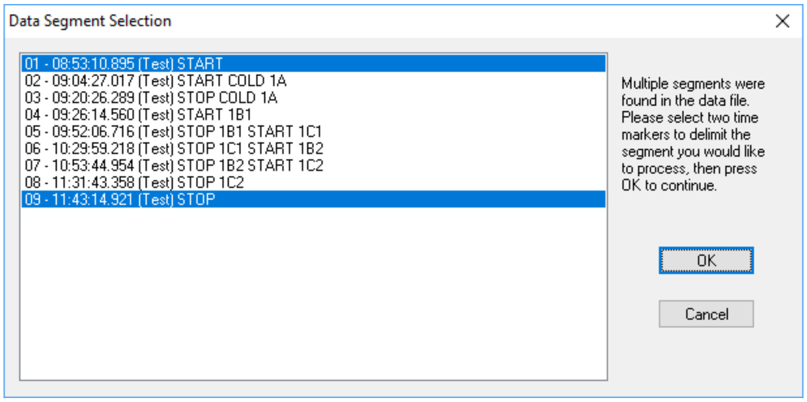


```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

Other Days of Testing:
Use the following User Marks when post-processing raw or converted data files (typical):

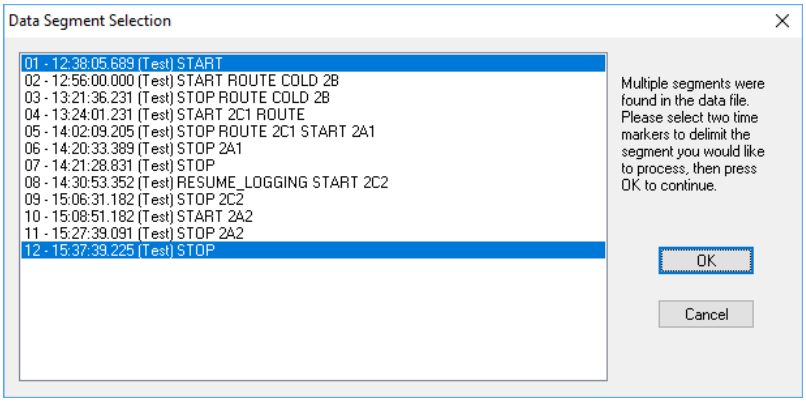
Test Two:



```
01 - 08:53:10.895 (Test) START
02 - 09:04:27.017 (Test) START COLD 1A
03 - 09:20:26.289 (Test) STOP COLD 1A
04 - 09:26:14.560 (Test) START 1B1
05 - 09:52:06.716 (Test) STOP 1B1 START 1C1
06 - 10:29:59.218 (Test) STOP 1C1 START 1B2
07 - 10:53:44.954 (Test) STOP 1B2 START 1C2
08 - 11:31:43.358 (Test) STOP 1C2
09 - 11:43:14.921 (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.

Test Three:



```
01 - 12:38:05.689 (Test) START
02 - 12:56:00.000 (Test) START ROUTE COLD 2B
03 - 13:21:36.231 (Test) STOP ROUTE COLD 2B
04 - 13:24:01.231 (Test) START 2C1 ROUTE
05 - 14:02:09.205 (Test) STOP ROUTE 2C1 START 2A1
06 - 14:20:33.389 (Test) STOP 2A1
07 - 14:21:28.831 (Test) STOP
08 - 14:30:53.352 (Test) RESUME_LOGGING START 2C2
09 - 15:06:31.182 (Test) STOP 2C2
10 - 15:08:51.182 (Test) START 2A2
11 - 15:27:39.091 (Test) STOP 2A2
12 - 15:37:39.225 (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.

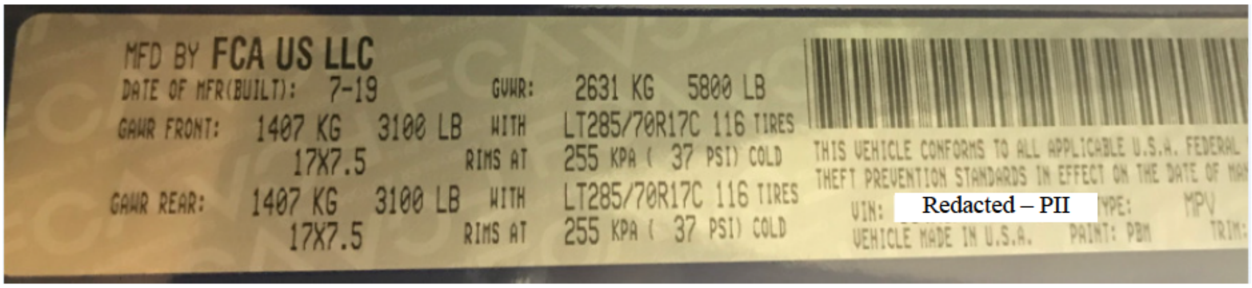
:

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

Test Vehicle

Exhaust Flowmeter and License Plate

Vehicle Identification Number


MFD BY FCA US LLC
DATE OF MFR(BUILT): 7-19 GVWR: 2631 KG 5800 LB
GAWR FRONT: 1407 KG 3100 LB WITH LT285/70R17C 116 TIRES
17X7.5 RIMS AT 255 KPA (37 PSI) COLD
GAWR REAR: 1407 KG 3100 LB WITH LT285/70R17C 116 TIRES
17X7.5 RIMS AT 255 KPA (37 PSI) COLD
THIS VEHICLE CONFORMS TO ALL APPLICABLE U.S.A. FEDERAL
THEFT PREVENTION STANDARDS IN EFFECT ON THE DATE OF MA
VIN: Redacted – PII YPE: MPV
VEHICLE MADE IN U.S.A. PAINT: PBM TRIM:

Emissions Tag


FCA US LLC | VEHICLE EMISSION CONTROL INFORMATION
GROUP: KCRXT03.65P0 EVAP: KCRXR0136PP0 17.5 gal
NO ADJUSTMENTS NEEDED KCRXR0172PP0 21.5 gal
EGR / EGRC / HO2S / SFI / TWC
U.S. EPA: T3 B70 LDT OBD: CA OBD II FUEL: GASOLINE
CA: ULEV70 LDT OBD: CA OBD II FUEL: GASOLINE
CONFORMS TO REGULATIONS: 2019 MY
ENGINE: 3.6L
68406 459AA

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 JEEP 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 JEEP summary reports.

SEMTECH LDV: Analytical Methods

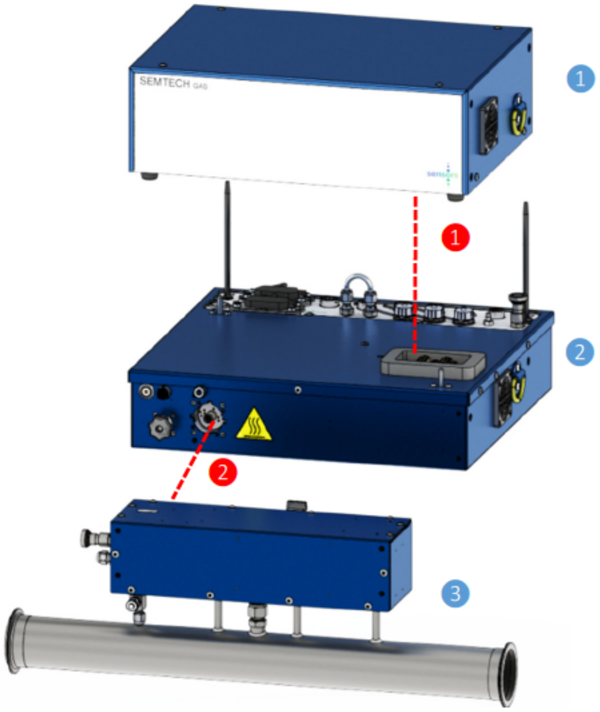
The three main modules of the SEMTECH® **L**ight **D**uty **V**ehicle PEMS analyzer consist of:

- **GAS** (**G**as **A**nalysis **S**ystem), measuring CO, CO2, NO and NO2.
- **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:
❶ SCS to GAS
❷ 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
l x_{min} $x(a_1- 1) + a_0$ l < 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

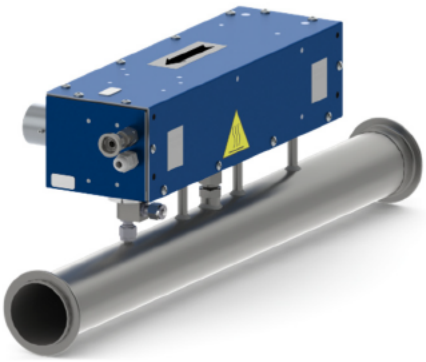
	Flow tube	SCS module	G.A.S. module	CAB module	Zero/Span box
Input voltage	12V supplied by base box	12 VDC	12V supplied by base box	ower over Ethernet (PoE	ower over Ethernet (PoE
Storage temperature	-10 °C to 60 °C dry				
Ambient operating temperature	-10 °C to 40 °C, up to 100% when used with a fairing *				
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)	$\lvert x_{min}\ \mathrm{x}\ (a_1 - 1) + a_0\rvert \le 0.5\%$ of selected range Slope a_1 between 0.99 and 1.01 Standard Error of Estimates (SEE) ≤ 1% of selected range Coefficient of Determination $r^2 \ge 0.998$
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 ($T_{10\text{-}90}$)	≤ 2.5 seconds
System Response Time ($T_{10\text{-}90}$)	≤ 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	$\lvert x_{min}$ x $(a_1 - 1) + a_0 \rvert \leq$ 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

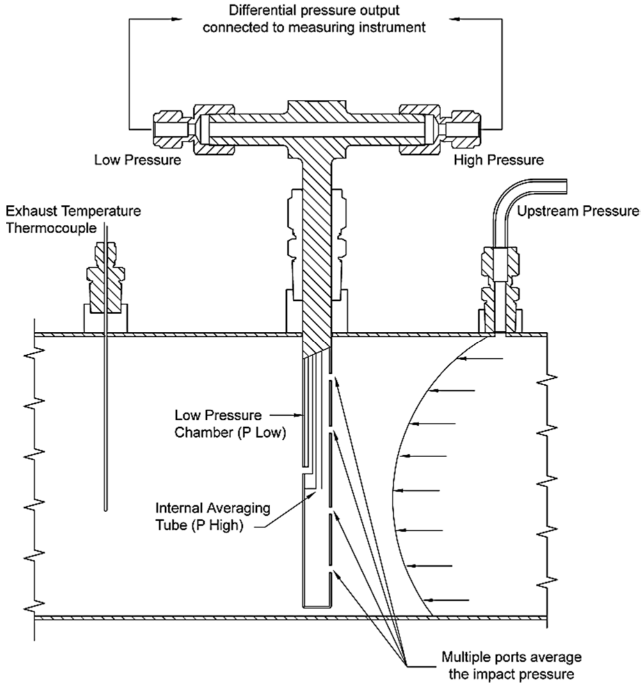
ρ = gas density

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.

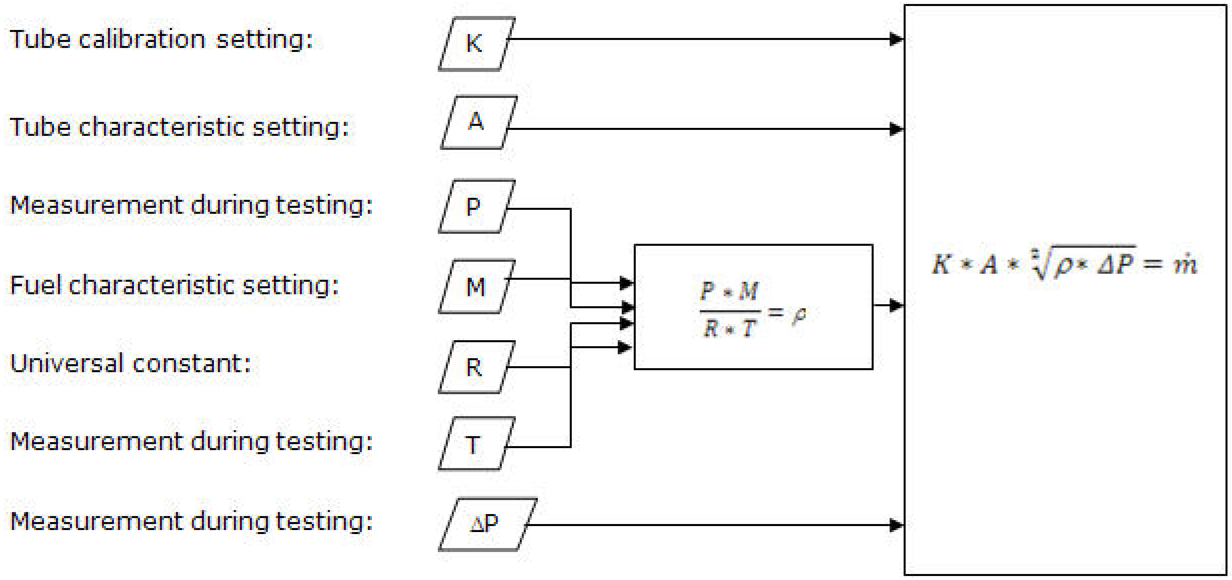
$$\rho = \frac{m}{V}$$

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.

$Reynold's\ Number: K = unitless$

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

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

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

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

$$Temperature: T = [K]$$

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

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

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

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.

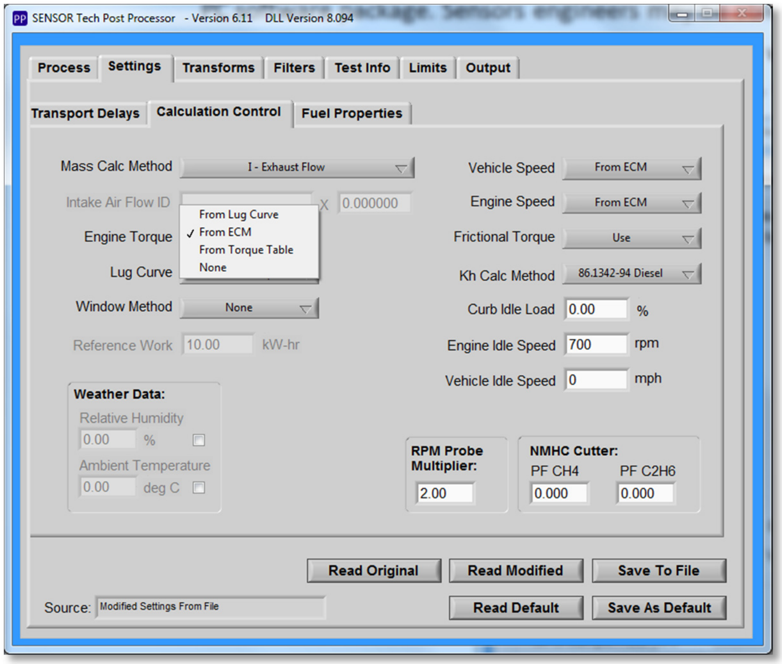
1.1.8.2.1 METHOD 1

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.



SENSOR Tech Post Processor - Version 6.11 DLL Version 8.094

Mass Calc Method I - Exhaust Flow
Intake Air Flow ID X 0.000000
Engine Torque ✓ From ECM
Window Method None
Reference Work 10.00 kW-hr
Vehicle Speed From ECM
Engine Speed From ECM
Frictional Torque Use
Kh Calc Method 86.1342-94 Diesel
Curb Idle Load 0.00 %
Engine Idle Speed 700 rpm
Vehicle Idle Speed 0 mph
Weather Data:
Relative Humidity 0.00 % ☐
Ambient Temperature 0.00 deg C ☐
RPM Probe Multiplier: 2.00
NMHC Cutter: PF CH4 0.000 PF C2H6 0.000
Source: Modified Settings From File

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:

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

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.

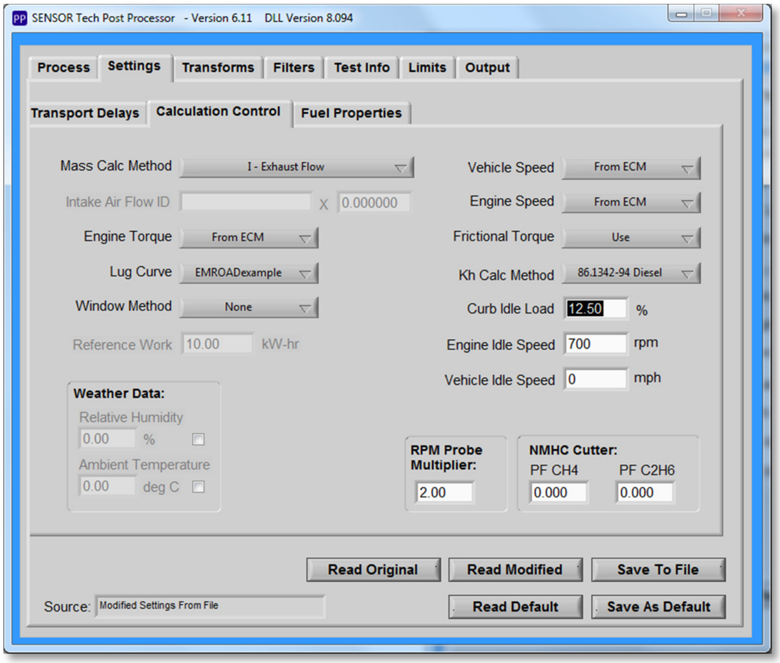
1.1.8.2.3 METHOD 3

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.



Mass Calc Method: I - Exhaust Flow
Intake Air Flow ID: x 0.000000
Engine Torque: From ECM
Lug Curve: EMROADexample
Window Method: None
Reference Work: 10.00 kW-hr
Weather Data:
Relative Humidity: 0.00 % ☐
Ambient Temperature: 0.00 deg C ☐
Vehicle Speed: From ECM
Engine Speed: From ECM
Frictional Torque: Use
Kh Calc Method: 86.1342-94 Diesel
Curb Idle Load: 12.50 %
Engine Idle Speed: 700 rpm
Vehicle Idle Speed: 0 mph
RPM Probe Multiplier: 2.00
NMHC Cutter: PF CH4 0.000 PF C2H6 0.000
Source: Modified Settings From File

Figure 2: Post Processor Curb Idle Load correction

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

Total Torque = Percent Torque x Reference Torque

Frictional Torque = Percent Frictional Torque x Reference Torque

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

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

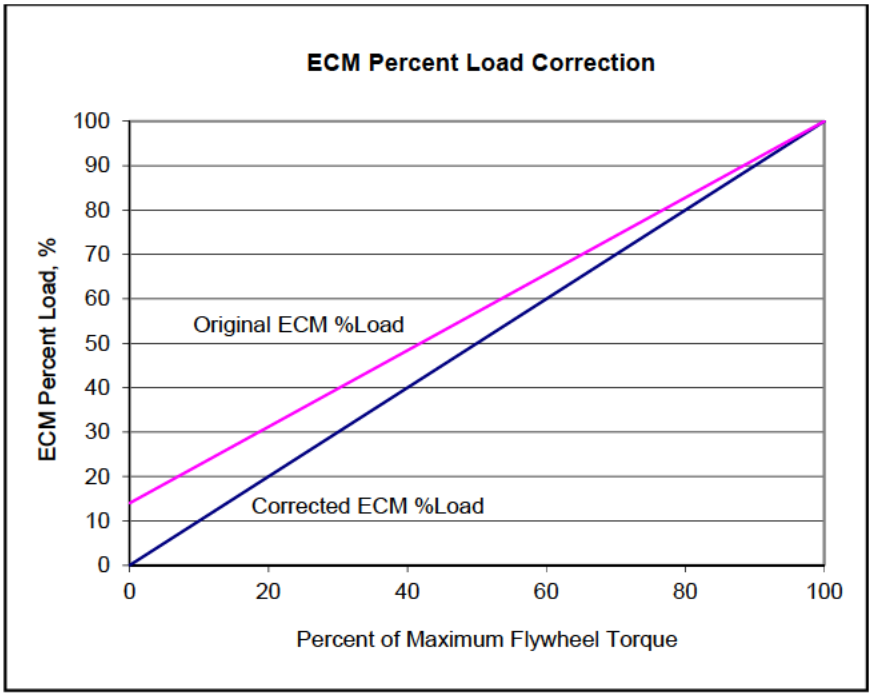


Figure 3: ECM percent load correction example

1.1.9 DISTANCE SPECIFIC EMISSIONS

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

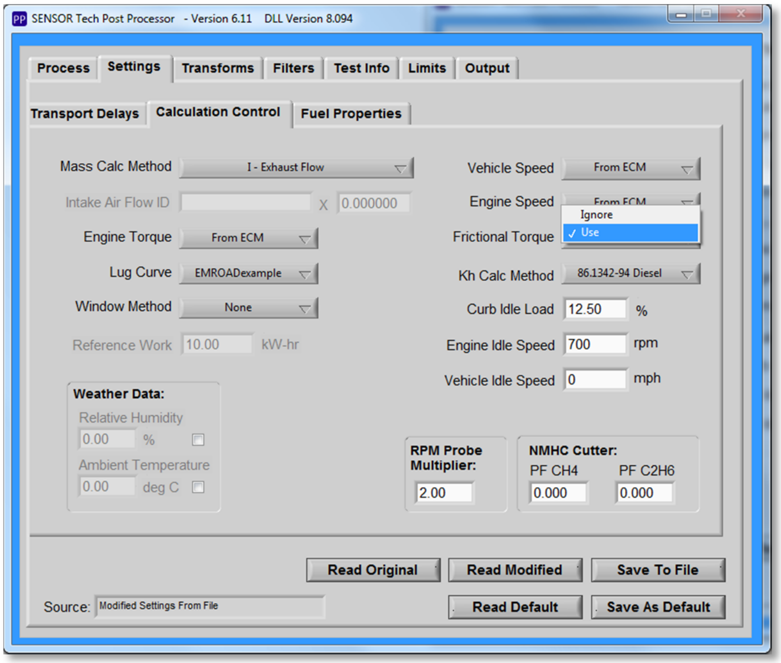
$$NO_x\left(\frac{g}{mi}\right) = \frac{\sum NO_x mass}{\sum miles\ travelled}\ and\ NO_x\left(\frac{g}{km}\right) = \frac{\sum NO_x mass}{\sum kilometers\ travelled}$$

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

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

1.1.10 BRAKE SPECIFIC EMISSIONS

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



Mass Calc Method: I - Exhaust Flow
Intake Air Flow ID: X 0.000000
Engine Torque: From ECM
Lug Curve: EMROADexample
Window Method: None
Reference Work: 10.00 kW-hr
Weather Data:
Relative Humidity: 0.00 % ☐
Ambient Temperature: 0.00 deg C ☐
Vehicle Speed: From ECM
Engine Speed: From ECM
Frictional Torque: Use
Kh Calc Method: 86.1342-94 Diesel
Curb Idle Load: 12.50 %
Engine Idle Speed: 700 rpm
Vehicle Idle Speed: 0 mph
RPM Probe Multiplier: 2.00
NMHC Cutter: PF CH4 0.000 PF C2H6 0.000
Source: Modified Settings From File

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.

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