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Plein Disposal Inc. and Turtle Island Recycling Trucks
Equipped with ***i-phi***™ **Hydrogen Generating Technology**

Prepared by

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For
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EXECUTIVE SUMMARY

In the fall of 2010, Stewardship Ontario representative Rick Denyes and Ontario Continuous Improvement Fund Representative Andy Campbell met with Innovative Hydrogen Solutions Inc. (IHS) to discuss what the impacts of installing the IHS *i-phi*™ (Partial Hydrogen Injection) system on Recycling Trucks used in the Stewardship's Blue Box Recycling Program by way of conducting a series of on-road tests. Based on these discussions, IHS contracted Global MRV to validate data from a series of four test runs over a six month period for the purpose of determining the impact of the *i-phi*™ system on Fuel Economy and Emissions Reduction. Global MRV would act as a Third Party Verification Entity to ascertain any noticeable emission and/or fuel reductions associated with using the *i-phi*™ system.

To determine the affects of the *i-phi*™ system, five Recycling Trucks were used in three separate evaluations. The test plan for the three evaluations each included a baseline segment and three different test segments. Treatment data was collected after 60 days, 120 days and 180 days, simulating real world driving conditions but in a controlled format. The test involved using three Trucks from Turtle Island in Aurora, Ontario and two Trucks from Plein Transport in Elmira, Ontario utilizing a predetermined city route and a predetermined rural route. Testing began on April 3rd, 2011 and was completed on October 2nd, 2011. The testing was conducted over this period of time to ensure that enough time passed to properly allow what IHS calls the "Hydrogen Break-in" phenomenon to purge the system.

The parties used Global MRV's Axion R/S Portable Emissions Measurement System (PEMS) for all testing to quantify both emissions and fuel improvements attributable to the *i-phi*™ system.

The test plan was based on the collection of vehicle data operating on repeated driving routes. In order to obtain comparable data, the vehicle emissions were mapped to engine operating parameters using modal analysis techniques. The analysis of the data yielded statistically significant results for three of the five vehicles tested. Mechanical repair unrelated to the project of one of the test vehicles further reduced the number of vehicles with statistically valid results to two.

The two successfully tested vehicles showed reductions in all pollutants tested, as well as fuel consumption. As more fully detailed in the attached report and after the Hydrogen Break-In phenomenon, the average reductions (excluding a confidence rating +/-) in NOx and PM averaged 29.89% and 38.26% respectively. The corresponding fuel reductions averaged 7.27%.

The trends of the actual results in Emission Reductions and Fuel Reductions in all of the Testing phases are reflective and supported by previous Third Party Testing Verifications conducted by Global MRV in September through November of 2005 in Manitoba and by the University of Auburn's Program for Advanced Vehicle Evaluation's SAE J1321 (TMC RP-1102) Type 2 Fuel Consumption Test in 2010 using the IHS *i-phi*™ Technology.

The general trends demonstrate that better fuel savings correlates to reduced emissions, which clearly backs up the claims that the *i-phi*™ system is enhancing the combustion process.

David Miller
Chief Technology Officer
Global MRV Clean Air Technologies International Division

OVERVIEW

Global MRV Clean Air Technologies Division (Global MRV) develops and manufactures portable emissions measurement systems (PEMS) and provides real-world emissions monitoring, consulting, and testing services.

In the spring of 2011, Global MRV rented equipment, namely Axion R/S System "AX08-013" to Innovative Hydrogen Solutions (IHS) to develop a multiple phase test plan for their *i-phi*™ Hydrogen Generation Module.

The baseline testing (B1) was completed on five separate trucks by a Consultant hired by IHS utilizing AX08-013 during the weekend of April 3rd and 4th, 2011.

Upon completion of baselining, IHS installed an individual *i-phi*™ Hydrogen Generation Module to each baselined vehicle and after a break-in period the trucks were comparatively tested against the aforementioned baseline.

Comparative testing was completed by the same Consultant hired by IHS utilizing AX08-013 during the weekend of May 28th and 29th, 2011. (C1)

A second round of comparative testing was completed by Global MRV engineers and technicians during the weekend of July 23rd and 24th, 2011. (C2)

Finally, a third round of comparative testing was completed by the same Consultant hired by IHS utilizing AX08-013 during the weekend of October 1st and 2nd, 2011. (C3)

PROJECT OBJECTIVES AND DELIVERABLES

For this project, deliverables were divided into four (4) testing phases (B1, C1, C2, C3) to be completed at two (2) sites conducted on multiple trucks at both sites. Each of the five (5) trucks included in this testing was outfitted with a unique and individual hydrogen generating module known as the *i-phi*™ from Innovative Hydrogen Solutions. "The *i-phi*™ produces a mixture of hydrogen and oxygen gases, on demand, through a controlled electrolysis process." Global MRV's Portable Emissions Measurement System (PEMS) known as the *Axion R/S* was procured to scientifically measure and document any improvements in fuel mileage and lowered vehicle emissions.

GLOBAL MRV Clean Air Technologies Division

Global MRV, through its Clean Air Technologies Division, continues to produce the most advanced PEMS equipment in the industry. The most current and cutting-edge device is the ***OEM2100-AX Series*** **Axion™ R/S.**

With LabVIEW-based software and continually progressing technology for collecting, measuring, and analyzing emission gases and particulate matter, Axion™ R/S represents the best concepts in state-of-the-art emissions testing methodology.

From the very first OEM2100, submitted to a rigorous evaluation by the United States Environmental Protection Agency (USEPA) Environmental Technology Verification (ETV) Program, Global MRV continues to set the standard for continuous PEMS field testing. The proven, effective, and accurate on-road, off-road, and non-road real-time approach of PEMS testing has become an international 'gold standard'. Even after a dozen years of success, Axion™ R/S is repeatedly verified at several independent laboratories and university programs ensuring ongoing accuracy and advancement. Axion™ R/S sampling techniques and methodology represent over a decade of continuous feedback from customers and the company's aggressive desire to meet regulations and standards.

Global MRV is also a leader in real-world mobile emissions consulting and has successfully assisted scientists at major universities including North Carolina State, Texas Transportation Institute, and Virginia Tech. Large private companies like Hyundai Motors, Frito Lay and many international private and public sector entities have placed their trust in the capabilities of Global MRV. The team is experienced in the verification and testing of numerous mobile sources.

IHS chose to initiate a test program that favored on-road testing using PEMS technology as opposed to laboratory testing using a dynamometer. IHS believed that such a testing program would more accurately reflect the benefits of the *i-phi*™, especially in documenting the Hydrogen Break-in phenomenon.

During the past 40 years, technology improved to the point where real-world, on-road emissions and fuel economy data can be accurately measured. Many organizations in government and industry are shifting the emphasis to actual on-road tests instead of laboratory testing because such tests are a better indication of real-world conditions. This shift is witnessed with Environmental Protection Agency (EPA) and California Air Resource Board (CARB) recent initiatives to test Original Equipment Manufacturer (OEM) diesel trucks using portable emission measuring equipment. These organizations indicate that this testing method is less cumbersome and more accurate.

AXION R/S SYSTEM (PEMS)

Emissions tests were performed using an Axion R/S System, Serial Number AX08-013 manufactured by Global MRV. This system is compact, easily portable, and can be quickly installed on a variety of engines without modification.

The system samples raw, undiluted exhaust gas, and measures the concentrations of hydrocarbons (HC), carbon monoxide (CO) and carbon dioxide (CO2) using nondispersive infra-red (NDIR) methodology, and nitrogen oxide (NO) and oxygen (O2) using an electrochemical cell. As most oxides of nitrogen (NOx) leave the engine as NO on most diesel vehicles, NOx concentration is calculated from measured NO. The system utilizes two gas analyzer subsystems running in parallel, to allow for uninterrupted measurements during background calibrations, and for quality control purposes.

Particulate Matter (PM) concentration is inferred from the total light side-scattering efficiency of the sample, which is measured by a laser light scattering detector. This method allows for a very low detection limit, a wide measurement range, and fast response time. It also is the only available method that is known to work with raw, undiluted samples. The particulate sampling system utilizes a virtual impactor, excluding particles larger than the cut-off size of 1-2.5 microns. (It is generally accepted that the particles generated by the diesel engine combustion process are typically smaller than 1 micrometer, and that larger particles are primarily dust, large agglomerates of particulate matter previously deposited within the exhaust system, and particles from engine wear).

The Axion System determines the intake airflow by sensing three critical engine operating parameters: engine RPM, intake air temperature, and turbocharger boost pressure. On electronically controlled engines, these parameters are often read from the engine control unit diagnostic port. Using the known engine displacement and other engine design characteristics, the mass intake airflow is then computed. From the known composition of the fuel and the exhaust gas, mass exhaust flow is determined. Second-by-second mass exhaust emissions are then computed from time-aligned flow and concentrations.

THE *i-phi*™ HYDROGEN GENERATING MODULE (IHS)

The *i-phi*™ is a Hydrogen Generating Module for diesel engines. The *i-phi*™ produces a mixture of hydrogen and oxygen gases, on demand, through a controlled electrolysis process using distilled water. These gases are delivered to the engine's air intake system through a simple ¼" port, where they are mixed with the incoming air stream. The *i-phi*™ obtains power from the vehicle's alternator. Thus, hydrogen is produced only while the engine is running, and is never stored or under significant pressure at any time. The product has no moving parts and makes no modifications to the engine, except for a small insertion point on the engine air intake manifold to introduce the gases. This process improves the overall engine combustion efficiency by producing a more complete and faster burn of the air-fuel mixture.

TEST PROTOCOL DESIGN AND APPROVAL

A third party consultant, hereafter referred to as "Consultant", in conjuction with Innovative Hydrogen Solutions, hereafter referred to as "IHS", designed a test route(s) and plans utilizing procured equipment from Global MRV *Clean Air Technologies Division*, hereafter referred to as Global MRV, at Site 1, Elmira, Ontario and Site 2, Aurora, Ontario. These routes were duplicated on each of the testing days by utilizing the same trucks, time of day, drivers and relative weather conditions, to all extents possible.

VEHICLE SELECTION

IHS and the fleets managing the vehicles selected representative vehicles from the fleets at each location. Two vehicles were selected at the Plein test site and three vehicles were selected at the Turtle Island test site. All vehicle selections were made by the owning fleets and IHS. Test vehicle details are found in Appendix A.

Baseline testing is usually conducted whenever a new emissions reduction technology is to be tested. It consists of utilizing the same test vehicle and driver combination and measuring baseline emissions and fuel consumption characteristics over a standardized test route. To determine the actual effect of the *i-phi*™ system, a series of baseline tests were conducted. In the baseline testing phase, recycling trucks at the Plein Disposal facility and at the Turtle Island Recycling facility were driven on the test routes shown in Appendix B and baseline emissions data were collected on them using the Global MRV Axion system.

The *i-phi*™ takes approximately two to four hours to install. It only has connections to the battery, alternator and piping to the intake air system. It does not have any connection to the ECM (Engine Control Module) or ECU (Engine Control Unit). It draws power from the alternator and produces hydrogen only when the engine is running. It requires periodic refilling of the water reservoir with distilled water.

HYDROGEN BREAK-IN

According to IHS, the Hydrogen Break-in phenomenon is the delay encountered before the *i-phi*™ is effectively reducing vehicle emissions and increasing fuel mileage to its fullest capability. The stated reason for the delay (according to IHS) relates to the build-up of carbon deposits in the vehicle's engine. This period is variable depending on the age, size, and application of the engine in question. An older engine, a larger engine displacement, and a heavier load, will all equate to a longer break-in period.

BASELINE TESTING

Baseline testing occurred the weekend of April 3rd and April 4th, 2011. During this baseline process no IHS equipment was installed on any of the five trucks being tested. This allowed unadulterated levels of the O2, CO, CO2, NOx, HC and PM levels to be obtained utilizing the Axion R/S.

The five trucks being tested were driven along the routes detailed in Appendix B and baselines were established.

IHS Equipment was installed during the period after April 4th, 2011, and before comparative testing session 1 commenced.

COMPARATIVE TESTING 1 (C1)

During C1, testing was performed on each of the trucks that had obtained a previous baseline and had the *i-phi*™ Hydrogen Generation Module installed. The trucks were driven over the same course that was established in B1.

COMPARATIVE TESTING 2 (C2)

During C2, testing was performed on each of the trucks that had obtained a previous baseline and had the *i-phi*™ Hydrogen Generation Module installed. The trucks were driven over the same course that was established in B1 and driven again in C1. This round of testing was performed by representatives of Global MRV with the IHS Consultant making the recommendations on where to place the relative components of the Axion R/S, to achieve as much repeatability as possible.

COMPARATIVE TESTING 3 (C3)

After comparison of the B1 to C1 to C2, it was recommended that a third round of comparative testing be completed, thus termed as C3. This testing was completed by the IHS Consultant.

TEST PROCEDURE

The test plan was designed to provide data that would allow for the quantification of fuel and emissions reduction accomplished by the *i-phi*™, for the purpose of product verification. Test routes were developed to simulate normal operating conditions for each type of test equipment and standardized to make them as repeatable as possible. The same procedure was used for each round of testing. Four (4) routes were designed by IHS and their consultants with route analysis decided to be the main method of understanding the comparisons in the subsequent tests.

The route analysis method was recommended by Global MRV and confirmed to be used by IHS. Route analysis refers to measurement of emissions over a specific route that has been previously agreed upon. Typically, when testing is conducted on a chassis/engine dynamometer a varied set of duty cycles such as the WVU-5 peak, City Suburban Cycle and Route (CSC) are used to simulate real-world driving conditions. The test cycle is required to be representative of the type of vehicle being used, requires precise timing of vehicle operation and most importantly has to be repeatable. In the real-world, typical drive cycles that represent standard vehicle operation procedures were chosen. To minimize variations, the same drivers and routes representative of functional use were chosen.

IHS and the Consultant designed Test Routes with fleet input with regards to availability and utilization. When recycling collection trucks were being tested, routes that simulated recycling collection were chosen. The Plein city route (approximately 5kms) and the Turtle Island city, which had lower speeds and more frequent stop, were chosen for the city testing. The Plein city rural (approximately 14kms) route and the Turtle Island rural route consisted of higher speeds and less frequent stops. Details about both these routes are available in appendix B. Each route had designated stops to simulate recycling collection and to engage the vehicle PTO (crushing of collected recycling).

The test plan provides data that will allow for the quantification of fuel and emissions reduction accomplished by the *i-phi*™, for the purpose of product verification. Test routes were developed to simulate normal operating conditions for each type of test equipment while standardizing test cycles to make them as repeatable as possible.

DATA COLLECTION

Emissions data was collected on each test vehicle during the baseline test and three comparative tests. Summary information for each round of testing is found in the following table.

Test	B1	C1	C2	C3
Dates	4/3-4/2011	5/28-29/2011	7/23-24/2011	10/1-2/2011
Testing Agency	IHS Consultant	IHS Consultant	Global MRV	IHS Consultant
PEMS Manufacturer	Global MRV	Global MRV	Global MRV	Global MRV
PEMS	AX08-013	AX08-013	AX08-013	AX08-013
PEMS Calibration	Pre-Rental	Pre-Rental	Pre-Rental	Pre-Rental

Table 1: Test Phase Data Collection Information.

Emissions testing started in April, 2011, with the baseline test phase and proceded until October, 2011, at the completion of the third comparative test. The same Global MRV PEMS was used for all test phases. IHS hired a consultant to operate the PEMS and conduct emissions testing procedures for the B1, C1, and C3 phases. Global MRV was hired to operate the PEMS and follow the emissions testing procedures developed by the IHS consultant during the C2 phase. For each test phase Global MRV performed calibration of the PEMS to BAR97 standards before the PEMS was shipped to the testing location.

Details on the number of test route runs completed and total amount of emissions data collected for each test vehicle during each test phase are found in the tables below.

Test	B1	C1	C2	C3
P-1 City Routes	5	5	5	4
P-1 Rural Routes	5	5	5	4
Total P-1 Test Time	4:24:50	3:21:35	3:53:23	2:32:37
P-2 City Routes	5	5	0	4
P-2 Rural Routes	5	5	3	4
Total P-2 Test Time	3:27:35	3:35:42	1:26:15	2:14:55

Table 2: Emissions data collected on Plein test vehicles.

Test	B1	C1	C2	C3
TI-1 City Routes	5	5	5	5
TI-1 Rural Routes	4	5	4	4
Total TI-1 Test Time	2:11:31	1:53:54	3:25:40	2:34:11
TI-2 City Routes	6	5	5	5
TI-2 Rural Routes	4	5	5	4
Total TI-2 Test Time	2:23:30	1:57:35	2:24:06	1:51:24
TI-3 City Routes	6	6	3	4
TI-3 Rural Routes	1	1	2	2
Total TI-3 Test Time	1:46:04	1:12:55	1:05:14	1:09:03

Table 3: Emissions data collected on Turtle Island test vehicles.

As indicated in the above tables, the inclusion of a third vehicle at the Turtle Island test location resulted in fewer average data being collected per test vehicle. This also resulted in the inability to complete the desired number of test route runs on the third vehicle at this location due to reaching the maximum number of working hours for the vehicle driver during each day of testing.

It is also notable that the initial test vehicle at each test site was used for the creation of test routes (phase B1) and the confirmation of test routes (phase C2) which resulted in a larger amount of data being collected on these vehicles.

DATA VERIFICATION

Team members including Global MRV personnel and the IHS consultant conducted each test to replicate the City and Rural drive cycles. One member of the team focused on monitoring the performance and proper functioning of the Axion system.

Data screening and quality assurance are procedures for reviewing the field data in order to produce a valid database of emission quantities. These procedures are used to: (a) determine whether any errors or problems exist in the data; (b) correct such errors or problems where possible; and (c) remove invalid data if errors or problems cannot be corrected.

Occasional data loss from the vehicle ECU was identified. Missing sections of 3 seconds or less have been interpolated and used to calculate mass emissions values. Missing sections longer than 3 seconds have been omitted from the analysis.

Several sections of incorrect (higher than ambient) oxygen concentrations were found for gas analyzer 1 during the B1 phase of testing. These values were excluded from the analyzed data.

The hydrocarbon values reported from gas analyzer 2 were found to drift throughout much of the emissions testing. These values were excluded from the analyzed data.

The data collected at the Turtle Island test site during C1 and C2 test phases was found to have different time alignment values than the remainder of the collected data. The subsystem alignment times for the Axion system were corrected and the mass emissions rate data recalculated.

Additionally, the control of the gas analyzer ambient reference function was handled manually by the operating technicians throughout the four rounds of data collection. In several instances the technician chose to reference both analyzers concurrently, resulting in no valid concentration data being collected. The affected data was not during the completion of any of the designated test routes. This data was also removed from the emissions database used for modal analysis.

DATA ANALYSIS

The intent of the project was to develop vehicle routes that would simulate the specific vehicle duty cycles and then perform repetitions of the routes with the vehicles to determine the emissions. This method requires precise repetition of vehicle operation during data collection but then yields easily analyzed data as the variability of the vehicle operation has been minimized.

Through completion of the route analysis it was found that variations in performing the routes limited the amount of data available for comparison. Identified causes for variations in the routes include driver operation caused by not maintaining the same drivers throughout the test rounds, PEMS technician and driver caused failures to complete the standardized route stops successfully, and environmental changes in traffic. Due to this, it was determined that a modal analysis method should be used to enable the comparison of all of the collected data to accurately determine the affects of the *i-phi*™system.

Modal Analysis

In order to estimate effects associated with driving dynamics, the modal operation of a vehicle and related emissions need to be analyzed. Modal emissions-based models relate emissions directly to the operating mode of vehicles based on mapping. This approach has been employed since the 1970s for fuel economy models.

The conceptual approach is to map real-time emissions rates to engine load. Engine load obtained through the vehicle ECU is recorded by the Axion system and is automatically aligned with the collected emissions data. Using the full set of vehicle operation and emissions data for each vehicle, the emissions rates are defined as a function of engine load for each of the rounds of emissions testing.

The mapping of vehicle emissions rates to engine load have been completed using engine modes defined in 10% segments. The modal emissions rates of carbon dioxide for test vehicle P-1 are shown in the chart below. Modal emissions charts for each emissions parameter tested for all test vehicles are found in the appendix.

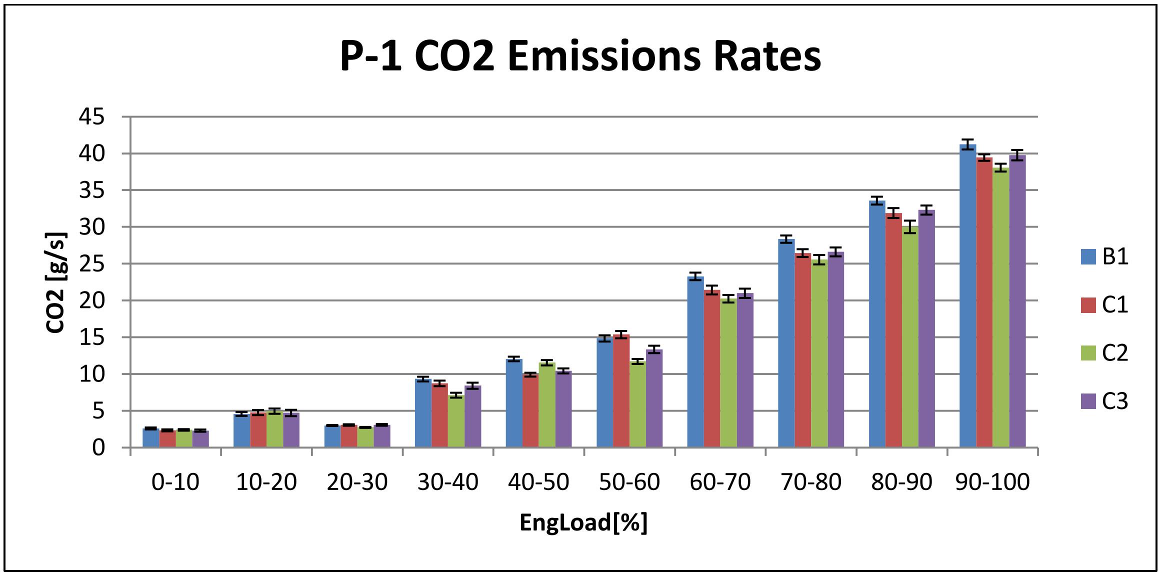


Figure A

The modal emissions in the chart above show the emission rates at each engine load range for all four rounds of testing (B1, C1, C2, C3) differentiated by the color of the data series. Plotted error bars indicate the 95% confidence interval.

The modal emissions rates can be used to estimate the total emissions for a given set of vehicle activities. This is accomplished by defining the desired vehicle activity as a function of engine load.

As two designated vehicle routes were defined for each test location of this project, the same routes have been used to define two vehicle activities for each test location; a 'City Route' and a 'Rural Route'.

For each test location a single data set for a City Route and a Rural Route were selected. The engine data for the route was classified within the defined 10% engine load ranges and the number of data points within each range was determined.

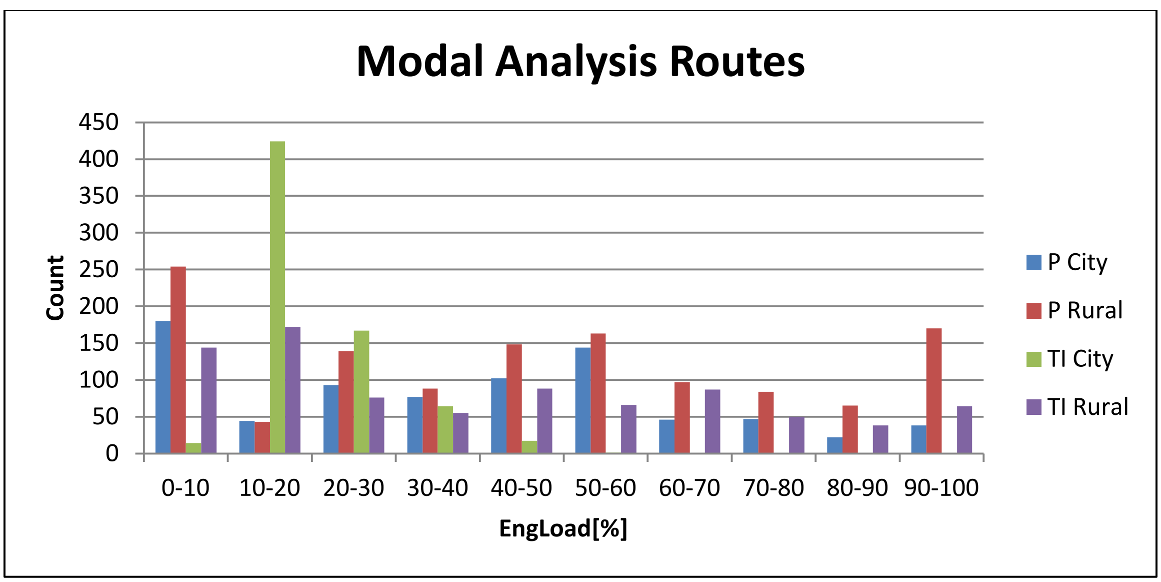


Figure B

Rural routes have higher average engine load due to higher speeds and less frequent vehicle stops.

The total emissions for the standardized vehicle routes was then calculated from the engine load based emission rates and the engine load based routes. Multiplying the emissions and fuel consumption rates for each engine load operating range by the number of seconds the vehicle operated within that range gives the total emissions or fuel consumption within the engine operating range for the route. The summation of the emissions and fuel consumption values for all engine operating ranges then yields the total emissions and fuel consumption for the vehicle route.

The 95% confidence intervals of the emissions rates are similarly multiplied by the frequency of route data points within each engine load range to determine the error associated with the vehicle test routes.

The total emissions and fuel used by vehicle P-1 for the P City route are shown below. Results from all test vehicles are found in the appendix.

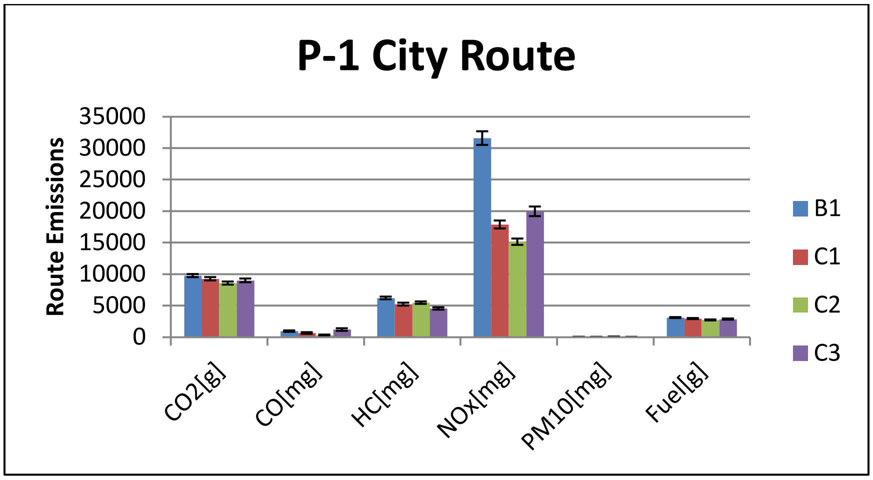


Figure C

The data series in the above chart show each of the pollutants tested and the fuel consumption for all four rounds of testing (B1, C1, C2, C3) differentiated by the color of the data series. Plotted error bars indicate the 95% confidence interval.

The total route emissions can then be used to calculate the difference in emissions between each round of testing. The percent change in each parameter has been calculated relative to the baseline results.

The chart below shows the changes in both the City and Rural route emissions and fuel consumption for test vehicle P-1 between the B1 and C1 test phases.

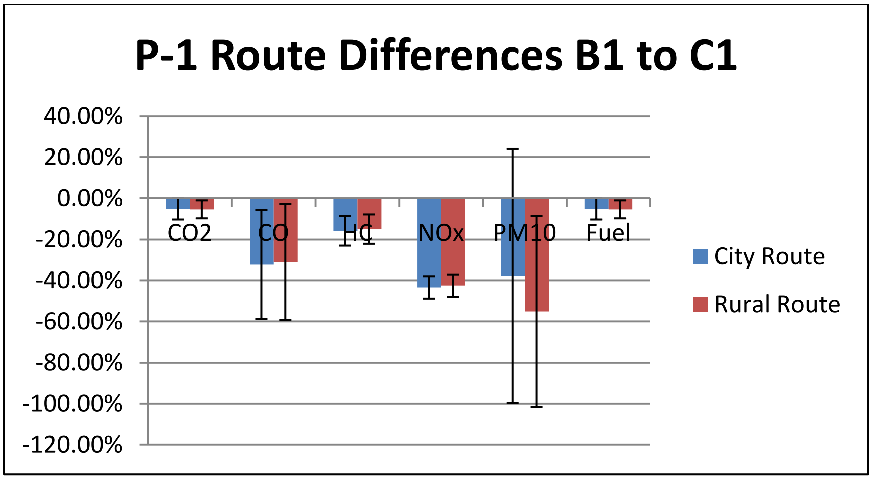


Figure D

The data series in the above chart show each of the pollutants tested and the fuel consumption for both of the two test routes (City and Rural) differentiated by the color of the data series. Plotted error bars indicate the 95% confidence interval.

Negative changes indicate reductions from the former to the latter phase (i.e. from B1 to C1). Conversely, positive changes indicate increases. If the error bars are completely on either the positive or negative side of the chart, it indicates a statistically significant change between test phases.

RESULTS

Global MRV has evaluated the data collected from the Plein City testing route and Turtle Island Rural testing route against their respective baseline to determine overall performance of the *i-phi*™. This method serves as the basis for Global MRV's performance claim conclusions. All analysis and explanations are supported by graphs and summary tables. The data is represented in suitable units. Since percentages are used, the unit of measurement is not of significance, and does not impact the results. Tables and graphs also show 95% confidence intervals and these are used to make determinations.

Test Nomenclature used:-

1. Plein City trucks are referred to as P-1 and P-2.
2. Turtle Island Rural trucks are referred to as TI-1, TI-2 & TI-3.
3. B1 = Baseline 1, C1 = Comparative 1, C2 = Comparative 2, C3 = Comparative 3.

Test Vehicle P-1

Tables 4, 5 and 6 show the results for Truck P-1 when comparing baseline (B1) to comparative tests C1, C2 and C3 respectively, for the City and Rural route.

Route Results Vehicle P-1		CO2	CO	HC	NOx	PM10	Fuel
B1 to C1 City Route	%Change	-5.13%	-32.27%	-15.84%	-43.44%	-37.79%	-5.14%
	95%Confidence	5.19%	26.58%	7.15%	5.43%	61.94%	5.18%
	SignificantChange	**NA**	**-5.68%**	**-8.69%**	**-38.01%**	**NA**	**NA**
B1 to C1 Rural Route	%Change	-5.38%	-31.04%	-14.97%	-42.56%	-55.14%	-5.39%
	95%Confidence	4.37%	28.26%	7.12%	5.42%	46.56%	4.37%
	SignificantChange	**-1.01%**	**-2.78%**	**-7.86%**	**-37.14%**	**-8.59%**	**-1.03%**

Table 4: Truck P-1, route emission comparison for B1 to C1.

Route Results Vehicle P-1		CO2	CO	HC	NOx	PM10	Fuel
B1 to C2 City Route	%Change	-12.17%	-69.43%	-12.05%	-52.10%	262.17%	-12.18%
	95%Confidence	5.02%	22.49%	6.56%	5.02%	192.03%	5.02%
	SignificantChange	**-7.15%**	**-46.94%**	**-5.49%**	**-47.09%**	**70.15%**	**-7.16%**
B1 to C2 Rural Route	%Change	-10.67%	-69.63%	-11.45%	-49.96%	179.35%	-10.68%
	95%Confidence	4.36%	24.59%	6.76%	5.10%	152.91%	4.36%
	SignificantChange	**-6.31%**	**-45.04%**	**-4.69%**	**-44.86%**	**26.44%**	**-6.32%**

Table 5: Truck P-1, route emission comparison for B1 to C2.

Route Results Vehicle P-1		CO2	CO	HC	NOx	PM10	Fuel
B1 to C3 City Route	%Change	-7.82%	26.72%	-26.93%	-36.83%	-41.54%	-7.83%
	95%Confidence	5.54%	34.71%	6.48%	5.85%	11.32%	5.54%
	SignificantChange	**-2.28%**	**NA**	**-20.44%**	**-30.97%**	**-30.22%**	**-2.29%**
B1 to C3 Rural Route	%Change	-6.56%	24.99%	-27.78%	-35.63%	-43.82%	-6.58%
	95%Confidence	4.75%	36.93%	6.59%	5.84%	13.68%	4.75%
	SignificantChange	**-1.81%**	**NA**	**-21.18%**	**-29.79%**	**-30.14%**	**-1.82%**

Table 6: Truck P-1, route emission comparison for B1 to C3.

In table 4, the City route shows statistically significant reductions for CO, HC and $NO_{x,}$ whereas the Rural route shows significant reductions for all categories.

In table 5, the City and Rural routes show statistically significant increases in particulate emissions and reductions for all other pollutants and fuel consumption.

In table 6, the City and Rural route show statistically significant reductions for CO_2, HC, NO_x and PM_{10} and also fuel consumption. CO emissions showed a probable increase that was not statistically significant due to the large 95% confidence interval.

Figures E, F and G, show graphical comparisons of pollutant concentrations and fuel used for the comparisons of the three different comparative tests to the baseline values. Each figure shows a comparison between the City route and the Rural route for that particular comparison. These figures correspond to the data found in the above route result tables for test vehicle P-1.

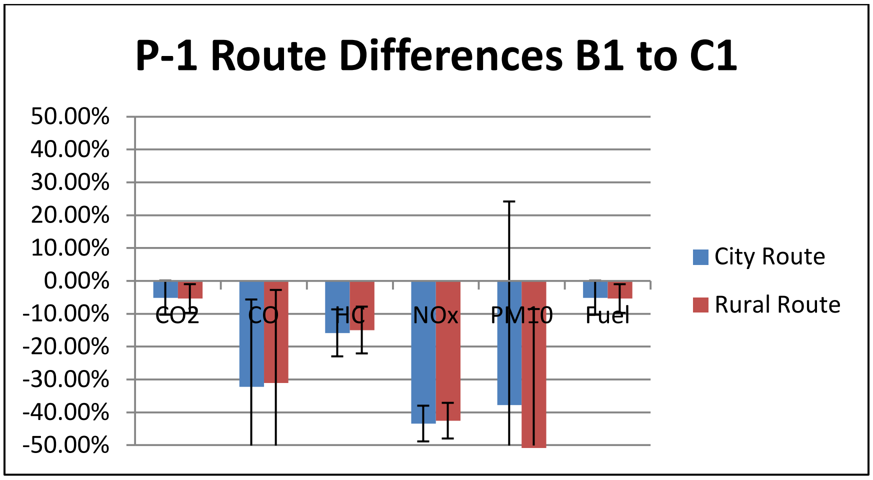


Fig.E: Truck P-1, route emission comparison for B1 to C1.

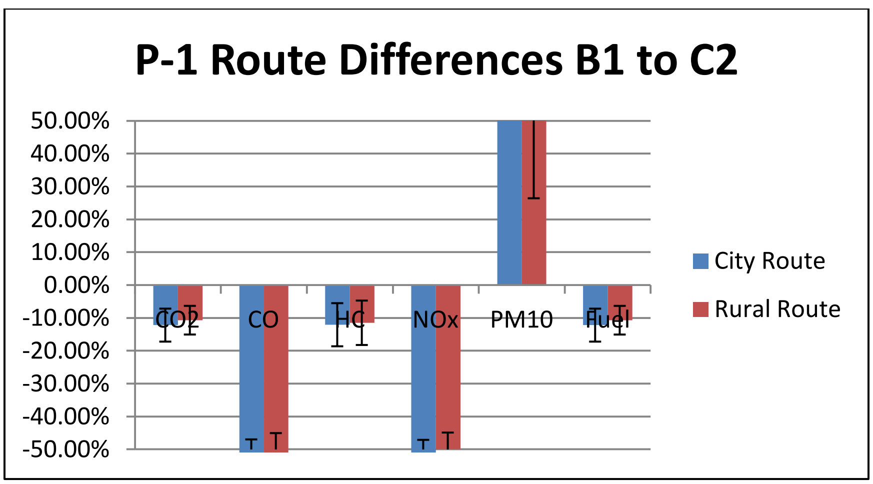


Fig. F: Truck P-1, route emission comparison for B1 to C2.

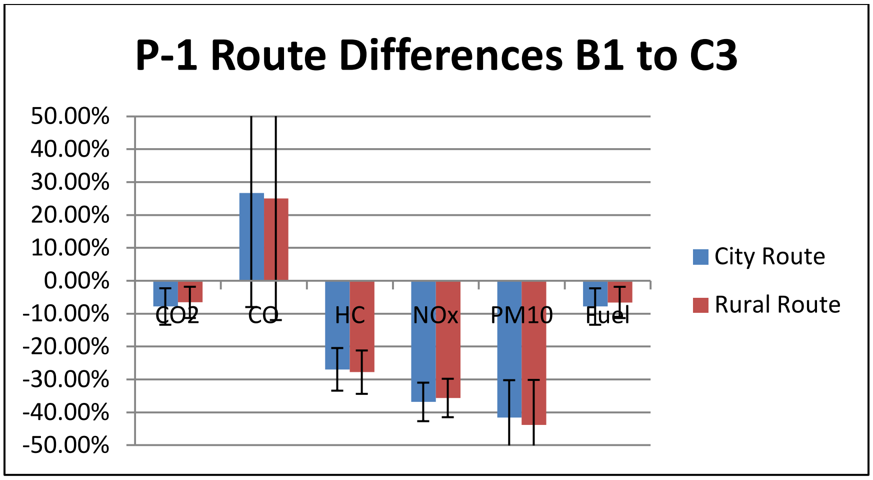


Fig. G: Truck P-1, route emission comparison for B1 to C3.

Where the previous result tables and figures have shown the results grouped by the comparative test (C1, C2, C3), Figures H and I show all three test comparisons by route (P City, P Rural). These figures provide the route results across time.

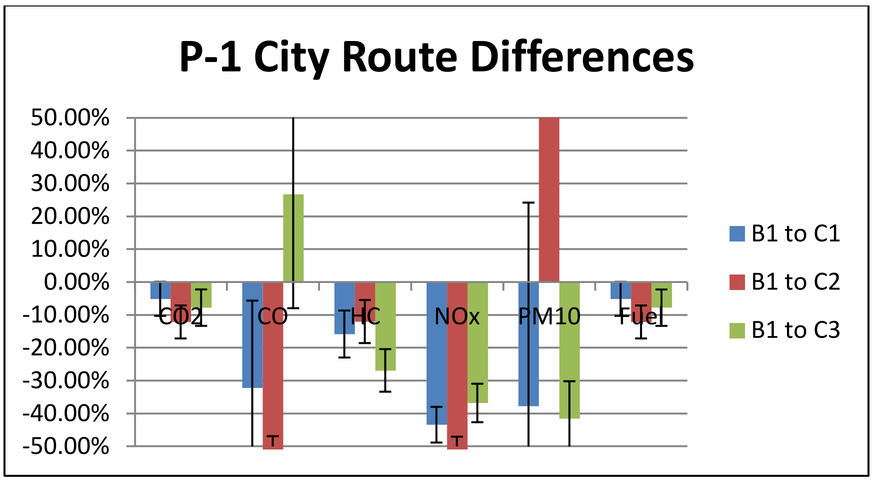


Fig. H: Truck P-1, City route comparison.

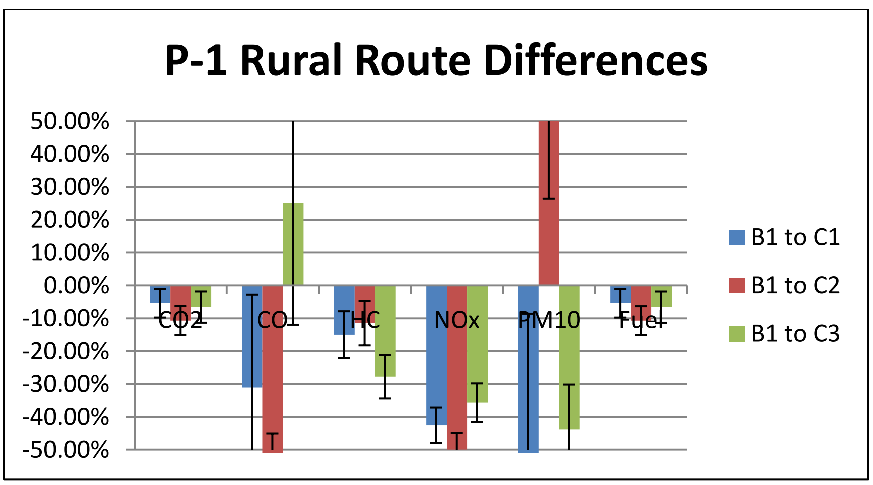


Fig. I: Truck P-1, Rural route comparison.

Figures H and I show similar trends in the results for the city and rural routes.

It is visible that the greatest reductions in CO_2, CO, NOx, and fuel use were achieved during the second comparative test (B1 to C2).

Also shown is a consistent statistically significant reduction in CO2, HC, NOx, and fuel consumption through all rounds of comparative testing.

Test Vehicle P-2

Truck P-2 had an EGR replacement between B1 and C1. This mechanical repair of the vehicle has introduced additional variables into the data collected during all three comparative tests.

Discussion is not provided on the results from vehicle P-2 due to the mechanical repair conducted prior to any of the comparative tests.

Test Vehicle TI-1

Tables 7, 8 and 9 show the results for Truck TI-1 when comparing baseline to sections 1, 2 and 3 respectively, for the City and Rural route.

Route Results Vehicle TI-1		CO2	CO	HC	NOx	PM10	Fuel
B1 to C1 City Route	%Change	-1.98%	-25.88%	-61.16%	-40.52%	0.41%	-2.23%
	95%Confidence	7.37%	23.44%	6.68%	5.89%	10.19%	7.35%
	SignificantChange	**NA**	**-2.44%**	**-54.48%**	**-34.63%**	**NA**	**NA**
B1 to C1 Rural Route	%Change	-7.49%	-56.99%	-60.12%	-36.45%	1.24%	-7.76%
	95%Confidence	6.17%	27.14%	8.79%	7.01%	10.72%	6.15%
	SignificantChange	**-1.32%**	**-29.85%**	**-51.34%**	**-29.44%**	**NA**	**-1.60%**

Table 7: Truck TI-1, route emission comparison for B1 to C1.

Route Results Vehicle TI-1		CO2	CO	HC	NOx	PM10	Fuel
B1 to C2 City Route	%Change	-15.52%	-15.60%	-67.64%	-37.98%	422.11%	-15.64%
	95%Confidence	6.07%	18.83%	6.28%	5.20%	21.53%	6.03%
	SignificantChange	**-9.44%**	**NA**	**-61.35%**	**-32.77%**	**400.59%**	**-9.61%**
B1 to C2 Rural Route	%Change	-13.85%	-76.62%	-52.00%	-31.60%	544.40%	-14.14%
	95%Confidence	6.88%	24.68%	9.38%	7.68%	33.16%	6.86%
	SignificantChange	**-6.97%**	**-51.94%**	**-42.61%**	**-23.93%**	**511.24%**	**-7.29%**

Table 8: Truck TI-1, route emission comparison for B1 to C2.

Route Results Vehicle TI-1		CO2	CO	HC	NOx	PM10	Fuel
B1 to C3 City Route	%Change	-8.03%	-51.95%	-74.28%	-23.72%	-45.01%	-8.37%
	95%Confidence	6.52%	21.08%	5.71%	5.97%	7.50%	6.51%
	SignificantChange	**-1.52%**	**-30.87%**	**-68.57%**	**-17.74%**	**-37.51%**	**-1.87%**
B1 to C3 Rural Route	%Change	-6.01%	-54.87%	-70.22%	-23.37%	-22.67%	-6.29%
	95%Confidence	6.09%	27.57%	8.06%	7.63%	12.77%	6.07%
	SignificantChange	**NA**	**-27.30%**	**-62.16%**	**-15.73%**	**-9.90%**	**-0.22%**

Table 9: Truck TI-1, route emission comparison for B1 to C3.

In table 7, the city route shows statistically significant reductions of CO, HC and NO_x, whereas the rural route shows reductions for all categories other than PM_{10}.

In table 8, reductions in CO2, HC, NOx, and fuel consumption are shown for both city and rural routes. PM emissions are found to increase for both routes. CO emissions show a statistically significant reduction in the rural route results and a probable reduction from the city route.

In table 9, a statistically significant reduction in CO2 emissions is found for the city route and a probable reduction is found for the rural route. All other route emissions and fuel consumption are found to have statistically significant reductions.

Figures J, K and L show graphical comparisons of pollutant concentrations and fuel used for the three different test comparisons for Truck TI-1. Each figure shows a comparison between the City route and the Rural route for that particular section. Figures M and N show overall city and rural route comparisons.

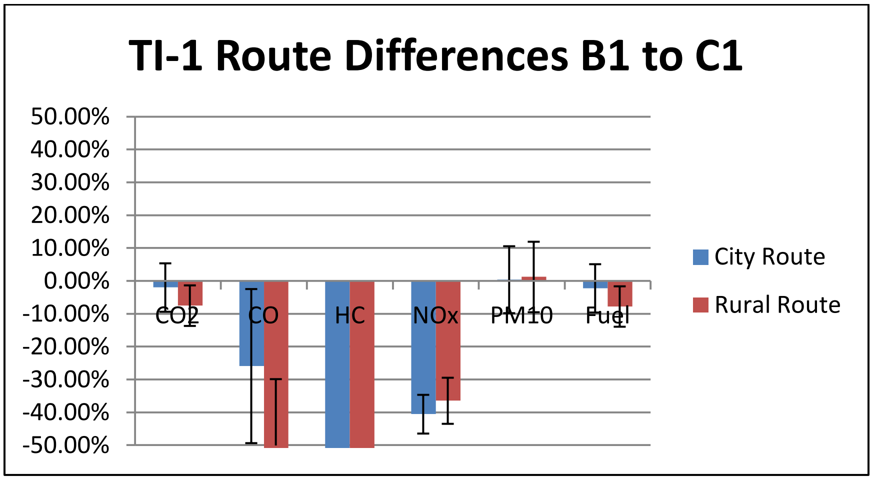


Fig. J: Truck TI-1, route emission comparison for B1 to C1.

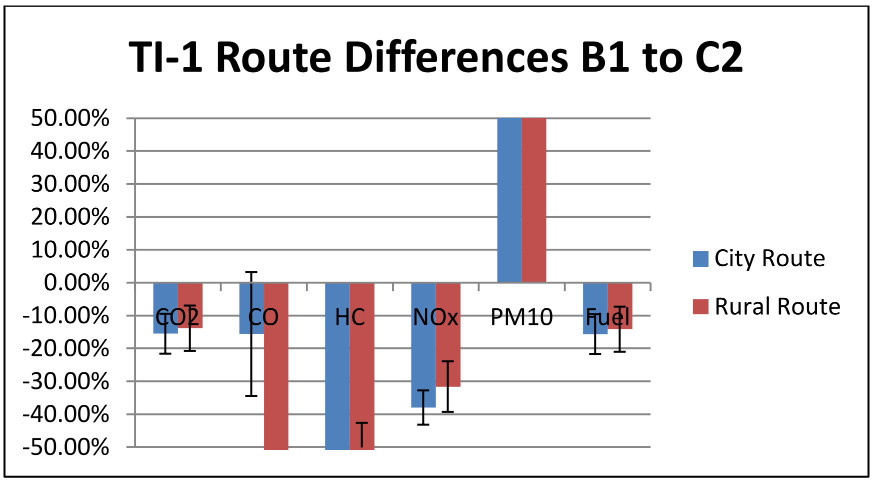


Fig. K: Truck TI-1, route emission comparison for B1 to C2.

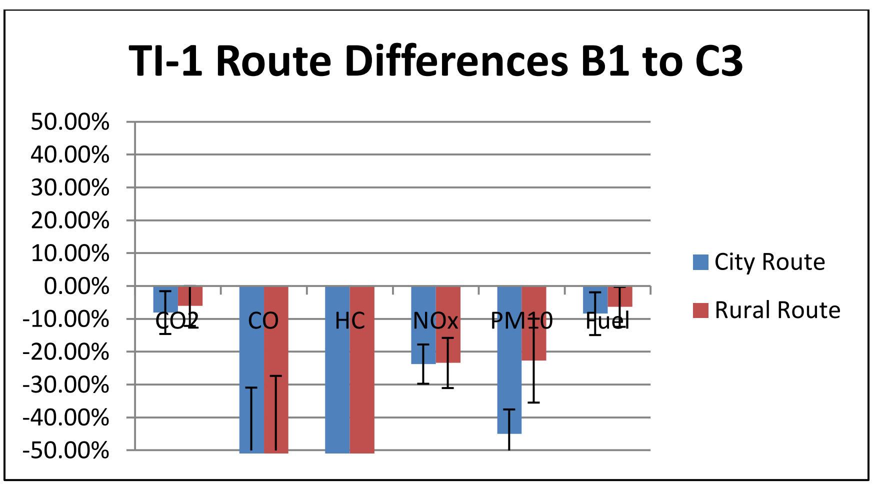


Fig. L: Truck TI-1, route emission comparison for B1 to C3.

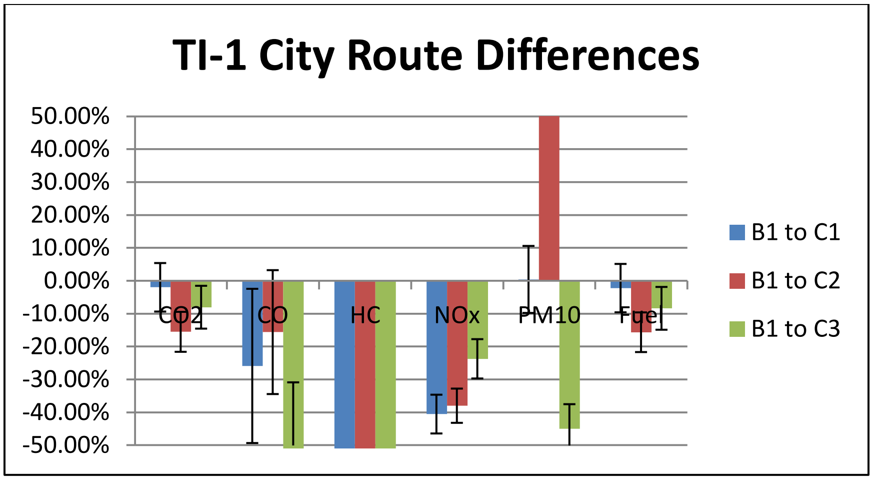


Fig. M: Truck TI-1, City route comparison.

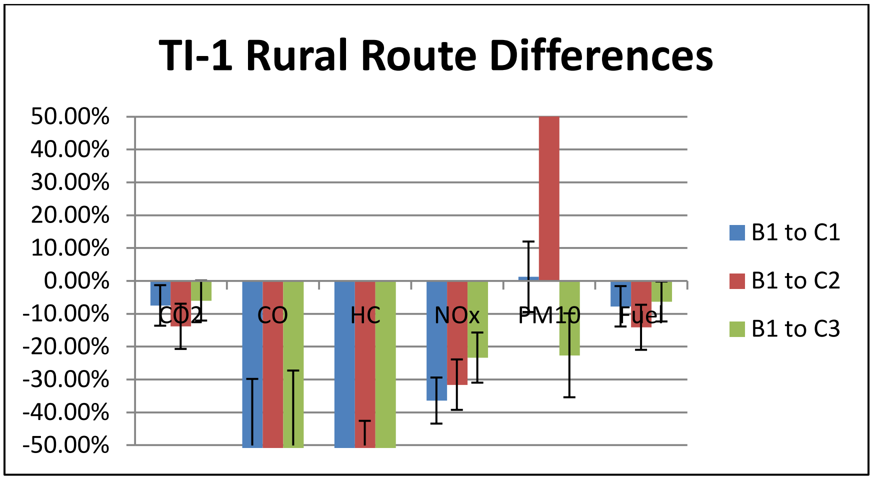


Fig. N: Truck TI-1, Rural route comparison.

It is visible that the greatest reductions in CO2 and fuel use were achieved during the second comparative test (B1 to C2). Significant or probable reductions in CO2 and fuel use were found during all rounds of comparative testing.

Excepting PM, all emissions and fuel consumption showed immediate reductions after the baseline testing.

Except for the first comparative test city route, there was consistent reduction in CO2, HC, NOx, and fuel consumption relative to the baseline test.

Test Vehicle TI-2

Test Vehicle TI-2 data did not provide statistically significant comparisons for any of the comparative emissions test relative to the baseline data.

Test Vehicle TI-3

Test Vehicle TI-3 data did not provide statistically significant comparisons for any of the comparative emissions test relative to the baseline data.

CONCLUSIONS

The completion of modality analysis provided comparable results from each phase of testing. As the decision to incorporate modal analysis was made after the completion of the second comparative test phase it was found that the uncertainty in the analysis was larger than desired due to the relatively small amount of data collected on each vehicle for each test phase. Increasing the amount of collected data will decrease the amount of uncertainty in the results. It is suggested that for future projects a minimum of four hours of data be collected per vehicle per test.

Results from test vehicles TI-2 and TI-3 contained larger uncertainty due to the smaller amount of data collected on these vehicles through all rounds of testing.

Of the three vehicles with larger emissions data sets, vehicle P-2 underwent mechanical repair between the baseline and comparative test phases. Therefore changes in emissions rates from this vehicle cannot be considered to be the result of the *i-phi*™ system alone.

Vehicle P-1 showed statistically significant reductions in CO2, HC, NOx, PM, and fuel consumption. Emissions reductions of CO were found during the first two comparative tests but were inconclusive during the final comparative test. Average reductions for the city and rural route were 7.19% (±5.15%) in CO2, 27.36% (±6.54%) in HC, 36.23% (±5.85%) in NOx, 42.68% (±12.50%) in PM, and 7.21% (±5.15%) in fuel consumption.

Similarly, vehicle TI-1 had statistically significant reductions for all pollutants measures as well as decreases in fuel consumption. Average reductions for the city and rural route were 7.02% (±6.31%) in CO2, 53.41% (±24.33%) in CO, 72.25% (±6.89%) in HC, 23.55% (±6.80%) in NOx, 33.84% (±10.14%) in PM, and 7.33% (±6.29%) in fuel consumption.

The statistically significant reductions in pollutants and fuel consumption averaged for both test vehicles was 7.11% (±5.73%) in CO2, 49.80% (±6.71%) in HC, 29.89% (±6.32%) in NOx, 38.26% (±11.32%) in PM, and 7.27% (±5.72%) in fuel consumption.

In both properly operating vehicles it was found that there was a increase in particulate emissions followed by a decrease relative to the baseline data. This is consistent with the break-in period results of a similar IHS combustion enhancement device previously documented by Global MRV and is an indication of the removal of built up particulates within the vehicle exhaust system.

Overall results from this project indicate favorable reductions in the emissions and in fuel consumption of vehicles equipped with the IHS *i-phi*™ system.

APPENDIX A: VEHICLE DATA

Test Vehicle Information					
Location	Plein	Plein	TurtleIsland	TurtleIsland	TurtleIsland
VehicleID	P-1	P-2	TI-1	TI-2	TI-3
Truck#	R15	R14	6482	6472	6485
lic.plate	690-7WX	249-4WS	803-9VM	826-4VL	807-3VM
VehicleYear	2009	2009	2007	2007	2007
VehicleMake	International	International	Fanotech	Fanotech	Fanotech
VehicleModel			F175HT3V	F175HT3V	F175HT3V
EngineMake	International	International	Caterpillar	Caterpillar	Caterpillar
EngineModel	GDT225	GDT225	C7	C7	C7
EngType	Compression	Compression	Compression	Compression	Compression
Displacement (L)	7.6	7.6	7.2	7.2	7.2
Turbo?	Yes	Yes	Yes	Yes	Yes
Transmission	Automatic	Automatic	Automatic	Automatic	Automatic
Description	Recycling Truck	Recycling Truck	Recycling Truck	Recycling Truck	Recycling Truck
Load Type	Side	Side	Back	Back	Back
Notes	Alum. Bed	Steel Bed	Steel Bed	Steel Bed	Steel Bed

Photographs of Vehicles

Photo: Plein Disposal Incorporated (Truck R-14)
License Plate Identification Tag: 249-4WS

Photo: Plein Disposal Incorporated (Truck R-15)
License Plate Identification Tag: 690-7WX

Photo: Turtle Island Recycling (Truck 6482)
License Plate Identification Number: 803-3VM

Photo: Turtle Island Recycling (Truck 6472)
License Plate Identification Tag: 826-4VL

Photo: Turtle Island Recycling (Truck 6485)
License Plate Identification Tag: 807-3VM

APPENDIX B: TEST ROUTES

PLEIN CITY ROUTE TESTING

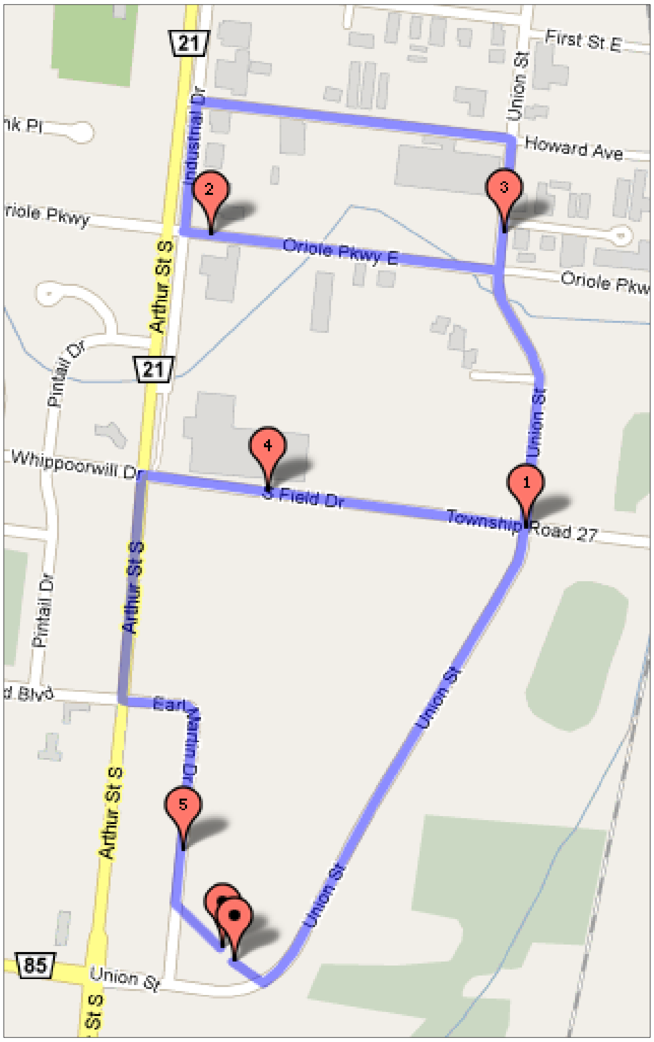


Figure DD: Plein City Route (Approximately 5km)

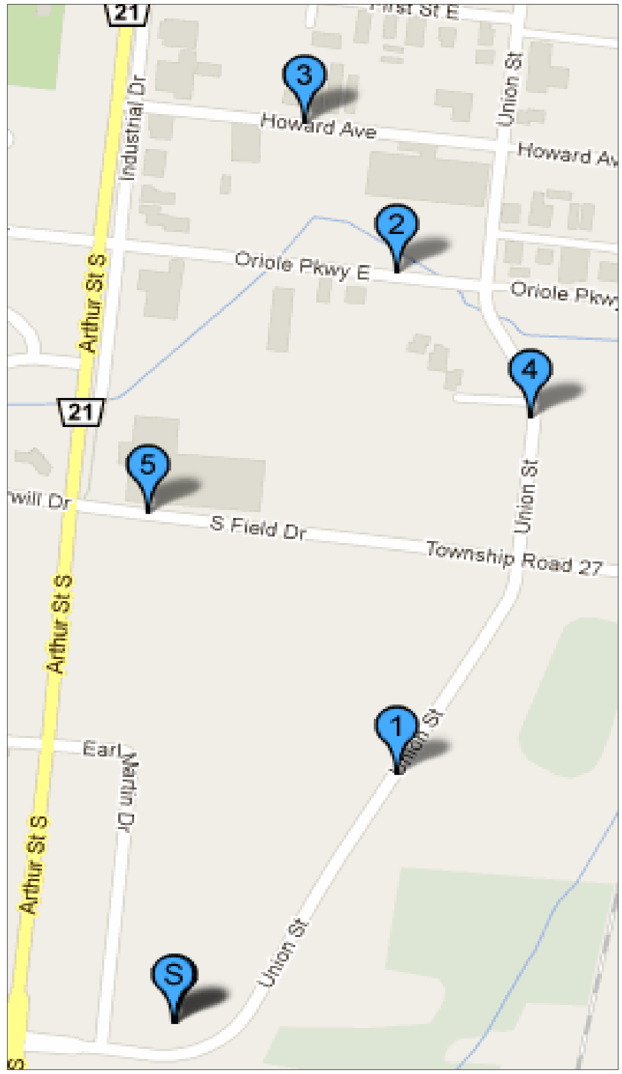


Figure EE: Plein City Route with PTO stops included, plotted on Google Maps.

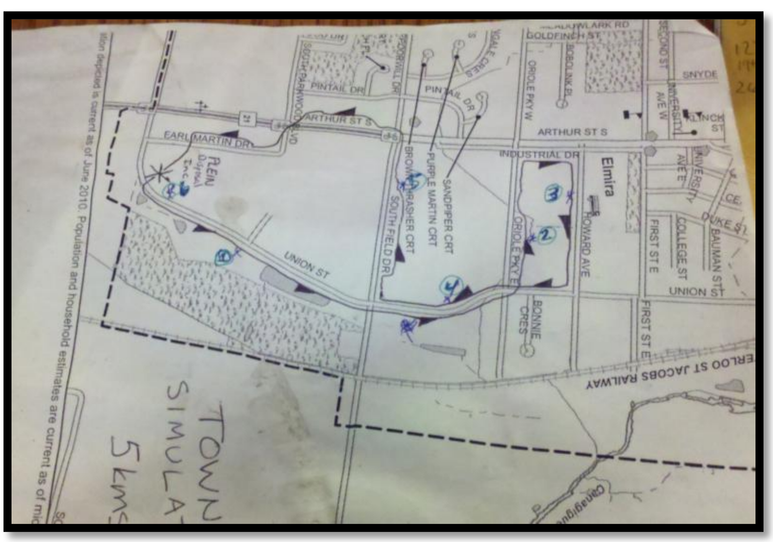


Figure FF: Plein City Route with PTO stops included, plotted on local map.

APPENDIX B: TEST ROUTES (CONTINUED)

Plein City Route Photographs:

Photo: Plein City Start Location

Photo: Plein City PTO Stop 1

Photo: Plein City PTO Stop 2

Photo: Plein City PTO Stop 3

Photo: Plein City PTO Stop 4

Photo: Plein City PTO Stop 5

APPENDIX B: TEST ROUTES (CONTINUED)

PLEIN RURAL ROUTE

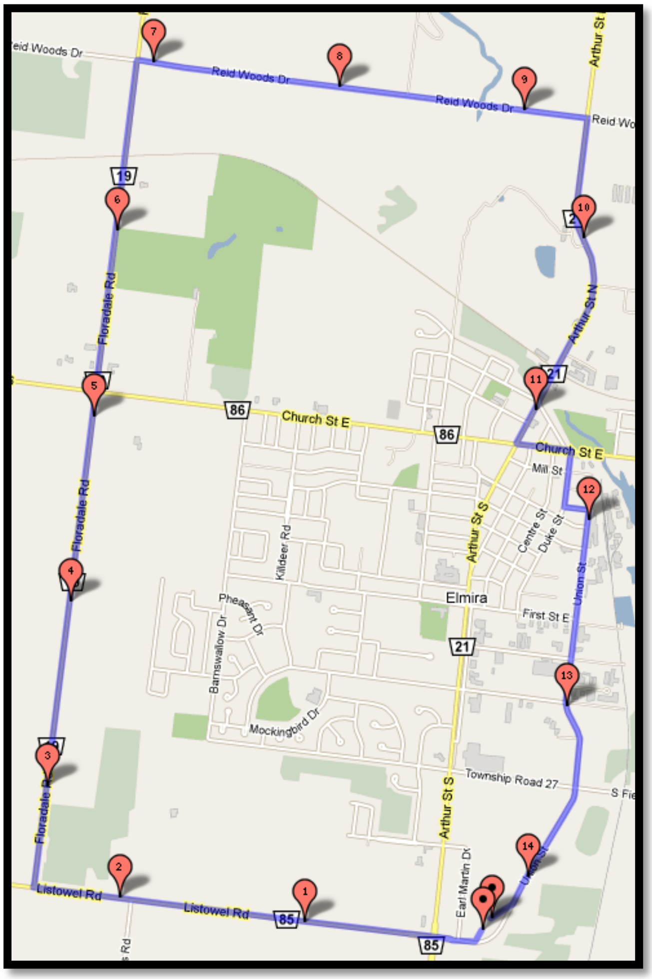


Figure GG: Plein Rural Route

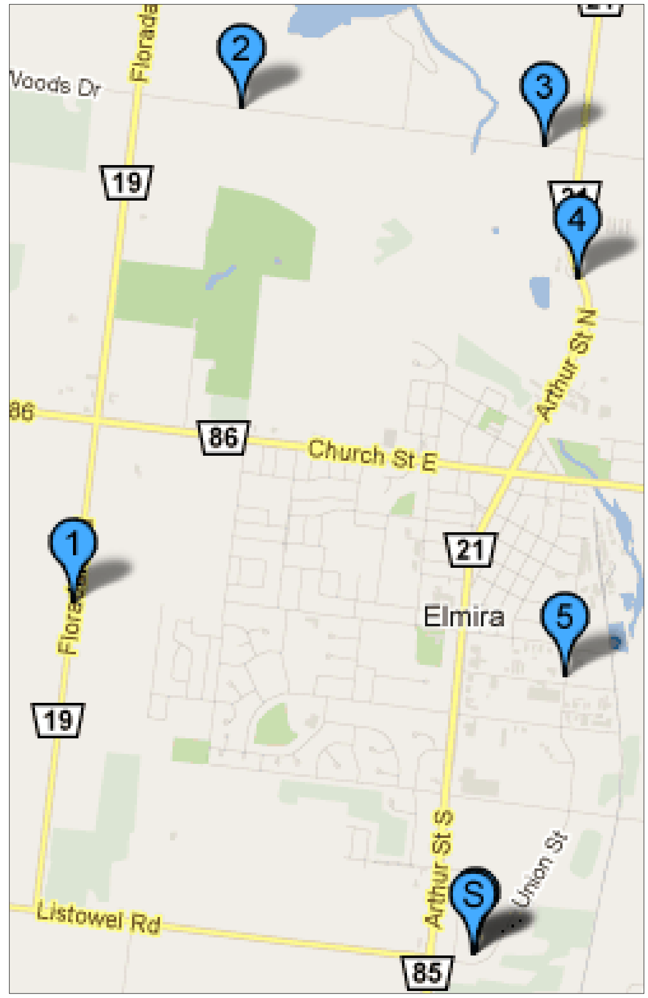


Figure HH: Plein Rural Route with PTO Stops Included, plotted on Google Maps

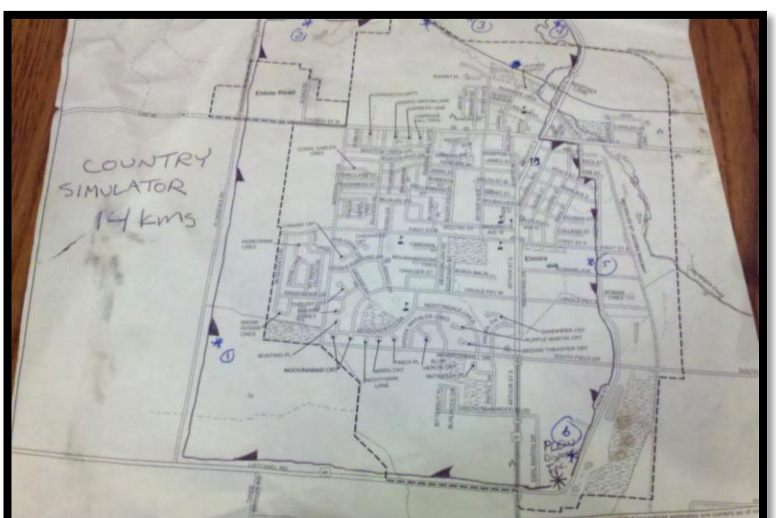


Figure II: Plein Rural Route with PTO stops included, plotted on local map.

APPENDIX B: TEST ROUTES (CONTINUED)

Plein Rural Route Photographs:

Photo: Plein Rural Route Start Location

Photo: Plein Rural Route First Stop Light

Photo: Plein Rural Route PTO Stop 1 Photo A

Photo: Plein Rural Route PTO Stop 1 Photo B

Photo: Plein Rural Route PTO First Rural Stop Sign

Photo: Plein Rural Route PTO 2

APPENDIX B: TEST ROUTES (CONTINUED)


Photo: Plein Rural Route PTO 3


Photo: Plein Rural Route PTO 4


Photo: Plein Rural Route PTO 5

Turtle Island City Route

Figure JJ: Turtle Island city route with stops included

Turtle Island City Route Photographs:

Due to the 38 stops being involved in the city portion of the testing, only the representative Google Map is displayed here.

APPENDIX B: TEST ROUTES (CONTINUED)

Turtle Island Rural Route

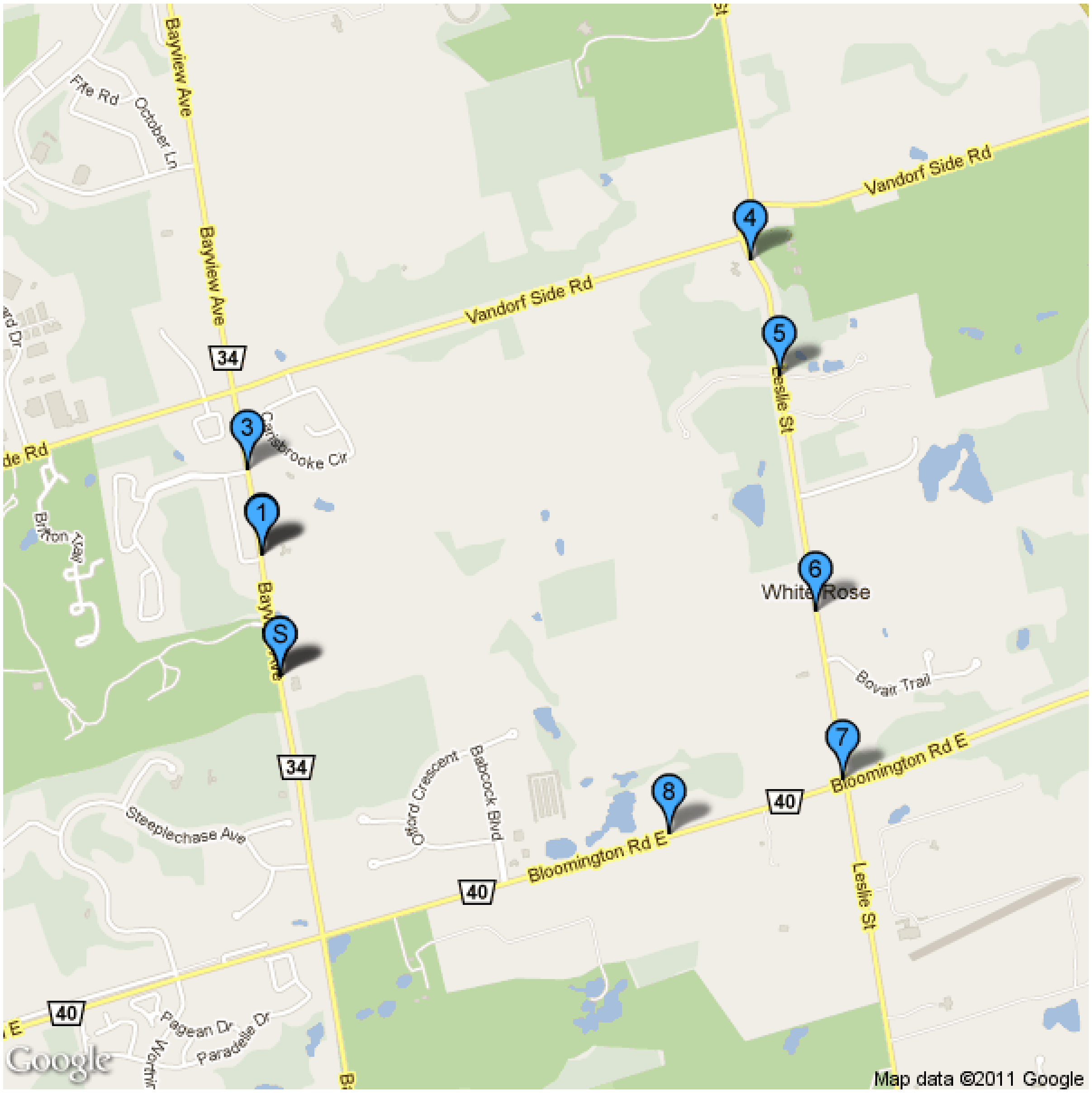


Figure KK: Turtle Island rural route with stops included

APPENDIX B: TEST ROUTES (CONTINUED)

Turtle Island Rural Route Photographs:

Photo: Turtle Island Rural Start/Stop

Photo: Turtle Island Rural Stop 1 PTO 1

Photo: Turtle Island Rural Stop 2 PTO 2

Photo: Turtle Island Rural Stop 3

Photo: Turtle Island Rural Stop 4

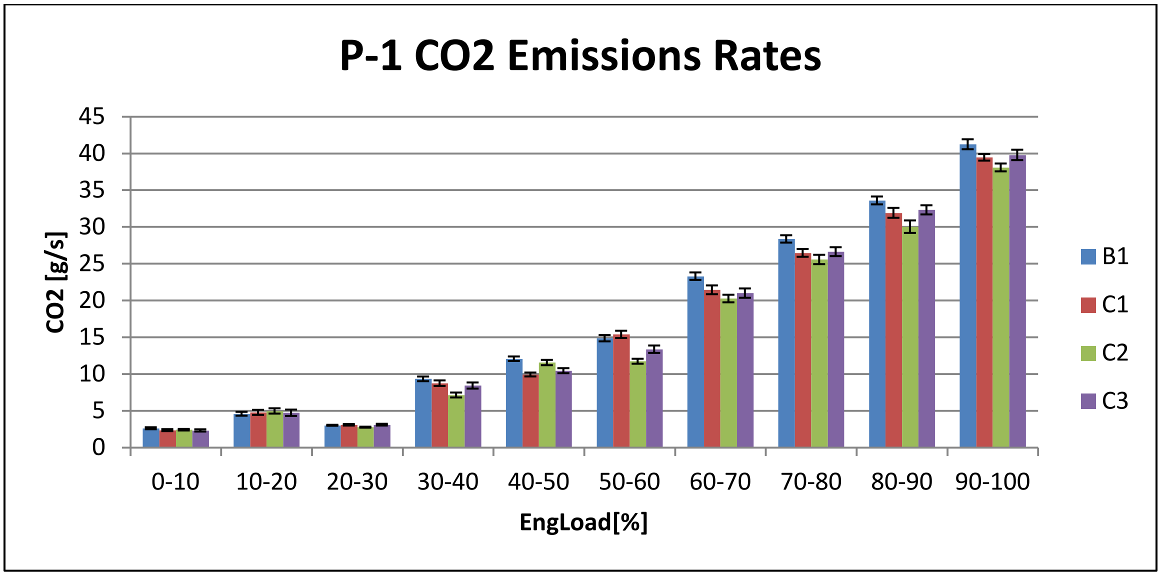
Photo: Turtle Island Rural Stop 5 Photo A

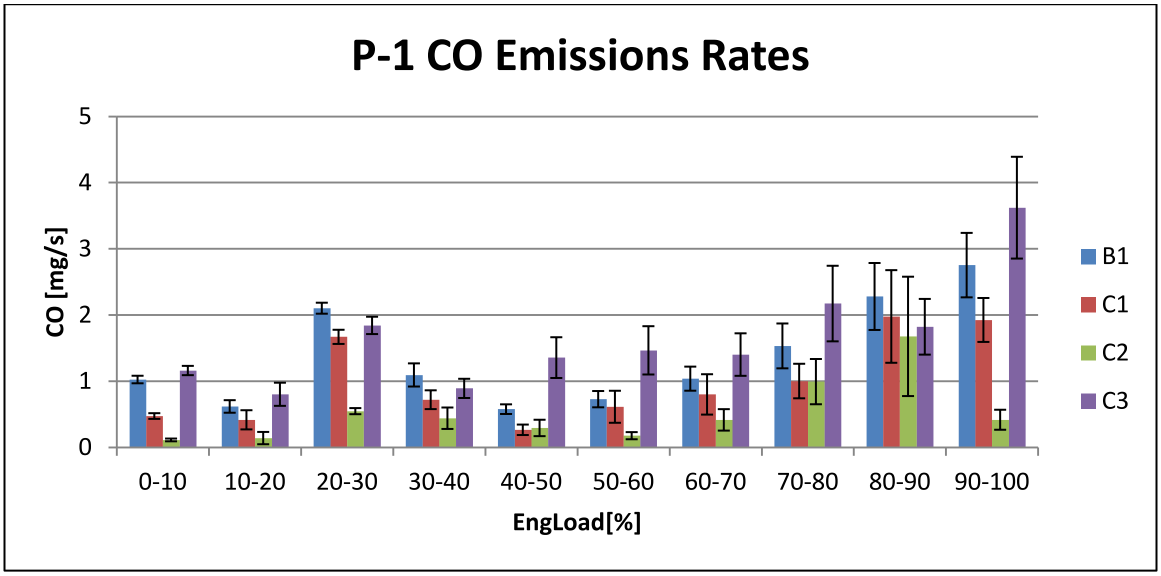
APPENDIX B: TEST ROUTES (CONTINUED)

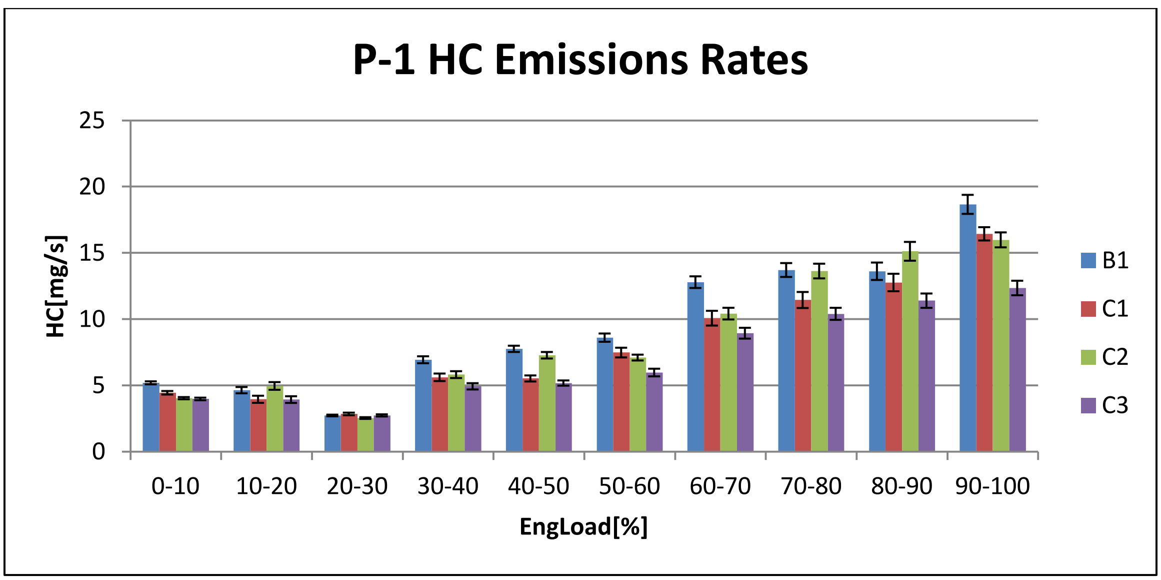
Photo: Turtle Island Rural Stop 5 Photo B

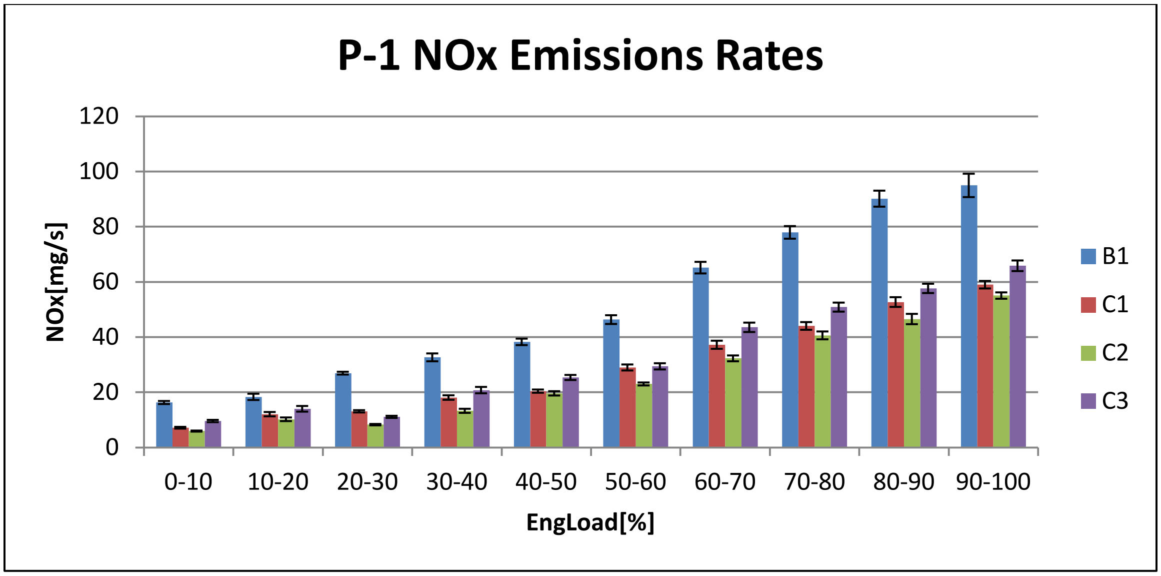
Photo: Turtle Island Rural Stop 6

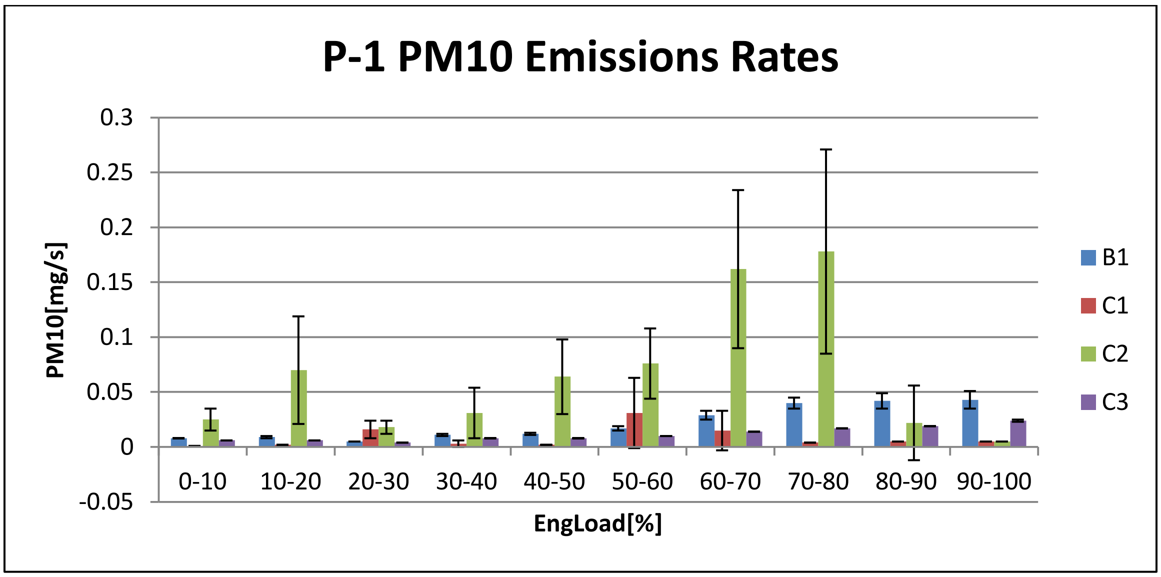
APPENDIX C: MODAL POLLUTANT EMISSIONS RATES

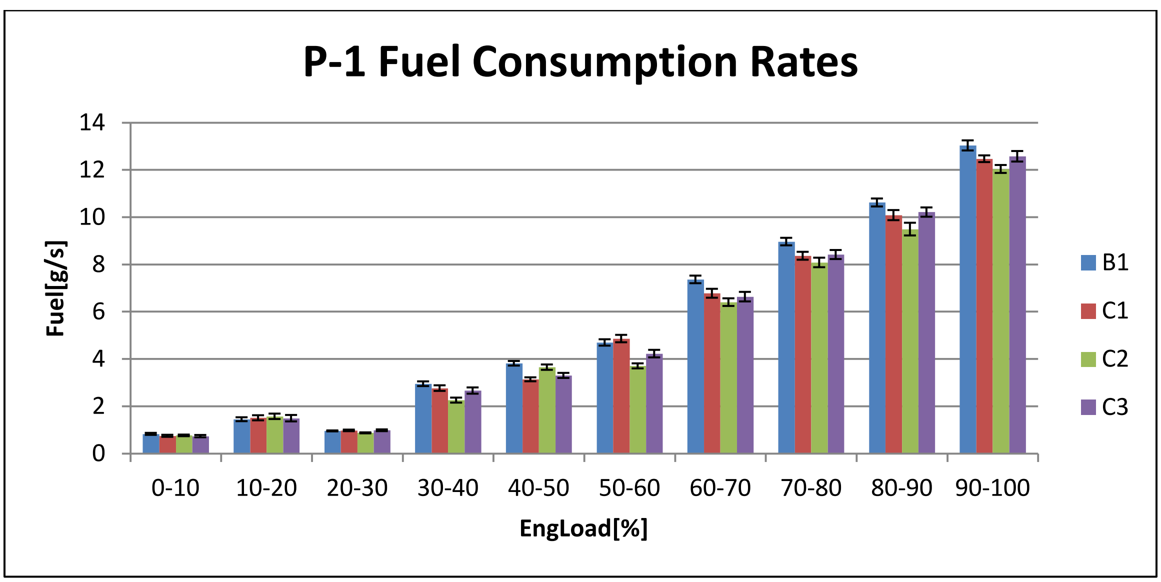


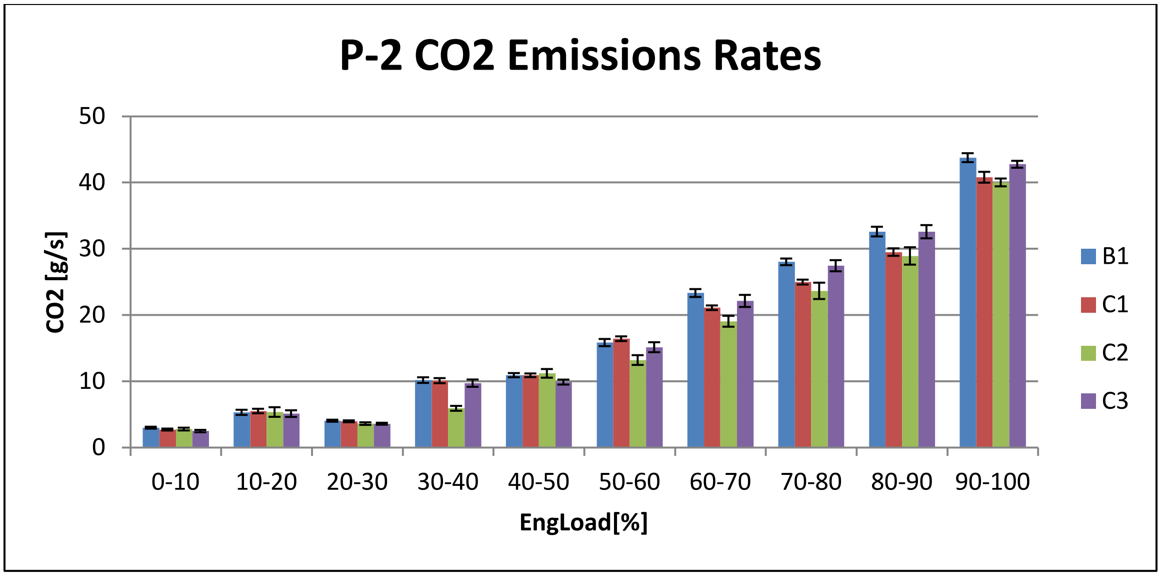


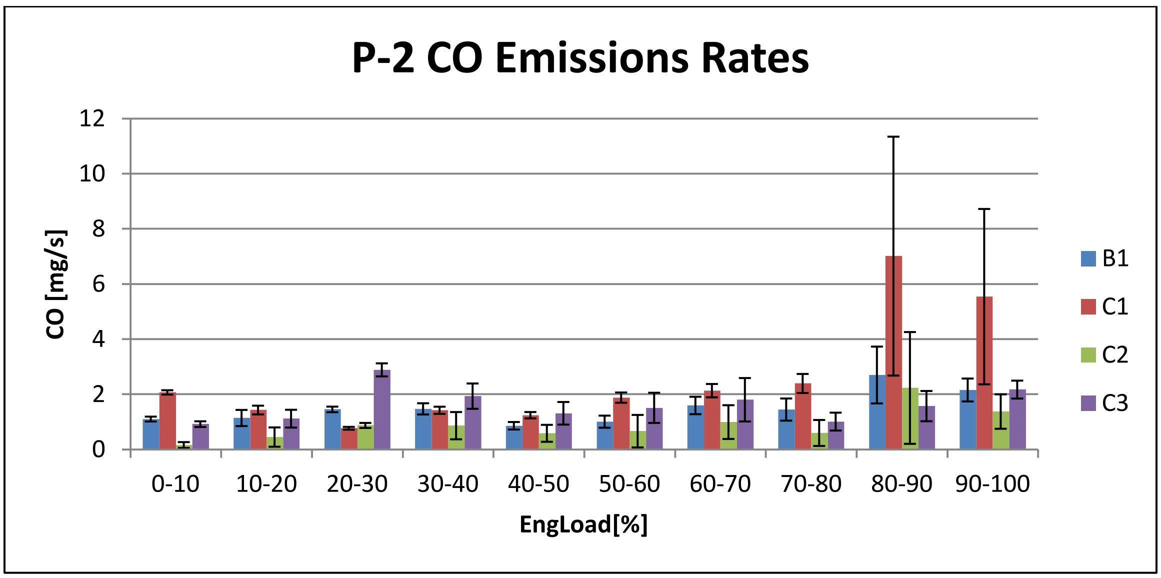


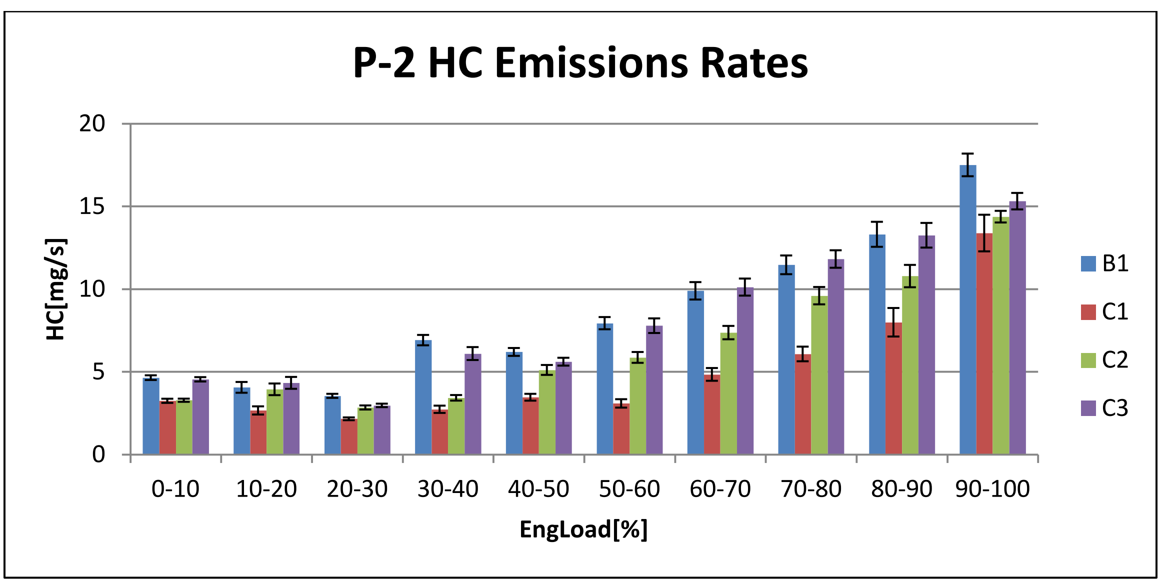

P-1 NOx Emissions Rates
NOx[mg/s]
120
100
80
60
40
20
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

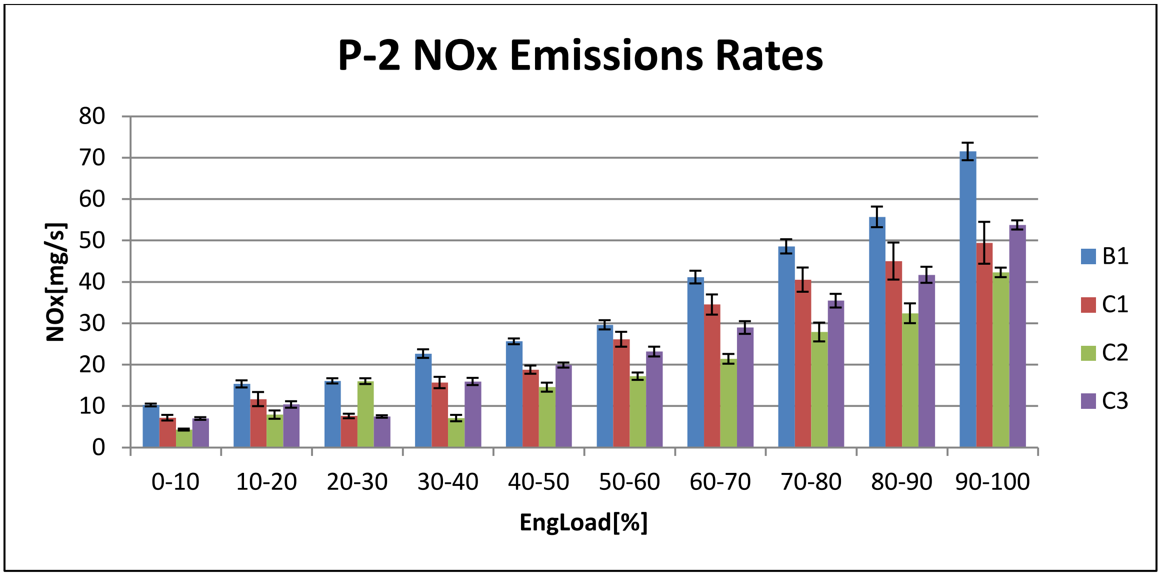

P-1 PM10 Emissions Rates
PM10[mg/s]
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3


P-1 Fuel Consumption Rates
Fuel[g/s]
14
12
10
8
6
4
2
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

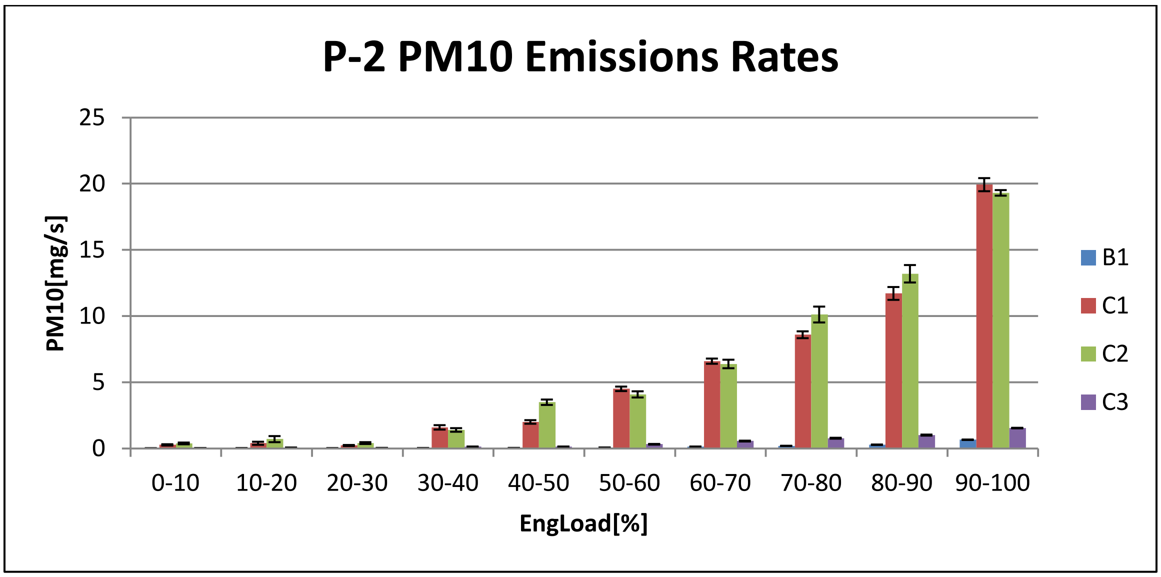

P-2 CO2 Emissions Rates
CO2 [g/s]
50
40
30
20
10
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3


P-2 CO Emissions Rates
CO [mg/s]
12
10
8
6
4
2
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

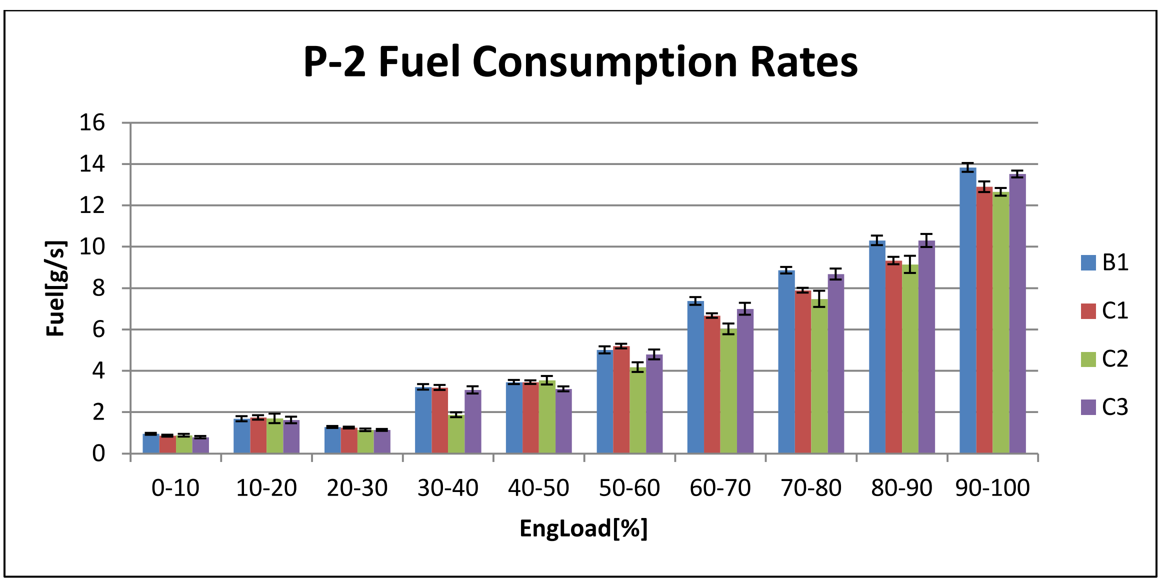

P-2 HC Emissions Rates
HC[mg/s]
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3



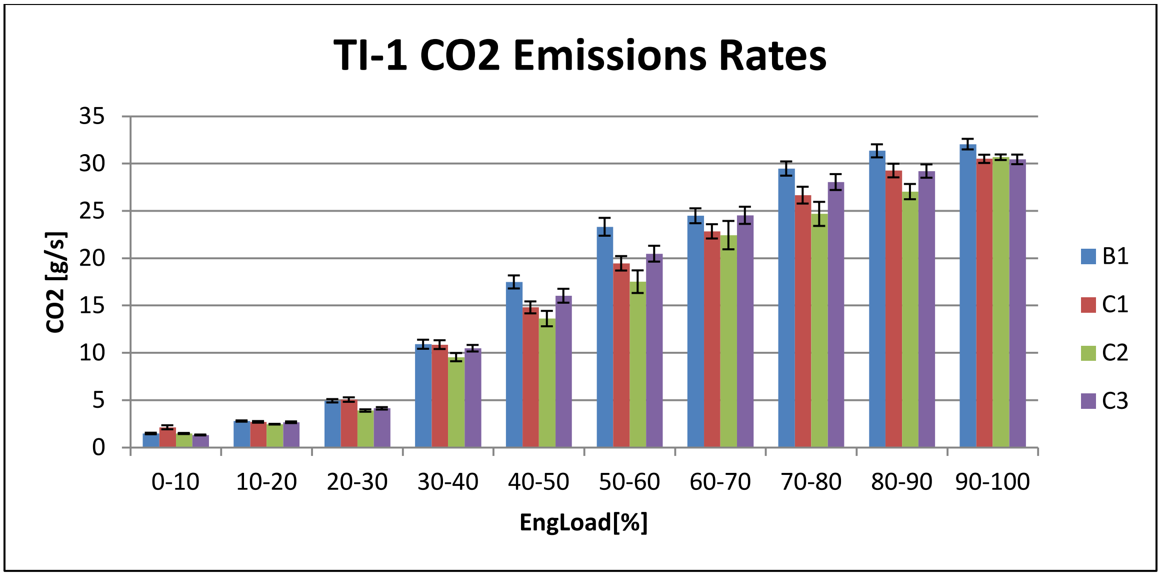
P-2 NOx Emissions Rates
0
10
20
30
40
50
60
70
80
NOx[mg/s]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

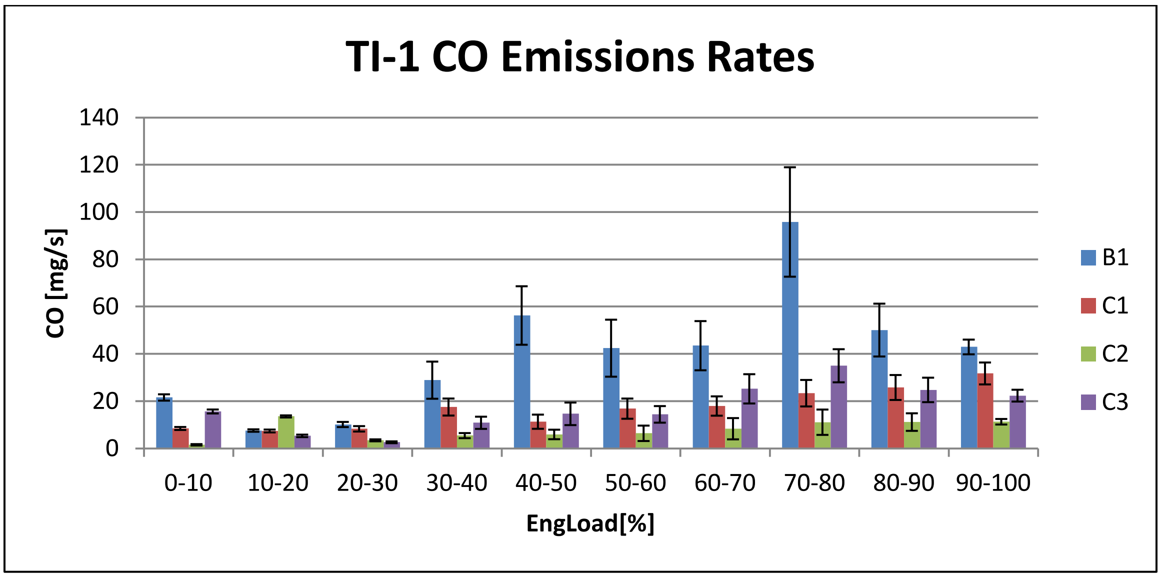


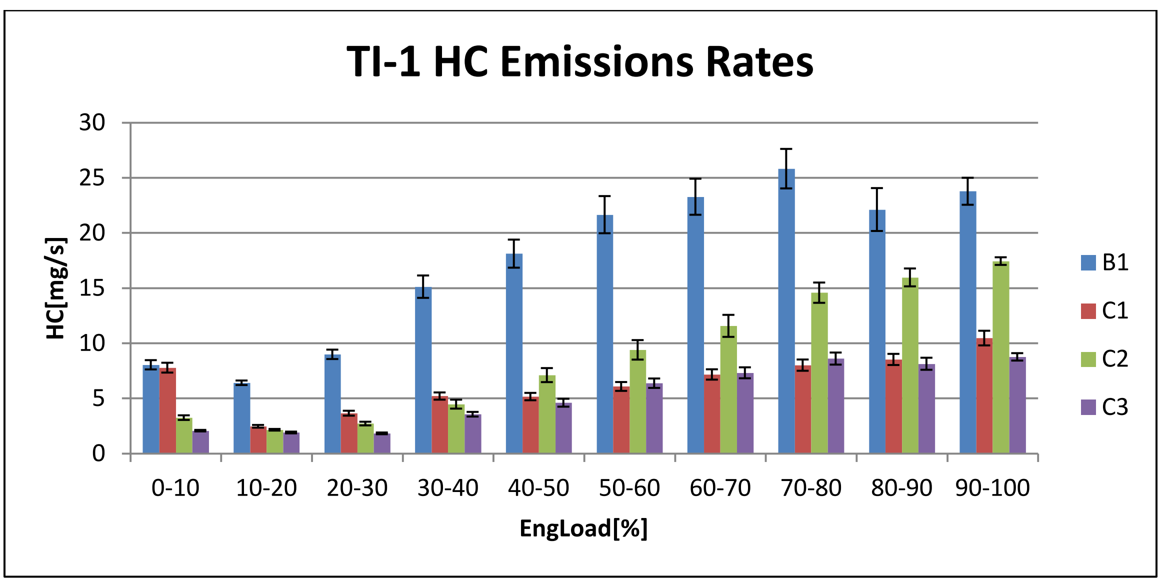
P-2 PM10 Emissions Rates
0
5
10
15
20
25
PM10[mg/s]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

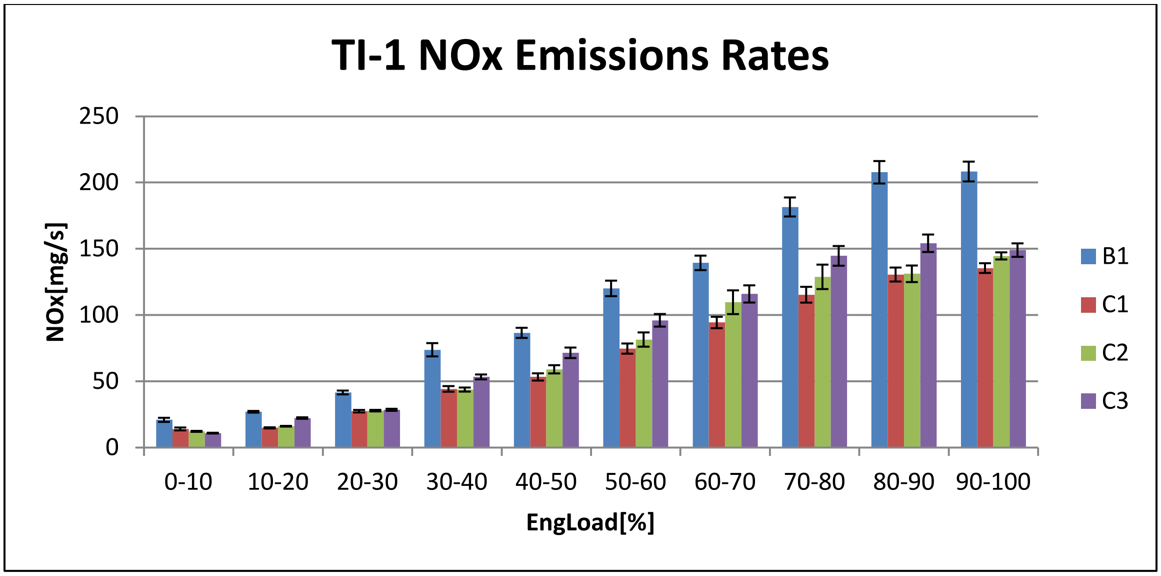


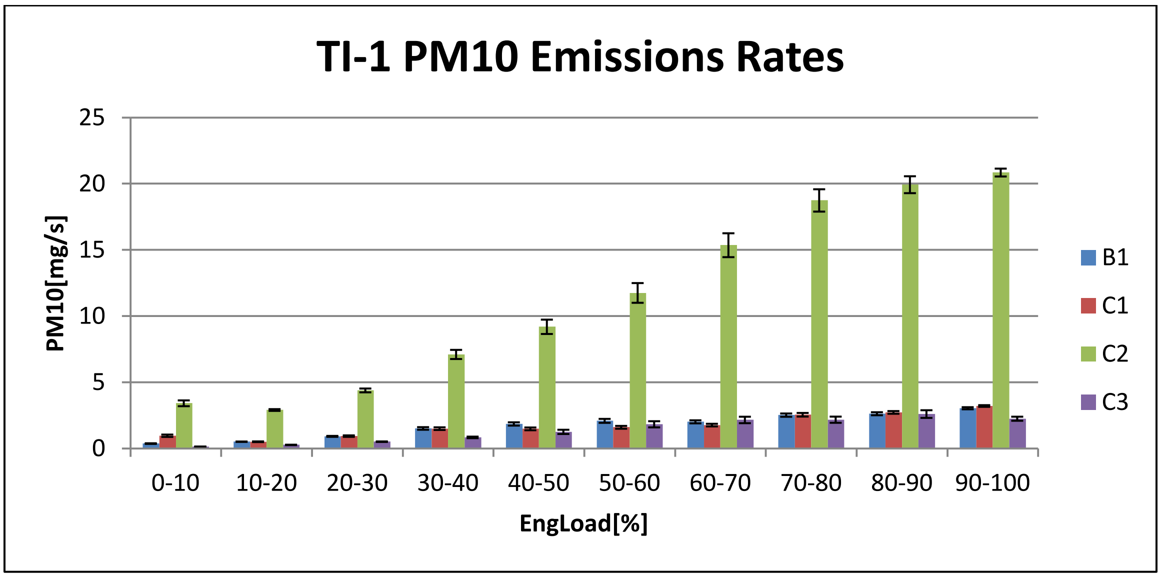
P-2 Fuel Consumption Rates
0
2
4
6
8
10
12
14
16
Fuel[g/s]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

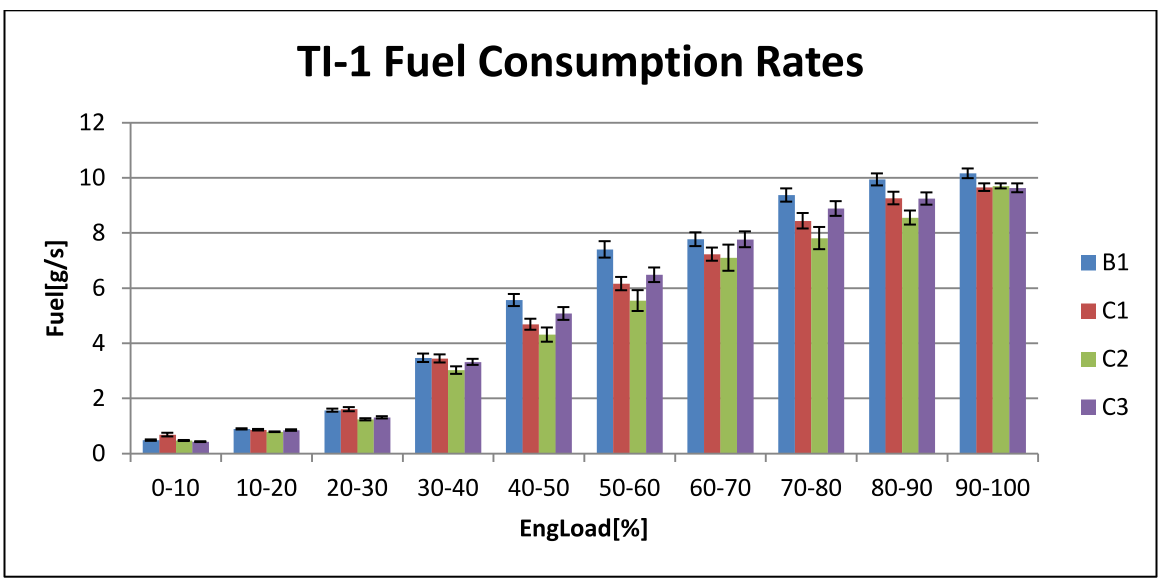

TI-1 CO2 Emissions Rates
CO2 [g/s]
0
5
10
15
20
25
30
35
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

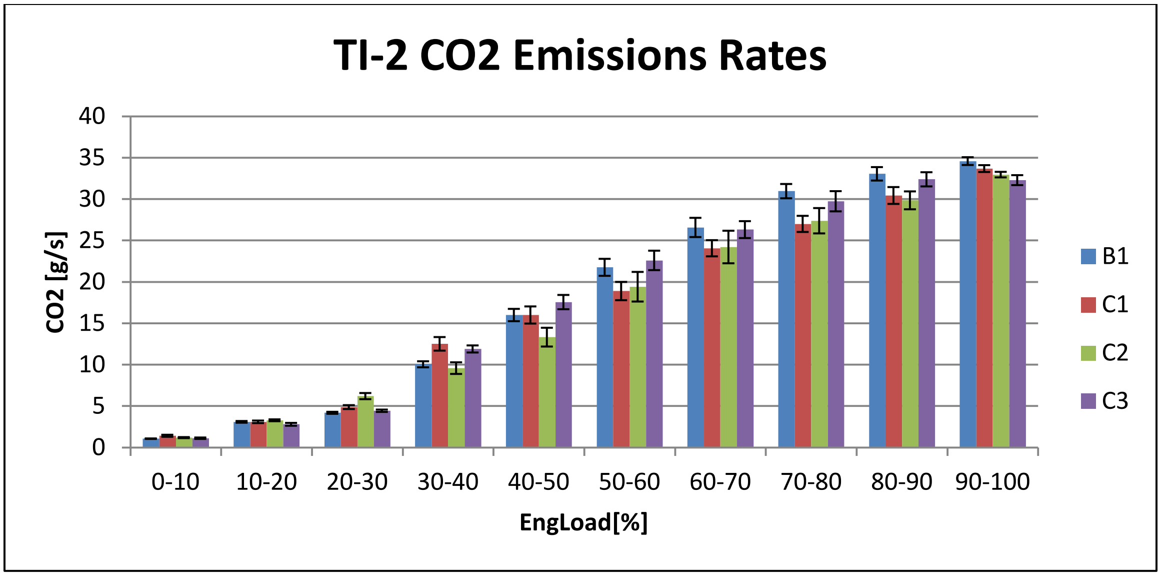

TI-1 CO Emissions Rates
CO [mg/s]
0
20
40
60
80
100
120
140
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

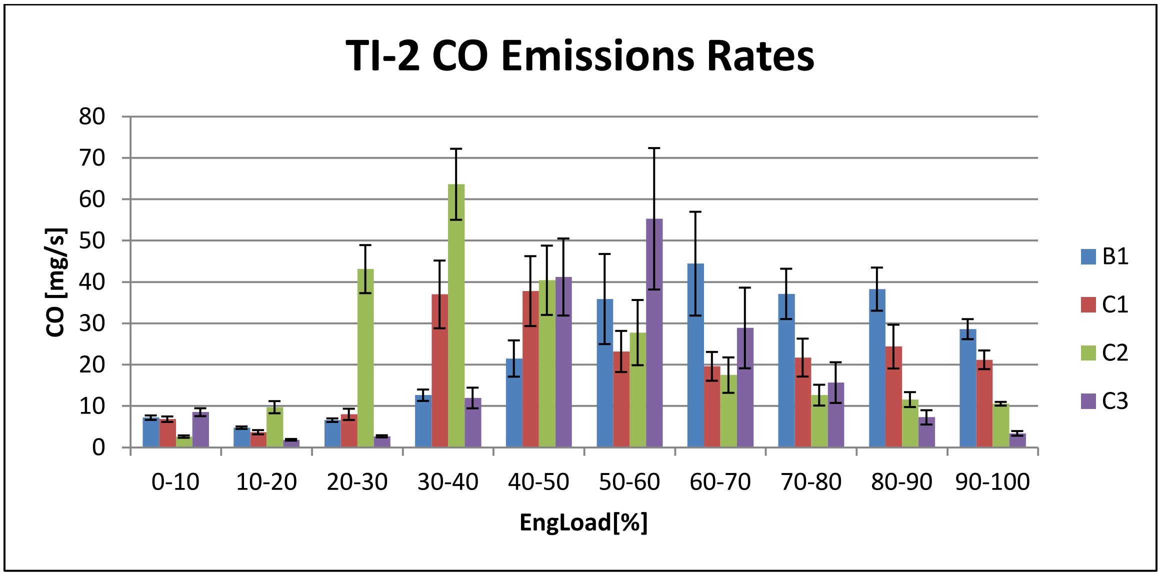

TI-1 HC Emissions Rates
HC[mg/s]
0
5
10
15
20
25
30
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

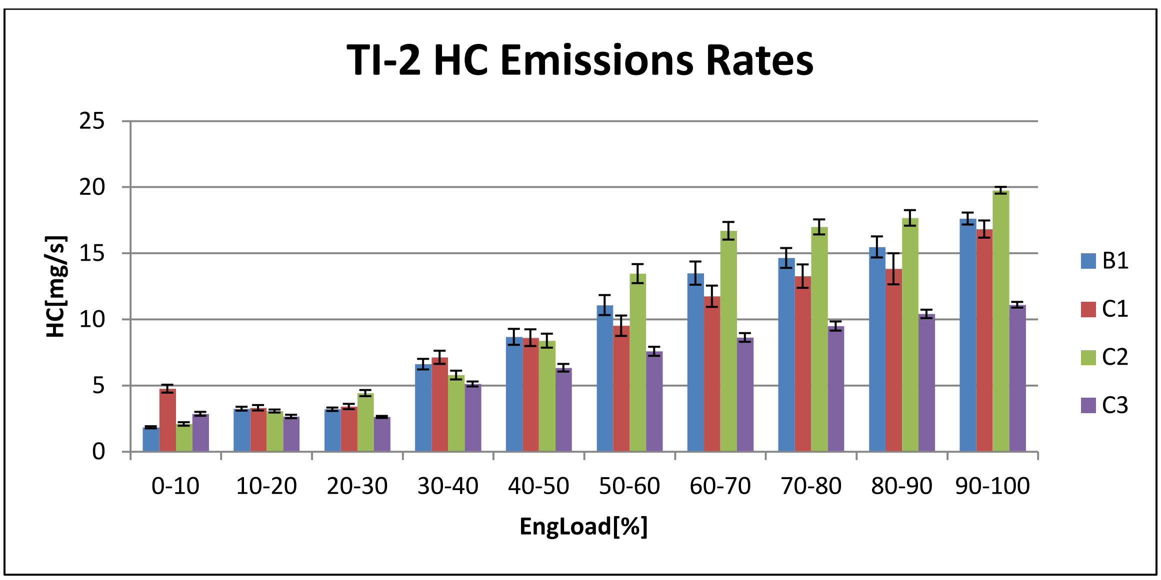

TI-1 NOx Emissions Rates
NOx[mg/s]
250
200
150
100
50
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

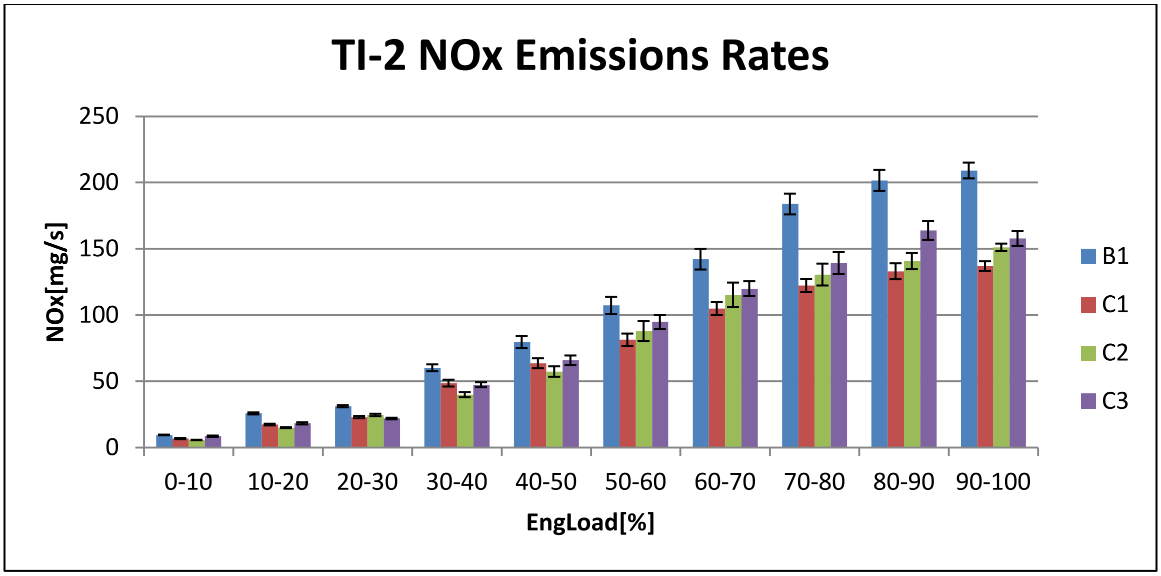

TI-1 PM10 Emissions Rates
PM10[mg/s]
25
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3


TI-1 Fuel Consumption Rates
Fuel[g/s]
12
10
8
6
4
2
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

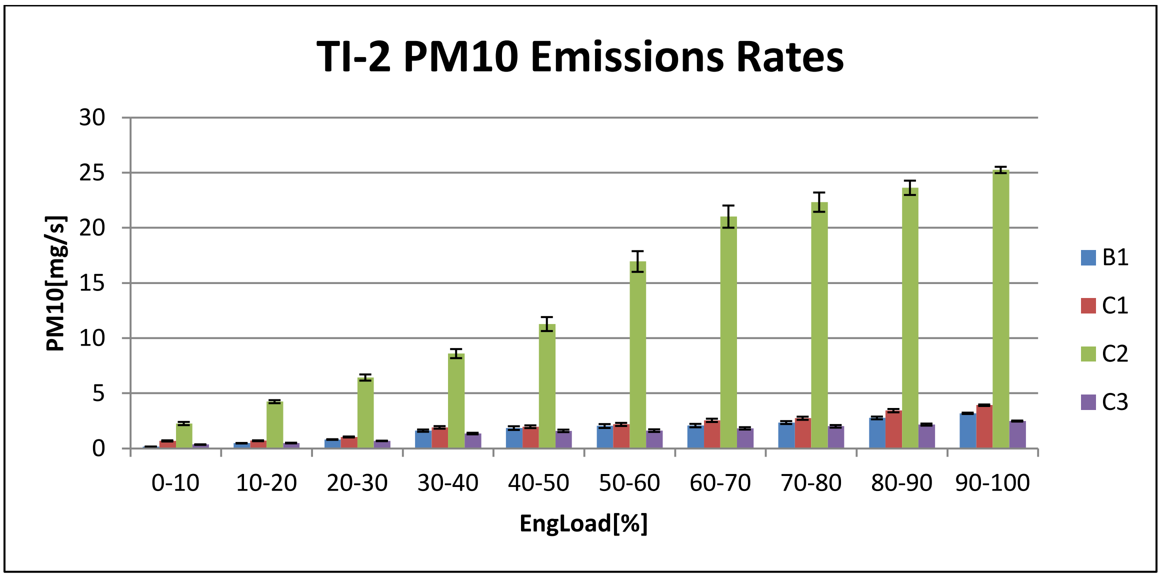

TI-2 CO2 Emissions Rates
CO2 [g/s]
40
35
30
25
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3


TI-2 CO Emissions Rates
CO [mg/s]
80
70
60
50
40
30
20
10
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

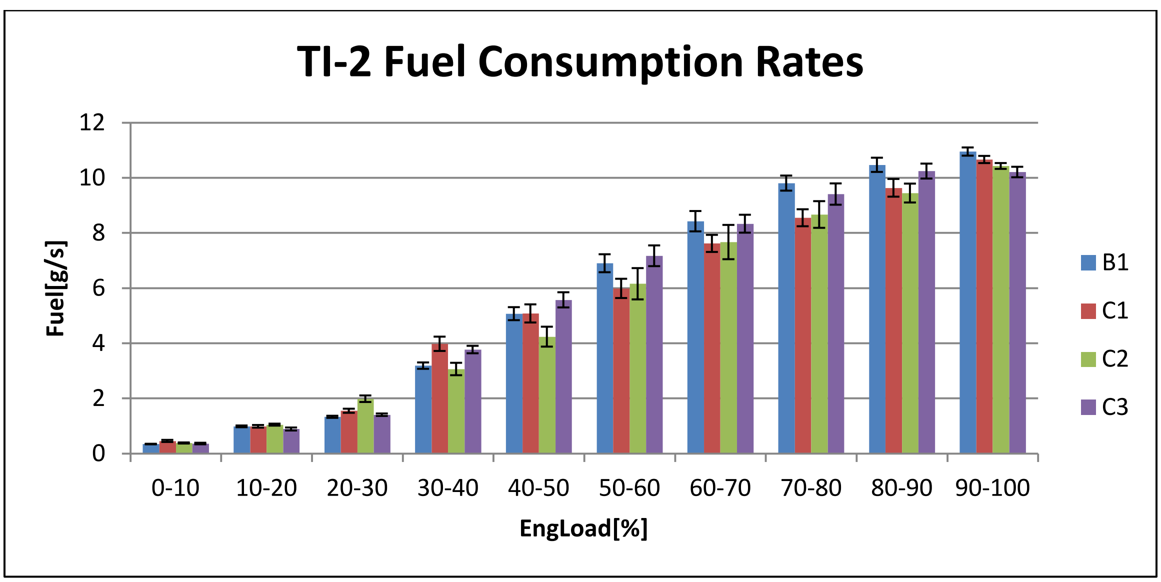

TI-2 HC Emissions Rates
HC[mg/s]
25
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3



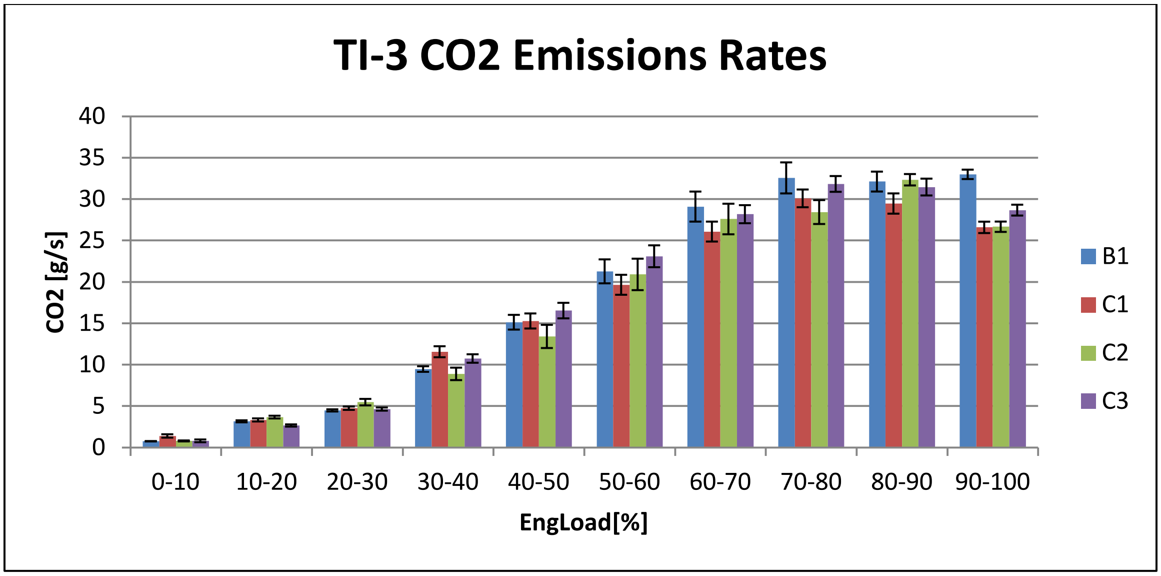
TI-2 NOx Emissions Rates
NOx[mg/s]
250
200
150
100
50
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

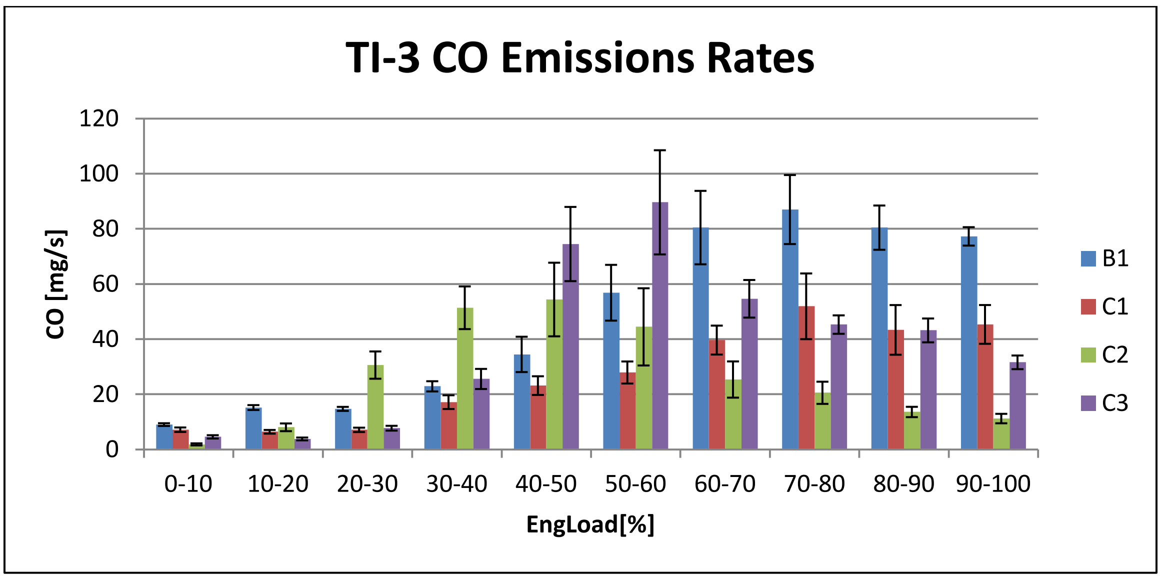


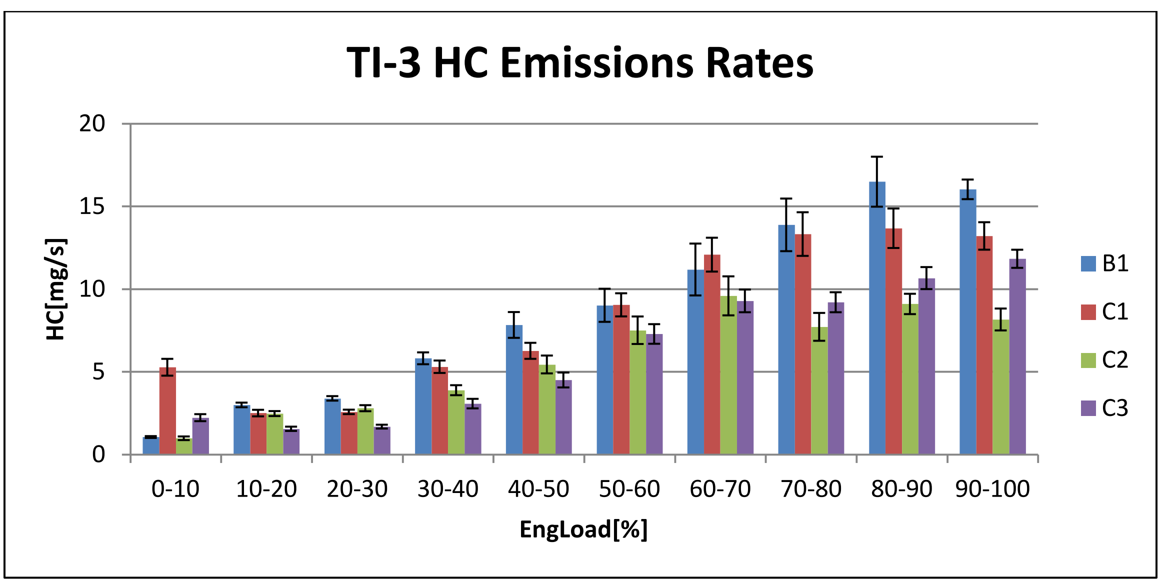
TI-2 PM10 Emissions Rates
PM10[mg/s]
30
25
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

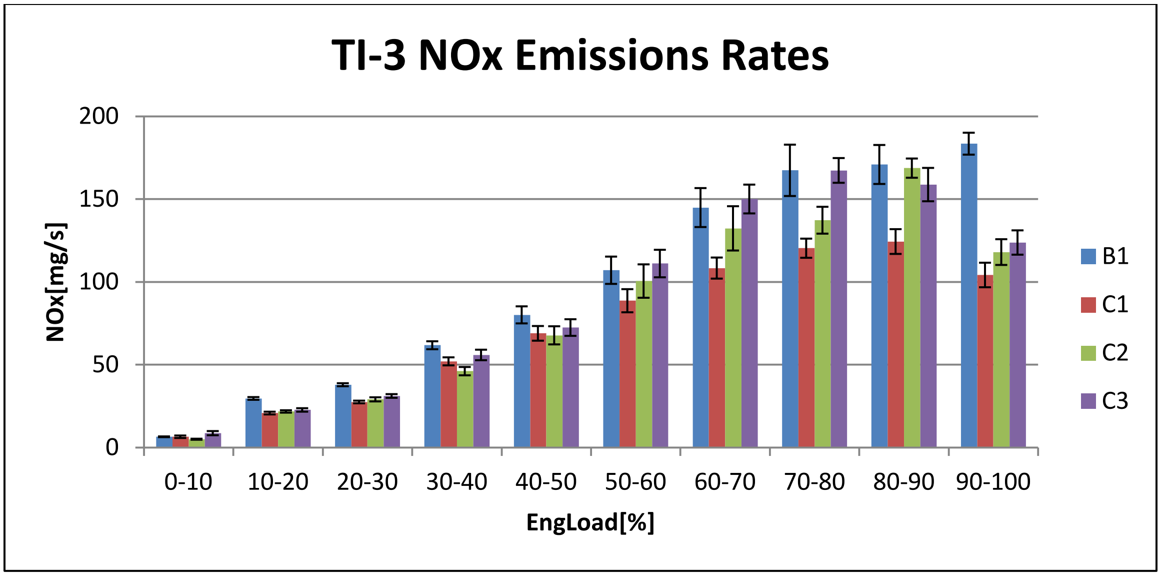


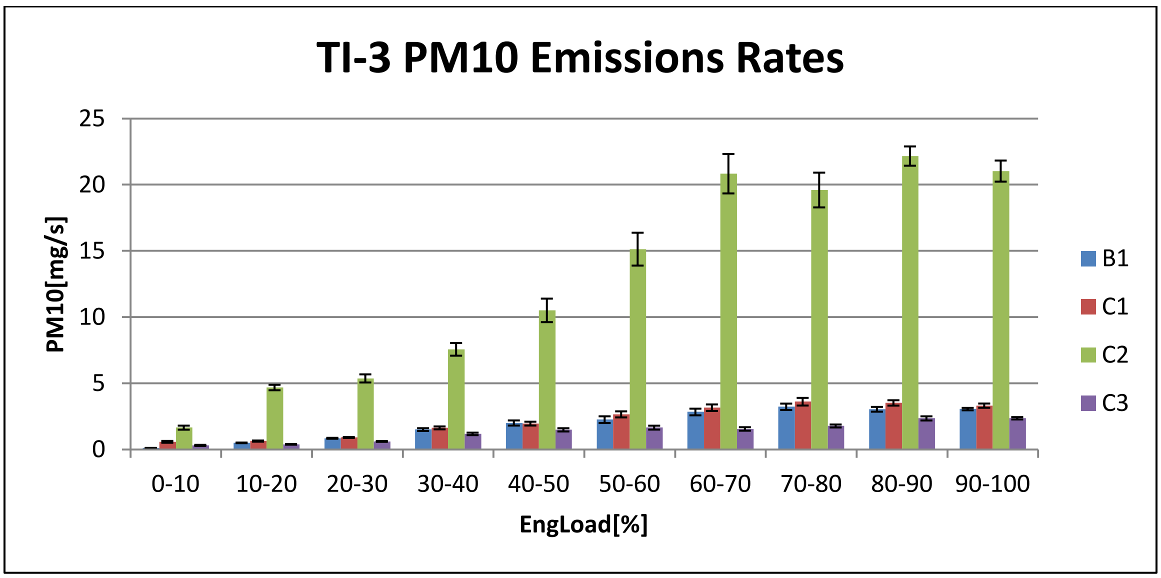
TI-2 Fuel Consumption Rates
Fuel[g/s]
12
10
8
6
4
2
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

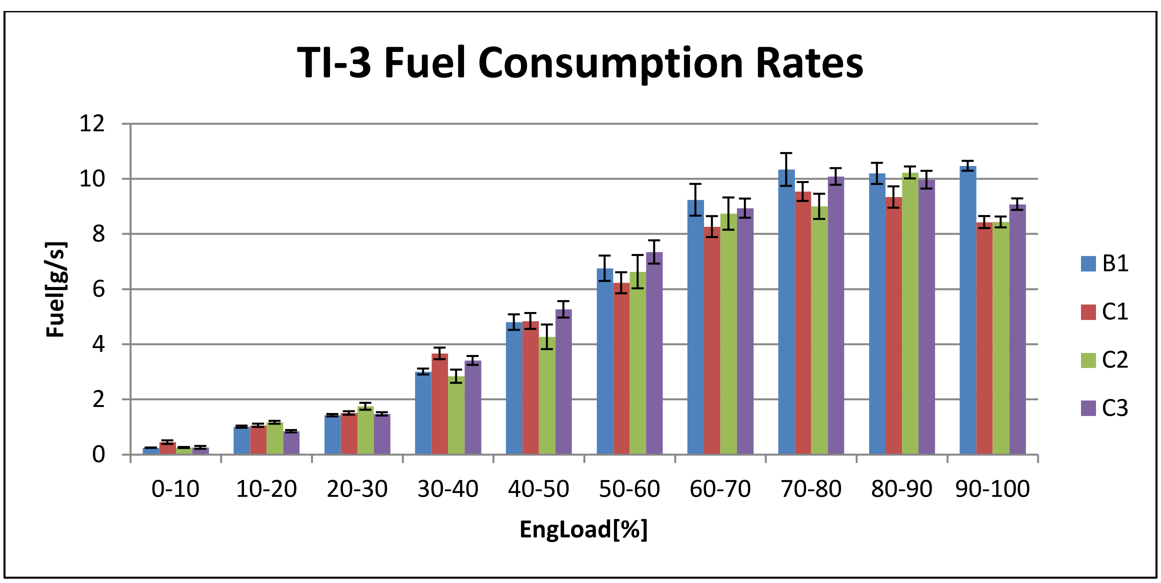

TI-3 CO2 Emissions Rates
CO2 [g/s]
40
35
30
25
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3


TI-3 CO Emissions Rates
CO [mg/s]
120
100
80
60
40
20
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

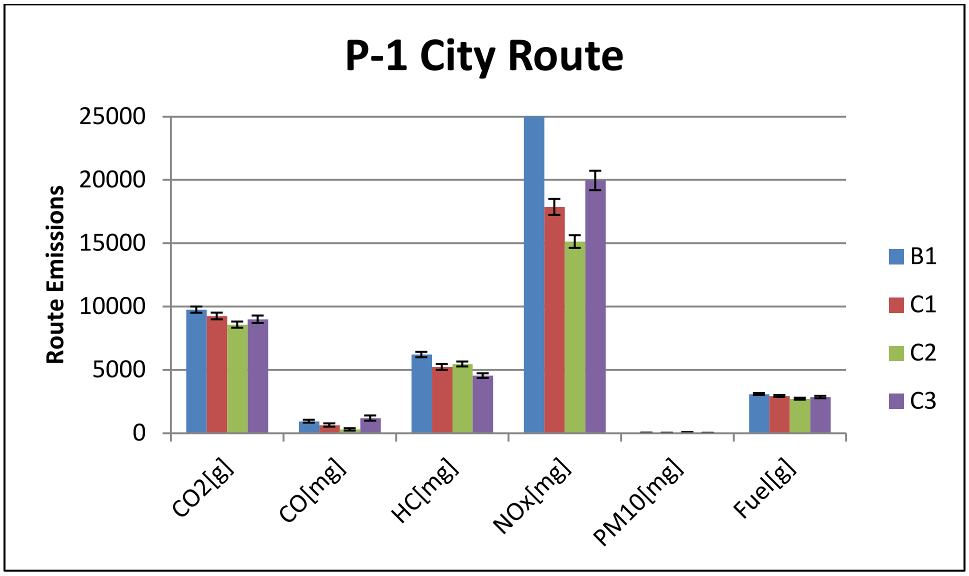

TI-3 HC Emissions Rates
HC[mg/s]
20
15
10
5
0
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

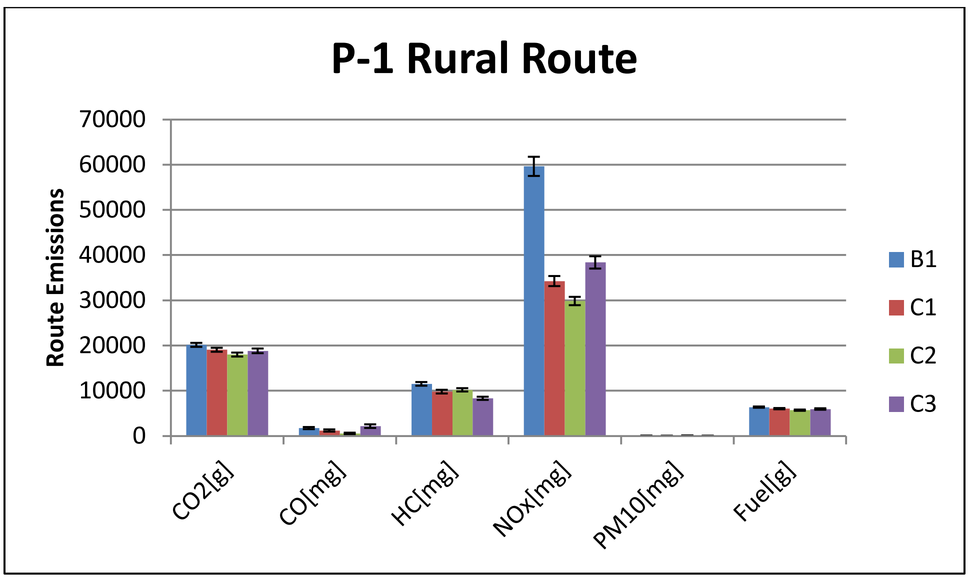

TI-3 NOx Emissions Rates
200
150
100
50
0
NOx[mg/s]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

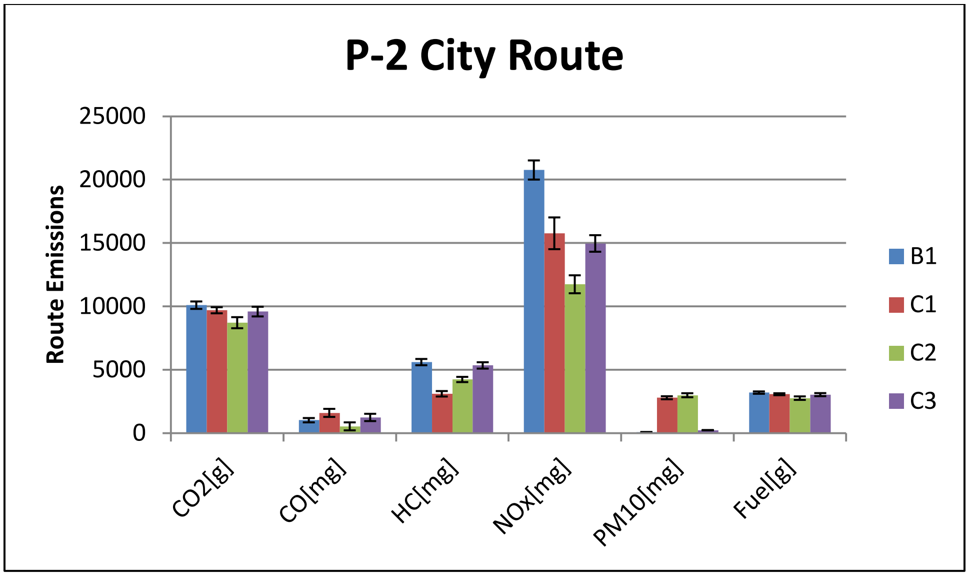

TI-3 PM10 Emissions Rates
25
20
15
10
5
0
PM10[mg/s]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

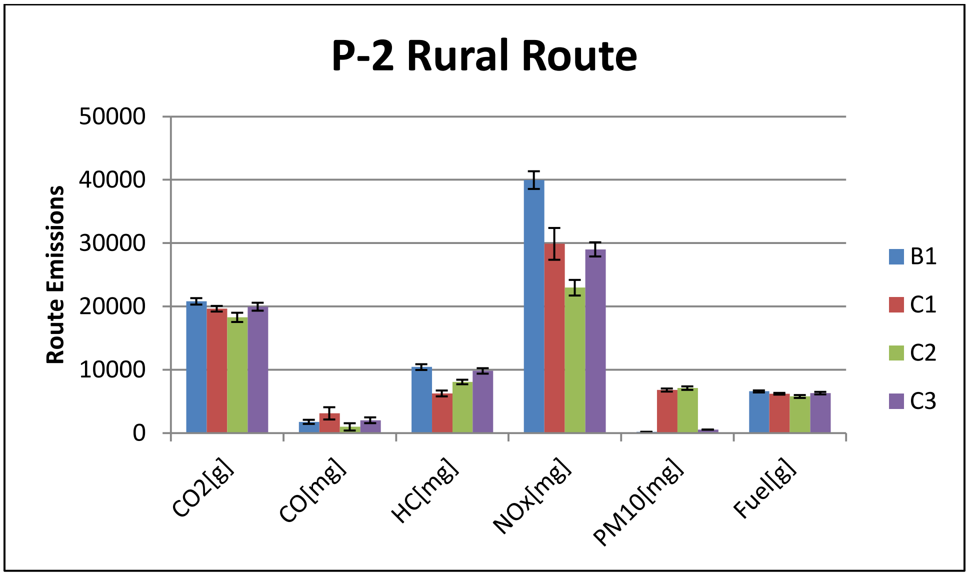

TI-3 Fuel Consumption Rates
12
10
8
6
4
2
0
Fuel[g/s]
0-10
10-20
20-30
30-40
40-50
50-60
60-70
70-80
80-90
90-100
EngLoad[%]
B1
C1
C2
C3

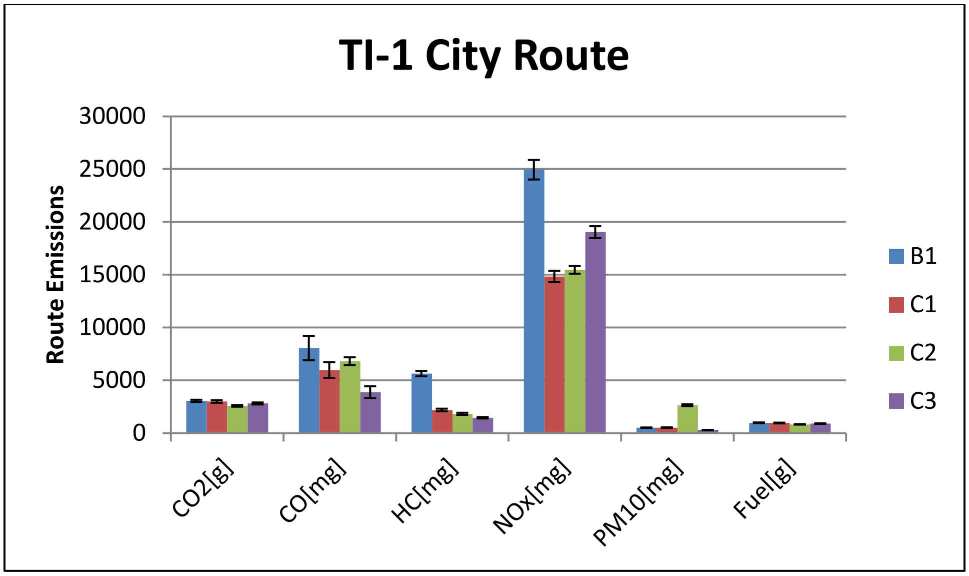
APPENDIX D: MODAL ROUTE EMISSIONS

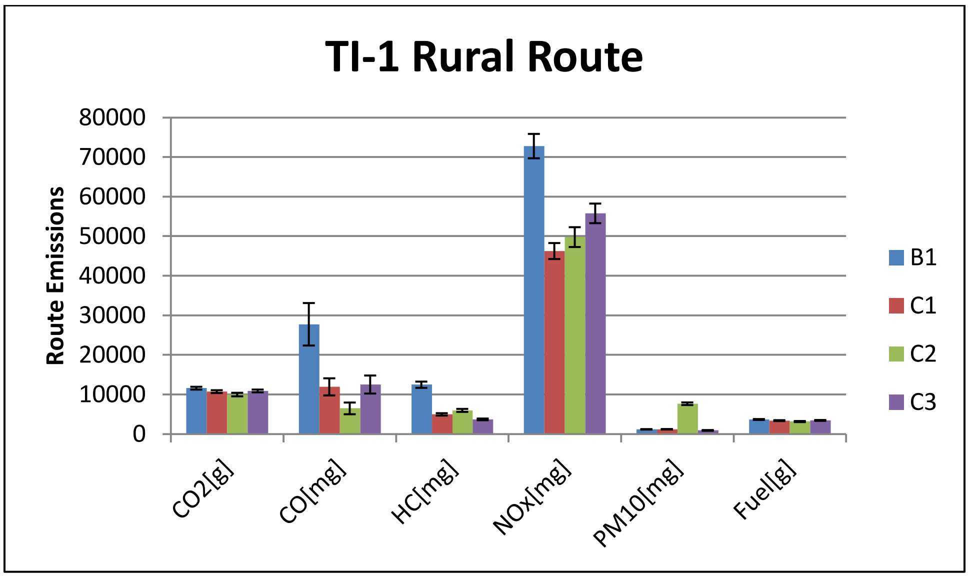


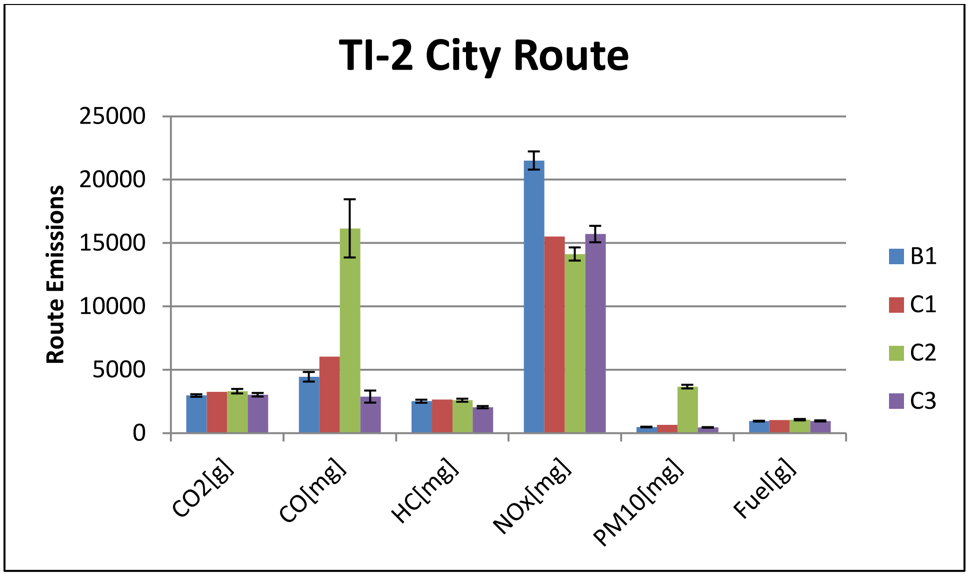


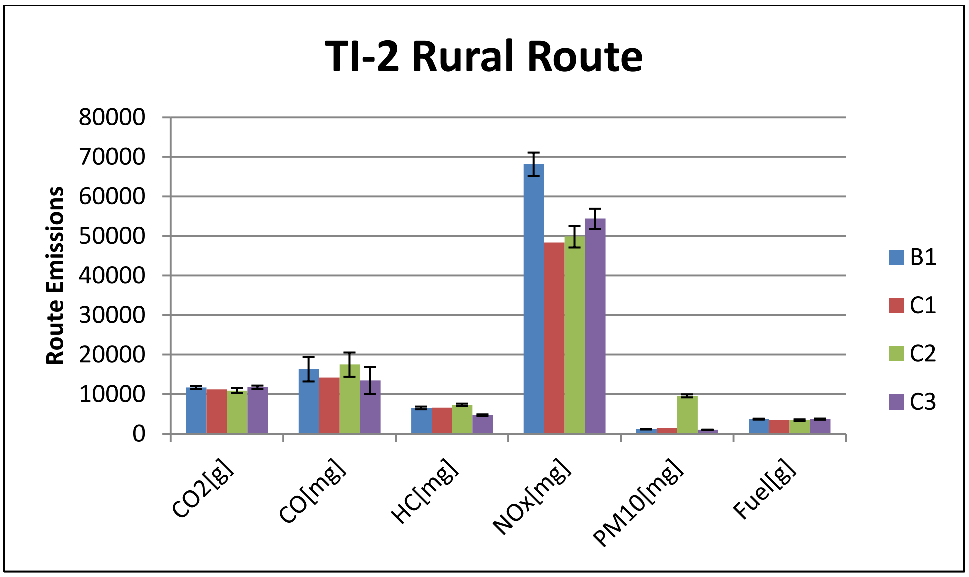

P-2 City Route
Route Emissions
25000
20000
15000
10000
5000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3

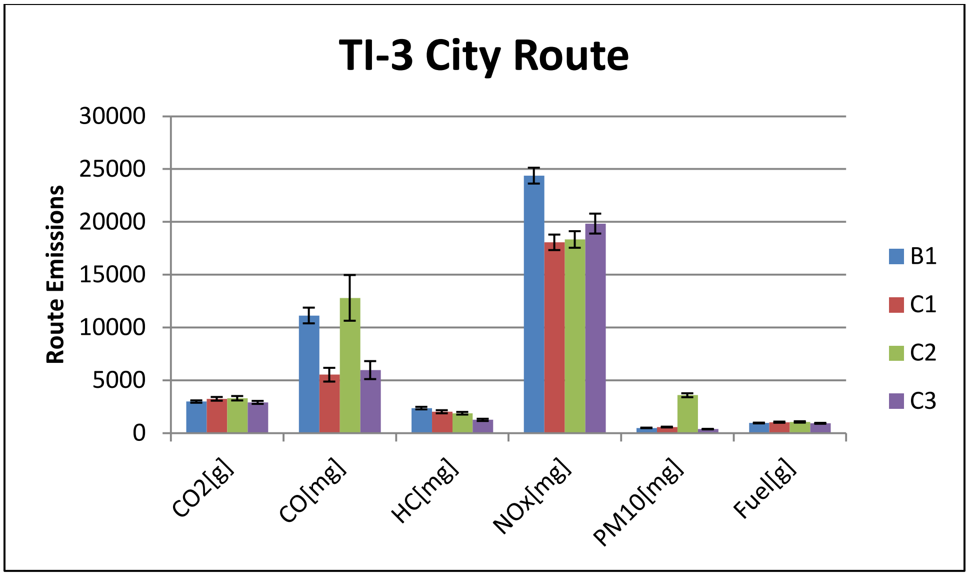

P-2 Rural Route
Route Emissions
50000
40000
30000
20000
10000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3

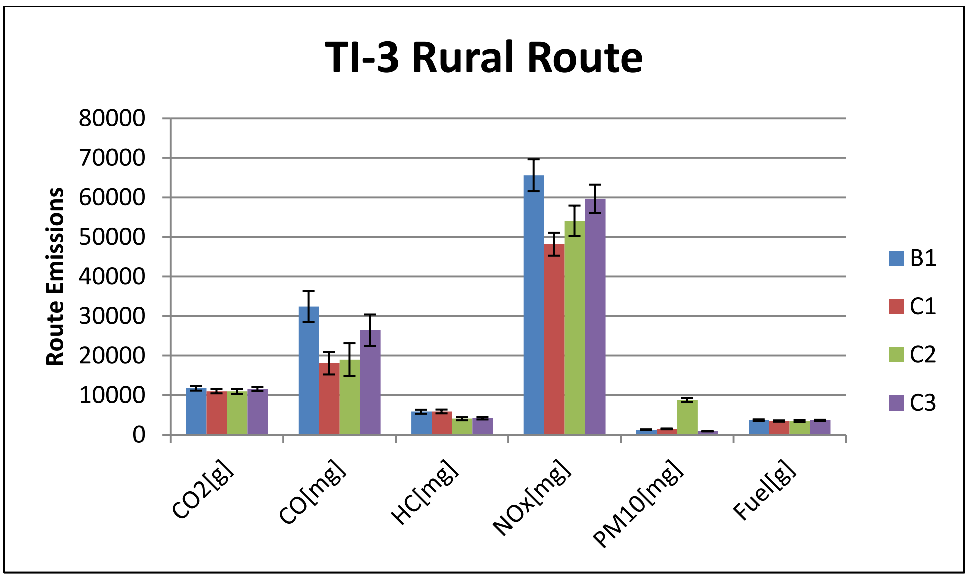

TI-1 City Route
Route Emissions
30000
25000
20000
15000
10000
5000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3


TI-1 Rural Route
Route Emissions
80000
70000
60000
50000
40000
30000
20000
10000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3


TI-2 City Route
Route Emissions
25000
20000
15000
10000
5000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3


TI-2 Rural Route
Route Emissions
80000
70000
60000
50000
40000
30000
20000
10000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3


TI-3 City Route
Route Emissions
30000
25000
20000
15000
10000
5000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3


TI-3 Rural Route
Route Emissions
80000
70000
60000
50000
40000
30000
20000
10000
0
CO2[g]
CO[mg]
HC[mg]
NOx[mg]
PM10[mg]
Fuel[g]
B1
C1
C2
C3