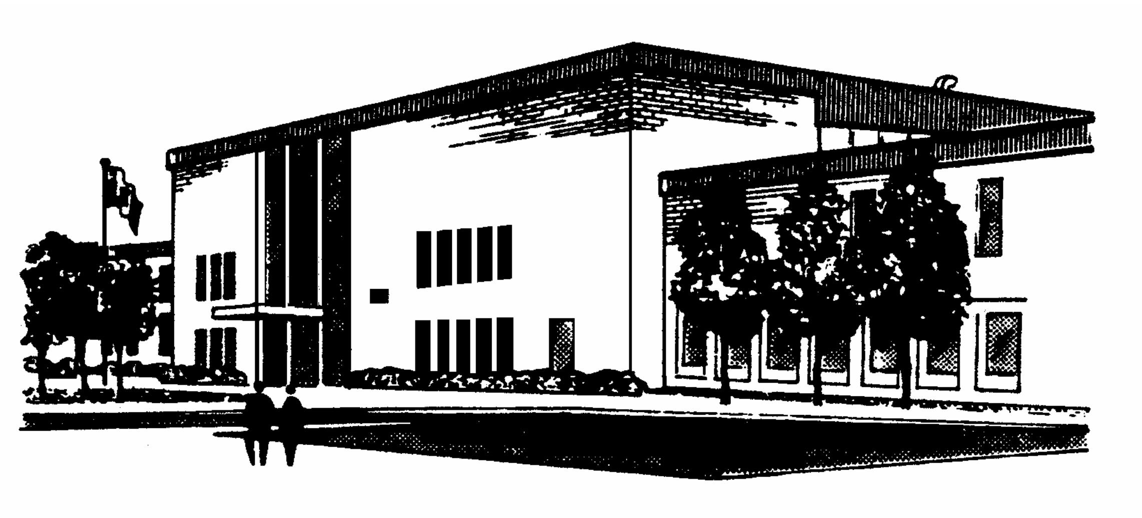
Emissions from 4 Different Light Duty Vehicle Technologies Operating on Low Blend Ethanol Gasoline

Report 04-27 A: Tailpipe Greenhouse Gases (CO_2, CH_4, N_2O)



ERMD Report #04-27 A
Prepared by: Cara Baas & Lisa Graham

ENVIRONMENTAL TECHNOLOGY CENTRE
EMISSIONS RESEARCH AND MEASUREMENT DIVISION

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Executive Summary

The primary objective of this research program was to characterize the emissions of vehicles with various engine and emission control technologies when operated on low blend ethanol gasolines. This program was undertaken to help identify and quantify the emissions impact of ethanol blended fuels on the tailpipe and evaporative emissions.

This report discusses tailpipe greenhouse gas emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from the research program. Both distance based (g/mile) and fuel volume based (g/L fuel) emission rates are discussed. The Appendix to this report presents all emission rate data and the detailed results of the statistical analyses. Separate reports from this research program discuss tailpipe gaseous emissions of other pollutants of interest, evaporative emissions, and particulate matter emissions.

Testing was conducted using the US06 driving cycle and a 4-phase implementation of the Federal Test Procedure (FTP). The FTP based driving cycle allows examination of a cold engine start, a hot engine start, and stabilized transient operation typical of a non-demanding style of urban and suburban driving. The US06 driving cycle represents aggressive, high speed driving and incorporates rapid speed fluctuations. Emissions measurements were performed on four vehicles:

- 1998 Ford Escort ZX2 (US EPA Tier 1 emission standard, available in North America)
- 2001 Nissan Sentra CA (California SULEV emission standard, available in North America)
- 2003 Dodge Caravan (US EPA LEV emission standard, available in North America)
- 2000 Mitsubishi Dion (Japanese LEV emission standard, not currently available in North America)

The Escort and the Sentra were tested at both 20°C and -10°C. The Caravan and the Dion were tested at 20°C only. Tests were performed using four summer grade fuels (for tests at 20°C) and four winter grade fuels (for tests at -10°C). For each seasonal grade, the test fuels included a base fuel containing no ethanol, a 20% ethanol tailor blend, a 10% ethanol tailor blend, and a 10% ethanol splash blend. The splash blend fuels were made by simply "splash" blending a volume of ethanol with the base fuel, resulting in lower sulphur, higher octane, and higher vapour pressure than the base fuel. Since changes in these fuel qualities will have an impact on emissions, tailor blend fuels were custom designed to have similar sulphur, octane, and vapour pressure as the base fuel. Each base fuel was tested twice for each vehicle, once at the beginning and once at the end of the test program.

The major findings include:

- For all vehicles and test temperatures, distance-based CO_2 emission rates were essentially unchanged as ethanol content increased. The effect from the lower energy density of the ethanol blend fuels cancelled out the effect from the lower carbon content per litre of ethanol blend fuel burned.

- In general, increasing ethanol content did not result in any significant changes to the CH_4 emission rates. Ethanol blend fuels may reduce CH_4 emissions from 20°C operation with Tier 1 vehicle technology, however there is not enough data to confidently support this theory.

- For all vehicles and test temperatures, the N_2O emission rates from the E0 fuel are not statistically different than those from the ethanol blend fuels.

- The Caravan "flex fuel" operation during this testing program was found to be unreliable. Monitoring of the on board fuel ethanol sensor via the OBD II access port indicated that the sensor continually measured an ethanol content of zero; therefore it is possible that the engine did not realize any specially designed engine parameters for ethanol fuel operation

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1. Introduction

1.1 Program Objective

The primary objective of the overall research program was to characterize the emissions of vehicles with various engine and emission control technologies when operated on low level ethanol-gasoline blends. The overall study examined the exhaust and evaporative emissions in a manner that focused on identifying specific modes of operation where elevated emissions may occur. The results of this research may be used to evaluate technologies that could be used to mitigate any elevated emissions identified during the initial characterization phase. The information gathered may also be used in emission inventory development and as input to atmospheric chemistry models.

This research program studied a wide range of emission species, including:

- *Regulated emissions*, including carbon monoxide (CO), oxides of nitrogen (NO_X), total hydrocarbons (THC) non-methane hydrocarbons (NMHC), non-methane organic gases (NMOG), total particulate matter (TPM), and formaldehyde (HCHO)
- *Greenhouse gases*, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)
- *Other criteria air contaminants*, such as sulphur dioxide (SO_2), ammonia (NH_3)
- Particulate phase organic and elemental carbon (OC/EC)
- Particulate phase organic and inorganic ions, including sulphate
- Vapour phase organic acids
- Polycyclic aromatic hydrocarbons (PAHs) and nitrated polycyclic aromatic hydrocarbons (N-PAHs)
- Carbonyl compounds, including acetaldehyde
- Ethanol
- Particulate matter sizing (aerodynamic diameter)

1.2 Report Objective

This report outlines the *tailpipe greenhouse gas* emissions from four test vehicles operated at two test temperatures (20°C and -10°C) on fuels of varying ethanol blends. Tailpipe emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are presented. Results include data from tests performed on all four vehicles using four summer grade fuels (one base fuel, three ethanol blend fuels) and data from tests performed on two vehicles using four winter grade fuels (one base fuel, three ethanol blend fuels).

Other reports from this program discuss other pollutants of interest and evaporative emissions:

- Report 04-27–B : Tailpipe Regulated and Unregulated Gaseous Emissions
- Report 04-27–C: Particulate Matter Emissions
- Report 04-27–D: Evaporative Emissions

2. Background

The air quality concerns at the local and regional level that arise from gasoline-powered mobile-source emissions are ground level ozone (smog), toxic air pollutants, and carbon monoxide. The major ozone precursors come from emissions of volatile organic compounds (VOC) and oxides of nitrogen (NO_X), and to a lesser extent carbon monoxide (CO). Because ozone formation is related to temperature and sunlight, ozone problems occur primarily in hot weather; however Toronto recently experienced its first winter smog event. Toxic air pollutants are a year-round problem, but these are also more pronounced in hot weather. Carbon monoxide emissions from mobile sources are greater in cold weather, and elevated levels of CO are primarily a wintertime air quality problem.

There have been significant advances over the past decade in the development of clean fuels and vehicles to address the deterioration of our urban air quality. One of the most significant advances has been in the area of reformulated gasoline. These fuels typically contain oxygenates such as methyl or ethyl –tertiary butyl ether (MTBE or ETBE), or ethanol. The primary objective of the oxygenated fuels is to maintain vehicle performance while reducing the emissions of smog forming volatile organic compounds, as well as other toxics associated with motor vehicle exhaust. Given the recent environmental concerns that have emerged concerning the detection of MTBE in groundwater in the US, there is growing potential for widespread replacement of MTBE by ethanol as the oxygenate of choice.

Compared with straight gasoline and gasoline containing MTBE, ethanol blended gasoline results in changes in some vehicle tailpipe emissions. Most toxic air pollutants and other pollutants (except acetaldehyde, formaldehyde, and Peroxyacetyl nitrate, or PAN) decrease when ethanol is added to gasoline.[1] This occurs primarily through dilution of the gasoline feedstock. Formaldehyde emissions are lower for ethanol blends than for MTBE blends. Atmospheric levels of formaldehyde and acetaldehyde are related to both primary emissions and atmospheric reactions. PAN is not directly emitted, but formed by atmospheric reaction.

Another consideration is the formation of organic sulphonic acids in the exhaust by reaction of aldehydes with sulphur dioxide. Ethanol may increase the emissions of acetaldehyde and if the ethanol fuel is also a higher sulphur fuel, increased formation of these organic sulphonic acids could be observed.

At present Environment Canada and the US EPA require automobile manufacturers to certify their emission control systems on a prescribed set of fuels. Except for ethanol flexible fuelled vehicles, gasoline-powered motor vehicles are not required to certify their tailpipe emission control systems on ethanol fuels. Ethanol flexible fuelled vehicles are required to certify their tailpipe emission systems on pure gasoline and 85% ethanol blend gasoline.

Another motivation for producing ethanol blended gasoline is to potentially mitigate greenhouse gases that contribute to climate change. Although there is no reduction of CO_2 emissions at the tailpipe due to the use of ethanol blended fuels, the lifecycle greenhouse gas emissions from ethanol as a fuel may be lower than petroleum based fuels because ethanol is produced from renewable sources such as corn, which draws CO_2 from the atmosphere as it grows. Quantifying the lifecycle greenhouse gas reductions from the use of ethanol blended fuel depends on a number of factors, such as how the feedstock is harvested, how the ethanol is produced, and how the final product is transported. There are currently differing views in the scientific community about the impact of ethanol blended gasoline on climate change. More research is needed for a conclusion to be drawn.

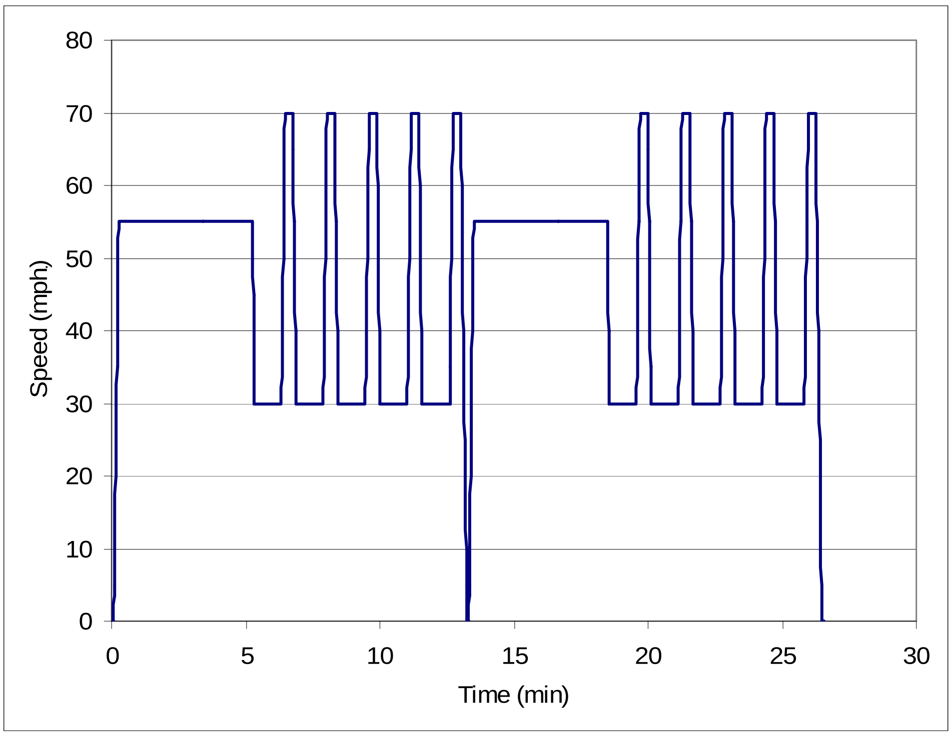
Research programs that investigate the emissions from vehicles running on ethanol blended gasoline, as well as research programs that study the lifecycle emission impact of ethanol blended gasoline are important for the development of policies that would determine support of the widespread introduction of ethanol as an oxygenate for Canadian gasoline.

3. Testing Details

3.1 Testing Procedure

To determine the effects of the low sulphur fuel used in this study, it was necessary to perform a conditioning sequence on each vehicle to remove residual sulphur from the catalyst. This sulphur removal procedure was developed by the University of California Riverside College of Engineering – Center for Environmental Research and Technology (CE-CERT).[2] The procedure involved running the vehicle at a rich air/fuel ratio and at a high catalyst temperature to facilitate the formation of hydrogen sulphide from the residual sulphur on the catalyst. The driving cycle is shown in Figure 1, and during each peak in the cycle it was necessary that the temperature of the exhaust going into the catalyst reached 700°C and that the air fuel ratio went rich. The sulphur removal procedure was complete after 10 peaks of high temperature and rich air/fuel ratio were completed.

Figure 1: Sulphur Removal Driving Cycle



A preparation procedure was conducted on each vehicle at the beginning of the testing program and whenever the test fuel was changed. This procedure is outlined in Table 1, and was done to minimize fuel carry over from test to test and to ensure that the vehicle condition was consistent for the beginning of each test.

Table 1: Vehicle Preparation Procedure

Step #	Action
1	Drain fuel
2	Fill vehicle with test fuel
3	Drive 2 LA4 driving cycles
4	Drain fuel
5	Fill vehicle with test fuel
6	Drive 2 LA4 driving cycles
7	Overnight soak at test temperature

The emissions testing procedure is outlined in Table 2. This procedure was conducted on each fuel until two sets of repeatable results were available for each phase of each driving cycle. Please note that steps 3 and 9 were conducted on the testing done at 20°C only.

Table 2: Emissions Testing Procedure

Step #	Action
1	Drain fuel
2	Fill vehicle with chilled test fuel
3 *	SHED test (Heat build) for 1 hour
4	Cold start LA4
5	20 minute soak
6	Hot start LA4
7	20 minute soak
8	US06
9 *	SHED test (Hot soak) for 1 hour
10	Overnight soak at test temperature

** step done for 20°C tests only*

The charcoal canister of the vehicle collects evaporative hydrocarbon emissions during the SHED tests. The collected vapours are then purged into the engine during the driving cycles. These canisters are never fully purged during driving and always maintain a fixed amount of trapped vapour, which is called the canister "heel". This presented a problem because of the possibility of carry over of fuel from test to test.

To mitigate this problem, two new canisters were purchased for each vehicle at the beginning of the program and seasoned using the summer grade base testing fuel. The 20°C testing began using Canister #1, and the fuels were tested in ascending ethanol content starting with the base fuel. Before the repeat 20°C tests were performed, Canister #1 was replaced with a new seasoned canister, Canister #2. The repeat base fuel tests were therefore performed with identical canister conditions as the initial base fuel tests.

To prepare for the -10°C testing, Canister #1 was purged for approximately 4 weeks alternately with pressurized clean air and under vacuum to remove as much of the canister heel as possible. The -10°C testing began using Canister #2 (previously only used for summer grade base fuel) and the fuels were tested in ascending ethanol content starting with the base fuel. Before the repeat -10°C tests were performed, Canister #2 was replaced with Canister #1. Although Canister #1 had been exposed to ethanol fuels from the 20°C testing, it is believed that the purging process removed most of the ethanol contamination making the initial and repeat base fuel tests as similar as possible with regards to canister conditions.

The canister conditioning and vehicle preparation procedures minimized but did not completely eliminate fuel carry-over. The details of the fuel carry over are discussed in report 04-27B.

3.2 Test Vehicles

Four vehicles of differing technologies were tested in this program. A summary of these vehicles is as follows:

- 1998 Ford Escort ZX2 (US EPA Tier 1 emission standard, available in North America)
- 2001 Nissan Sentra CA (California SULEV emission standard, available in North America)
- 2003 Dodge Caravan (US EPA LEV emission standard, available in North America)
- 2000 Mitsubishi Dion (Japanese LEV emission standard, not currently available in North America)

1998 Ford Escort ZX2

The 1998 Ford Escort ZX2 test vehicle was a 2.0 L, 4 cylinder subcompact car with an automatic transmission, a 130 hP (at 5750 rpm) engine, and a curb weight of 2478 lb. The EnerGuide fuel economy for the Escort is 30 mpg in the city and 43 mpg on the highway (fuel consumption of 9.3 L/100 km city, 6.5 L/100km highway) when running on regular unleaded gasoline [3]. At the beginning of the testing program, the Escort odometer read approximately 80,000 km (approximately 50,000 mi).

This vehicle was manufactured under the United States Environmental Protection Agency (US EPA) Tier 1 Emission Standard for Passenger Cars, which is outlined in Table 3.[4] Note that because of the age and mileage of the vehicle, it falls into the "*100,000 miles / 10 years*" category. These standards apply to measurements made over the Federal Test Procedure (FTP) driving cycle. Of the three test vehicles available in North America, the Escort was the oldest and had the least stringent emission standard. It was therefore expected to have the highest emission rates out of the three North American vehicles.

Table 3: US EPA Tier 1 Emission Standard for Gasoline Passenger Cars (g/mile)

Driving Cycle	Time Frame	Total Hydrocarbon (THC)	Non-Methane Hydrocarbon (NMHC)	Carbon Monoxide (CO)	Oxides of Nitrogen (NO_X)	Particulate Matter (PM)
FTP	50,000 miles / 5 years	0.41	0.25	3.4	0.4	0.08
	100,000 miles / 10 years	-	0.31	4.2	0.6	0.10

2001 Nissan Sentra CA

The 2001 Nissan Sentra CA (Clean Air) test vehicle was a 1.8 L, 4 cylinder compact car with an automatic transmission, a 122 hP (at 6000 rpm) engine, and a curb weight of 2627 lb. The EnerGuide fuel economy for the Sentra is 31 mpg in the city and 43 mpg on the highway (fuel consumption of 9.0 L/100km city, 6.5 L/100km highway) when running on regular unleaded gasoline.[5] At the beginning of the testing program, the Sentra odometer read approximately 12,000 km (approximately 8,000 mi).

This vehicle was manufactured under the California Super Ultra Low Emission Vehicle (SULEV) Emission Standard for Passenger Cars, which is outlined in Table 4.[6] This standard applies to measurements made over the FTP driving cycle. Emissions regulations for the Supplemental Federal Test Procedure (SFTP), which includes the US06 driving cycle and the SC03 driving cycle, are also included in this standard. The SC03 driving cycle examines the effect of air conditioner use on emissions, and is not relevant to this study. SULEV designated vehicles are also regulated to zero evaporative emissions. Of the vehicles tested in this study, the Sentra is regulated under the most stringent emissions standard and was therefore expected to have the lowest emissions when compared to the other vehicles.

Table 4: California LEV II, SULEV Emission Standard for Passenger Cars (g/mile)

Driving Cycle	Time Frame	Non-Methane Organic Gases (NMOG)	Carbon Monoxide (CO)	Oxides of Nitrogen (NO_X)	Particulate Matter (PM)	Formaldehyde (HCHO)
FTP	120,000 miles / 11 years	0.010	1.0	0.02	0.01	0.004

2003 Dodge Caravan SE FFV

The 2003 Dodge Caravan SE FFV test vehicle was a 3.3 L, 6 cylinder minivan with an automatic transmission, a 180 hP (at 5200 rpm) engine, and a curb weight of 3869 lb. This vehicle was manufactured as a flex fuel vehicle and is capable of running on gasoline-ethanol blended fuels of up to 85% ethanol (E85). The EnerGuide fuel economy for the Caravan is 24 mpg in the city and 34 mpg on the highway (fuel consumption of 12.0 L/100km city, 8.2 L/100km highway) when running on regular unleaded gasoline. When running on E85, the EnerGuide fuel economy is 15 mpg in the city and 23 mpg on the highway (fuel consumption of 18.5 L/100km city, 12.5 L/100km highway).[7] At the beginning of the testing program, the Caravan odometer read approximately 25,000 km (approximately 15,000 mi).

The Caravan was manufactured under the US EPA Low Emission Vehicle (LEV) Emission Standard for Light Duty Trucks as part of the US EPA National Low Emission Vehicle (NLEV) Program. The NLEV program began in the north-eastern states with vehicle model year 1999, and became a US national program with vehicle model year 2001. This program was designed to harmonize the US Federal and the more stringent California vehicle emission standards. The details of the emission standard are outlined in Table 5.[8] Note that because of the age and mileage of the Caravan, it falls into the "*50,000 miles / 5 years*" category. This standard applies to measurements made over the FTP driving cycle. Emissions regulations for the Supplemental Federal Test Procedure (SFTP), which includes the US06 driving cycle and the SC03 driving cycle, are also included in this standard.

Table 5: US EPA LEV Emission Standard for Light Duty Trucks, Weight 3751 – 5750 lb (g/mile)

Driving Cycle	Time Frame	Non-Methane Organic Gases (NMOG)	Carbon Monoxide (CO)	Oxides of Nitrogen (NO_X)	Particulate Matter (PM)	Formaldehyde (HCHO)
FTP	50,000 miles / 5 years	0.100	4.4	0.4	n/a	0.018
	100,000 miles / 10 years	0.130	5.5	0.5	0.10	0.023

2000 Mitsubishi Dion Exceed

The 2000 Mitsubishi Dion Exceed test vehicle was a 2.0 L, 4 cylinder small utility wagon with an automatic transmission, a curb weight of 3115 lb and a 133 hP (at 5800 rpm) gasoline direct injection (GDI) engine. Mitsubishi has stated that, as compared to a conventional gasoline engine, their GDI engine delivers up to 20% less fuel consumption and lower NO_X, SO_X, CO, THC, and particulate emissions. EnerGuide fuel economy values are not available for this vehicle; however Mitsubishi has stated that the Dion has fuel consumption of 13.0 km/L during the Japan 10.15 Mode driving cycle[9] (equal to 37 mpg or 7.7 L/100km). This vehicle was manufactured under the Japanese Low Emission Vehicle (LEV) Emission Standard, which is outlined in Table 6.[10] At the beginning of the testing program, the Dion odometer read approximately 25,000 km (approximately 15,000 mi).

Table 6: Japanese LEV Emission Standard for Light Duty Vehicles, Weight > 1.7 t (g/mile)

Driving Cycle	Carbon Monoxide (CO)	Total Hydrocarbon (THC)	Oxides of Nitrogen (NO_X)
J-LEV	1.08	0.13	0.13

The Japanese emission standards and fuel economy ratings cannot be directly compared to the US EPA emission standards and EnerGuide fuel economy ratings. This is because the Japanese standards and fuel economy ratings are applicable to measurements made over the Japan 10.15 Mode driving cycle. This driving cycle is quiet different from the Federal Test Procedure, which is used for the US EPA emission standards and EnerGuide fuel economy ratings. In 2001 ERMD conducted emissions tests on the Dion using standard FTP testing conditions. The vehicle emission levels were found to comply with Tier 1 LDV emission standards, as outlined in Table 3. The fuel economy was found to be 32 mpg in the city and 45 mpg on the highway (fuel consumption of 8.8 L/100 km city and 6.3 L/100 km highway).

With a conventional multi point injection (MPI) fuel system, the fuel is injected into the engine intake ports, where it mixes with air before entering the cylinder. With a GDI fuel system, the fuel is injected directly into the cylinder, similar to a diesel engine fuel intake system. By eliminating the step of air/fuel mixing in the intake port and by incorporating a relatively high compression ratio, the GDI engine can more tightly control injection timing to meet vehicle load requirements. According to Mitsubishi, under most driving conditions and up to speeds of 120 km/h the GDI engine operates using an ultra lean air/fuel ratio (A/F ratio of 30 – 40), which is expected to result in a decrease in fuel consumption and fuel-enrichment related emissions. At higher speeds, or when operating at high loads, the GDI engine operates with a more rich air/fuel ratio (A/F ratio of 13 – 24), which sacrifices improved fuel consumption and lower emissions for enhanced performance.[11]

Although not currently sold in Canada, analysis of this technology is beneficial because as more stringent emissions standards are introduced, technology will change to meet these standards. If the reductions in fuel consumption and pollutant emission rates are valid, this technology may become available for sale in Canada. Canada is moving towards using ethanol blended fuels; The *Government of Canada Action Plan 2000 on Climate Change* (released in 2000) set a goal of 10% ethanol blended gasoline in 25% of the Canadian gasoline market[12], and The *Climate Change Plan for Canada* (released in 2002) increased this goal to reach 35% of the Canadian market[13]. With this in mind, the effect of ethanol blend fuels on GDI equipped vehicles must be well understood before this technology is embraced in Canada.

3.3 Test Fuels

The test fuel names, grades and descriptions are summarized in Table 7. Summer grade fuels were used for the testing conducted at 20°C, while winter grade fuels were used for the testing conducted at -10°C. The winter grade fuels were formulated to have higher RVP than the summer grade fuels, which is necessary to obtain proper fuel vaporization in the vehicle combustion chambers at cold temperatures.

One possible method of preparing ethanol blend fuels is to simply “splash” blend a volume of ethanol with a base fuel. This method results in an ethanol blend fuel that has lower sulphur, higher octane, and higher vapour pressure than the base fuel. Since changes in these fuel qualities will have an impact on emissions, tailor blend fuels were also examined in this study. The tailor blend fuels were designed to have similar sulphur, octane, and vapour pressure as the base fuel and to represent typical Canadian fuel properties. Selected fuel properties for the summer grade and the winter grade fuels are outlined in Table 8 and Table 9 respectively. The complete fuel analysis data set is included in Appendix 1.

Table 7: Fuel Names and Descriptions

Fuel Grade	Fuel Name	Fuel Description
Summer	S-E0	Base Fuel, no ethanol
	S-E10	Tailor blend, 10% ethanol
	S-E10-Spl	Splash blend, 10% ethanol
	S-E20	Tailor blend, 20% ethanol
Winter	W-E0	Base Fuel, no ethanol
	W-E10	Tailor blend, 10% ethanol
	W-E10-Spl	Splash blend, 10% ethanol
	W-E20	Tailor blend, 20% ethanol

Table 8: Summer Grade Fuel Analysis Results

Fuel Property	Units	E0	E10	E10-Spl	E20
Specific Gravity	kg/L	0.705	0.725	0.717	0.734
Net Heating Value	BTU/lb_m	18927	18127	18182	17319
Energy Density	BTU/L	29358	28923	28674	27948
Fuel Fraction Carbon	Wt. Fraction	0.848	0.825	0.812	0.789
Fuel Fraction Oxygen	Wt. Fraction	0	0.036	0.036	0.073
Sulphur Content	ppm	34	34	31	35
Research Octane No.	n/a	88.6	90.0	96.0	92.0
Motor Octane No.	n/a	86.0	85.0	89.0	85.7
RVP	Psi	8.8	8.6	9.4	8.7

Table 9: Winter Grade Fuel Analysis Results

Fuel Property	Units	E0	E10	E10-Spl	E20
Specific Gravity	kg/L	0.693	0.726	0.705	0.714
Net Heating Value	BTU/lb_m	18975	18096	18200	17494
Energy Density	BTU/L	28927	28903	28216	27463
Fuel Fraction Carbon	Wt. Fraction	0.847	0.816	0.805	0.774
Fuel Fraction Oxygen	Wt. Fraction	0	0.036	0.037	0.073
Sulphur Content	ppm	33	33	26	27
Research Octane No.	n/a	88.2	90.0	94.0	100.0
Motor Octane No.	n/a	85.0	84.3	89.5	90.0
RVP	psi	13.4	13.1	13.8	13.2

The theoretical fuel volume based CO_2 emission rates per litre of fuel burned assuming perfect combustion (100% conversion of the fuel carbon to CO_2) were calculated from the fraction of carbon in the fuels along with the specific gravities. From this calculation, using the energy densities, the theoretical fuel volume based CO_2 emission rates per BTU were calculated. Because the fuels have differing fuel carbon fractions, specific gravities, and energy densities, the theoretical CO_2 emission rates also vary. These theoretical CO_2 emission rates are outlined in Table 10.

For example, the summer grade E10 fuel has essentially the same CO_2 emissions per volume as the base fuel, however since it has less energy per volume, the CO_2 emission rate per unit energy is 1.6% higher than the E0 fuel. This results in a potential net increase in CO_2 emissions at the tailpipe. In contrast, the summer grade E20 fuel has a volume based CO_2 emission rate 3.2% lower than the base fuel, however this is offset by the lower energy content of the fuel and the corresponding 1.7% increase in CO_2 emissions per unit energy. The net result is a potential 1.5% decrease in CO_2 emissions at the tailpipe.

Table 10: Theoretical CO_2 Emissions Assuming 100% Conversion

Fuel Grade	Fuel Blend	CO_2 per Volume		CO_2 per Energy Unit	
		g CO_2 / L fuel	% Diff from E0	mg CO_2 / BTU	% Diff from E0
Summer	E0	2191	--	74.6	--
	E10	2192	0.06 %	75.8	1.6 %
	E10-Spl	2133	-2.7 %	74.4	-0.3 %
	E20	2121	-3.2 %	75.9	1.7 %
Winter	E0	2151	--	74.3	--
	E10	2171	0.9 %	75.1	1.0 %
	E10-Spl	2079	-3.3 %	73.7	-0.9 %
	E20	2024	-5.9 %	73.7	-0.9 %

3.4 Driving Cycles & Test Temperatures

Testing was conducted at two temperatures: 20°C and -10°C. The testing at 20°C was conducted with the summer grade fuels. The testing at -10°C was performed with the winter grade fuels.

The vehicles were tested over two driving cycles to investigate the change in emissions from the vehicle technologies while operating on the various fuel compositions and under the different driving conditions.

LA4 Driving Cycle

The test cycle used to determine compliance with criteria emissions standards was based on the 3-phase Federal Test Procedure (FTP). In this study a 4-phase version was used to simplify particulate matter sample collection and still provide the desired information on cold and hot start effects.

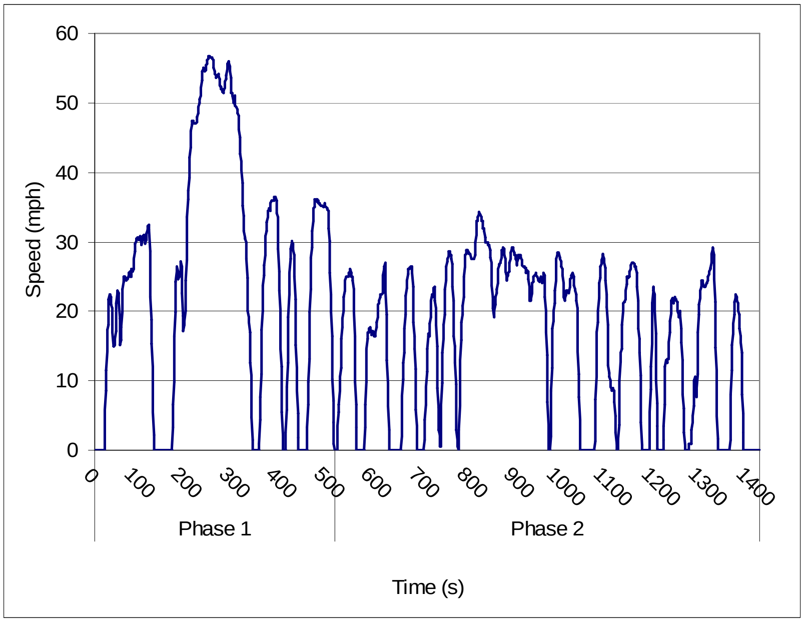
Phase 1 and 2 of the FTP driving cycle are collectively referred to as the LA4 cycle. Phase 1 allows examination of engine start-up conditions, while Phase 2 represents stabilized transient operation typical of a non-demanding style of urban and suburban driving as well as city fuel economy. Phases 1 is 505 seconds in length and covers a distance of 3.6 mi with an average speed of 25.6 mph and a maximum speed of 56.7 mph. Phase 2 of the LA4 follows immediately from Phase 1. This phase is 865 seconds in duration and covers a distance of 3.9 mi with an average speed of 16.1 mph and a maximum speed of 34.3 mph. For this study, the LA4 cycle was performed twice, with a 20 minutes soak period in between to facilitate filter changes for particulate matter sample collection.

The vehicle was allowed to soak overnight at the test temperature before the first LA4 cycle of each testing day. Because of the resulting cold engine conditions at start-up, this first LA4 cycle is referred to as a "Cold Start LA4" or "CSLA4". At the conclusion of the CSLA4, the vehicle and sampling systems were turned off for a twenty-minute soak period. After the soak, the vehicle and sampling systems were restarted and the LA4 cycle was repeated. Because the engine conditions were warm for the start-up of this second LA4 cycle, it is referred to as a "Hot Start LA4" or "HSLA4".

The differences in emissions between the Phase 1 CSLA4 and the Phase 1 HSLA4 were due primarily to the difference in engine start temperature and how long the emissions control technology took to reach operating temperature. During the Phase 2 CSLA4 and Phase 2 HSLA4 the emission control technology should have been functioning optimally and emissions from these two tests should be nearly identical.

Figure 2 illustrates the LA4 driving cycle. Note that while Phase 1 of the LA4 reaches higher speeds, Phase 2 of the LA4 contains more stop/start and acceleration/deceleration sequences.

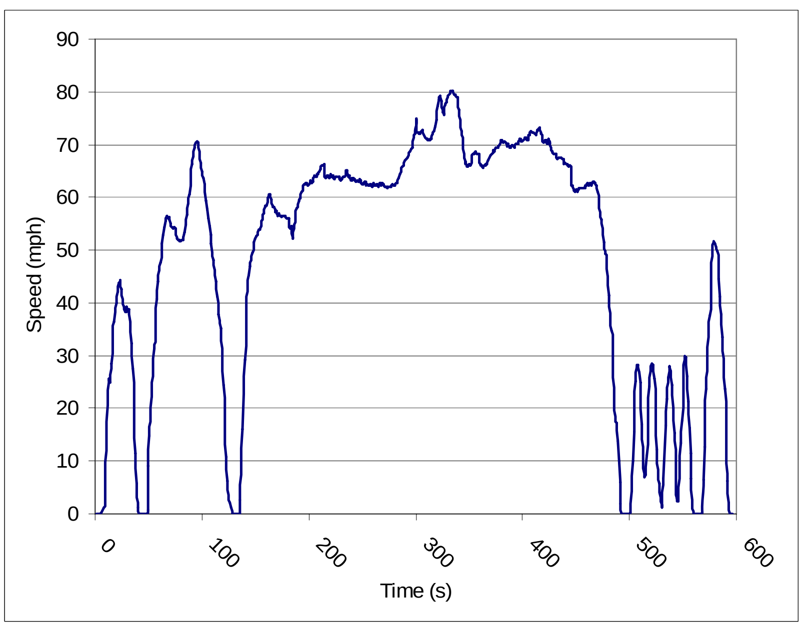
Figure 2: LA4 Driving Cycle



US06 Driving Cycle

The US06 driving cycle was developed to represent aggressive, high speed, hard acceleration/deceleration driving. It incorporates rapid speed fluctuations and better represents "real world" driving behaviour following start-up as compared to the LA4 driving cycle. This single-phase cycle is 600 seconds long and covers a distance of 8.1 mi with an average speed of 48.4 mph and a maximum speed of 80.3 mph. Figure 3 illustrates this driving cycle.

Figure 3: US06 Driving Cycle



4. Sample Collection & Analytical Methods

Test procedures used in this program comply with those specified in the Canadian Environmental Protection Act and are equivalent to those specified in the U.S. Code of Federal Regulations (US CFR) Title 40 Part 86 unless otherwise specified.

The total volume of exhaust produced by the vehicle was collected and diluted using a total exhaust dilution constant volume sampling (CVS) system. The total dilute exhaust volume flow rate was 330 scfm (9,345 L/min). The dilution air was taken from the test cell and was conditioned using a HEPA filter, which removed particulate matter with an efficiency of 99.9%. The organic composition of the dilution air was reduced and stabilized by passing it through a bed of activated carbon. Dilution was accomplished within 3 feet of the vehicle tailpipe to minimize particulate matter losses. The transfer line from the vehicle tailpipe to the dilution system was stainless steel to minimize contamination of the dilute exhaust.

Prior to the start of this test program, the dilution system was pressure washed to avoid contamination from previous experiments. During vehicle preconditioning, the inner surfaces of the tunnel were equilibrated with the exhaust of the vehicle before emissions samples were collected. The particulate matter levels in the dilution air were routinely monitored throughout the testing program.

Samples for determining emissions of CO_2 were collected on a per phase basis, resulting in two samples for each LA4 driving cycle and one sample for each US06 driving cycle. For each dilute exhaust sample collected, a corresponding dilution air sample was collected. Samples were collected at a constant rate through a venturied probe to fill large Tedlar™ bags. The bag samples were automatically analyzed at the end of each driving cycle using the automated instruments located in the test cell.

Dilute exhaust samples for determining CH_4 and N_2O were collected from the CVS from all driving cycles on a per phase basis, resulting in two samples for each LA4 driving cycle and one sample for each US06 driving cycle. In addition, one dilution air sample was collected for each LA4 and US06 driving cycle. The samples were drawn from the dilution tunnel using a diaphragm pump and an electronic mass flow controller to provide a constant sample flow rate. The samples were collected in Tedlar ™ bags and underwent analysis within 8 hours of collection at an on-site laboratory.

4.1 Carbon Dioxide (CO_2)

Dilute exhaust and dilution air concentrations of CO_2, were determined using a Horiba Non-Dispersive Infra-Red (NDIR) instrument (Model AIA 23). This is a dedicated analyzer, specifically used for vehicle emissions testing. The samples were measured using a 2% full-scale range, yielding a detection limit of 0.02% CO_2 in dilute exhaust.

4.2 Methane (CH_4)

CH_4 was determined by gas chromatography using a simple gas loop injection onto a capillary column. The sample loop was flushed with sample and the pressure inside the loop was allowed to equilibrate to ambient conditions. The contents of the loop were then injected directly onto the capillary column. A Hewlett Packard 5890 Series II gas chromatograph (GC) equipped with a gas sampling valve and a flame ionization detector (FID) was used for the analysis. Data was acquired using the Hewlett Packard GC ChemStation (Windows NT) software. The analytical conditions are summarized in Table 11.

Table 11: GC-FID Parameters for CH_4 Analysis.

Column	GS-Q, 30 m x 0.53 mm Column head pressure 9 psig Helium carrier gas
Oven Program	Hold for 1.1 min @ 40^{o}C 25 ^{o}C/min to 130 ^{o}C Hold for 7.3 min @ 130 ^{o}C
Detector	Flame Ionization Detector (FID) Maintained at 180 ^{o}C
Sample	0.25 mL sample loop Sample valve at 100 ^{o}C
Detection Limit	10 ng/L

4.3 Nitrous Oxide (N_2O)

N_2O was determined using a Hewlett Packard 5890A Series II gas chromatograph (GC) with an electron capture detector (ECD). Component identification was made by analysis of certified standards with retention time comparison. CO_2 interference was handled by using an Ascarite^{TM} trap to remove CO_2 from the sample stream during the loop flush. Water interference was minimized by using a sodium sulphate (anhydrous) trap upstream of the Ascarite^{TM} trap. Data was acquired using the Hewlett Packard GC ChemStation software. A gas-sampling valve was used for sample injection. Table 12 lists the analytical conditions.

Table 12: GC-ECD Parameters for N_2O Analysis.

Column	HP-PLOT Q, 15 m x 0.53 mm 40 µm film thickness Helium carrier gas
Oven Program	Hold for 5 min @ 40°C 40°/min to 120° Hold for 1 min. @ 120°C.
Detector	Electron Capture Detector (ECD) 5% methane/argon ECD gas Maintained at 180°C
Sample size	0.25 ml sample loop Sample valve at 100 ^{o}C
Detection Limit	4.2 ppb

5. Data Analysis

5.1 Average & Standard Deviation

Each driving cycle was repeated 2 to 6 times for each fuel. The number of repeats conducted was determined by the consistency of the emission rate results. The averages of these tests are presented in this report along with the corresponding standard deviations. Outlying data, as determined by the Grubbs' Outlier Test using a 95% confidence interval, have been removed from these results. The Grubbs' test is outlined below[14]. Note that the "critical value" is chosen by comparing the number of data points to the Grubbs' critical value table. Less than 0.5% of the data were found to be outliers.

$$G_1 = \frac{\left|\bar{x} - x_i\right|}{s} \qquad \begin{aligned} where: \bar{x} &= sample\ set\ mean \\ x_i &= suspected\ single\ outlier \\ s &= standard\ deviation\ for\ sample\ set \end{aligned}$$

$$if\ G_1 > critical\ value \Rightarrow then\ x_i = outlier$$

5.2 Statistical Analysis (ANOVA Test)

The potential difference between the emissions from the E0 fuel as compared to the ethanol blend fuels were evaluated using analysis of variance (ANOVA) tests. The Microsoft Excel "Single Factor ANOVA" tool was used. The P-value given by this tool can be interpreted as the probability that the observed difference between the two fuels being compared is not greater than the differences within the repeat tests on the fuels. In other words, the P-value can bee seen as the probability that the differences between the two fuels is not statistically significant but due to random error. The P-value is a number between 0 and 1, where 1 equals 100% probability that the differences are due to random error.

In this report, two types of comparisons were made using the ANOVA test. Firstly, the CO_2 emission rates from the initial tests on the E0 (base) fuel were compared to the CO_2 emission rates from the repeat tests on the E0 fuel. This comparison was done to determine if the vehicle operation had shifted during the testing program. The second type of comparison compared the emission rates from the ethanol blend fuels to the emission rates from the E0 fuel. This comparison was made to evaluate the effect of ethanol on the emission rates.

For this study a 95% confidence interval was used, meaning that P-values less than 0.05 indicate a statistically significant difference. When using a P-value less than 0.05, there is less than 1 chance in 20 that any statistically significant differences observed were due only to random error.

The P-values for these comparisons are summarized for each emission type in the Appendices. For those comparisons that showed a statistically significant difference, the change is indicated in the table. NSD indicates no statistically significant difference. For those comparisons that showed a statistically significant difference, the percent difference between the fuels was also determined, using the following calculation:

$$\%\ Difference = \frac{Emission\ Rate\ of\ Ethanol\ Blend\ Fuel - Emission\ Rate\ of\ E0\ Fuel}{Emission\ Rate\ of\ E0\ Fuel}$$

$$Positive\ \%\ Difference = Emission\ Rate\ of\ Ethanol\ Blend\ Fuel > Emission\ Rate\ of\ E0\ Fuel$$

$$Negative\ \%\ Difference = Emission\ Rate\ of\ E0\ Fuel > Emission\ Rate\ of\ Ethanol\ Blend\ Fuel$$

5.3 Enrichment Ratios

Two types of enrichment ratios are presented in this report:

1. To demonstrate the emissions impact from start-up of a cold engine, the emission rates from the Phase 1 CSLA4 driving cycle were divided by those from the Phase 1 HSLA4 driving cycle. These driving cycles were chosen for comparison because they are identical aside from the engine conditions at start-up.

$$Start-Up\ Temp\ Enrichment\ Ratio = \frac{Emission\ Rate\ from\ Phase\ 1\ CSLA4}{Emission\ Rate\ from\ Phase\ 1\ HSLA4}$$

2. To demonstrate the emissions impact from aggressive driving, the emission rates from the US06 driving cycle were divided by those from the Phase 1 HSLA4 driving cycle. These driving cycles were chosen for comparison because they both involve start-up of a warm engine, but the US06 driving cycle is much more aggressive than the Phase 1 HSLA4 driving cycle.

$$Aggressive\ Driving\ Enrichment\ Ratio = \frac{Emission\ Rate\ from\ US06}{Emission\ Rate\ from\ Phase\ 1\ HSLA4}$$

An enrichment ratio of “1” indicates that the emission rates are similar between the compared driving cycles, which suggests that the examined engine/driving conditions have no effect on the emission rates.

6. Results and Discussion – Repeatability of E0 Fuel Tests

Each vehicle was tested twice on the E0 fuel – once before the ethanol blend fuels were tested and once following the ethanol blend fuel tests. This was done to enable the detection of vehicle shift over the testing program. CO_2 emission rates are indicative of repeatability because CO_2 emissions are largely associated with fuel consumption and do not greatly vary from test to test (when using the same vehicle and fuel). This section presents only the CO_2 emission rates from the initial and repeat E0 tests. Further details on CO_2 emission rates from all tests are discussed in Section 7.1.

20°C Testing

Table 13 outlines the average and standard deviation of the CO_2 distance based emission rates from the initial and repeat E0 fuel tests, along with the P-values from the statistical comparison between the initial and repeat tests. P-values that indicate a statistical difference between the initial and repeat E0 fuel tests (those less than 0.05) are italicized and shown in bold text.

Table 13: CO_2 Emission Rates (g/mile) from 20°C Tests – Initial vs. Repeat E0 Fuel Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dv	Avg	St Dev
ESCORT										
E0	306	7	295	7	261	9	291	5	264	8
E0-Rep	324	5	315	6	282	8	307	2	288	4
P-Value	0.062		***0.042***		0.078		***0.028***		***0.033***	
SENTRA										
E0	293	4	263	4	244	2	261	3	270	2
E0-Rep	301	3	273	2	252	3	271	4	280	3
P-Value	0.064		***0.031***		***0.049***		***0.041***		***0.026***	
CARAVAN										
E0	423	0.5	455	10	377	6	432	8	370	11
E0-Rep	418	0.07	438	1	366	3	426	4	374	6
P-Value	***0.001***		0.101		0.096		0.379		0.680	
DION										
E0	390	3	342	10	320	6	321	5	342	6
E0-Rep	386	27	339	5	313	2	319	6	332	10
P-Value	0.833		0.720		0.200		0.711		0.280	

The first set of vehicles tested included the Escort and the Sentra. After the initial E0 fuel tests were completed, the muffler on the Escort was found to be faulty. The vehicle was an older model in-use vehicle, and was equipped with its original OEM (original equipment manufacturer) muffler. Because of its age, the inside of the muffler had begun to rust and become frail. The stresses placed upon it during vehicle preconditioning had torn sections of the insulating material out of the muffler, and this material became lodged in the sampling system. After this problem was discovered, the sampling system was cleaned and the muffler on the Escort was replaced before continuing with the tests on the ethanol blend fuels and the repeat E0 fuel tests.

The results in Table 13 reveal that for the majority of the tests on the Escort and the Sentra, the initial E0 fuel CO_2 emission rates were statistically different than those from the repeat E0 fuel tests. These statistical differences are believed to have been caused by the faulty Escort muffler , which invalidated the initial set of test results for both the Escort and the Sentra. For the Escort, any holes in the muffler may have allowed exhaust to escape and/or additional dilution air to enter. For both the Escort and the Sentra, the muffler material that became lodged in the sampling system may have changed the flow rate through the system by interfering with the critical flow venturi. For these reasons, the initial E0 fuel results from both the Escort and the Sentra are considered void and were not used in further analyses in this report. All future references to E0 fuel results at 20°C from the Escort and the Sentra refer only to the repeat E0 fuel tests results.

The statistical analysis results in Table 13 from the Caravan and the Dion reveal that for all but one of the comparisons there was no statistically significant difference between the initial E0 fuel CO_2 emission rates and those from the repeat E0 fuel. The one test that did show a statistically significant difference is the Phase 1 CSLA4 driving cycle for the Caravan.   This value of this difference was 1.2%, which is relatively small; however the difference was statistically significant because of the unusually low standard deviations associated with these tests. Since the CO_2 emission rates from the initial E0 fuel were generally not statistically different than those from the repeat E0 fuel, the results were combined. All future references to E0 fuel results at 20°C from the Caravan and the Dion refer the combined results from the initial and repeat E0 fuel tests.

-10°C Testing

Table 14 outlines the average and standard deviation of the CO_2 distance based emission rates from the initial and repeat E0 fuel tests, along with the P-values from the statistical comparison between the initial and repeat tests. Note that there are no P-values that indicate a statistical difference between the initial and repeat E0 fuel tests (no P-values less than 0.05).

Table 14: CO_2 Emission Rates (g/mile) from -10°C Tests – Initial vs. Repeat E0 Fuel Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dv	Avg	St Dev
ESCORT										
E0	380	0.03	344	4	309	4	324	6	295	9
E0-Rep	377	9	344	15	316	18	341	33	298	7
P-Value	0.728		0.984		0.623		0.562		0.634	
SENTRA										
E0	402	17	351	27	295	5	312	10	295	6
E0-Rep	384	5	332	7	299	8	318	10	290	5
P-Value	0.141		0.308		0.506		0.531		0.384	

The CO_2 emission rates from the initial E0 fuel were not statistically different than those from the repeat E0 fuel, therefore the results were combined. All future references to E0 fuel results at -10°C from the Escort and the Sentra refer the combined results from the initial and repeat E0 fuel tests.

7. Results and Discussion – E0 Fuel Compared to Ethanol Blend Fuels

7.1 Carbon Dioxide (CO_2)

Figure 4 and Figure 5 illustrate the CO_2 emission rates from the four vehicles over the LA4 and US06 driving cycles at the two test temperatures (20°C and -10°C respectively). These figures use units of grams of CO_2 per mile travelled. Figure 6 and Figure 7 give the same data for 20°C and -10°C respectively, using units of grams of CO_2 per litre of fuel used. Numerical emission rates and results from the statistical analysis on these data can be found in Appendix 2. Unless stated otherwise, the results in the following paragraphs apply to both test temperatures for the Escort and Sentra, and to 20°C only for the Caravan and Dion. Recall that the Caravan and Dion were not tested at -10°C

<u>*Distance Based Emission Rates*</u>

Analysis of the figures and of the statistical analysis results reveals that the distance based CO_2 emission rates from the ethanol blend fuels were not different than those from the base fuel. Although the ethanol blend fuels had a lower energy density as compared to the E0 fuel (see Table 8 and Table 9), which would theoretically lead to an increase in the distance based CO_2 emission rate (a larger volume of fuel is needed to go the same distance), the ethanol blends also had lower carbon content per litre of fuel, resulting in less carbon being emitted per litre of fuel burned. The test results suggest that these two effects appear to have cancelled each other at the tailpipe.

The distance based CO_2 emission rates from the -10°C tests were higher than those from the 20°C tests. This is expected because the winter grade fuels had lower energy densities as compared to the summer grade fuels (see Table 8 and Table 9). Also, cold temperature operation typically increases fuel consumption.

Enrichment ratios that compare the distance based CO_2 emission rates from the Phase 1 CSLA4 driving cycle to those from the Phase 1 HSLA4 driving cycle are presented in Table 15. Not surprisingly, all of the enrichment ratios are greater than 1, indicating that the cold engine conditions of the Phase 1 CSLA4 caused an increase in distance based CO_2 emission rates. This increase is on the order of 15-20%. Operation at cold temperature further increased the enrichment ratios, by 5-10%. The presence of ethanol in the fuels did not alter the magnitude of the enrichment ratios.

Table 15: CO_2 Enrichment Ratios: Phase 1 CSLA4 vs. Phase 1 HSLA4 (distance based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	1.15	0.05	1.19	0.02	1.13	0.02	1.22	0.04
E10	1.18	0.03	1.21	0.02	1.15	0.02	1.26	0.006
E10-Spl	1.19	0.03	1.19	0.01	1.15	0.01	1.24	0.04
E20	1.16	0.01	1.21	0.003	1.15	0.04	1.20	0.04
-10°C Testing								
E0	1.21	0.04	1.32	0.06				
E10	1.22	0.01	1.30	0.03				
E10-Spl	1.23	0.02	1.28	0.03				
E20	1.22	0.02	1.33	0.005				

Enrichment ratios that compare the distance based CO_2 emission rates from the US06 driving cycle to those from the Phase 1 HSLA4 driving cycle are presented in Table 16. All of the ratios for 20ºC are approximately equal to 1, indicating that the Phase 1 HSLA4 and US06 driving cycles had similar distance based CO_2 emission rates. Again, the ethanol blend fuels resulted in the same enrichment ratios as the base fuel.

Table 16: CO_2 Enrichment Ratios: US06 vs. Phase 1 HSLA4 (distance based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	1.02	0.01	1.11	0.001	1.00	0.03	1.06	0.02
E10	1.03	0.01	1.07	0.03	1.02	0.03	1.08	0.01
E10-Spl	1.03	0.01	1.11	0.006	1.02	0.02	1.08	0.04
E20	1.03	0.006	1.12	0.003	1.03	0.03	1.09	0.01
-10°C Testing								
E0	0.95	0.03	0.99	0.02				
E10	0.93	0.02	1.00	0.001				
E10-Spl	0.93	0.04	0.99	0.01				
E20	0.94	0.02	1.02	0.004				

Fuel Volume Based Emission Rates

With the 20°C tests, the E10-Spl and E20 fuels resulted in a statistically lower fuel volume based CO_2 emission rates as compared to the E0 fuel, while those from the E10 fuel were not statistically different than those from the E0 fuel. This is expected since, as shown in Table 10, the E10 fuel had similar theoretical CO_2 emission rates (assuming 100% conversion of carbon to CO_2) as the E0 fuel. The experimental CO_2 emission rates from the E10-Spl and E20 fuels were 2 to 3% lower than the E0 fuel, which corresponds well with the theoretical data in Table 10.

With the -10°C tests, the E10 fuel resulted in a statistically higher fuel volume based CO_2 emission rate as compared to the E0 fuel, while the E10-Spl and E20 fuels resulted in a statistically lower fuel volume based CO_2 emission rate. As with the 20°C tests this was expected since, as compared to the E0 fuel, the E10 fuel had higher theoretical CO_2 emission rates and the E10-Spl and E20 fuels had lower theoretical CO_2 emission rates. The experimental results correspond quite well with the theoretical data in Table 10.

Overall Conclusions

- Distance-based CO_2 emission rates were essentially unchanged as ethanol content increased. The effect from the lower energy density of the ethanol blend fuels cancelled out the effect from the lower carbon content per litre of ethanol blend fuel burned.
- The presence of ethanol in the fuels did not alter the amount of enrichment needed for cold engine start or aggressive driving.
- With Tier 1 vehicle technology (Escort), operation at cold temperature increased distance based fuel consumption by ~16-19% on cold engine start, by ~10-15% under stabilized operation (Phase 2) and by ~1-4% under aggressive driving conditions (US06). These increases were similar between the base fuel and the ethanol blend fuels.
- With SULEV vehicle technology (Sentra), operation at cold temperature increased distance based fuel consumption by ~24-31% on cold engine start, by ~14-18% under stabilized operation and by ~3-7% under aggressive driving conditions. These increases were similar between the base fuel and the ethanol blend fuels.

Figure 4: CO_2 Distance Based Emission Rates (g/mile) from 20°C Tests

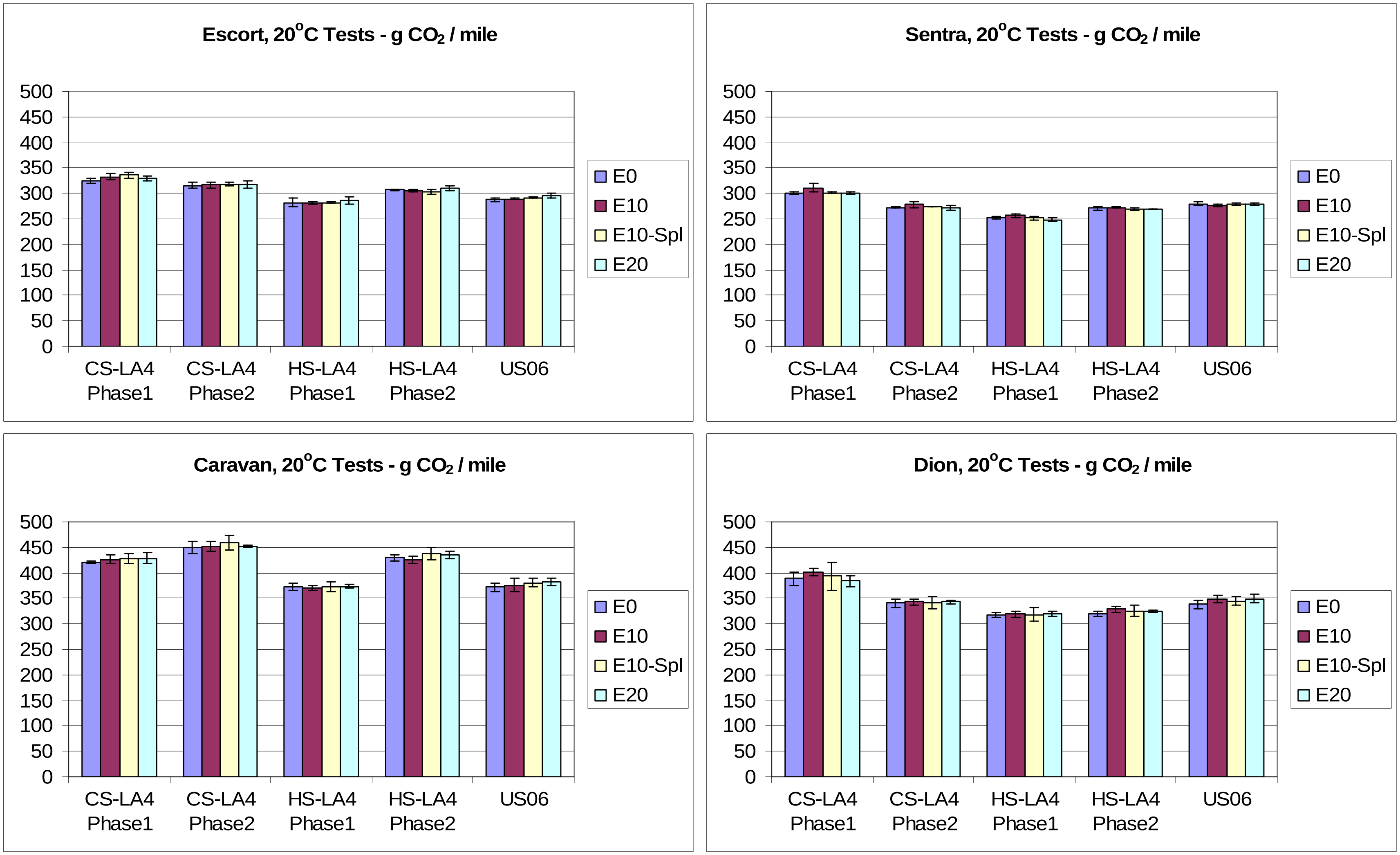


Figure 5: CO_2 Distance Based Emission Rates (g/mile) from -10℃ Tests

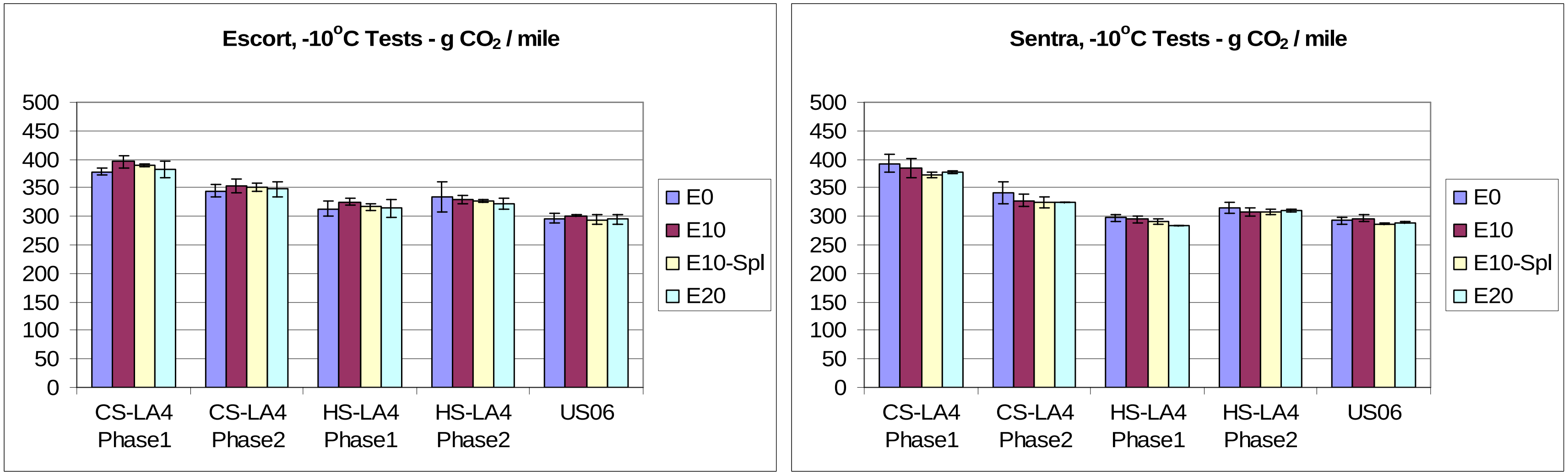


Figure 6: CO_2 Fuel Volume Based Emission Rates (g/L) from 20°C Tests

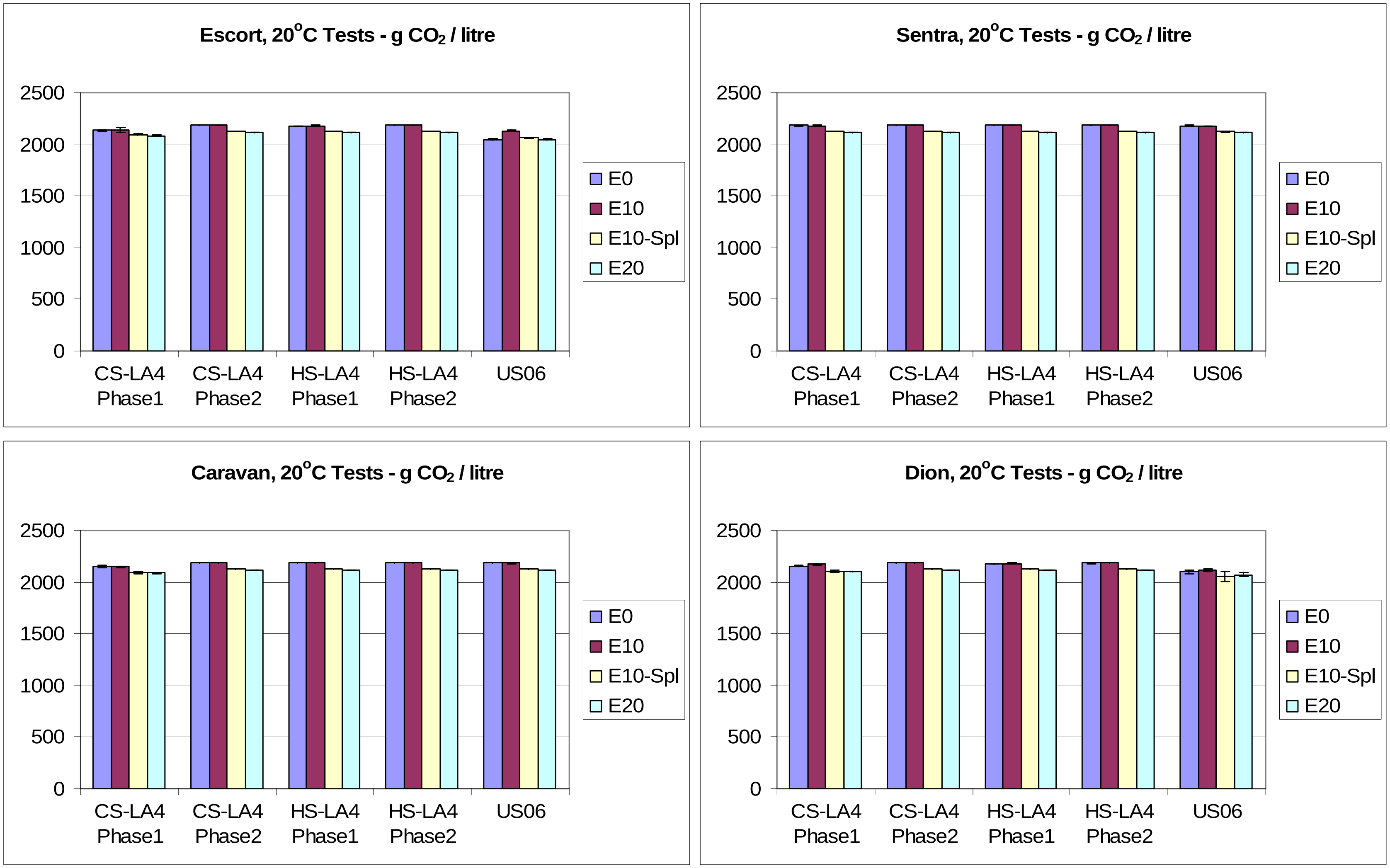
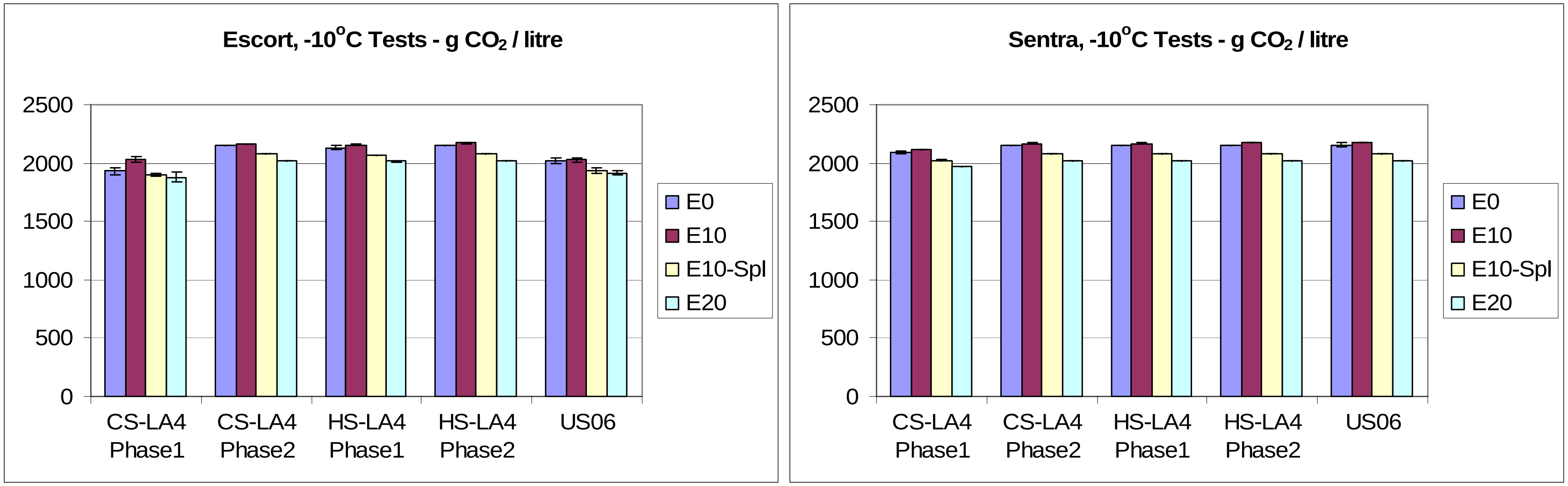


Figure 7: CO_2 Fuel Volume Based Emission Rates (g/L) from -10℃ Tests



7.2 Methane (CH_4)

Figure 8 and Figure 9 illustrate the CH_4 emission rates from the four vehicles over the LA4 and US06 driving cycles, at the two test temperatures (20°C and -10°C respectively). These figures use units of grams of CH_4 per mile travelled. Figure 10 and Figure 11 give the same data for 20°C and -10°C respectively, using units of grams of CH_4 per litre of fuel used. Numerical emission rates and results from the statistical analysis on these data can be found in Appendix 3. Unless stated otherwise, the results in the following paragraphs apply to both test temperatures for the Escort and Sentra, and to 20°C only for the Caravan and Dion. Recall that the Caravan and Dion were not tested at -10°C.

There is an underlying issue surrounding CH_4 tailpipe emission rate measurements because modern day vehicles generally have very low CH_4 emission rates. Often the dilute exhaust CH_4 concentrations are similar to ambient concentrations, resulting in negative or zero value emission rates. This can produce misleading trends. While studying the results presented in this section, this issue must be kept in mind.

<u>Distance Based Emission Rates</u>

The distance based CH_4 emission rates from the -10°C tests were higher than those from the 20°C tests. This is expected because cold temperature operation generally requires more fuel enrichment, which leads to higher hydrocarbon emissions. This is especially apparent for the CSLA4 cycles, in which the vehicle was started from a cold engine state.

For the Sentra, the CH_4 emission rates from the E0 fuel were not statistically different than those from the ethanol blend fuels for the 20°C tests during all of the driving cycles and for the -10°C tests during the LA4 driving cycles. With the -10°C tests during the US06 driving cycle, the CH_4 emission rates from the E0 fuel were statistically lower than those from the E10-Spl and E20 fuels. Because of the aforementioned issues surrounding CH_4 measurement, and the low emission rates seen with the Sentra, this trend is not conclusive.

For the Caravan and the Dion, the CH_4 emission rates from the E0 fuel were generally not statistically different than those from the ethanol blend fuels for all of the driving cycles. This was also true for the Escort LA4 driving cycles performed at 20°C and for all of the Escort driving cycles performed at -10°C. However, with the 20°C tests during the US06 driving cycle the Escort CH_4 emission rates from the ethanol blend fuels were statistically lower than those from the E0 fuel. This suggests that 20°C operation using ethanol blended fuels may reduce CH_4 emissions from older (Tier 1) vehicles under aggressive, high-speed driving conditions.

The Dion CH_4 emission rates showed a very different pattern than the three multi point fuel injection (MPFI) vehicles because the Dion operated with a lean air/fuel rather than with a stoichiometric A/F ratio. Although the Dion experienced increased CH_4 emission rates during the Phase 1 CSLA4 (due to enrichment), all other driving cycles had similar CH_4 emissions. The US06 test did not seem to push the vehicle out of this lean operation.

Enrichment ratios that compare the distance based CH_4 emission rates from the Phase 1 CSLA4 driving cycle to those from the Phase 1 HSLA4 driving cycle are presented in Table 17. All of the enrichment ratios are greater than 1, indicating that the cold engine conditions of the Phase 1 CSLA4 caused an increase in distance based CH_4 emission rates. This is not surprising, as cold engine start-up requires more fuel enrichment than warm engine start-up, which leads to higher hydrocarbon emissions. Cold temperature operation increased these enrichment ratios substantially, with ratios that are 5 to 10 times higher than those at standard temperature. The presence of ethanol in the fuels did not alter the magnitude of the enrichment ratios.

Table 17: CH_4 Enrichment Ratios: Phase 1 CSLA4 vs. Phase 1 HSLA4 (distance based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	3.1	n/a	2.2	0.4	3.5	1.0	2.2	0.4
E10	2.9	0.1	3.3	1.0	3.8	0.9	2.2	0.1
E10-Spl	2.4	0.09	2.9	0.2	3.3	0.3	2.6	0.2
E20	3.1	0.8	2.1	0.2	3.2	0.06	2.1	0.1
-10°C Testing								
E0	16.3	1.9	22.4	8.3				
E10	15.2	1.5	22.8	n/a				
E10-Spl	13.8	0.8	14.1	0.7				
E20	12.7	5.9	20.1	3.2				

Enrichment ratios that compare the distance based CH_4 emission rates from the US06 driving cycle to those from the Phase 1 HSLA4 driving cycle are presented in Table 18. For the Escort the ratios are greater than 1, for the Sentra the ratios are less than 1, and for the Caravan and Dion the ratios are approximately equal to 1. These results indicate that the aggressive driving conditions of the US06 caused an increase in CH_4 emissions from the Tier 1 technology, a reduction in CH_4 emissions from the SULEV technology, and did not affect the CH_4 emissions from the NLEV and GDI technology. The majority of the data show enrichment factors of the same magnitude for both the base fuel and the ethanol blend fuels, with the exception of the Escort tests at 20°C which have smaller enrichment factors for ethanol blends. However in this case there was only one data point used to calculate the base fuel factor, therefore a standard deviation is not available and this trend cannot be confirmed. The enrichment factors from the 20°C tests are similar in magnitude to those from the -10°C tests.

Table 18: CH_4 Enrichment Ratios: US06 vs. Phase 1 HSLA4 (distance based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	4.3	n/a	0.6	0.2	0.8	0.1	0.9	0.1
E10	2.4	0.2	0.6	0.008	1.0	0.1	1.1	n/a
E10-Spl	2.4	0.06	0.4	0.03	0.8	0.05	1.0	0.06
E20	2.9	0.3	0.5	0.02	0.8	0.02	0.5	n/a
-10°C Testing								
E0	3.6	0.4	0.4	0.01				
E10	3.4	1.2	0.2	n/a				
E10-Spl	3.6	0.5	0.3	0.09				
E20	2.7	0.6	0.4	0.03				

<u>*Fuel Volume Based Emission Rates*</u>

The fuel volume based CH_4 emission rates follow the same pattern as the distance based CH_4 emission rates.

The enrichment ratios comparing volume based emissions ratios from the Phase 1 CSLA4 to those from the Phase 1 HSLA4 are presented in Table 19. As with the distance based enrichment ratios, all ratios are greater than 1, the ratios at -10°C tests are larger in magnitude than those from the 20°C tests, and the presence of ethanol in the fuel has no effect on the ratios.

Table 19: CH_4 Enrichment Ratios: Phase 1 CSLA4 vs. Phase 1 HSLA4 (volume based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	2.8	n/a	1.9	0.3	3.1	0.8	1.8	0.4
E10	2.4	0.04	2.7	0.9	3.3	0.9	1.7	0.1
E10-Spl	2.0	0.1	2.4	0.1	2.8	0.2	2.1	0.1
E20	2.7	0.7	1.8	0.1	2.9	0.04	1.7	0.07
-10°C Testing								
E0	12.0	1.5	16.5	5.9				
E10	11.7	1.4	16.8	n/a				
E10-Spl	10.2	0.7	10.8	0.4				
E20	9.6	4.1	14.8	2.4				

The enrichment ratios comparing volume based emissions ratios from the US06 to those from the Phase 1 HSLA4 are presented in Table 20. Again the patterns were similar to those from the distance based results.

Table 20: CH_4 Enrichment Ratios: US06 vs. Phase 1 HSLA4 (volume based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	4.0	n/a	0.5	0.2	0.8	0.2	0.8	0.1
E10	2.3	0.2	0.6	0.009	1.0	0.1	1.0	n/a
E10-Spl	2.3	0.05	0.4	0.02	0.7	0.06	0.9	0.04
E20	2.7	0.3	0.4	0.02	0.8	0.001	0.5	n/a
-10°C Testing								
E0	3.5	0.4	0.4	0.01				
E10	3.4	1.1	0.2	n/a				
E10-Spl	3.5	0.5	0.4	0.08				
E20	2.7	0.5	0.4	0.03				

<u>*Overall Conclusions*</u>

- Vehicle technology had an influence – the three multi point fuel injection (MPFI) vehicles behaved differently than the GDI vehicle
- For the three MPFI vehicles
  - Cold engine start increased CH_4 emissions. Cold engine start at cold operating temperature increased CH_4 emissions substantially more than cold engine start at standard temperature, with enrichment ratios 5 to 10 times higher at -10°C as compared to those at 20°C.
  - Aggressive driving increased CH_4 emissions from the Tier 1 technology, reduced CH_4 emissions from the SULEV technology, and had no effect on CH_4 emissions from the NLEV technology.
  - The effect of cold temperature operation was to further increase the methane emissions on cold engine start, but once the vehicle reached optimum operating temperature cold temperature did not affect methane emissions as greatly.
  - In general, increasing ethanol content did not result in any significant changes to these trends or to the emission rates. Ethanol blend fuels may have reduced CH_4 emissions from the 20°C tests with Tier 1 technology; however there is not enough data to confidently support this theory.
- For the GDI vehicle
  - Enrichment on cold start increased CH_4 emissions, similar to the trend seen with the MPFI vehicles.

- Since the vehicle operated with a lean air/fuel rather than with a stoichiometric A/F ratio, all other driving cycles had similar CH_4 emissions. The US06 did not seem to push the vehicle out of this lean operation.
- Increasing ethanol content appears to have reduced CH_4 emissions slightly, though in most cases the reduction was not statistically significant.

Figure 8: CH_4 Distance Based Emission Rates (mg/mile) from 20°C Tests

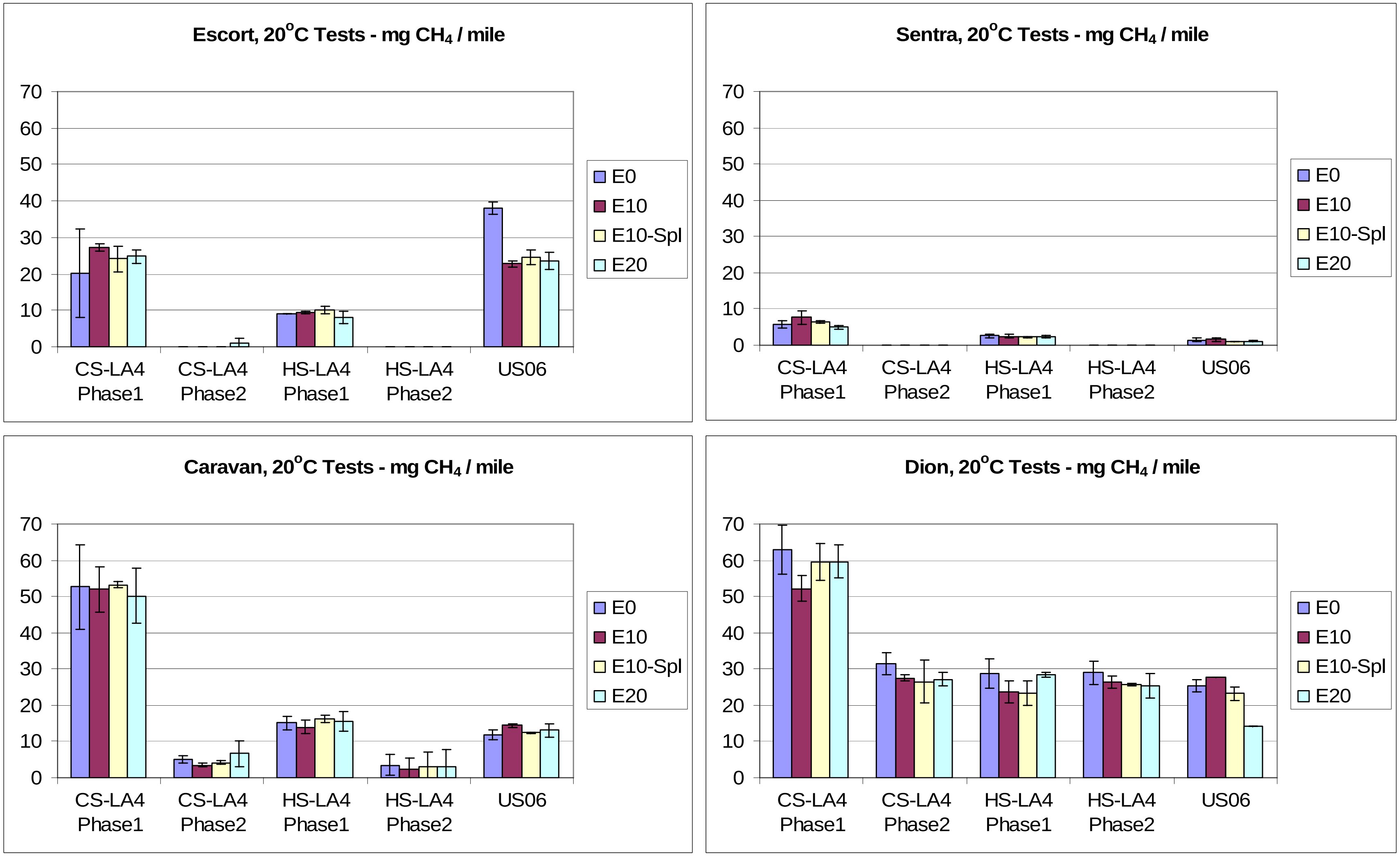


Figure 9: CH_4 Distance Based Emission Rates (mg/mile) from -10℃ Tests

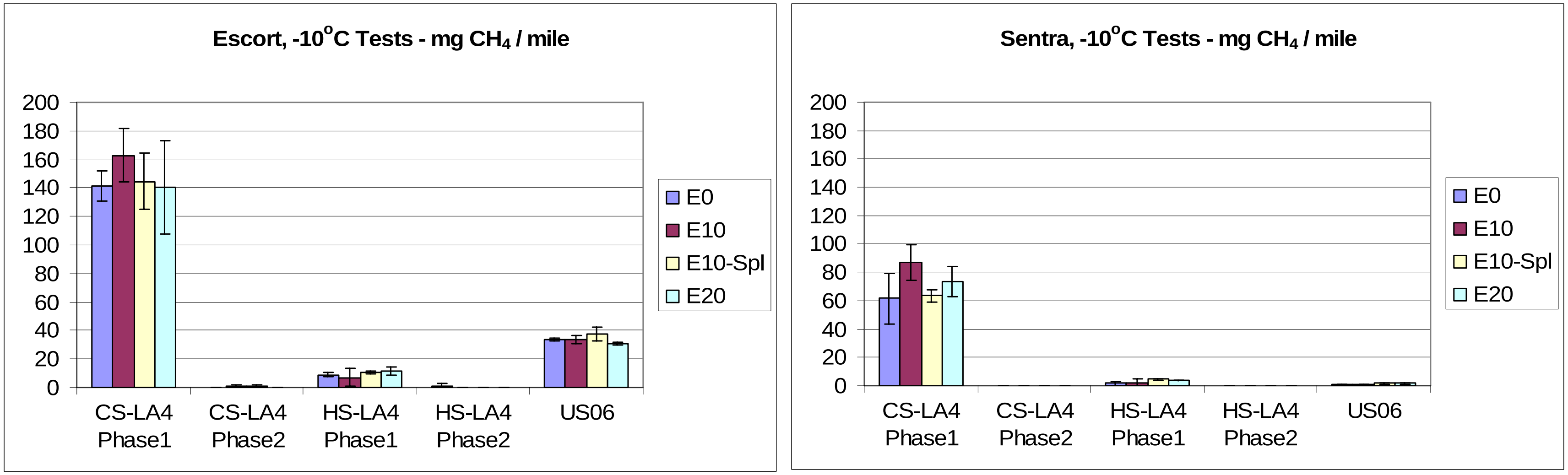


Figure 10: CH_4 Fuel Volume Based Emission Rates (mg/L fuel) from 20℃ Tests

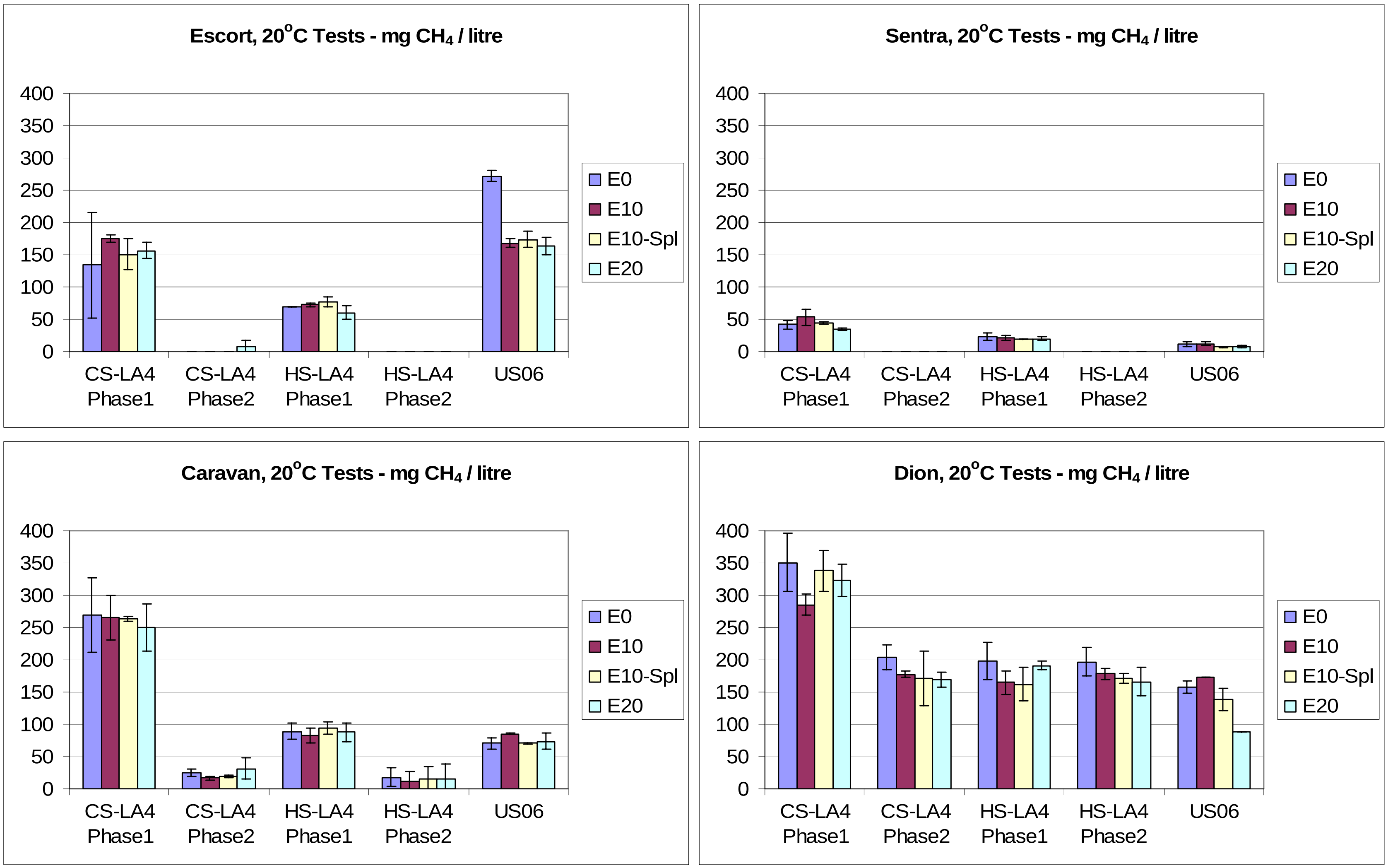
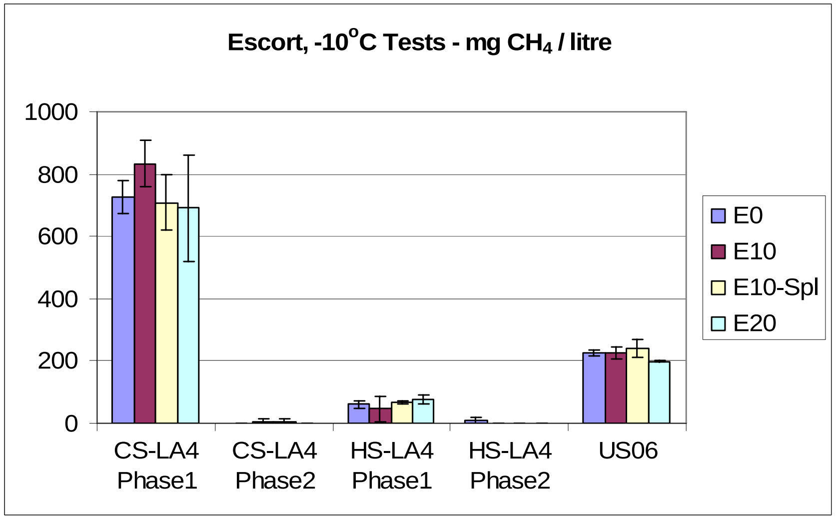
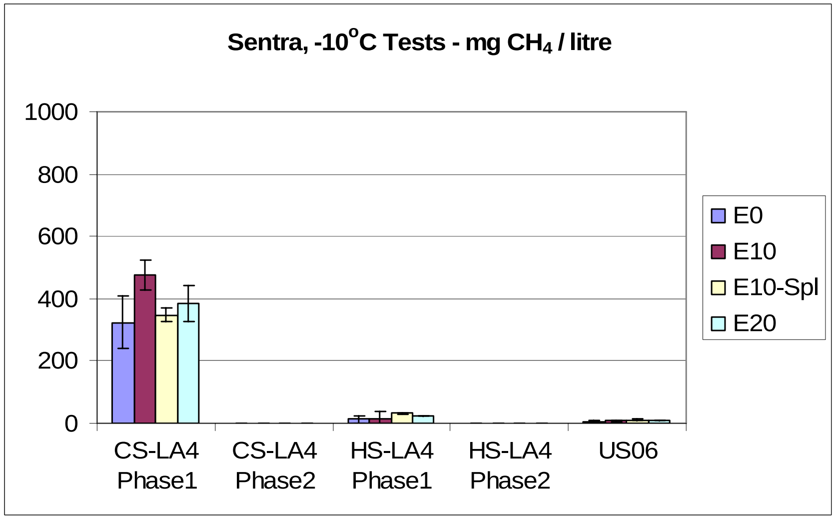


Figure 11: CH_4 Fuel Volume Based Emission Rates (mg/L fuel) from -10℃ Tests





7.3 Nitrous Oxide (N_2O)

Figure 12 and Figure 13 illustrate the N_2O emission rates from the four vehicles over the LA4 and US06 driving cycles, at the two test temperatures (20°C and -10°C respectively). These figures use units of grams of N_2O per mile travelled. Figure 10 and Figure 11 give the same data for 20°C and -10°C respectively, using units of grams of N_2O per litre of fuel used. Numerical emission rates and results from the statistical analysis on these data can be found in Appendix 4. Unless stated otherwise, the results in the following paragraphs apply to both temperatures for the Escort and Sentra, and 20°C only for the Caravan and Dion. Recall that the Caravan and Dion were not tested at -10°C.

Distance Based Emission Rates

The N_2O emission rates from the Escort were similar at -10°C and 20°C, while the Sentra had significantly higher N_2O emission rates at -10°C as compared to 20°C. This behaviour was likely due to differences in the NO_X reducing activity of the catalysts, with the more active SULEV catalyst being more sensitive to operating temperature than the less active Tier 1 catalyst.

For all of the vehicles, statistical analysis indicates that the distance based N_2O emission rates from the E0 fuel were generally not statistically different than those from the ethanol blend fuel. There were a few exceptions to this, as can be seen in the Appendix; however there was no specific trend concerning test temperature or driving cycle.

The N_2O emission rates from the Escort, Sentra and Caravan were generally higher for driving cycles that began with low catalyst temperature (e.g. cold engine start). This was expected as N_2O formation primarily occurs during cold catalyst operation. The pattern from the Sentra was slightly different. For this vehicle, the Phase 1 HSLA4 N_2O emission rates were not elevated, indicating that once warm, the Sentra catalyst was able to reach its operating temperature quickly. However, the Sentra had an increase in N_2O emission rates during the US06 driving cycle even with the hot catalyst. This may be due to fuel enrichment needed to meet the high power demand, or this may be a result of an increased exhaust flow through the catalyst, with exhaust gases travelling too quickly through the catalyst for an effective reaction.

The N_2O emissions from the Dion behaved quite differently than the N_2O results from the three MPFI vehicles. For this vehicle the N_2O emission rates were fairly consistent over all driving cycles. The GDI technology maintains lean air/fuel ratio operation whenever possible, and would only produce N_2O while running rich. For this reason, the Dion catalyst is likely designed differently than the catalysts on the MPFI vehicles and does not show elevated levels when the catalyst is at lower temperatures.

Enrichment ratios that compare the distance based N_2O emission rates from the Phase 1 CSLA4 driving cycle to those from the Phase 1 HSLA4 driving cycle are presented in Table 21. These ratios indicate that the cold start engine conditions of the Phase 1 CSLA4 resulted in a comparatively large increase in N_2O for the Sentra, a slight increase in N_2O emissions from the Caravan, a slight reduction in N_2O emissions from the Dion and -10°C Escort tests, and did not affect the N_2O emissions from the 20°C Escort tests. The presence of ethanol in the fuel did not alter the magnitude of the enrichment ratios.

Table 21: N_2O Enrichment Ratios: Phase 1 CSLA4 vs. Phase 1 HSLA4 (distance based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	0.8	0.05	4.3	0.6	1.2	0.08	0.7	0.1
E10	1.2	0.1	4.3	0.5	1.6	0.1	0.6	0.1
E10-Spl	1.0	0.04	n/a	n/a	1.4	0.7	0.5	0.01
E20	1.4	0.4	4.1	n/a	1.5	0.2	0.6	0.05
-10°C Testing								
E0	0.6	0.1	3.0	2.0				
E10	0.8	0.08	4.9	3.5				
E10-Spl	0.9	0.3	3.5	n/a				
E20	0.8	0.04	4.9	0.5				

Enrichment ratios that compare the distance based N_2O emission rates from the US06 driving cycle to those from the Phase 1 HSLA4 driving cycle are presented in Table 22. For the Escort, Caravan and Dion the ratios are all less than 1, indicating that aggressive driving resulted in a decrease in N_2O emissions, likely due to hotter catalyst conditions. The Sentra behaved differently at 20°C and -10°C. At 20°C the aggressive driving of the US06 resulted in an increase in N_2O emission rates, likely from fuel enrichment. However at -10°C the increased temperature of the catalyst during the US06 cycle outweighed the effect of fuel enrichment, resulting in a decrease in N_2O emissions. For all of the vehicles, the presence of ethanol in the fuel did not alter the magnitude of the enrichment ratios.

Table 22: N_2O Enrichment Ratios: US06 vs. Phase 1 HSLA4 (distance based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20°C Testing								
E0	0.5	0.1	4.1	1.1	0.6	0.2	0.4	0.05
E10	0.9	0.1	8.0	3.2	0.8	0.2	0.3	n/a
E10-Spl	0.7	0.1	n/a	n/a	0.7	0.2	0.3	0.04
E20	0.9	0.3	1.9	n/a	0.7	0.1	0.3	n/a
-10°C Testing								
E0	0.5	0.2	0.7	0.7				
E10	0.5	0.04	0.4	0.3				
E10-Spl	0.5	0.1	0.2	n/a				
E20	0.5	0.1	0.1	0.05				

Fuel Volume Based Emission Rates

The fuel volume based N_2O emission rates follow the same pattern as the distance based N_2O emission rates. This was expected since N_2O emission rates are not dependent on fuel consumption.

The enrichment ratios comparing volume based emissions ratios from the Phase 1 CSLA4 to those from the Phase 1 HSLA4 are presented in Table 23. The ratio patterns were similar to those from the distance based results.

Table 23: N_2O Enrichment Ratios: Phase 1 CSLA4 vs. Phase 1 HSLA4 (volume based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20℃ Testing								
E0	0.7	0.01	3.6	0.6	1.1	0.07	0.6	0.1
E10	1.0	0.1	3.6	0.4	1.3	0.09	0.5	0.08
E10-Spl	0.8	0.01	n/a	n/a	1.2	0.6	0.4	0.02
E20	1.2	0.3	3.4	n/a	1.4	0.1	0.5	0.04
-10℃ Testing								
E0	0.4	0.08	2.1	1.4				
E10	0.6	0.06	3.7	2.7				
E10-Spl	0.7	0.2	2.7	n/a				
E20	0.6	0.004	3.6	0.4				

The enrichment ratios comparing volume based emissions ratios from the US06 to those from the Phase 1 HSLA4 are presented in Table 24. Again the patterns were similar to the patterns of the distance based enrichment ratios.

Table 24: N_2O Enrichment Ratios: US06 vs. Phase 1 HSLA4 (volume based)

	Escort		Sentra		Caravan		Dion	
	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.	Avg.	StDev.
20℃ Testing								
E0	0.5	0.1	3.6	1.0	0.6	0.2	0.4	0.05
E10	0.8	0.1	7.4	2.8	0.8	0.1	0.2	n/a
E10-Spl	0.6	0.09	n/a	n/a	0.7	0.2	0.3	0.03
E20	0.9	0.3	1.7	n/a	0.7	0.2	0.3	n/a
-10℃ Testing								
E0	0.5	0.2	0.7	0.7				
E10	0.5	0.03	0.4	0.3				
E10-Spl	0.5	0.09	0.2	n/a				
E20	0.5	0.08	0.1	0.05				

<u>*Overall Conclusions*</u>

- Vehicle technology affected N_2O emissions (MPFI vehicles behave differently than the GDI vehicle).
- For the three MPFI vehicles:
  - N_2O was formed over the catalyst when the catalyst temperature was low – during engine start.
  - With the Tier 1 and NLEV technologies N_2O emissions were higher for cold start conditions and lower for hot start condition, due to hotter catalyst conditions.
  - Aggressive driving increased the SULEV technology N_2O emissions, even with hot catalyst conditions. This was likely due to fuel enrichment needed to meet the high power demand.
  - With the SULEV technology cold temperature operation increased N_2O emissions, especially during cold engine start. This trend was not seen with the Tier 1 technology.
  - Fuel ethanol content did not have a statistically significant effect on N_2O emissions.
- For the GDI vehicle:
  - N_2O emission rates were reasonably constant over all driving cycles.
  - N_2O emissions were higher during hot engine start as compared to cold engine start. This may be due to the particular combination of exhaust gas composition and catalyst temperatures seen during this operation.
  - Increasing ethanol content appears to have caused a slight increase in N_2O emissions but the change is not statistically significant.

Figure 12: N_2O Distance Based Emission Rates (mg/mile) from 20℃ Tests

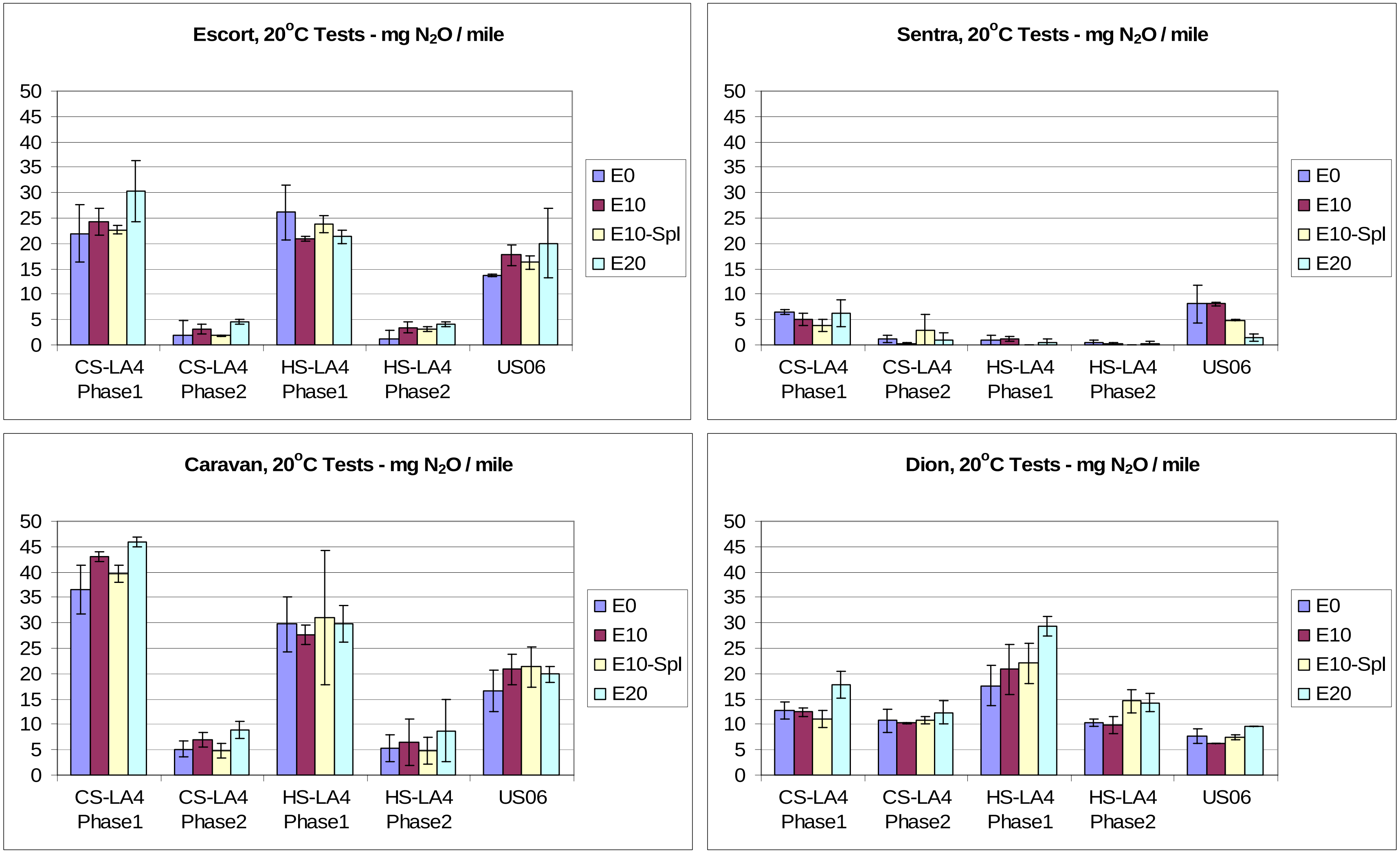


Figure 13: N_2O Distance Based Emission Rates (mg/mile) from -10℃ Tests

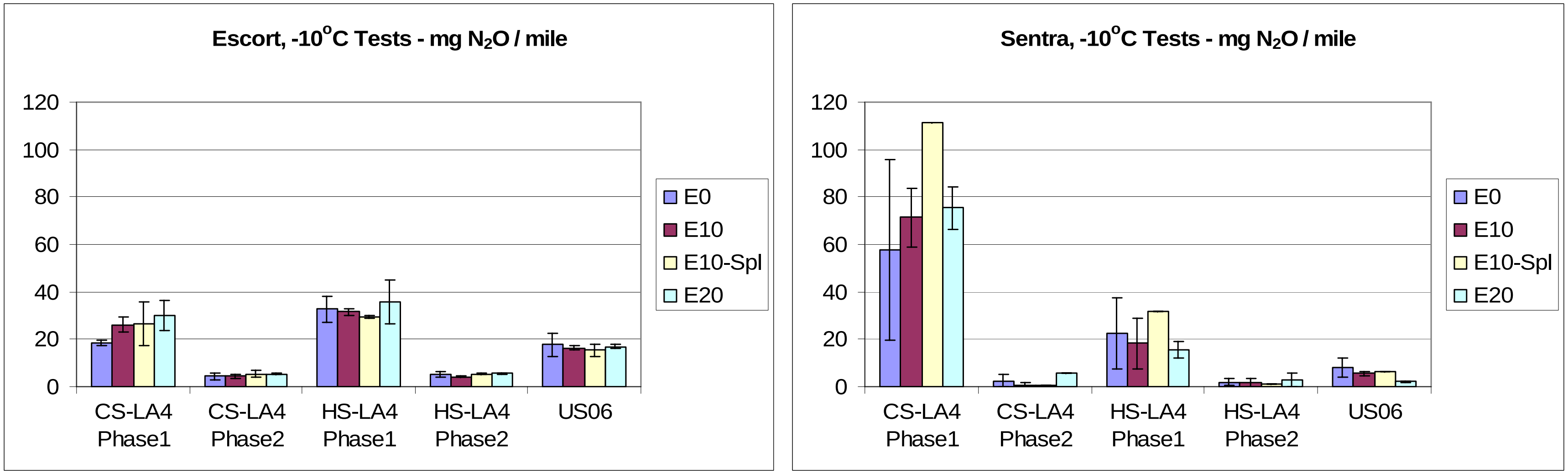


Figure 14: N_2O Fuel Volume Based Emission Rates (mg/L) from 20°C Tests

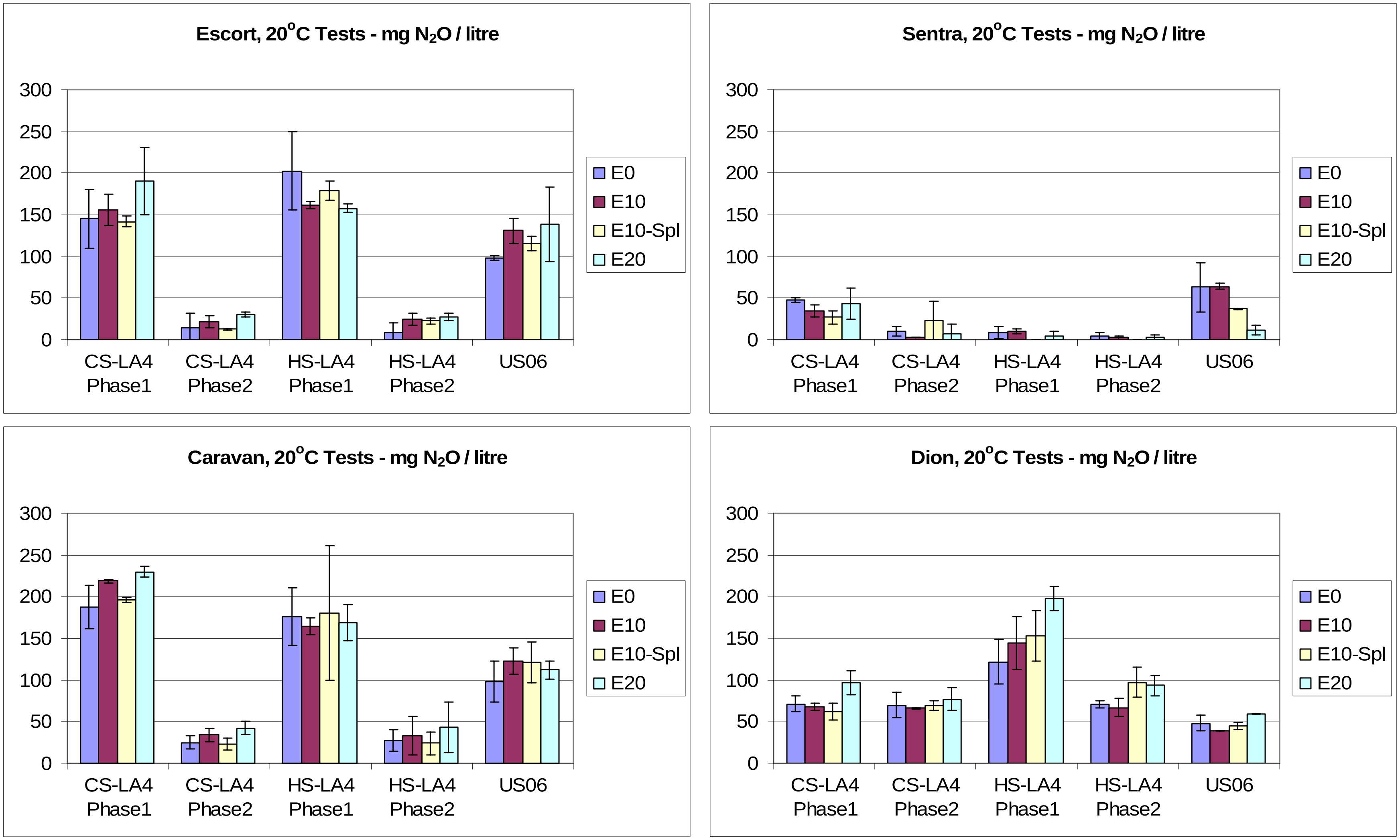
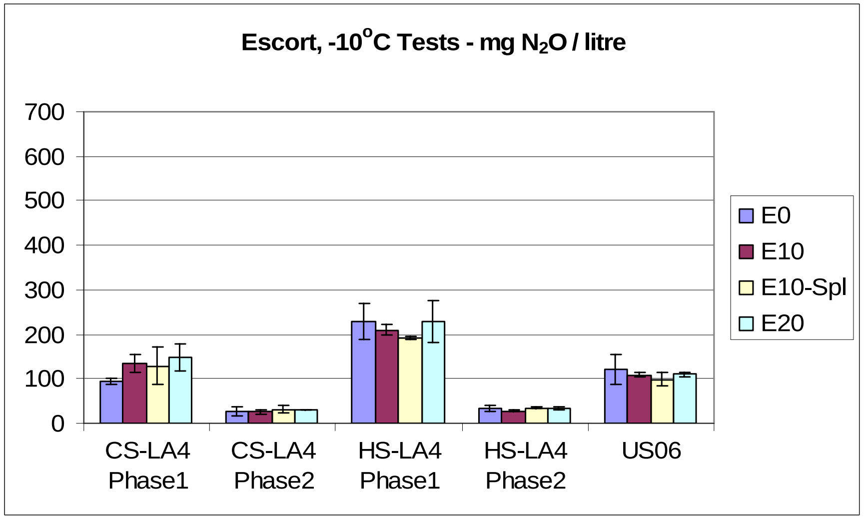
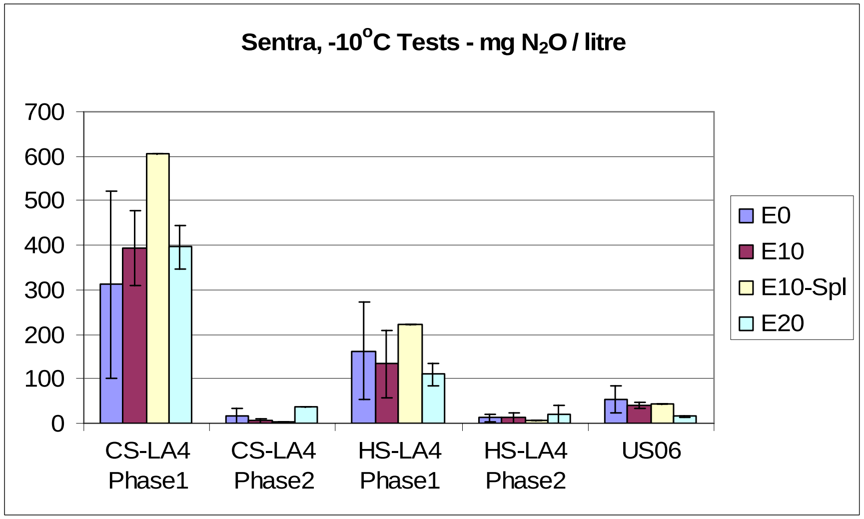


Figure 15: N_2O Volume Based Emission Rates (mg/L) from -10°C Tests





8. Other Observations

Being designed as a "flex fuel" vehicle capable of running on ethanol-gasoline blends of up to 85% ethanol, the Caravan fuel system incorporates a fuel-line sensor that measures ethanol content in the fuel. This information is then used to adjust the engine parameters to best suit the fuel blend. This sensor can be surveyed through the OBD II (On-Board Diagnostic) access port to ensure proper operation. Analysis of the information from the ethanol sensor indicates that the sensor continually measured an ethanol content of zero; therefore it is possible that the engine did not realize any specially designed engine parameters for ethanol fuel operation.

9. Conclusions

CO_2 Emissions

- Distance-based CO_2 emission rates were essentially unchanged as ethanol content increased. The effect from the lower energy density of the ethanol blend fuels cancelled out the effect from the lower carbon content per litre of ethanol blend fuel burned.
- The presence of ethanol in the fuels did not alter the amount of enrichment needed for cold engine start or aggressive driving.
- With Tier 1 vehicle technology (Escort), operation at cold temperature increased distance based fuel consumption by ~16-19% on cold engine start, by ~10-15% under stabilized operation (Phase 2) and by ~1-4% under aggressive driving conditions (US06). These increases were similar between the base fuel and the ethanol blend fuels.
- With SULEV vehicle technology (Sentra), operation at cold temperature increased distance based fuel consumption by ~24-31% on cold engine start, by ~14-18% under stabilized operation and by ~3-7% under aggressive driving conditions. These increases were similar between the base fuel and the ethanol blend fuels.

CH_4 Emissions

- Vehicle technology had an influence – the three multi point fuel injection (MPFI) vehicles behaved differently than the GDI vehicle
- For the three MPFI vehicles
  - Cold engine start increased CH_4 emissions, more so at cold temperature testing.
  - Aggressive driving increased CH_4 emissions from the Tier 1 technology, reduced CH_4 emissions from the SULEV technology, and had no effect on CH_4 emissions from the NLEV technology.
  - The effect of cold temperature operation was to further increase the methane emissions on cold engine start, but once the vehicle reached optimum operating temperature cold temperature did not affect methane emissions as greatly.
  - In general, increasing ethanol content did not result in any significant changes to these trends or to the emission rates. Ethanol blend fuels may have reduced CH_4 emissions from the 20°C tests with Tier 1 technology; however there is not enough data to confidently support this theory.
- For the GDI vehicle
  - Enrichment on cold start increased CH_4 emissions, similar to the trend seen with the MPFI vehicles.
  - Since the vehicle operated with a lean air/fuel rather than with a stoichiometric A/F ratio, all other driving cycles had similar CH_4 emissions. The US06 did not seem to push the vehicle out of this lean operation.
  - Increasing ethanol content appears to have reduced CH_4 emissions slightly, though in most cases the reduction was not statistically significant.

N_2O Emissions

- N_2O emissions depend on vehicle technology, with the three MPFI vehicles behaving differently than the GDI vehicle.
- For the three MPFI vehicles:
  - N_2O was formed over the catalyst when the catalyst temperature was low – during engine start.
  - With the Tier 1 and NLEV technologies N_2O emissions were higher for cold start conditions and lower for hot start condition, due to hotter catalyst conditions.
  - Aggressive driving increased the SULEV technology N_2O emissions, even with hot catalyst conditions. This was likely due to fuel enrichment needed to meet the high power demand.
  - With the SULEV technology cold temperature operation increased N_2O emissions, especially during cold engine start. This trend was not seen with the Tier 1 technology.
  - Fuel ethanol content did not have a statistically significant effect on N_2O emissions.
- For the GDI vehicle:
  - N_2O emission rates were reasonably constant over all driving cycles.

- N_2O emissions were higher during hot engine start as compared to cold engine start. This may be due to the particular combination of exhaust gas composition and catalyst temperatures seen during this operation.
- Increasing ethanol content appears to have caused a slight increase in N_2O emissions but the change was not statistically significant.

General

- The Caravan “flex fuel” operation during this testing program was found to be unreliable. Monitoring of the on board fuel-line ethanol sensor via the OBD II access port indicated that the sensor continually measured an ethanol content of zero; therefore it is possible that the engine did not realize any specially designed engine parameters for ethanol fuel operation.

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Appendices

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD"***
- ***When the E0 results are null value, "% Diff" cannot be calculated and is listed as "n/a"***

Appendix 1 Detailed Fuel Analysis

Test	Method	Units	Summer Grade Fuel				Winter Grade Fuel			
			E0	E10	E10-Spl	E20	E0	E10	E10-Spl	E20
Distillation - IBP	ASTM D86	^oC	32	42	39	38	32	35	30	32
5%	ASTM D86	^oC	49	54	49	51	40	42	36	38
10%	ASTM D86	^oC	58	59	55	56	46	53	41	43
20%	ASTM D86	^oC	72	64	62	62	55	64	48	51
30%	ASTM D86	^oC	84	68	66	66	65	69	55	58
40%	ASTM D86	^oC	93	78	70	69	78	74	62	65
50%	ASTM D86	^oC	100	104	99	71	95	104	68	70
60%	ASTM D86	^oC	105	110	105	73	106	112	100	72
70%	ASTM D86	^oC	110	118	109	112	112	120	109	79
80%	ASTM D86	^oC	116	130	117	125	121	132	118	115
90%	ASTM D86	^oC	134	158	135	153	141	158	138	135
95%	ASTM D86	^oC	167	174	166	170	168	173	166	164
Distillation - EP	ASTM D86	^oC	201	202	198	192	198	196	197	195
Recovery	ASTM D86	vol %	97.5	97.9	97.0	98.3	96.9	95.0	96.6	97.1
Residue	ASTM D86	vol %	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Loss	ASTM D86	vol %	1.5	1.1	2.0	0.7	2.1	4.0	2.4	1.9
% Evaporated @ 200^oC	ASTM D86	vol %	97.5	>98	>97	>97	--	--	--	--
% Evaporated @ 300^oC	ASTM D86	vol %	--	>98	>97	>97	--	--	--	--
Gravity	ASTM D4052	^{o}API	69.2	63.6	65.9	61.4	72.7	63.4	69.3	66.8
Reid Vapor Pressure	ASTM D5191	psi	8.8	8.6	9.4	8.7	13.4	13.1	13.8	13.2
Driveability Index	ASTM D4814	^oC	521	559	515	450	495	554	404	410
Carbon	ASTM D5291	wt fraction	84.82	85.62	84.26	85.08	84.7	84.6	83.6	83.4
Hydrogen	ASTM D5291	wt fraction	15.18	14.38	15.74	14.92	15.3	15.4	16.4	16.4
Ethanol Content	ASTM D4815	vol %	<0.01	10.0	10.0	20.2	0.0	9.9	10.2	20.2
Sulfur	ASTM D5453	ppm	34	34	31	35	33	33	26	27
Lead	ASTM D3237	mg/l	<2	<2	<2	<2	<2	<2	<2	<2
Manganese	ASTM D3831	mg/l	<0.2	<0.2	<0.2	<0.2	<1	<1	<1	<1
Phosphorus	ASTM D3231	mg/l	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3	<1.3
Group Types		vol %								
Paraffins	ASTM D6623B	vol %	9.8	9.5	8.1	13.1	5.8	11.1	5.4	4.9
Isoparaffins	ASTM D6623B	vol %	72.4	56.5	67.1	37.3	78.5	51.7	71.9	61.7
Olefins	ASTM D6623B	vol %	1.2	1.3	1.1	1.5	0.8	1.2	0.8	0.7
Naphthenes	ASTM D6623B	vol %	5.3	9.2	4.5	13.0	4.7	11.0	4.6	4.0
Aromatics	ASTM D6623B	vol %	7.9	11.0	8.1	14.1	8.3	12.6	7.3	6.3
Unknowns	ASTM D6623B	vol %	3.4	2.5	1.1	1.0	1.9	2.4	0.0	2.4
Oxygenates	ASTM D6623B	vol %	0.0	10.0	10.0	20.0	0.0	10.0	10.0	20.0
Benzene Content	ASTM D3606	vol %	0.1	0.5	0.7	0.8	0.5	0.5	0.4	0.3
Oxidation Stability	ASTM D525	minutes	>240	>240	>240	>240	>240	<240	<240	>240
Copper Corrosion	ASTM D130	-	1	1	1	1	1	1	1	1
Ferrous Corrosion	D665 M	-	B++	B++	A	B+	B+	B++	A	A
Existent Gum, Washed	ASTM D381	mg/100min	<1	<1	<1	<1	<1	<1	<1	<1
Research Octane No.	ASTM D2699	-	88.6	90.0	96.0	92.0	88.2	90.0	94.0	100.0
Motor Octane No.	ASTM D2700	-	86.0	85.0	89.0	85.7	85.0	84.3	89.5	90.0
R+M / 2	D2699/2700	-	87.8	87.5	92.5	88.9	86.6	87.2	91.8	95.0
Additives										
Ornite OGA 402	Calculated	ptb	50	50	50	50	50	50	50	50
Corrosion Inhibitor	Calculated	ptb	5	5	5	5	5	5	5	5

Appendix 2 Statistical Analysis of CO_2 Results

1.a 1998 Ford Escort ZX2

Escort, CO_2 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (g / mile)										
E0	324	5	315	6	282	8	307	2	288	4
E10	333	5	317	6	282	3	306	3	290	0.4
E10-Spl	335	6	318	3	282	2	303	5	291	1
E20	330	5	317	7	286	7	310	5	296	6
Fuel Consumption Based Measurements (g / L)										
E0	2138	6	2189	0.7	2180	1	2188	2	2049	4
E10	2140	20	2190	0.08	2181	8	2190	0.2	2131	5
E10-Spl	2095	10	2132	0.05	2127	0.5	2131	0.2	2062	11
E20	2083	4	2120	0.07	2116	0.8	2119	0.2	2047	8

Escort, CO_2 Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.151	NSD	--	0.821	NSD	--
	E10-Spl	0.166	NSD	--	0.601	NSD	--
	E20	0.317	NSD	--	0.826	NSD	--
HS LA4	E10	0.942	NSD	--	0.745	NSD	--
	E10-Spl	0.934	NSD	--	0.443	NSD	--
	E20	0.694	NSD	--	0.483	NSD	--
US06	E10	0.433	NSD	--			
	E10-Spl	0.349	NSD	--			
	E20	0.253	NSD	--			

Escort, CO_2 Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.903	NSD	--	0.051	NSD	--
	E10-Spl	0.033	E0 > E10-Spl	-2.0%	5.6×10^{-05}	E0 > E10-Spl	-2.6%
	E20	0.008	E0 > E20	-2.6%	4.0×10^{-05}	E0 > E20	-3.2%
HS LA4	E10	0.871	NSD	--	0.152	NSD	--
	E10-Spl	0.0003	E0 > E10-Spl	-2.4%	0.0008	E0 > E10-Spl	-2.6%
	E20	0.0003	E0 > E20	-2.9%	0.0006	E0 > E20	-3.1%
US06	E10	0.0002	E10 > E0	4.0%			
	E10-Spl	0.250	NSD	--			
	E20	0.771	NSD	--			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Escort, CO_2 Emission Rates from -10°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (g / mile)										
E0	378	7	344	10	313	13	334	26	297	7
E10	395	10	353	13	325	6	329	7	302	0.4
E10-Spl	389	3	351	7	316	7	326	3	294	9
E20	382	13	348	13	314	16	322	10	295	9
Fuel Consumption Based Measurements (g / L)										
E0	1929	26	2149	0.2	2133	15	2149	0.5	2020	26
E10	2028	24	2169	0.4	2157	11	2170	0.3	2027	16
E10-Spl	1902	10	2076	0.2	2068	4	2077	0.03	1935	21
E20	1881	43	2022	0.09	2015	2	2022	0.02	1915	18

Escort, CO_2 Emission Rates (g/mile) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.024	E10 > E0	4.6%	0.308	NSD	--
	E10-Spl	0.018	E10-Spl > E0	2.9%	0.299	NSD	--
	E20	0.585	NSD	--	0.727	NSD	--
HS LA4	E10	0.197	NSD	--	0.766	NSD	--
	E10-Spl	0.707	NSD	--	0.568	NSD	--
	E20	0.936	NSD	--	0.569	NSD	--
US06	E10	0.311	NSD	--			
	E10-Spl	0.616	NSD	--			
	E20	0.834	NSD	--			

Escort, CO_2 Emission Rates (g/L fuel) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.002	E10 > E0	5.1%	4.8×10^{-11}	E10 > E0	0.9%
	E10-Spl	0.082	NSD	--	1.6×10^{-17}	E0 > E10-Spl	-3.4%
	E20	0.106	NSD	--	1.6×10^{-14}	E0 > E20	-5.9%
HS LA4	E10	0.055	NSD	--	1.1×10^{-09}	E10 > E0	0.9%
	E10-Spl	8.6×10^{-05}	E0 > E10-Spl	-3.0%	2.2×10^{-15}	E0 > E10-Spl	-3.3%
	E20	0.0002	E0 > E20	-5.5%	4.8×10^{-12}	E0 > E20	-5.9%
US06	E10	0.718	NSD	--			
	E10-Spl	0.001	E0 > E10-Spl	-4.2%			
	E20	0.004	E0 > E20	-5.2%			

Please note:
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- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

1.b 2001 Nissan Sentra CA

Sentra, CO_2 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (g / mile)										
E0	301	3	273	2	252	3	271	4	280	3
E10	311	8	279	6	256	4	273	0.9	276	2
E10-Spl	301	1	274	0.4	251	3	269	3	279	3
E20	300	3	272	5	249	3	269	0.3	279	3
Fuel Consumption Based Measurements (g / L)										
E0	2183	4	2190	0.7	2190	0.9	2191	0.08	2178	5
E10	2181	6	2191	0.07	2191	0.1	2191	0.1	2180	0.3
E10-Spl	2126	0.5	2132	0.01	2132	0.06	2132	0.09	2125	5
E20	2118	0.8	2120	0.09	2120	0.06	2120	0.01	2117	0.8

Sentra, CO_2 Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.099	NSD	--	0.164	NSD	--
	E10-Spl	0.710	NSD	--	0.439	NSD	--
	E20	0.867	NSD	--	0.950	NSD	--
HS LA4	E10	0.214	NSD	--	0.500	NSD	--
	E10-Spl	0.816	NSD	--	0.563	NSD	--
	E20	0.326	NSD	--	0.454	NSD	--
US06	E10	0.262	NSD	--			
	E10-Spl	0.803	NSD	--			
	E20	0.770	NSD	--			

Sentra, CO_2 Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.602	NSD	--	0.074	NSD	--
	E10-Spl	0.0003	E0 > E10-Spl	-2.6%	1.5×10^{-06}	E0 > E10-Spl	-2.7%
	E20	0.0002	E0 > E20	-3.0%	8.5×10^{-07}	E0 > E20	-3.2%
HS LA4	E10	0.105	NSD	--	0.002	E10 > E0	0.02%
	E10-Spl	3.6×10^{-08}	E0 > E10-Spl	-2.7%	3.0×10^{-12}	E0 > E10-Spl	-2.7%
	E20	1.9×10^{-06}	E0 > E20	-3.2%	1.9×10^{-09}	E0 > E20	-3.2%
US06	E10	0.705	NSD	--			
	E10-Spl	0.001	E0 > E10-Spl	-2.4%			
	E20	0.0004	E0 > E20	-2.8%			

Please note:
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- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Sentra, CO_2 Emission Rates from -10°C Tests

Fuel	Cold Start LA4 Phase 1 Avg	Cold Start LA4 Phase 1 St Dev	Cold Start LA4 Phase 2 Avg	Cold Start LA4 Phase 2 St Dev	Hot Start LA4 Phase 1 Avg	Hot Start LA4 Phase 1 St Dev	Hot Start LA4 Phase 2 Avg	Hot Start LA4 Phase 2 St Dev	US06 Avg	US06 St Dev
Distance Based Measurements (g / mile)										
E0	393	15	341	20	297	6	315	10	293	6
E10	385	16	328	10	295	6	308	6	296	6
E10-Spl	373	4	325	10	290	5	308	5	286	1
E20	377	3	324	0.2	283	0.9	310	2	289	2
Fuel Consumption Based Measurements (g / L)										
E0	2088	13	2149	0.4	2149	0.8	2149	0.7	2149	0.6
E10	2116	3	2169	1	2168	2	2170	0.08	2170	0.2
E10-Spl	2024	1	2076	0.2	2075	0.9	2077	0.6	2077	0.4
E20	1975	1	2022	0.2	2022	0.02	2022	0.3	2022	0.01

Sentra, CO_2 Emission Rates (g/mile) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.525	NSD	--	0.416	NSD	--
	E10-Spl	0.063	NSD	--	0.248	NSD	--
	E20	0.195	NSD	--	0.297	NSD	--
HS LA4	E10	0.686	NSD	--	0.385	NSD	--
	E10-Spl	0.148	NSD	--	0.310	NSD	--
	E20	0.024	E0 > E20	-4.5%	0.583	NSD	--
US06	E10	0.452	NSD	--			
	E10-Spl	0.113	NSD	--			
	E20	0.478	NSD	--			

Sentra, CO_2 Emission Rates (g/L fuel) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.028	E10 > E0	1.3%	2.1×10^{-08}	E10 > E0	0.9%
	E10-Spl	6.2×10^{-05}	E0 > E10-Spl	-3.1%	2.9×10^{-15}	E0 > E10-Spl	-3.4%
	E20	1.9×10^{-05}	E0 > E20	-5.4%	2.4×10^{-14}	E0 > E20	-5.9%
HS LA4	E10	3.9×10^{-07}	E10 > E0	0.9%	1.3×10^{-08}	E10 > E0	1.0%
	E10-Spl	4.2×10^{-13}	E0 > E10-Spl	-3.4%	1.0×10^{-13}	E0 > E10-Spl	-3.4%
	E20	4.8×10^{-13}	E0 > E20	-5.9%	2.5×10^{-13}	E0 > E20	-5.9%
US06	E10	0.266	NSD	--			
	E10-Spl	6.5×10^{-05}	E0 > E10-Spl	-3.4%			
	E20	2.6×10^{-05}	E0 > E20	-5.9%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

1.c 2003 Dodge Caravan SE FFV

Caravan, CO_2 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (g / mile)										
E0	421	3	448	12	373	8	429	7	372	9
E10	426	8	451	10	370	4	425	7	376	12
E10-Spl	428	10	458	14	374	10	438	12	381	8
E20	429	11	453	2	373	4	436	8	383	7
Fuel Consumption Based Measurements (g / L)										
E0	2149	9	2190	0.2	2187	0.8	2190	0.1	2185	1
E10	2150	6	2191	0.1	2189	0.3	2191	0.09	2184	3
E10-Spl	2089	9	2131	0.1	2129	0.8	2131	0.09	2127	1
E20	2088	6	2119	0.3	2118	0.8	2120	0.1	2115	1

Caravan, CO_2 Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.214	NSD	--	0.729	NSD	--
	E10-Spl	0.190	NSD	--	0.298	NSD	--
	E20	0.159	NSD	--	0.395	NSD	--
HS LA4	E10	0.551	NSD	--	0.405	NSD	--
	E10-Spl	0.884	NSD	--	0.219	NSD	--
	E20	0.903	NSD	--	0.192	NSD	--
US06	E10	0.579	NSD	--			
	E10-Spl	0.155	NSD	--			
	E20	0.047	E20 > E0	3.0%			

Caravan, CO_2 Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.842	NSD	--	0.002	E10 > E0	0.03%
	E10-Spl	2.6×10^{-05}	E0 > E10-Spl	-2.8%	1.6×10^{-17}	E0 > E10-Spl	-2.7%
	E20	3.5×10^{-07}	E0 > E20	-2.8%	2.1×10^{-21}	E0 > E20	-3.2%
HS LA4	E10	0.022	E10 > E0	0.07%	0.0008	E10 > E0	0.02%
	E10-Spl	1.6×10^{-12}	E0 > E10-Spl	-2.6%	7.2×10^{-19}	E0 > E10-Spl	-2.7%
	E20	2.7×10^{-16}	E0 > E20	-3.2%	1.4×10^{-24}	E0 > E20	-3.2%
US06	E10	0.583	NSD	--			
	E10-Spl	4.0×10^{-11}	E0 > E10-Spl	-2.6%			
	E20	9.9×10^{-15}	E0 > E20	-3.2%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

1.d 2000 Mitsubishi Dion Exceed

Dion, CO_2 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (g / mile)										
E0	388	14	340	8	317	6	321	5	338	9
E10	402	7	343	6	319	6	328	6	348	8
E10-Spl	394	27	341	12	318	13	325	11	344	8
E20	384	11	343	3	319	5	324	3	349	9
Fuel Consumption Based Measurements (g / L)										
E0	2154	7	2185	2	2177	2	2184	4	2099	17
E10	2172	2	2189	0.9	2180	4	2188	3	2120	13
E10-Spl	2101	9	2128	3	2123	1	2129	1	2076	21
E20	2102	3	2118	2	2112	2	2117	3	2073	19

Dion, CO_2 Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.133	NSD	--	0.552	NSD	--
	E10-Spl	0.711	NSD	--	0.975	NSD	--
	E20	0.606	NSD	--	0.538	NSD	--
HS LA4	E10	0.625	NSD	--	0.065	NSD	--
	E10-Spl	0.900	NSD	--	0.427	NSD	--
	E20	0.590	NSD	--	0.161	NSD	--
US06	E10	0.133	NSD	--			
	E10-Spl	0.292	NSD	--			
	E20	0.064	NSD	--			

Dion, CO_2 Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.003	E10 > E0	0.8%	0.034	E10 > E0	0.1%
	E10-Spl	2.0×10^{-05}	E0 > E10-Spl	-2.5%	9.1×10^{-09}	E0 > E10-Spl	-2.6%
	E20	5.8×10^{-08}	E0 > E20	-2.4%	8.3×10^{-13}	E0 > E20	-3.1%
HS LA4	E10	0.239	NSD	--	0.186	NSD	--
	E10-Spl	8.7×10^{-10}	E0 > E10-Spl	-2.5%	3.3×10^{-08}	E0 > E10-Spl	-2.6%
	E20	5.5×10^{-12}	E0 > E20	-3.0%	1.1×10^{-10}	E0 > E20	-3.1%
US06	E10	0.120	NSD	--			
	E10-Spl	0.112	NSD	--			
	E20	0.047	E0 > E20	-1.3%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Appendix 3 Statistical Analysis of CH_4 Results

2.a 1998 Ford Escort ZX2

Escort, CH_4 Emission Rates from 20°C Tests

Fuel	Cold Start LA4 Phase 1 Avg	Cold Start LA4 Phase 1 St Dev	Cold Start LA4 Phase 2 Avg	Cold Start LA4 Phase 2 St Dev	Hot Start LA4 Phase 1 Avg	Hot Start LA4 Phase 1 St Dev	Hot Start LA4 Phase 2 Avg	Hot Start LA4 Phase 2 St Dev	US06 Avg	US06 St Dev
Distance Based Measurements (mg / mile)										
E0	20.2	12.1	< DL	n/a	9.2	n/a	< DL	n/a	38.1	1.7
E10	27.2	1.0	< DL	n/a	9.4	0.4	< DL	n/a	22.9	0.9
E10-Spl	24.1	3.4	< DL	n/a	10.1	1.0	< DL	n/a	24.6	1.9
E20	24.8	1.7	1.0	1.5	8.2	1.6	< DL	n/a	23.6	2.3
Fuel Consumption Based Measurements (mg / L)										
E0	134.0	81.6	< DL	n/a	69.7	n/a	< DL	n/a	271.7	8.7
E10	174.7	5.2	< DL	n/a	72.5	2.9	< DL	n/a	168.2	6.2
E10-Spl	150.8	23.4	< DL	n/a	76.5	7.5	< DL	n/a	174.0	13.2
E20	156.3	12.9	7.0	9.9	60.3	10.4	< DL	n/a	163.0	13.1

Escort, CH_4 Emission Rates (mg/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.359	NSD	--	n/a	NSD	--
	E10-Spl	0.704	NSD	--	n/a	NSD	--
	E20	0.652	NSD	--	0.423	NSD	--
HS LA4	E10	0.750	NSD	--	n/a	NSD	--
	E10-Spl	0.598	NSD	--	n/a	NSD	--
	E20	0.692	NSD	--	n/a	NSD	--
US06	E10	0.0008	E0 > E10	-40.1%			
	E10-Spl	0.017	E0 > E10-Spl	-35.6%			
	E20	0.018	E0 > E20	-38.2%			

Escort, CH_4 Emission Rates (mg/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.416	NSD	--	n/a	NSD	--
	E10-Spl	0.806	NSD	--	n/a	NSD	--
	E20	0.740	NSD	--	0.423	NSD	--
HS LA4	E10	0.486	NSD	--	n/a	NSD	--
	E10-Spl	0.593	NSD	--	n/a	NSD	--
	E20	0.596	NSD	--	n/a	NSD	--
US06	E10	0.0005	E0 > E10	-38.1%			
	E10-Spl	0.013	E0 > E10-Spl	-36.0%			
	E20	0.010	E0 > E20	-40.0%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Escort, CH_4 Emission Rates from -10℃ Tests

Fuel	Cold Start LA4 Phase 1 Avg	Cold Start LA4 Phase 1 St Dev	Cold Start LA4 Phase 2 Avg	Cold Start LA4 Phase 2 St Dev	Hot Start LA4 Phase 1 Avg	Hot Start LA4 Phase 1 St Dev	Hot Start LA4 Phase 2 Avg	Hot Start LA4 Phase 2 St Dev	US06 Avg	US06 St Dev
Distance Based Measurements (mg / mile)										
E0	141.4	10.2	< DL	n/a	8.8	1.5	1.4	1.6	33.7	1.4
E10	162.9	18.6	0.8	1.5	7.1	6.5	< DL	n/a	33.5	2.9
E10-Spl	144.7	20.1	0.8	1.4	10.5	0.9	< DL	n/a	37.2	4.9
E20	140.4	33.1	< DL	n/a	11.7	2.8	< DL	n/a	30.6	0.9
Fuel Consumption Based Measurements (mg / L)										
E0	727.0	51.8	< DL	n/a	61.3	10.9	9.4	10.9	227.7	9.1
E10	834.3	75.2	5.2	9.0	46.8	42.1	< DL	n/a	225.2	18.6
E10-Spl	709.1	91.1	4.7	8.1	69.1	4.8	< DL	n/a	240.5	30.9
E20	691.7	171.2	< DL	n/a	74.9	14.3	< DL	n/a	198.4	1.7

Escort, CH_4 Emission Rates (mg/mile) from -10℃ Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.103	NSD	--	0.286	NSD	--
	E10-Spl	0.782	NSD	--	0.286	NSD	--
	E20	0.954	NSD	--	n/a	NSD	--
HS LA4	E10	0.629	NSD	--	0.205	NSD	--
	E10-Spl	0.154	NSD	--	0.205	NSD	--
	E20	0.155	NSD	--	0.314	NSD	--
US06	E10	0.953	NSD	--			
	E10-Spl	0.284	NSD	--			
	E20	0.072	NSD	--			

Escort, CH_4 Emission Rates (mg/L fuel) from -10℃ Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.074	NSD	--	0.286	NSD	--
	E10-Spl	0.750	NSD	--	0.286	NSD	--
	E20	0.691	NSD	--	n/a	NSD	--
HS LA4	E10	0.064	NSD	--	0.205	NSD	--
	E10-Spl	0.307	NSD	--	0.205	NSD	--
	E20	0.255	NSD	--	0.315	NSD	--
US06	E10	0.848	NSD	--			
	E10-Spl	0.529	NSD	--			
	E20	0.024	E0 > E20	-12.9%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

2.b 2001 Nissan Sentra CA

Sentra, CH_4 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	5.7	1.0	< DL	n/a	2.6	0.6	< DL	n/a	1.5	0.4
E10	7.6	1.8	< DL	n/a	2.4	0.5	< DL	n/a	1.6	0.4
E10-Spl	6.4	0.3	< DL	n/a	2.2	0.05	< DL	n/a	1.0	0.08
E20	4.9	0.4	< DL	n/a	2.3	0.4	< DL	n/a	1.1	0.2
Fuel Consumption Based Measurements (mg / L)										
E0	41.5	6.8	< DL	n/a	22.6	5.6	< DL	n/a	11.4	3.1
E10	53.5	12.5	< DL	n/a	20.7	4.3	< DL	n/a	12.4	3.6
E10-Spl	44.8	2.2	< DL	n/a	18.7	0.2	< DL	n/a	7.2	0.5
E20	34.8	2.7	< DL	n/a	19.7	2.9	< DL	n/a	8.2	1.6

Sentra, CH_4 Emission Rates (mg/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.176	NSD	--	n/a	NSD	--
	E10-Spl	0.439	NSD	--	n/a	NSD	--
	E20	0.377	NSD	--	n/a	NSD	--
HS LA4	E10	0.748	NSD	--	n/a	NSD	--
	E10-Spl	0.466	NSD	--	n/a	NSD	--
	E20	0.611	NSD	--	n/a	NSD	--
US06	E10	0.801	NSD	--			
	E10-Spl	0.197	NSD	--			
	E20	0.330	NSD	--			

Sentra, CH_4 Emission Rates (mg/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.217	NSD	--	n/a	NSD	--
	E10-Spl	0.560	NSD	--	n/a	NSD	--
	E20	0.296	NSD	--	n/a	NSD	--
HS LA4	E10	0.673	NSD	--	n/a	NSD	--
	E10-Spl	0.421	NSD	--	n/a	NSD	--
	E20	0.564	NSD	--	n/a	NSD	--
US06	E10	0.757	NSD	--			
	E10-Spl	0.175	NSD	--			
	E20	0.289	NSD	--			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Sentra, CH_4 Emission Rates from -10°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	61.4	17.5	< DL	n/a	1.7	1.6	< DL	n/a	0.9	0.1
E10	86.9	12.6	< DL	n/a	2.1	3.0	< DL	n/a	1.0	0.1
E10-Spl	63.7	4.3	< DL	n/a	4.5	0.5	< DL	n/a	1.5	0.2
E20	73.1	10.6	< DL	n/a	3.6	0.05	< DL	n/a	1.5	0.09
Fuel Consumption Based Measurements (mg / L)										
E0	324.2	84.4	< DL	n/a	12.5	11.5	< DL	n/a	6.8	0.9
E10	477.0	48.3	< DL	n/a	15.3	21.6	< DL	n/a	7.7	1.2
E10-Spl	348.1	22.8	< DL	n/a	32.2	3.4	< DL	n/a	11.2	1.5
E20	383.4	57.8	< DL	n/a	26.0	0.3	< DL	n/a	10.1	0.7

Sentra, CH_4 Emission Rates (mg/mile) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.127	NSD	--	n/a	NSD	--
	E10-Spl	0.870	NSD	--	n/a	NSD	--
	E20	0.433	NSD	--	n/a	NSD	--
HS LA4	E10	0.823	NSD	--	n/a	NSD	--
	E10-Spl	0.066	NSD	--	n/a	NSD	--
	E20	0.168	NSD	--	n/a	NSD	--
US06	E10	0.358	NSD	--			
	E10-Spl	0.004	E10-Spl > E0	64.7%			
	E20	0.004	E20 > E0	54.5%			

Sentra, CH_4 Emission Rates (mg/L fuel) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.068	NSD	--	n/a	NSD	--
	E10-Spl	0.724	NSD	--	n/a	NSD	--
	E20	0.417	NSD	--	n/a	NSD	--
HS LA4	E10	0.823	NSD	--	n/a	NSD	--
	E10-Spl	0.072	NSD	--	n/a	NSD	--
	E20	0.178	NSD	--	n/a	NSD	--
US06	E10	0.370	NSD	--			
	E10-Spl	0.004	E10-Spl > E0	64.7%			
	E20	0.005	E20 > E0	49.2%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

2.c 2003 Dodge Caravan SE FFV

Caravan, CH_4 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	52.7	11.7	5.0	1.0	15.1	1.9	3.5	2.8	11.8	1.4
E10	52.0	6.2	3.5	0.5	14.0	1.8	2.2	3.1	14.5	0.4
E10-Spl	53.2	0.8	4.2	0.5	16.3	1.1	2.9	4.1	12.4	0.09
E20	50.2	7.6	6.6	3.4	15.5	2.6	3.2	4.5	13.1	1.9
Fuel Consumption Based Measurements (mg / L)										
E0	268.9	57.6	24.6	5.4	89.2	12.2	17.7	14.5	70.2	8.9
E10	265.3	34.7	16.9	2.7	83.1	11.6	11.3	16.0	85.5	1.6
E10-Spl	264.2	3.7	19.6	1.7	94.4	8.9	14.7	20.8	70.4	1.3
E20	250.7	36.7	31.0	16.1	87.8	14.2	15.8	22.3	74.0	11.8

Caravan, CH_4 Emission Rates (mg/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.943	NSD	--	0.126	NSD	--
	E10-Spl	0.951	NSD	--	0.357	NSD	--
	E20	0.802	NSD	--	0.385	NSD	--
HS LA4	E10	0.528	NSD	--	0.646	NSD	--
	E10-Spl	0.461	NSD	--	0.854	NSD	--
	E20	0.805	NSD	--	0.936	NSD	--
US06	E10	0.065	NSD	--			
	E10-Spl	0.623	NSD	--			
	E20	0.389	NSD	--			

Caravan, CH_4 Emission Rates (mg/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.941	NSD	--	0.142	NSD	--
	E10-Spl	0.919	NSD	--	0.288	NSD	--
	E20	0.712	NSD	--	0.470	NSD	--
HS LA4	E10	0.593	NSD	--	0.649	NSD	--
	E10-Spl	0.631	NSD	--	0.845	NSD	--
	E20	0.909	NSD	--	0.904	NSD	--
US06	E10	0.086	NSD	--			
	E10-Spl	0.980	NSD	--			
	E20	0.679	NSD	--			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

2.d 2000 Mitsubishi Dion Exceed

Dion, CH_4 Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	63.0	6.8	31.4	2.9	28.7	4.2	28.9	3.3	25.3	1.7
E10	52.2	3.6	27.5	0.8	23.8	3.1	26.4	1.6	27.8	n/a
E10-Spl	59.5	5.0	26.5	6.0	23.4	3.5	25.7	0.5	23.2	1.9
E20	59.6	4.6	27.1	1.8	28.5	0.7	25.3	3.4	14.1	n/a
Fuel Consumption Based Measurements (mg / L)										
E0	350.4	45.1	203.1	19.3	198.6	28.9	196.9	22.3	158.0	9.7
E10	285.6	15.5	177.7	5.4	164.7	18.8	178.4	8.9	173.4	n/a
E10-Spl	337.6	31.4	171.3	41.7	162.1	26.6	171.0	7.0	141.1	13.6
E20	322.9	25.5	168.9	11.5	191.0	6.7	165.7	22.4	88.5	n/a

Dion, CH_4 Emission Rates (mg/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.112	NSD	--	0.159	NSD	--
	E10-Spl	0.561	NSD	--	0.226	NSD	--
	E20	0.560	NSD	--	0.142	NSD	--
HS LA4	E10	0.221	NSD	--	0.383	NSD	--
	E10-Spl	0.202	NSD	--	0.261	NSD	--
	E20	0.935	NSD	--	0.276	NSD	--
US06	E10	0.263	NSD	--			
	E10-Spl	0.249	NSD	--			
	E20	0.009	E0 > E20	-44.1%			

Dion, CH_4 Emission Rates (mg/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.133	NSD	--	0.159	NSD	--
	E10-Spl	0.743	NSD	--	0.242	NSD	--
	E20	0.481	NSD	--	0.089	NSD	--
HS LA4	E10	0.216	NSD	--	0.341	NSD	--
	E10-Spl	0.211	NSD	--	0.202	NSD	--
	E20	0.745	NSD	--	0.182	NSD	--
US06	E10	0.249	NSD	--			
	E10-Spl	0.136	NSD	--			
	E20	0.008	E0 > E20	-44.0%			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Appendix 4 Statistical Analysis of N_2O Results

3.a 1998 Ford Escort ZX2

Escort, N_2O Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	22.0	5.7	2.0	2.7	26.1	5.3	1.2	1.7	13.8	0.2
E10	24.2	2.6	3.1	1.0	20.9	0.4	3.4	1.0	17.8	2.0
E10-Spl	22.7	0.8	1.8	0.1	23.7	1.7	3.2	0.5	16.3	1.3
E20	30.2	6.0	4.6	0.4	21.3	1.3	4.0	0.5	20.1	6.8
Fuel Consumption Based Measurements (mg / L)										
E0	145.0	35.6	13.9	18.4	202.1	46.7	8.4	11.9	98.2	2.6
E10	156.1	19.0	21.8	7.4	161.7	4.3	24.5	7.5	130.7	15.1
E10-Spl	141.6	6.7	12.3	0.6	179.1	11.8	22.4	3.1	115.3	9.2
E20	190.7	40.3	30.7	3.2	157.6	5.4	27.4	3.7	138.6	45.0

Escort, N_2O Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.575	NSD	--	0.539	NSD	--
	E10-Spl	0.882	NSD	--	0.931	NSD	--
	E20	0.296	NSD	--	0.315	NSD	--
HS LA4	E10	0.164	NSD	--	0.148	NSD	--
	E10-Spl	0.611	NSD	--	0.239	NSD	--
	E20	0.341	NSD	--	0.146	NSD	--
US06	E10	0.078	NSD	--			
	E10-Spl	0.111	NSD	--			
	E20	0.322	NSD	--			

Escort, N_2O Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.669	NSD	--	0.531	NSD	--
	E10-Spl	0.908	NSD	--	0.915	NSD	--
	E20	0.352	NSD	--	0.332	NSD	--
HS LA4	E10	0.202	NSD	--	0.150	NSD	--
	E10-Spl	0.568	NSD	--	0.247	NSD	--
	E20	0.312	NSD	--	0.163	NSD	--
US06	E10	0.064	NSD	--			
	E10-Spl	0.128	NSD	--			
	E20	0.333	NSD	--			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Escort, N_2O Emission Rates from -10°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	18.4	1.3	4.4	1.5	32.8	5.5	5.0	1.2	17.6	5.1
E10	26.0	3.2	4.3	0.7	31.7	1.5	4.2	0.2	16.3	0.9
E10-Spl	26.5	9.1	5.2	1.4	29.4	0.3	5.5	0.5	15.4	2.6
E20	30.2	6.4	5.3	0.3	35.9	9.2	5.6	0.4	17.0	1.0
Fuel Consumption Based Measurements (mg / L)										
E0	94.6	6.5	27.7	9.6	228.3	39.5	33.3	7.8	120.5	34.4
E10	133.9	19.7	26.7	4.9	210.0	12.6	27.4	1.8	109.3	6.1
E10-Spl	129.4	42.8	30.7	8.8	192.3	2.4	34.7	2.7	98.3	15.4
E20	148.3	29.6	30.5	0.6	229.2	47.4	34.9	3.3	109.9	4.5

Escort, N_2O Emission Rates (g/mile) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.007	E10 > E0	42%	0.957	NSD	--
	E10-Spl	0.115	NSD	--	0.564	NSD	--
	E20	0.016	E20 > E0	64%	0.487	NSD	--
HS LA4	E10	0.745	NSD	--	0.291	NSD	--
	E10-Spl	0.458	NSD	--	0.662	NSD	--
	E20	0.615	NSD	--	0.588	NSD	--
US06	E10	0.672	NSD	--			
	E10-Spl	0.599	NSD	--			
	E20	0.871	NSD	--			

Escort, N_2O Emission Rates (g/L fuel) from -10°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.012	E10 > E0	41.5%	0.867	NSD	--
	E10-Spl	0.144	NSD	--	0.737	NSD	--
	E20	0.017	E20 > E0	56.8%	0.719	NSD	--
HS LA4	E10	0.482	NSD	--	0.261	NSD	--
	E10-Spl	0.291	NSD	--	0.822	NSD	--
	E20	0.980	NSD	--	0.802	NSD	--
US06	E10	0.607	NSD	--			
	E10-Spl	0.450	NSD	--			
	E20	0.701	NSD	--			

Please note:
- ***<DL = value less than detection limit***
- ***NSD = no statistically significant difference***
- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

3.b 2001 Nissan Sentra CA

Sentra, N_2O Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	6.6	0.4	1.3	0.7	1.0	0.9	0.5	0.5	8.1	3.7
E10	5.0	1.2	0.4	0.06	1.2	0.4	0.3	0.3	8.1	0.4
E10-Spl	3.8	1.1	2.9	3.0	< DL	n/a	< DL	n/a	4.9	0.2
E20	6.2	2.6	1.0	1.4	0.5	0.7	0.3	0.4	1.5	0.7
Fuel Consumption Based Measurements (mg / L)										
E0	47.7	3.0	10.3	5.7	8.7	7.8	4.2	3.9	63.2	29.5
E10	35.0	7.4	2.8	0.5	10.1	3.1	2.6	2.2	64.1	3.6
E10-Spl	27.1	8.0	22.9	23.4	< DL	n/a	< DL	n/a	37.1	1.0
E20	43.7	18.7	7.7	10.9	4.4	6.3	2.2	3.2	11.6	5.4

Sentra, N_2O Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.098	NSD	--	0.090	NSD	--
	E10-Spl	0.029	E0 > E10-Spl	-41.5%	0.395	NSD	--
	E20	0.799	NSD	--	0.753	NSD	--
HS LA4	E10	0.771	NSD	--	0.552	NSD	--
	E10-Spl	0.232	NSD	--	0.241	NSD	--
	E20	0.578	NSD	--	0.600	NSD	--
US06	E10	0.991	NSD	--			
	E10-Spl	0.326	NSD	--			
	E20	0.098	NSD	--			

Sentra, N_2O Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.051	NSD	--	0.087	NSD	--
	E10-Spl	0.023	E0 > E10-Spl	-43.3%	0.405	NSD	--
	E20	0.719	NSD	--	0.737	NSD	--
HS LA4	E10	0.788	NSD	--	0.552	NSD	--
	E10-Spl	0.232	NSD	--	0.241	NSD	--
	E20	0.568	NSD	--	0.591	NSD	--
US06	E10	0.970	NSD	--			
	E10-Spl	0.320	NSD	--			
	E20	0.102	NSD	--			

Please note:
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- ***When the emission rates for both groups in a comparison are zero, ANOVA tests cannot be performed, hence the p-value is listed as "n/a" and the change as "NSD".***

Sentra, N_2O Emission Rates from -10℃ Tests

Fuel	Cold Start LA4 Phase 1 Avg	Cold Start LA4 Phase 1 St Dev	Cold Start LA4 Phase 2 Avg	Cold Start LA4 Phase 2 St Dev	Hot Start LA4 Phase 1 Avg	Hot Start LA4 Phase 1 St Dev	Hot Start LA4 Phase 2 Avg	Hot Start LA4 Phase 2 St Dev	US06 Avg	US06 St Dev
Distance Based Measurements (mg / mile)										
E0	57.7	38.1	2.5	2.5	22.3	15.1	1.9	1.3	8.3	4.0
E10	71.2	12.3	0.8	0.7	18.2	10.5	1.7	1.7	5.5	1.0
E10-Spl	111.4	n/a	0.8	n/a	31.8	n/a	1.2	n/a	6.2	n/a
E20	75.4	9.0	5.9	0.06	15.5	3.5	3.0	3.0	2.2	0.3
Fuel Consumption Based Measurements (mg / L)										
E0	311.4	211.0	16.2	16.1	162.6	109.8	12.8	8.7	54.6	29.9
E10	393.7	85.0	5.3	4.8	132.9	74.4	12.1	11.9	40.4	7.9
E10-Spl	607.3	n/a	4.9	n/a	223.4	n/a	8.2	n/a	44.9	n/a
E20	395.6	49.6	36.5	0.4	110.5	25.1	19.6	19.7	15.4	2.2

Sentra, N_2O Emission Rates (g/mile) from -10℃ Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.660	NSD	--	0.393	NSD	--
	E10-Spl	0.268	NSD	--	0.554	NSD	--
	E20	0.564	NSD	--	0.136	NSD	--
HS LA4	E10	0.743	NSD	--	0.898	NSD	--
	E10-Spl	0.596	NSD	--	0.666	NSD	--
	E20	0.573	NSD	--	0.492	NSD	--
US06	E10	0.400	NSD	--			
	E10-Spl	0.662	NSD	--			
	E20	0.100	NSD	--			

Sentra, N_2O Emission Rates (g/L fuel) from -10℃ Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared To E0	Phase 1 P-Value	Phase 1 Change	Phase 1 % Diff	Phase 2 P-Value	Phase 2 Change	Phase 2 % Diff
CS LA4	E10	0.631	NSD	--	0.415	NSD	--
	E10-Spl	0.270	NSD	--	0.559	NSD	--
	E20	0.619	NSD	--	0.153	NSD	--
HS LA4	E10	0.746	NSD	--	0.931	NSD	--
	E10-Spl	0.640	NSD	--	0.650	NSD	--
	E20	0.556	NSD	--	0.519	NSD	--
US06	E10	0.393	NSD	--			
	E10-Spl	0.642	NSD	--			
	E20	0.093	NSD	--			

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3.c 2003 Dodge Caravan SE FFV

Caravan, N_2O Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	36.6	4.8	5.1	1.6	29.7	5.5	5.3	2.6	16.5	4.1
E10	43.0	1.0	6.9	1.4	27.7	1.9	6.5	4.6	20.8	2.9
E10-Spl	39.6	1.7	4.8	1.4	30.9	13.2	4.8	2.6	21.3	4.0
E20	46.0	1.0	9.0	1.7	29.9	3.6	8.7	6.2	19.9	1.5
Fuel Consumption Based Measurements (mg / L)										
E0	187.0	25.8	25.0	8.0	175.9	34.6	27.3	13.2	97.9	24.5
E10	219.1	2.2	33.9	7.9	164.7	10.1	33.4	23.3	122.9	16.0
E10-Spl	196.6	2.8	22.6	7.3	180.2	81.3	24.0	14.1	121.3	24.1
E20	229.9	6.1	42.1	7.9	169.0	22.0	43.0	30.5	112.1	10.8

Caravan, N_2O Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.155	NSD	--	0.233	NSD	--
	E10-Spl	0.454	NSD	--	0.830	NSD	--
	E20	0.062	NSD	--	0.046	E20 > E0	77.3%
HS LA4	E10	0.656	NSD	--	0.702	NSD	--
	E10-Spl	0.869	NSD	--	0.842	NSD	--
	E20	0.973	NSD	--	0.362	NSD	--
US06	E10	0.266	NSD	--			
	E10-Spl	0.244	NSD	--			
	E20	0.346	NSD	--			

Caravan, N_2O Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.173	NSD	--	0.268	NSD	--
	E10-Spl	0.647	NSD	--	0.738	NSD	--
	E20	0.093	NSD	--	0.068	NSD	--
HS LA4	E10	0.694	NSD	--	0.687	NSD	--
	E10-Spl	0.925	NSD	--	0.794	NSD	--
	E20	0.817	NSD	--	0.395	NSD	--
US06	E10	0.271	NSD	--			
	E10-Spl	0.330	NSD	--			
	E20	0.496	NSD	--			

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3.d 2000 Mitsubishi Dion Exceed

Dion, N_2O Emission Rates from 20°C Tests

	Cold Start LA4				Hot Start LA4				US06	
	Phase 1		Phase 2		Phase 1		Phase 2			
Fuel	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev	Avg	St Dev
Distance Based Measurements (mg / mile)										
E0	12.8	1.7	10.8	2.3	17.6	4.0	10.3	0.7	7.7	1.4
E10	12.4	0.9	10.2	0.1	20.8	4.9	9.9	1.7	6.2	n/a
E10-Spl	11.0	1.7	10.8	0.7	22.0	4.1	14.5	2.3	7.4	0.4
E20	17.8	2.6	12.4	2.2	29.4	1.9	14.3	1.8	9.5	n/a
Fuel Consumption Based Measurements (mg / L)										
E0	71.1	9.7	69.9	15.2	121.3	26.8	70.0	4.3	48.1	9.5
E10	67.7	3.9	66.0	0.8	144.2	32.1	66.7	10.6	39.0	n/a
E10-Spl	62.5	10.2	69.5	6.0	152.4	30.5	97.1	17.7	45.1	3.0
E20	96.6	14.2	77.0	14.0	197.4	14.8	93.4	12.2	59.6	n/a

Dion, N_2O Emission Rates (g/mile) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.769	NSD	--	0.756	NSD	--
	E10-Spl	0.291	NSD	--	0.994	NSD	--
	E20	0.042	E20 > E0	39.2%	0.471	NSD	--
HS LA4	E10	0.421	NSD	--	0.668	NSD	--
	E10-Spl	0.268	NSD	--	0.020	E10-Spl > E0	41.4%
	E20	0.019	E20 > E0	67.4%	0.014	E20 > E0	38.6%
US06	E10	0.423	NSD	--			
	E10-Spl	0.830	NSD	--			
	E20	0.322	NSD	--			

Dion, N_2O Emission Rates (g/L fuel) from 20°C Tests, ANOVA Results – E0 vs. Ethanol Blends

	Fuel Compared	Phase 1			Phase 2		
	To E0	P-Value	Change	% Diff	P-Value	Change	% Diff
CS LA4	E10	0.676	NSD	--	0.750	NSD	--
	E10-Spl	0.368	NSD	--	0.973	NSD	--
	E20	0.055	NSD	--	0.616	NSD	--
HS LA4	E10	0.401	NSD	--	0.581	NSD	--
	E10-Spl	0.265	NSD	--	0.031	E10-Spl > E0	38.6%
	E20	0.023	E20 > E0	62.7%	0.019	E20 > E0	33.4%
US06	E10	0.452	NSD	--			
	E10-Spl	0.638	NSD	--			
	E20	0.360	NSD	--			

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