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Investigation on Emissions from Buses with Compressed Natural Gas and Diesel Engines

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by

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ABSTRACT

This project investigated the chemical composition of exhaust emissions from buses with three types of engines and estimated annual emissions of key compounds including carbon dioxide (CO_2), methane (CH_4), ethyne (C_2H_2), ethane (C_2H_6), ethene (C_2H_4), propane (C_3H_8), and other volatile organic compounds (VOCs) from buses in the city of Syracuse. Exhaust samples were taken from one bus with a CNG ISL engine, one with a diesel ISL engine, and the final one with a C Gas plus engine in the idling, cruising, acceleration, and deceleration modes. The emissions were estimated both in kg per year and kg per km over three CENTRO bus routes that service the Syracuse University area. Carbon dioxide was the most dominant chemical in the exhaust emissions for all engines over all the routes, and the diesel engine produced the most out of the three engine types. The diesel engine had the highest CO_2 mixing ratio with a value of 304,501 ppmv when cruising. That value is 295,879 ppmv above the next largest mixing ratio, which was emitted by the diesel engine when decelerating and was equal to 8,622 ppmv. The diesel created 2.27 x 10^9 kg CO_2 for a single bus per year. The second most dominant chemical was methane. The C Gas Plus created the most CH_4 with a cruising mode mixing ratio of 273 ppmv. It released 3.26 x 10^5 kg of methane per year. Of the VOCs, C_3H_8 had the highest mixing ratio for a given engine running mode in more cases than any of the others. Those cases were when the C Gas Plus was idling (7.0403 ppmv), the diesel was accelerating (11.497 ppmv), and when the C Gas Plus was cruising (8.7813 ppmv). Ethene produced by the C Gas Plus engine had the highest mixing ratio for deceleration (7.2748 ppmv). The CNG ISL produced 2.56 x 10^7 kg of emissions per year, the diesel created 2.27 x 10^9 kg/yr, and the C Gas Plus made 2.43 x 10^7 kg/yr.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOLEDGEMENTS

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1. INTRODUCTION

Global climate change is a huge issue right now, and global warming has been linked to increases in greenhouse gases. Greenhouse gases, such as carbon dioxide, are released from the tailpipes of vehicles when they burn fuels made from oil. Increases in their warming effect can be detrimental to many industries, such as agriculture, fisheries, and eco-tourism, that depend on a certain climate (Brown and McLachlan, 2002). Mobile combustion also releases trace gases and particulates, which can impact air quality and human health. The ultrafine particulates can penetrate cell walls and enter the bloodstream and lungs leading to asthma and other breathing problems (Pietikainen et al., 2009). Air quality is also impacted by volatile organic compounds. VOCs are important because they contribute to pollution through photochemical processes which can lead to harm from human health. Reducing them is therefore beneficial.

For diesel vehicles, NO_x and fine particulates are of bigger concern. While there has been a 99% reduction in emissions from 1970 to today, these improvements mostly apply to newer, lighter vehicles. Heavy-duty diesel vehicles have a longer life span on the road (so they tend to be older) and regulation of them has lagged. Traps and selective catalytic reduction technology that have recently been introduced have reduced mobile emissions of particulates and NO_x, respectively (Sawyer, 2010). Also, 77% of inhaled particulates from a compressed natural gas (CNG) bus will end up in the respiratory tract, while only 56% from a diesel oxidation catalyst does so, because the CNG particulates tend to be smaller. However, the diesel bus emits more particulates overall making its emissions more harmful to human health (Pietikäinen, 2012).

The four economies of sustainable automotive transportation are emissions, fuel consumption, water usage, and cost of vehicle operation. In Gifford and Brown (2011), 30 wells-to-wheels analyses of different engine platforms and fuel types were carried out and a score out of 100 was given to grade the performance of each engine and fuel type. The compressed natural gas hybrid electric engine did by far the best, with a score of 74.34. The CNG internal combustion engine did second best, with a score of 70.61. This illustrates that CNG is much more efficient than any other combination of fuel and engine platform available today. Based on this data, it was hypothesized that the results of this experiment would result in one of the compressed natural gas buses releasing the fewest emissions for a given power output when compared with the diesel engine.

While the studies mentioned above measured emissions from cars and other vehicles, none of them measured the annual emissions from buses. Considering how many buses are found across the US, this is an important point. The objective of this project was to compare emissions output of different fuel types. This experiment tested the emissions of a Cummins C Gas Plus 2005 engine, a Cummins ISL compressed natural gas 2011 engine, and a Cummins ISL Diesel 2009 engine. The chemicals of interest were carbon dioxide (CO_2), methane (CH_4), and VOCs. All of these buses belonged to CENTRO bus company located in Syracuse, NY. Their fleet has 250 buses.

2. METHODS

2.1 Emission Sampling

The first step in this project was taking samples of the bus emissions. Prior to sampling, the 2-liter electropolished stainless steel canisters (University of California, Irvine, CA) were prepared by flushing with UHP helium that had passed through an activated charcoal/molecular sieve (13X) trap immersed in liquid nitrogen. The canisters were then evacuated to 10^{-2} torr. During sampling, the canisters were opened and ambient air was pulled in. The 24 vacuum canisters were brought to CENTRO garage. Each bus was placed on a dynometer and made to idle, accelerate, hold cruising speed, and decelerate. At each mode two samples were taken. There were a total of 24 samples.

2.2 Sample Analysis

The canisters were brought back to Appalachian State University, where they have a world-class gas chromatography (GC) mass spectroscopy system where the cans can be attached and their contents analyzed. A three gas chromatograph system equipped with two flame ionization detectors (FID), two electron capture detectors (ECD), and a mass spectrometer (MS) was used for sample analysis. Details of the system configuration are given in Sive et al. (2005) and Russo et al. (2010). Briefly, the samples were analyzed by trapping 1500 cc (STP) of air on a glass bead filled loop immersed in liquid nitrogen. Following completion of sample trapping, the loop was isolated and warmed to 80°C with hot water. Helium carrier gas flushed the contents of the loop and the stream was split into five with each sub-stream feeding a separate GC column. A secondary He carrier with a slower flow rate (1.0 sccm) was used for the MS in order to improve the instrument sensitivity. A 1500 cc aliquot from one of two working standards was assayed every ninth analysis. The measurement precision for the whole air standards (i.e., relative standard deviation (RSD) = (standard deviation of peak areas/average of peak areas) was <1-4% for the C_2-C_8 NMHCs, 5% for C_2HCl_3 and C_2Cl_4 at 0.50 and 6.0 pptv, respectively.

2.3 Calculation Methods

Once all the chromatograms were analyzed, they were converted from arbitrary units (microvolts*minutes) to ppmv. Those calculations were done using known mixing ratios for the standard, HPP-A. Dividing the peak area by the HPP-A standard mixing ratios gave the retention factor for each chemical of interest. Then the peak areas were divided by the retention factor to get the sample mixing ratios in pptv.

Conversion of peak area to mixing ratios in ppmv is shown in equation (1). Standard retention factor is acquired by dividing the standard peak area by the standard mixing ratio.

$$\frac{\text{peak area}}{\text{standard retention factor}} * 10^{-6} = ppmv \qquad \textbf{(1)}$$

In order to convert the mixing ratios to kg/m^3, use the following equation:

$$\frac{\text{mixing ratio of the chemical}}{40.9\frac{\text{mol}}{\text{m}^3}(\text{standard for the atmosphere})} * \text{molecular weight} * 10^{-6} = \text{kg/m}^3 \qquad \textbf{(2)}$$

Multiply the values from equation (2) by the flow rate of the emissions for each bus, then multiply the result by seconds per year to get the kg/yr emitted for each bus (Equation 3).

$$\frac{\text{kg}}{\text{m}^3} * \text{flow rate } \left(\frac{\text{m}^3}{\text{seconds}}\right) * \frac{\text{seconds}}{\text{year}} = \text{kg/year} \qquad \textbf{(3)}$$

The flow rates for equation (3) were estimated from values found in the Engine Horsepower and Exhaust Flow Guide (Donaldson, 2013). For each bus three bus routes in Syracuse, NY were considered for city limit emission estimation. They were the CENTRO East Campus, Connective Corridor, and South Campus routes. These routes were chosen because between them most of the main campus university area is covered. The kg of emissions per kilometer produced in each engine mode was calculated for the three bus routes using equation 4. Once the emissions for each mode were calculated, they were added together to get the total emissions for the route.

$$\frac{\left(\frac{\text{kg}}{\text{year}} * \frac{1\text{ year}}{525{,}948.6\text{ minutes}} * \text{length of time in the engine mode (minutes)}\right)}{\text{distance traveled in that mode (km)}} \quad \textbf{(4)}$$

The times spent in idling, accelerating, cruising, and decelerating were calculated for each route using the CENTRO bus schedules. They had the time the buses arrived at each stop and the route they took to get there.

Each engine mode was measured twice, so there were two sample values for idling, accelerating, cruising, and decelerating. The values were averaged in order to account for small differences in the measurements.

3. RESULTS

3.1 Chemical Composition of Exhaust Emissions

3.1.1 Carbon dioxide in the exhaust emissions from three engine types

Thirty organic compounds were found to be present above their respective limits of detection in the samples. Twelve key compounds were chosen to presented here.

Carbon dioxide was one of those. Mixing ratios of other compounds will be discussed in Sections 3.1.2 and 3.1.3. The peak areas were converted to mixing ratios using Equation (1). Carbon dioxide is the dominant constituent in all of the samples as exemplified by its large ratios (Fig. 1). The diesel engine had the highest carbon dioxide mixing ratio with a value of 304,501 ppmv during cruising. That value is 295,879 ppmv above the next largest mixing ratio, which was emitted by the diesel engine when decelerating and was equal to 8,622 ppmv. Considering that possible error, carbon dioxide was the dominant constituent in all other engine modes for all three engine types because its mixing ratios dwarfed those of the other chemicals in the emissions.

Compared within the same engine type, all three engines produced their highest carbon dioxide mixing ratios during cruising than in other running modes. The CNG ISL engine's CO_2 mixing ratio was 2,553 ppmv and the C Gas Plus's value was 2561 ppmv. As stated above, the diesel's value was 304,501 ppmv. The CNG ISL and C Gas Plus engine emitted the least when they were idling with 1251 ppmv and 749 ppmv respectively. Different from the other two engine types, the diesel engine produced its smallest mixing ratio (2530 ppmv) when accelerating.

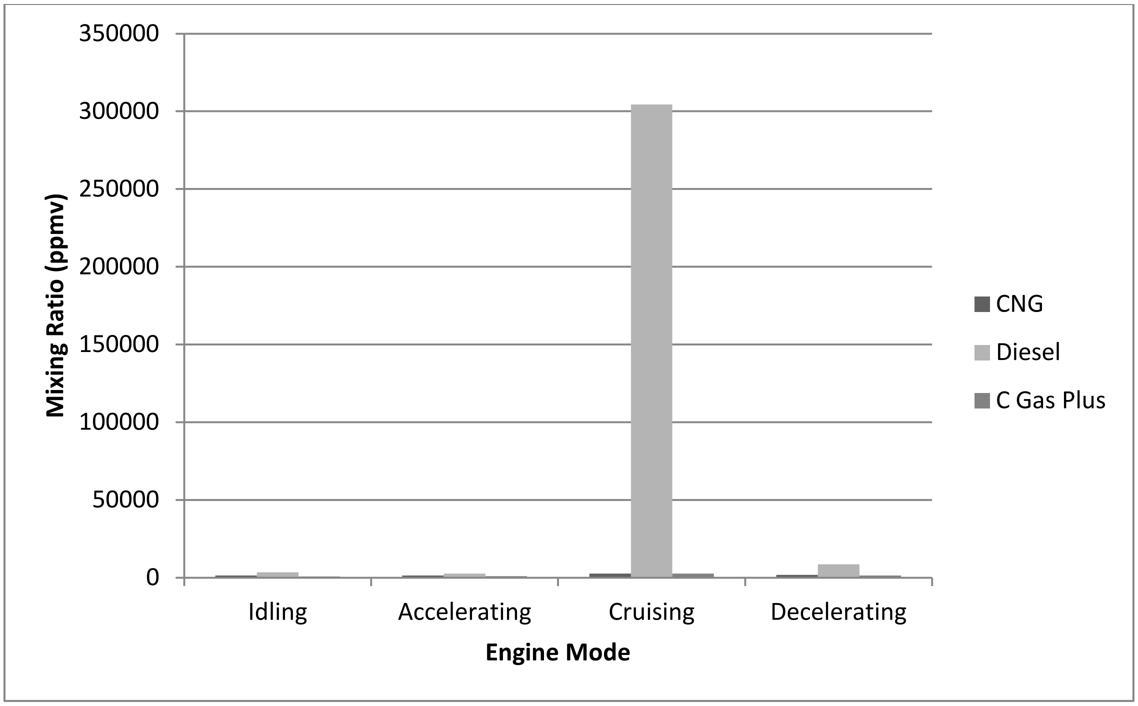

Fig.1. Carbon dioxide mixing ratios for each engine mode and type.

3.1.2 Methane in the exhaust emissions from the three engine types

Methane was the second most abundant chemical in the exhaust emissions (Fig.2). Compared to the other two engine types, the C Gas Plus engine produced the largest CH_4 mixing ratio with mixing ratios of 11 ppmv during idling, 17 ppmv during acceleration, and 770 ppmv during decelerating. The only running mode during which it did not create the highest concentration of methane gas was when cruising. In that case, the diesel engine had the greatest value (273 ppmv) among the three engine types.

Compared to C Gas Plus and Diesel engines, the CNG ISL engine produced the lowest concentrations when idling (3.6 ppmv), cruising (33 ppmv), and decelerating (1.5 ppmv). However, it only did second best when accelerating with a mixing ratio of 15 ppmv. The engine with the lowest concentration when accelerating was the diesel (4.1

ppmv). Having low mixing ratios is desirable because it indicates less emissions released into air, and therefore less pollution.

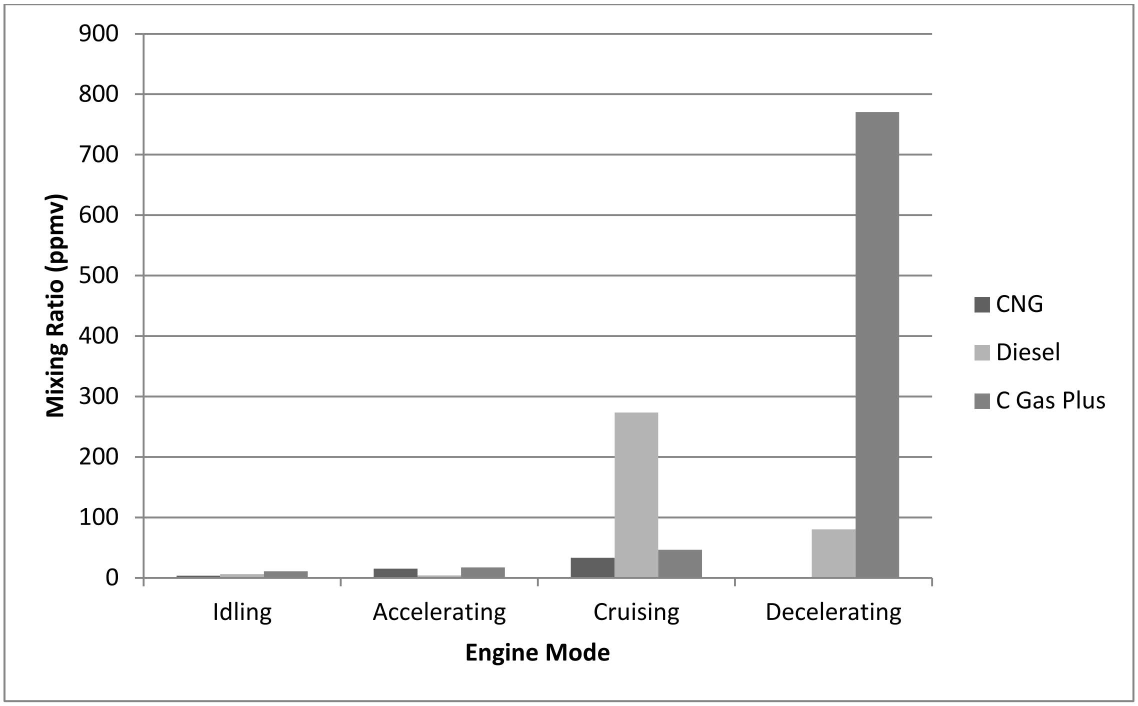

Fig.2. Methane mixing ratios for each engine mode and type

3.1.3 VOCs in the exhaust emissions of the three engine types

The other chemicals analyzed were C_2H_6, ethyne (C_2H_2), C_3H_8, propene (C_3H_6), i-butane, n-butane, i-pentane, n-pentane, n-hexane, and benzene. These are all trace gases. Of these compounds, C_3H_8 had the highest mixing ratio for a given engine running mode in more cases than any of the others. Those cases were when the C Gas Plus was idling (7.0403 ppmv, Fig. 3), the diesel was accelerating (11.497 ppmv, Fig.4), and when the C Gas Plus was cruising (8.7813 ppmv, Fig. 5). Ethene produced by the C Gas Plus engine had the highest mixing ratio for deceleration (7.2748 ppmv, Fig.6). Ethyne, n-butane, i-pentane, n-pentane, n-hexane, propene, and benzene never had mixing ratios above 1 ppmv for any engine in any running mode. Ethane only broke 1 ppmv when the CNG ISL engine was accelerating (1.2 ppmv) and when the C Gas Plus engine was decelerating (3.2 ppmv). I-pentane had the absolute lowest concentrations in three engine modes (4 x 10^{-3} ppmv when idling, 8.7 x 10^{-5} ppmv when cruising, and 5.1 x 10^{-3} ppmv when decelerating. The only mode it did not have the lowest concentration was acceleration, where benzene had a concentration of 2 x 10^{-4} ppmv.

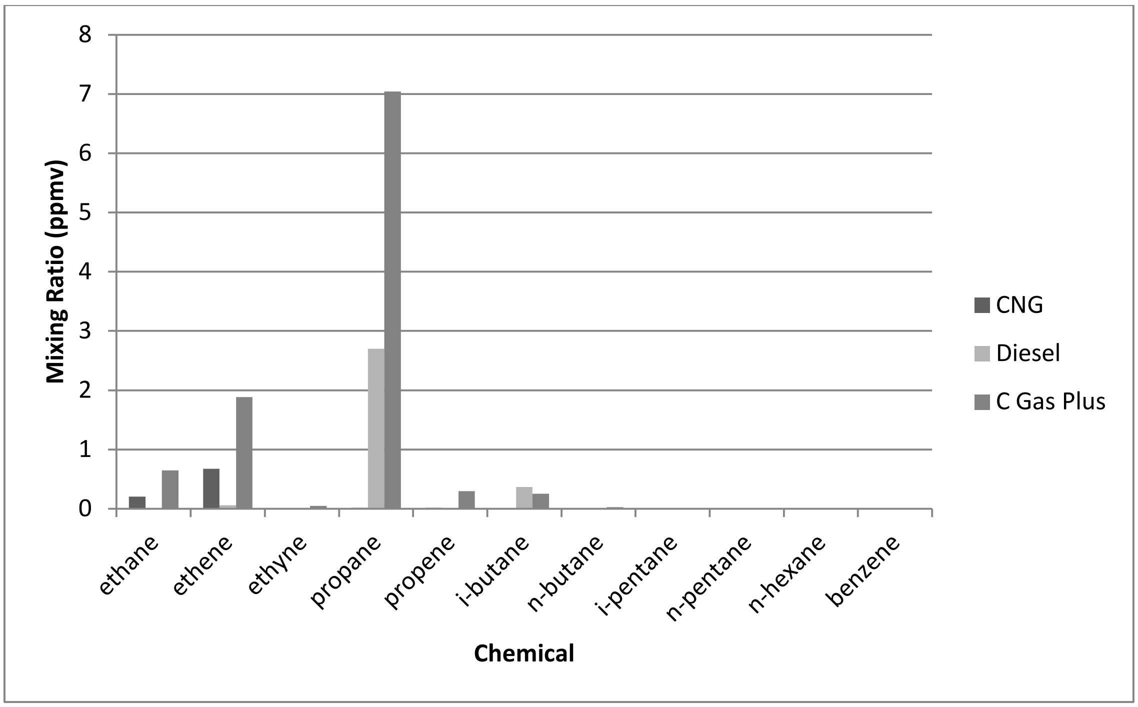

Fig.3. Idling VOC emission mixing ratios

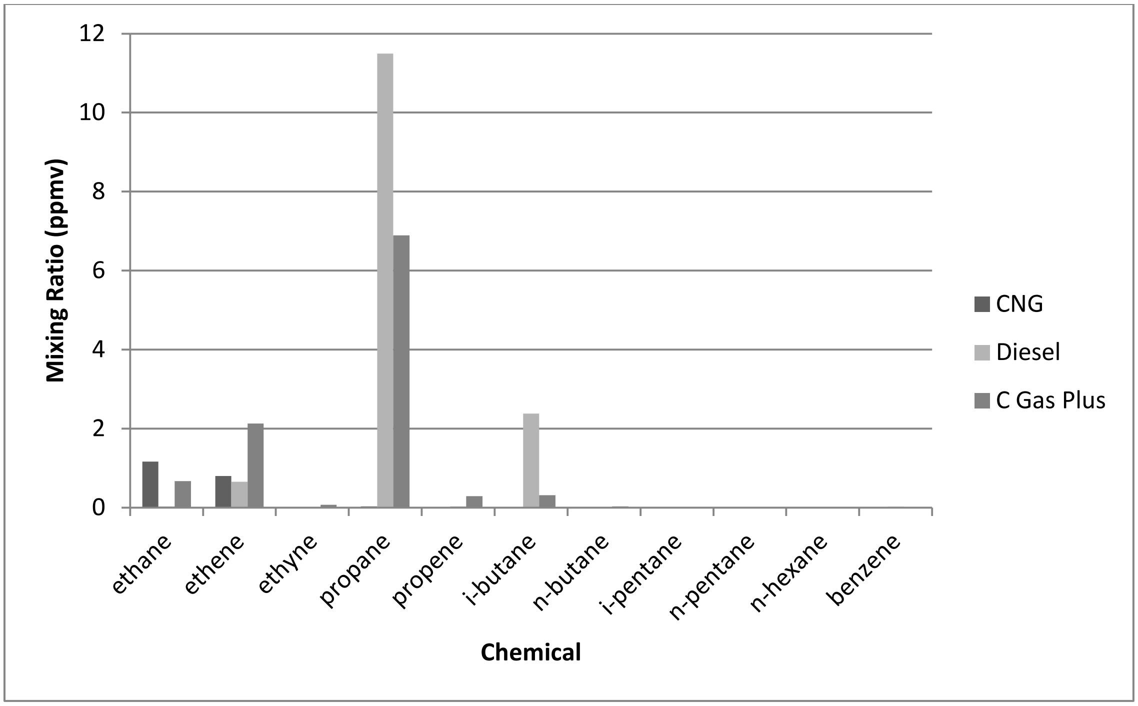

Fig.4. Acceleration VOC emission mixing ratios

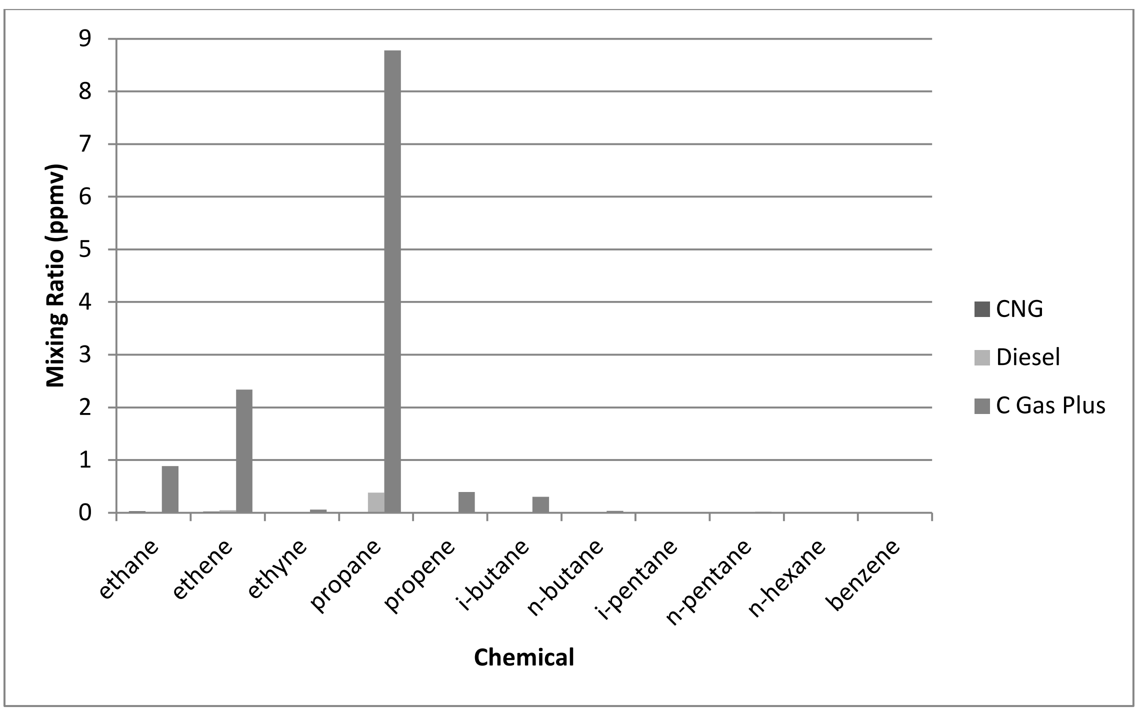

Fig.5. Cruising VOC emission mixing ratios

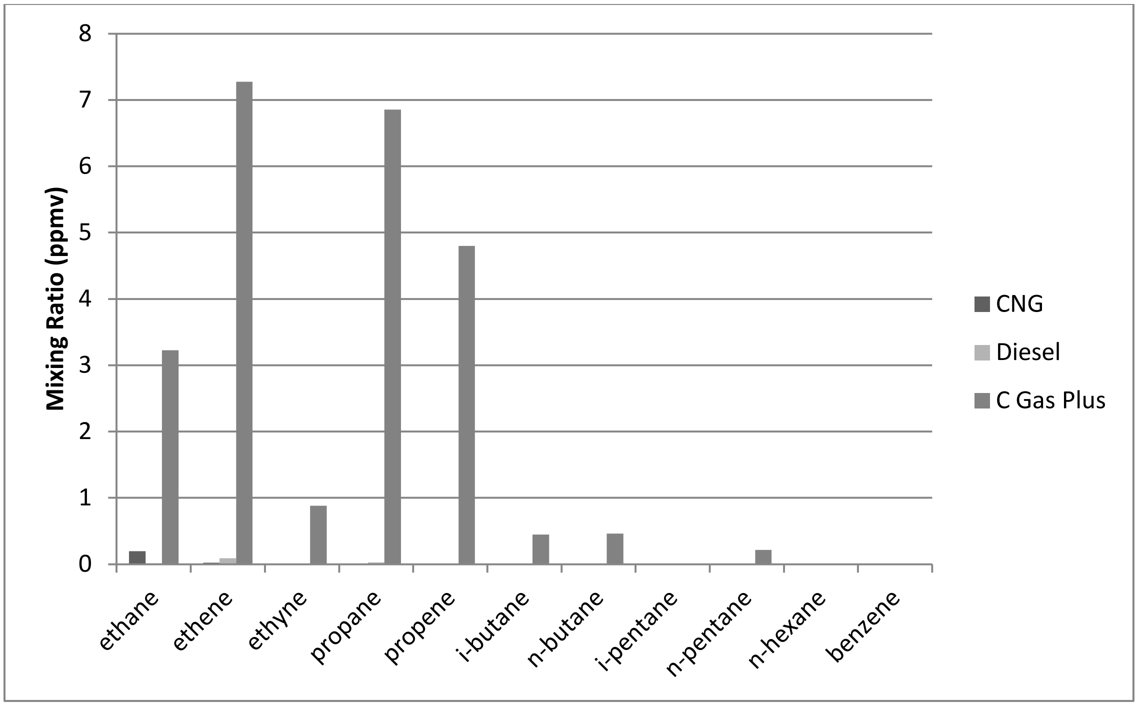

Fig.6. Decelerating VOC emission mixing ratios

3.2 Mass of emissions per kilometer

Using the mixing ratios of the major trace gases, flow rates for the three engine types, estimated time of idling, acceleration, deceleration, and cursing over the three university area bus routes, we calculated the total kilograms of emissions of major trace gases per kilometer and results are presented in Tables 1, 2, and 3. Emissions are often expressed in kg/km or g/km and it is necessary to know because the United States has air quality standards that need to be met. As shown in the tables, the diesel engine emitted the most CO_2, i-butane, and benzene over per kilometer distance over the course of all three bus routes. For instance, on the East Campus route the diesel engine produced 1.8 x 10^3 kg/km CO_2, 8. 8 x 10^{-3} kg/km i-butane, and 2.5 x 10^{-4} kg/km of benzene. It also emitted the most methane over the South Campus route (1 x 10^{-3} kg/km) and n-hexane over the South Campus (4.8 x 10^{-4} kg/km) and East Campus (8.1 x 10^{-5} kg/km) routes.

For all other chemicals, the C Gas Plus engine produced the most emissions per kilometer. Once again, this is probably because it is the oldest engine, being made in 2005.

Table 1. East Campus Emissions in kg/km

Chemical	CNG	Diesel	C Gas Plus
Methane	8.43E-02	6.67E-01	8.93E-01
Carbon Dioxide	2.27E+01	1.81E+03	2.12E+01
Ethane	2.59E-03	1.40E-04	1.09E-02
Ethene	1.49E-03	1.48E-03	2.53E-02
Ethyne	1.16E-05	3.63E-05	1.77E-03
Propane	1.07E-04	3.41E-02	8.97E-02
Propene	5.70E-05	1.31E-04	1.57E-02
i-butane	1.37E-05	8.78E-03	5.09E-03
n-butane	1.35E-05	2.06E-05	2.05E-03
i-pentane	6.43E-06	9.64E-06	7.56E-05
n-pentane	1.17E-05	3.37E-05	1.18E-03
n-hexane	2.01E-06	8.14E-05	6.95E-05

Table 2. Connective Corridor Emissions in kg/km

Chemical	CNG	Diesel	C Gas Plus
Methane	4.34E-01	2.62E+00	2.73E+00
Carbon Dioxide	2.09E+02	7.07E+03	1.55E+02
Ethane	2.14E-02	1.17E-03	8.06E-02
Ethene	5.00E-02	7.89E-03	2.07E-01
Ethyne	2.29E-04	6.74E-04	7.62E-03
Propane	2.15E-03	3.87E-01	1.07E+00
Propene	1.58E-03	1.30E-03	7.24E-02
i-butane	3.10E-04	7.57E-02	5.27E-02
n-butane	2.21E-04	3.26E-04	9.24E-03
i-pentane	8.72E-05	1.32E-04	1.84E-03
n-pentane	2.37E-04	8.24E-04	4.59E-03
n-hexane	4.83E-06	6.91E-04	7.93E-04
benzene	6.61E-04	1.66E-03	4.21E-04

Table 3. South Campus Emissions in kg/km

Chemical	CNG	Diesel	C Gas Plus
Methane	2.07E-01	1.05E+00	5.66E-01
Carbon Dioxide	1.20E+02	2.40E+03	1.13E+02
Ethane	1.54E-02	7.35E-04	3.80E-02
Ethene	3.21E-02	5.88E-03	1.03E-01
Ethyne	1.47E-04	4.11E-04	2.46E-03
Propane	1.41E-03	2.66E-01	5.97E-01
Propene	1.01E-03	8.71E-04	2.42E-02
i-butane	1.97E-04	5.47E-02	2.86E-02
n-butane	1.45E-04	1.95E-04	3.02E-03
i-pentane	5.82E-05	8.29E-05	1.18E-03
n-pentane	1.52E-04	4.99E-04	1.29E-03
n-hexane	4.83E-06	4.81E-04	4.46E-04
benzene	4.09E-04	1.04E-03	2.62E-04

The CNG ISL engine did not produce the most of any chemical. However, it produced the second largest amount of CO_2 per km, following the diesel engine. It emitted 23 kg/km on the East Campus route, 120 kg/km on the South Campus route, and 209 kg/km on the Connective Corridor route.

3.3 Annual emission estimates

The total emissions emitted per year over the three bus routes are included in Tables 4, 5, and 6. These values were obtained by using Eq. 4 and then multiplying the solutions by the distances in each route. Then that value was multiplied by the number of times the route was driven in a year to get the annual estimate for a single bus. The dominant gas was carbon dioxide across the board. The diesel engine emitted the most CO_2 by far with 3.39×10^8 kg/yr on the East Campus route, 7.78×10^8 kg/yr on the Connective Corridor route, and 1.15×10^9 kg/yr on the South Campus route. It emitted so much more over South Campus because more buses drive that course 755 times per week, while they only drive the Connective Corridor route 184 times and the East

Campus route 140 times. The diesel engine also emitted the most methane, n-hexane, and benzene over all the routes. For instance, over the Connective Corridor route it produced 2.62 kg CO_2/yr, 18.3 kg hexane/yr, and 70.8 kg benzene/yr (Table 5). It produced the most i-butane over the South Campus (216 kg/yr) and Connective Corridor (1,690 kg/yr) routes. For all other chemicals, the C Gas Plus engine yielded the most.

Table 4. Kilograms of emissions per year from East Campus route

Chemical	CNG	Diesel	C Gas Plus
Methane	1.34E+04	1.12E+05	2.53E+04
Carbon Dioxide	3.05E+06	3.39E+08	3.05E+06
Ethane	7.58E+01	1.31E+01	8.21E+02
Ethene	1.14E+02	5.47E+01	2.03E+03
Ethyne	8.91E-01	4.82E+00	5.70E+01
Propane	6.25E+00	1.32E+03	1.15E+04
Propene	4.25E+00	7.54E+00	5.74E+02
i-butane	1.26E+00	2.16E+02	5.33E+02
n-butane	8.50E-01	2.86E+00	7.08E+01
i-pentane	3.31E-01	9.43E-01	4.29E+00
n-pentane	9.81E-01	5.28E+00	3.96E+01

Table 5. Kilograms of emissions per year from Connective Corridor route

Chemical	CNG	Diesel	C Gas Plus
Methane	3.29E+04	2.62E+05	1.10E+05
Carbon Dioxide	8.38E+06	7.78E+08	7.93E+06
Ethane	4.96E+02	4.15E+01	2.66E+03
Ethene	6.61E+02	2.75E+02	6.56E+03
Ethyne	4.04E+00	1.56E+01	2.48E+02
Propane	3.39E+01	7.98E+03	3.39E+04
Propene	2.26E+01	3.27E+01	2.35E+03
i-butane	5.24E+00	1.69E+03	1.64E+03
n-butane	4.00E+00	8.61E+00	2.98E+02
i-pentane	1.64E+00	3.24E+00	2.61E+01
n-pentane	4.15E+00	1.72E+01	1.65E+02
n-hexane	2.60E-01	1.83E+01	2.03E+01
benzene	8.29E+00	7.08E+01	1.48E+01

Table 6. Kilograms of emissions per year from South Campus route

Chemical	**CNG**	**Diesel**	**C Gas Plus**
Methane	5.08E+04	3.92E+05	1.91E+05
Carbon Dioxide	1.41E+07	1.15E+09	1.28E+07
Ethane	1.00E+03	7.26E+01	4.67E+03
Ethene	1.52E+03	5.09E+02	1.16E+04
Ethyne	8.40E+00	2.94E+01	4.46E+02
Propane	7.36E+01	1.64E+04	5.96E+04
Propene	5.03E+01	6.27E+01	4.21E+03
i-butane	1.09E+01	3.47E+03	2.91E+03
n-butane	8.29E+00	1.57E+01	5.35E+02
i-pentane	3.37E+00	6.09E+00	5.87E+01
n-pentane	8.59E+00	3.32E+01	2.90E+02
n-hexane	4.83E-01	3.54E+01	3.78E+01
benzene	1.89E+01	1.20E+02	2.59E+01

The total kilograms of each chemical for each bus route was summed to give an estimate of the total emissions each type of engine would produce per year (Table 7). Diesel produced by far the most, with a value of 2.27×10^9 kg/yr.

Table 7. Total kilograms of emissions per year over all three routes

Chemical	**CNG**	**Diesel**	**C Gas Plus**
Carbon Dioxide	2.55E+07	2.27E+09	2.38E+07
Methane	9.71E+04	7.66E+05	3.26E+05
VOCs	4.15E+03	3.26E+04	1.48E+05
Total	2.56E+07	2.27E+09	2.43E+07

4. DISCUSSION AND CONCLUSION

According to the findings of this project, over the course of a year the CNG ISL engine produces 4,150 kg of VOCs per year, the diesel ISL produces 32,600 kg/yr, and the C Gas Plus produces 148,000 kg/yr (Table 7). Added together these buses produce 184,750 kg of emissions per year. To put these values in perspective, we compared them with the county level annual emission. A total amount of 6,381,139.29 kg VOCs from mobile emissions are produced annually in Onondaga County alone (EPA State and County Emission Summaries, 2013). This number includes those from cars, trucks, and other vehicles, not just buses. 184,750 kg/yr is 2.9% of the VOCs created in Onondaga yearly. The CNG ISL engine produced the smallest amount so it would be the best choice of the three engine types if a bus company was looking to reduce their VOC production to meet EPA emission standards.

The CNG ISL engine in this study produced 2.55×10^7 kg of CO_2 per year and 9.71×10^4 kg of methane, the diesel created 2.27×10^9 kg CO_2 and 7.66×10^5 kg methane, and the C Gas Plus created 2.38×10^7 kg CO_2/yr and 3.26×10^5 kg of methane (Table 7) . That gives a total of 2.32×10^9 kg CO_2/yr and 1.19×10^6 kg CH_4/yr. In 2011, the fossil fuel combustion due to transportation in the USA produced 1.75×10^{12} kg of CO_2 and 1.7×10^9 kg of CH_4 (Inventory of U.S. Greenhouse Gas Emissions and Sinks, 2013). The values in this study are 0.06% and 0.1% of the EPA totals, respectively.

In most cases, the C Gas Plus engine had the largest amount of emissions per kilometer distance. For instance, it emitted 1.09×10^{-2} kg/km of ethane over the East Campus route (Table 1). This value is higher than either the diesel (1.40×10^{-4} kg/km) or new compressed natural gas engine (2.59×10^{-3} kg/km). As stated previously, this is probably because it was an older engine. As time has moved on, technology has advanced and become better. It should be noted that the C Gas Plus engine is no longer sold in North America because of new emission regulations that went into effect in 2010 (Cummins Westport, 2013). This means that the only buses with C Gas Plus engines on the road are old and will slowly be phased out as they age and are replaced.

However, the diesel engine produced the most CO_2 and CH_4 in all cases, as well as producing the most emissions overall with a value of 2.27×10^9 kg/yr (Table 7).

Apparently a diesel engine would be a poor choice for that purpose based on these results.

All the engines produced trace compounds, such as n-hexane and benzene. Only small quantities were present when observing a single bus route, but were found to add up to substantial amounts when looked at over a year. For instance, the CNG ISL engine produced 2.59×10^{-3} kg/ km of ethane over the course of the East Campus bus route (Table 1). However, it was found to create 75.8 kg/ year of ethane over that same route (Table 4). If every bus currently running produces a similar amount of ethane and other trace chemicals per year, harm could come to human health. Since the CNG ISL engine produced the less than the other two, it can be concluded that it is an overall cleaner engine and a better one for urban environments when considering VOCs.

If CENTRO were to pick one engine and place it in all their buses, the annual emissions in Table 7 would be multiplied by 250 because that is how many buses they have in their fleet. The CNG ISL fleet would produce 6.40×10^{9} kg of emissions/year, the diesel ISL would produce 5.67×10^{11} kg/yr, and the C Gas Plus would produce 6.08×10^{9} kg/yr. The diesel would be the worst pick, producing by far the most. Interestingly, a C Gas Plus fleet would produce less than the newer CNG ISL, even though the C Gas Plus engine doesn't meet emissions standards in the US anymore. Since the C Gas Plus engine can no longer be bought in the states, the CNG ISL engine would be the best pick for CENTRO in terms of total released carbon emissions.

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