2007

Reviewing The Effects Of Alternative Fuels, Average Speed And Idling Time On Emissions From Orange County School Bus Fleet

Ali Bayat
University of Central Florida

REVIEWING THE EFFECTS OF ALTERNATIVE FUELS, AVERAGE SPEED AND IDLING TIME ON EMISSIONS FROM ORANGE COUNTY SCHOOL BUS FLEET

by

ALI BAYAT
B.S. Shiraz University, 1997

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science in Environmental Engineering
in the Department of Civil and Environmental Engineering
in the College of Engineering and Computer Science
at the University of Central Florida
Orlando, Florida

Summer Term
2007

Major Professor: C. David Cooper

ABSTRACT

Orange County, FL has been experiencing ozone concentrations in the past several years which in some cases exceeded the national and state standards. The high concentration of ground level ozone can cause a variety of health problems including chest pain, coughing, throat irritation, and congestion or it can worsen bronchitis, emphysema, and asthma. Other effects include reduction of agricultural crop and commercial forest yields, lower growth and survivability of tree seedlings, and higher susceptibility of plant to diseases, pests and other stresses such as harsh weather. The ozone generation rate is directly related to the ambient concentration of nitrogen oxides (NO_X) and volatile organic carbons (VOC_S). These two air pollutants, mostly produced from combustion of fossil fuels, react with oxygen to form ozone in presence of sunlight. In urban areas, ozone generation rate can be decreased by reduction of ozone precursors, NO_X and VOC_S.

The Air Quality Research group of University of Central Florida proposed that one of the emission reduction strategies be for school bus fleets in the area. School buses were chosen because of their important impact on ambient air quality in general and on student health in particular. There were about 473,000 school buses in the 2004-05 school year nationwide which traveled for a total mileage of about 4 billion miles in that year. Orange County Public School (OCPS) system owns about 1400 school buses which traveled about 17 million miles in 2005-06 school year, serving 71000 students.

The use of diesel fuels, Ultra Low Sulfur Diesel (ULSD, diesel fuel containing 15 ppm sulfur) and Biodiesel (B20, a mixture of 20% biodiesel and 80% ULSD), were

chosen as the first proposed action to be studied. Also the effects of transportation parameters, average speed and idling time on fleet emissions were selected to be reviewed. This report reviews the fuel option and transportation parameters, effects on school bus fleet emissions and it does a comparison analysis in order to show advantages and disadvantages of each fuel. The Conventional Diesel (CD) and ULSD emissions were estimated by using MOBILE6.2 model, and effects of B20 on emissions were derived from published studies. It was found that using B20 or ULSD can reduce the emissions significantly for the most of major pollutants but in the case of NOx, the percentage changes is not certain yet and more investigation is required. Emissions vary for different average speeds and 27 miles per hour can be defined as the optimum average speed. Also reduction of idling time is an excellent control option for decreasing emissions, and should be considered for OCPS.

ACKNOWLEDGMENTS

I have been greatly fortunate to have an excellent advisor, Dr. C. David Cooper, to educate me and guide my research over the past two years. This research would not be complete without recognizing his support. I am always grateful for his support, “Thank you”. Also I would like to thank the Metroplan Orlando for their financial support and the Orange County Public School Bus Fleet Management, Mr. Arby Creach and Mr. Bill Wen for their assistance. Finally, I would like to thank my family and friends who provided essential support and encouragement during my time in UCF.

This paper was accepted for presentation at Air &Waste Management Association 100th Annual Conference, Pittsburgh, PA (2007) and also at Annual Transportation/Land Use Planning and Air Quality Conference, Orlando, FL (2007).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 : INTRODUCTION

Background Information

Air quality has become one of the greatest concerns for the stakeholders of large modern communities. As energy consumption and population grow, the emissions of air pollutants increase which is associated with a number of health and environmental effects. Ground level ozone is one of the federally regulated pollutants which is generated during photochemical reactions in the atmosphere. It has been proved that the high concentration of nitrogen oxides (NO_X) and volatile organic compounds (VOC_S) in ambient air of large cities can accelerate the ozone generation rate dramatically. To control the situation reduction of these chemical compounds is one of the priorities which can be done trough different strategies. NO_X and VOC_S are mainly generated during combustion of fossil fuels from transportation activities and electricity production.

In recent years, the Orlando area has been facing high concentrations of ground level ozone which is mainly due to growth of energy consumption and transportation activities. Orlando is one of the fastest growing metropolitan nationally and is projected to be home for thousands of new residents in the next decades. It is widely known that in the Orlando area, mobile sources are the largest producer of NO_X and VOC_S. This fact should be considered for any air quality improvement plan focused on reduction of ozone concentration.

Research Objectives and Scope of Work

The objectives of this study were to review the effects of recently introduced fuels, biodiesel and ultra low sulfur diesel, and transportation parameters, speed and idling time, on emissions from heavy duty vehicles, specifically on school buses. The emissions saving by particular fuel switching or idling time and average speed optimizing were quantified and compared.

Thesis Organization

This thesis is organized in there chapters. Chapter 1 presents background information and the scope of the research. Chapter 2 presents a review of effects of alternative fuels (biodiesel, ultra low sulfur diesel and conventional diesel) and transportation parameters (speed and idling) on emissions from Orange County Public School Bus Fleet and Chapter 3 reviews the costs and benefits of fuel switching or idling time and average speed optimizing.

CHAPTER 2 : THE EFFECTS OF ALTERNATIVE FUELS AND TRANSPORTATION PARAMETERS ON EMISSIONS FROM ORANGE COUNTY PUBLIC SCHOOL BUS FLEET*

Introduction

The high concentration of ground level ozone can cause a variety of human health problems including chest pain, coughing, throat irritation, and congestion or it can worsen bronchitis, emphysema, and asthma. Other effects include reduction of agricultural crop and commercial forest yields, lower growth and survivability of tree seedlings, and higher susceptibility of plant to diseases, pests and other stresses such as harsh weather[1].The U.S Environmental Protection Agency (EPA) has set National Ambient Air Quality Standards (NAAQS) for ground level ozone concentration. According to these standards, average ozone concentration over an eight-hour period can not be higher than 80 parts per billion (80 ppb). If, in any area, the average of the annual 4th highest ozone concentration for three years in row is equal to or higher than 80 ppb, it is considered a violation of standards and can cause the county to be designated as a nonattainment area[2]. Orange County, FL has experienced ozone concentrations in the past several years which in some cases exceeded the national and state standards (Figure 2-1)[2]. One important consequence of high concentration of ozone, in addition to the conventional ozone effects, can be decreasing the area's attractiveness. As a result the number of tourists and visitors will decrease which can bring some harsh social and economic impacts.

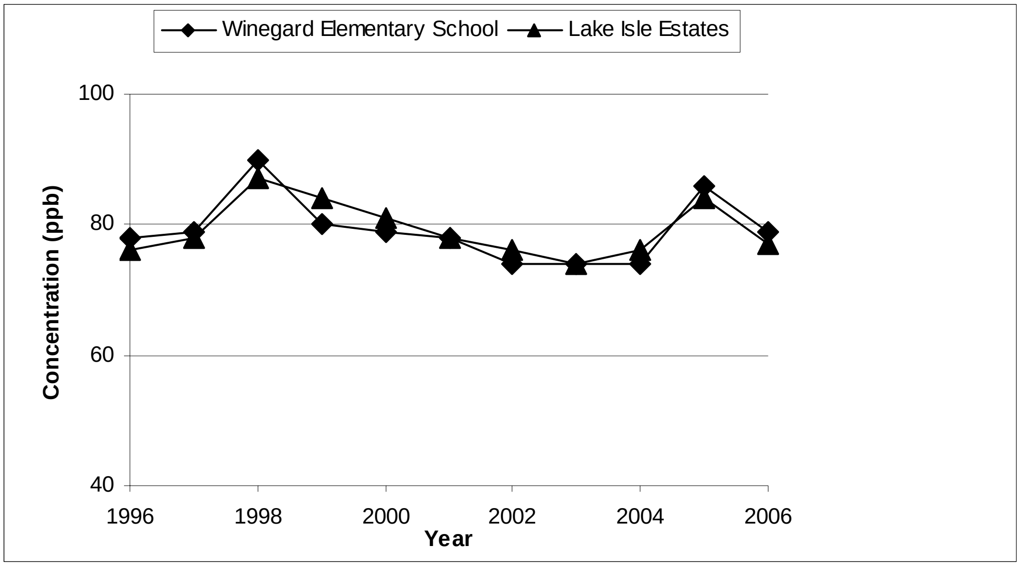

Figure 2-1: Annual 4th maximum ground level ozone concentration from Orange County ozone monitoring stations

Ozone generation rate is directly related to the ambient concentration of nitrogen oxides (NO_X) and volatile organic carbons (VOC_S). These two air pollutants, mostly produced from combustion of fossil fuels, react with oxygen, to form ozone in presence of sunlight. Previous studies have indicated that mobile sources are the largest source of emissions in the area, releasing tons of NO_X and VOC_S into the atmosphere annually[3]. This unpleasant situation can be exacerbated by the rapid rate of population growth, which boosts the two largest emissions sources in the area, transportation activities and electricity consumption.

Actions must be taken in order to continue meeting the current regulations and to keep the area's attainment status. Also, policies must be implemented to fully comply with future more stringent standards. Mainly focusing on the reduction of mobile sources emissions, the Air Quality Research group of the University of Central Florida proposed that one of the emissions reduction strategies be for school bus fleets in the area. School buses were chosen because of their important impact on ambient air quality in general and on student health in particular. Their emissions can be decreased by using cleaner fuels, installing aftertreatment equipment, replacing the old buses with advanced technology engine buses, improving driving skills and decreasing the idling time. One or a combination of some or all of these options can be employed simultaneously to achieve desired emissions reduction. The use of diesel fuels Ultra Low Sulfur Diesel (ULSD, diesel fuel containing 15 ppm sulfur) and Biodiesel (B20, a mixture of 20% biodiesel and 80% ULSD) were chosen as the first proposed action to be studied. This paper reviews the effects of ULSD, B20 and Conventional Diesel (CD, diesel fuel containing 350 ppm sulfur) on school bus fleet emissions and it does a comparison analysis in order to show advantages and disadvantages of each fuel. The CD and ULSD emissions were estimated by using MOBILE6.2 model and effects of B20 on emissions were derived from previous published studies.

School Buses

With a significant economical and environmental role, school bus fleets are usually one of the largest diesel engine fleets in urban areas. They provide a safe and reliable daily transportation service to millions of students; however they generate tons of emissions while doing so. There were about 473,000 school buses in 2004-05 school year nationwide which traveled for a total mileage of about 4 billion miles in that period[4]. On average, students spend an hour and a half each weekday in school bus during the school year[5]. Buses can be self-polluting, exposing children on-board to elevated levels of diesel-related air pollutants and toxics. There are a number of studies showing that diesel air pollutants aggravate asthma, increase the number of respiratory infections and reduce lung function[6].

School buses are organized into four major groups based on their size and carried passengers. Types A&B are smaller with the engine in the front and usually designed for about 10-20 passengers. Type C&D are larger and can carry about 45-60 passengers. A previous study has indicated that Type A/B, C and D buses represent 20%, 57% and 23 % of the population[7].

Figure 2-2: Type A school bus[8]

Figure 2-3: Type B school bus

Figure 2-4: Type C school bus

Figure 2-5: Type D school bus

Orange County Public Schools (OCPS) Fleet Characteristics

The OCPS owns over 1400 buses and usually about 1100 of them are in service. They traveled about 17 million miles and transported over 71,000 students in the school year of 2005-06[9]. Most of the buses are equipped with International diesel engine, and the dominant engine type in the fleet is the International 466 series with horsepower rating about 210 to 300.

Factors that Effect Heavy Duty Vehicles Emissions

Clark and coworkers (2002)[10] reported vehicle class and weight, driving cycle, vehicle vocation, fuel type, engine exhaust treatment, vehicle age and the terrain traveled as the major effective factors on NO_X and particulate matters (PM) emissions. For the purpose of this paper only the effects of fuel and transportation parameters were reviewed.

Fuel Type Effects on Emissions

Fuels depend on their physical and chemical characteristics; generating different amount and type of emissions. Diesel fuel is defined as a complex combination of hydrocarbons produced by the distillation of crude oil. It is mainly composed of saturated and aromatic hydrocarbons associated with a tiny amount of sulfur and very little oxygen. Containing very low sulfur, ULSD produces much lower sulfur oxides (SO_X)

compared to CD fuel. As the result, the concentration of acidic gases in the exhaust stream drops, reducing PM and helping the use of aftertreatment equipment. Biodiesel is a renewable, biodegradable and non-toxic diesel fuel which can be made by chemically combining any natural oil or fat with an alcohol such as methanol or ethanol in the presence of strong base. It is highly oxygenated which helps combustion to be more complete, resulting in relatively lower level of unburned hydrocarbons (HC_S), carbon monoxide (CO) and PM emissions. PM can also be reduced by the absence of aromatics and sulfur in biodiesel[11].

Methodology

In order to estimate the effects of different fuels, speed changes and idling time on emissions of CO, HC_S, NO_X, PM and SO_X from the OCPS bus fleet a three steps planned was used. In the first part three scenarios based on the fuel type differences were designed, holding everything else constant, and emission factors for the fleet real average speed were estimated. In the second part the annual emissions from OCPS for different fuels were assessed based on the previously estimated emission factors. Finally the effects of average speed changes and reduction of idling time on annual emissions were evaluated in the third section.

The first scenario was to estimate emissions from the buses, running on CD. The results of the first scenario were defined as the emissions baselines. The second scenario was designed to evaluate bus emissions when using ULSD. Emission estimation for use of biodiesel by school buses was intended to be the third scenario. For conducting the first and second scenarios, the MOBILE6.2 model was employed and for the third one, estimated emissions changes were obtained from the literature review. It should be mentioned that MOBILE6.2 is not designed to recognize biodiesel as a suitable fuel but the new EPA mobile source emission evaluation model "Motor Vehicle Emission Simulator" or MOVES will be able to calculate emissions from biodiesel.

MOBILE6.2

As the latest version of EPA MOBILE series, MOBILE6.2 evaluates the emissions for a range of vehicles, from light duty gasoline engines to heavy duty diesel engines. Its method for evaluating heavy duty diesel vehicles emissions is based on adopting the results of certified emission tests and adjusting them for the effects of speed, altitude and deterioration[12]. The certified emission test refers to the EPA federal test procedure which is done on an engine dynamometer for specific driving cycle. Because these emissions are usually reported in grams of emissions per unit of energy (brake horsepower-hour), the model uses the following equations to express emissions as grams per vehicle-mile traveled[12].

$$Conversion\ \ Factor\ \left({}^{bhp-h}\!/\!_{mi} \right) = \frac{Fuel\,Density\ \left({}^{lb}\!/\!_{gal} \right)}{BSFC\left({}^{lb}\!/\!_{bhp-h} \right) \times \ Fuel\,Economy\ \left({}^{mi}\!/\!_{gal} \right)} \tag{1}$$

$$Emissions\left(\frac{g}{vehicle-mi}\right) = Emissions\left(\frac{g}{bhp-h}\right) \times Conversion\ \ Factor\left(\frac{bhp-h}{mi}\right) \qquad (2)$$

Where BSFC refers to the brake specific fuel consumption and is calculated through a curve fit equation (equation # 3). EPA derived this equation from a number of reported school bus BSFCs for different model years[12].

$$Y = -0.5311 \times \ln(x) + 2.8123 \qquad (3)$$

Where,

Y is BSFC (lb/bhp-h) and,

X is the last two digits of the model year (X= MY – 1900). The range for the model year was 1988-1995.

Table 2-1: EPA emission standards for heavy duty diesel engines (g/bhp-hr)

Model Year	HC	NO_x	CO	PM
1974-78	-	-	40	-
1979-83	1.5	-	25	-
1984-87	1.3	10.7	15.5	-
1988-89	1.3	10.7	15.5	0.6
1990	1.3	6	15.5	0.6
1991-93	1.3	5	15.5	0.25
1994-97	1.3	5	15.5	0.1
1998-2003	1.3	4	15.5	0.1
2004-06	0.5	2*	15.5	0.1
2007+	0.14	0.2	15.5	0.01

* Or (NMHC + NO_x) should not exceed 2.4 g/bhp-h
*Source: www.dieselnet.com/standards, (June 12, 2007)

MOBILE6.2 Input File and Sensitivity Analysis

Different data sets were needed to overwrite the default values of model input files for accuracy purposes. Min/Max temperature, facility type, average speed, altitude, vehicle age and fuel economy input files were provided into the model. Sensitivity analyses for the major input variables were done and it was noted that vehicle speed has a considerable impact on emissions. It was also observed that the model did not show significant changes for temperature variation. Figure 2-6 shows that not all emissions behave the same with speed variation (the model does not show any effect of speed changes on PM and SO_X emissions therefore they are not shown). For emissions inventory purposes, an average speed should be evaluated which is explained in the following section.

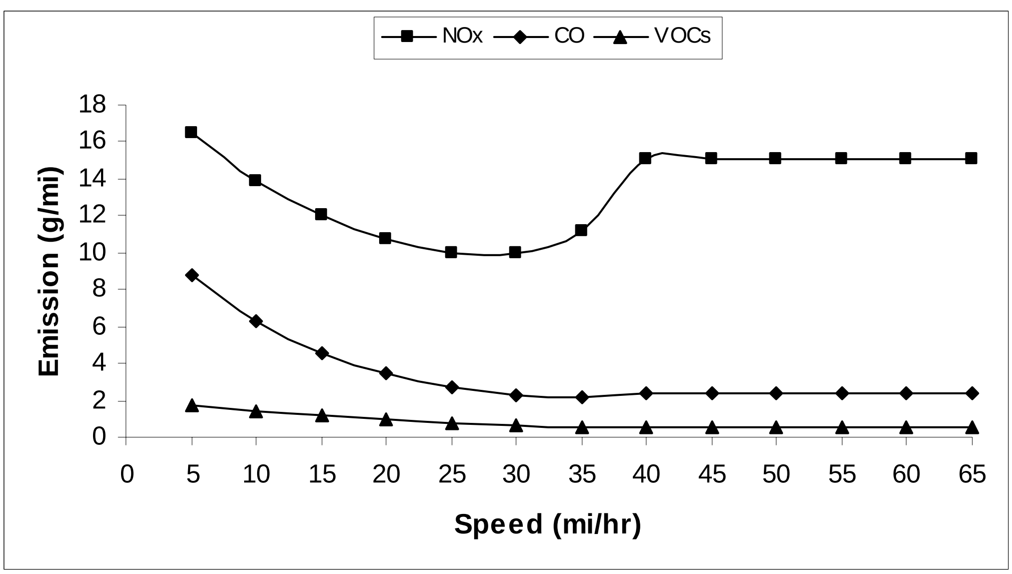

Figure 2-6: Speed sensitivity analysis for school buses, road type arterial

Average Speed Evaluation

The OCPS school bus average speed was determined by using the OCPS Automatic Vehicle Location (AVL) system. The AVL system is a set of equipment using satellite positioning for determining the geographic location of a vehicle and transmitting this information to a point where it can be used[13]. It provides real time location, average speed, maximum speed, total trip time and total idling time for each bus-trip. The majority of the OCPS buses are equipped with this system which allowed us to get a more realistic sense regarding the fleet average speed. Over 2700 data points reported by AVL system were analyzed statistically and the fleet average speed was calculated to be 25.2 miles per hour with a standard deviation equal to 5.4 (Figure 2-7).

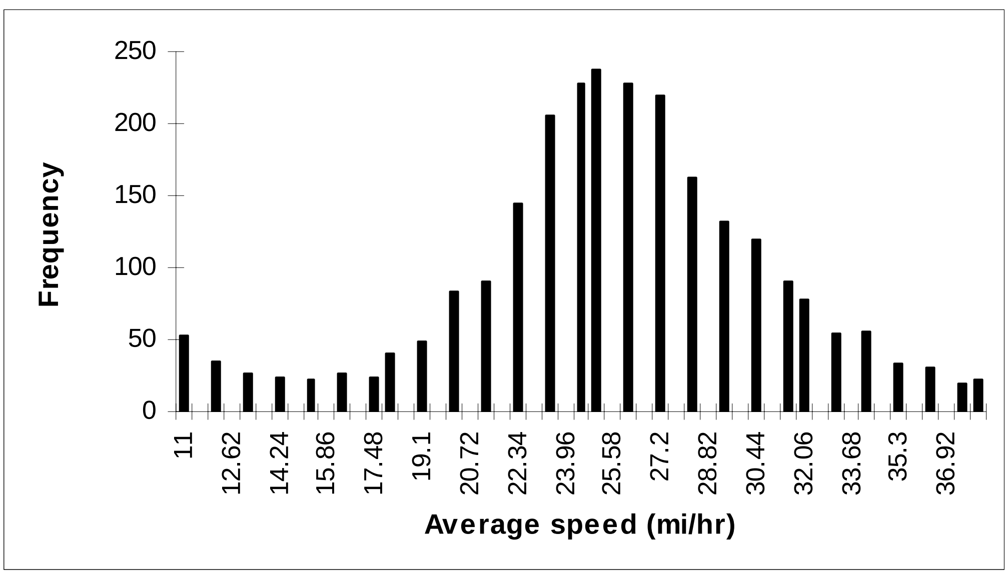

Figure 2-7: The distribution of average speed data points

Biodiesel Emissions

In the past several years a number of studies have been conducted for measuring the biodiesel emissions from heavy duty vehicles. Engine and chassis dynamometers have been commonly used by researchers for emission testing activities in laboratory. Another method which has gotten popular recently, is measuring the real world emissions. It is done by using a portable emission measurement unit which can be installed onboard for measuring emissions when the vehicle travels. Based on which approach was used, preceding studies can be classified in two major groups, laboratory and real world emission testing.

Laboratory Emission Testing Studies

EPA (2002)[14] reported their findings from engine dynamometer testing on a variety of engines, mostly from 1997 or earlier model years. Figure 2-11 is adopted from EPA work on biodiesel which was criticized by another research group for not using a proper engine composition to represent the actual existing diesel fleet existing in U.S[15]. McCormick and coworkers (2006)[15], with the National Renewable Energy Laboratory (NREL), used a chassis dynamometer and tested a variety of diesel vehicles from different classes against explicit driving cycles. They also tested two school buses which were equipped with exhaust aftertreatment devices. Holden and coworkers (2006)[16] also tested a number of on- and off-road diesel engine vehicles in their research which was conducted for Naval Facilities Engineering Command (NAVFAC), Department of Defense. The summarized results from these studies can be found in Table 2.

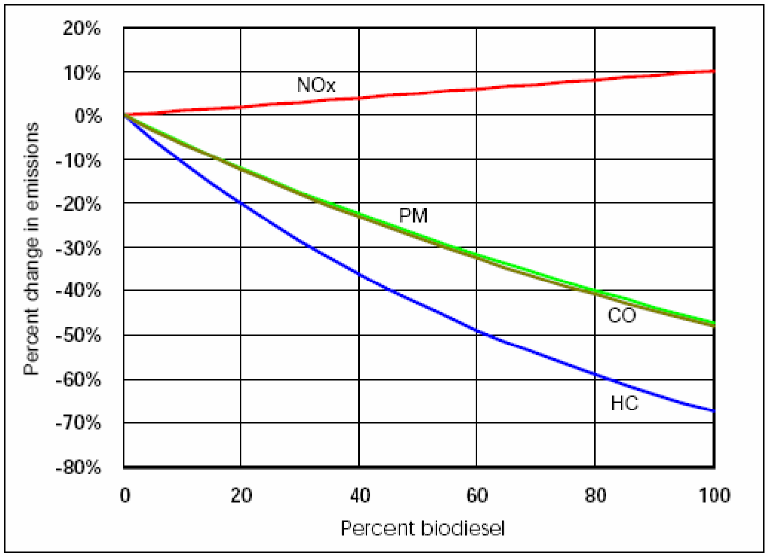

Figure 2-8: EPA reported emissions percentage changes for biodiesel relative to conventional petroleum diesel

Table 2-2: Reported emission percent change for B20 from comprehensive studies

	Test procedure	Emission percent change			
		PM	HC	CO	NOx
NREL (2006)	Chassis dynamometer	-16 to -17	-12	-16 to -17	+0.6
NAVFAC (2006)*	Chassis dynamometer	-8.2	-7.6	-4.1	+1.1
EPA (2002)	Engine dynamometer	-10.1	-21.1	-11	+2

***** Based on emissions per gallon of fuel used

Real World Emission Testing Studies

Frey and Kim (2005)[17] used a portable emission measurement system (PEMS) for testing biodiesel emissions from dump trucks in North Carolina. They reported lower NO, CO, PM and HC emissions for B20 compared with CD. Farzaneh and coworkers

(2006)[18] with the Texas Transportation Institute also used PEMS in their studies of the effect of B20 on NOx emission. They tested biodiesel emissions from five school buses, all equipped with 466 International diesel engines, for both rural and urban driving cycle conditions. School buses were selected from specific model years to simulate an actual school bus fleet in the area of study. They found that B20 does not have a significant effect on NOx emissions from tested school buses. Hearne and coworkers (2004)[19] at Rowan University developed a driving cycle for school buses and three school buses were tested for CD, ULSD and B20. They reported ULSD, compared with CD fuel, has little or no effect on HC, NO_X and CO_2 emissions, however reduced CO emissions by 32%.They also reported B20 has almost the same effect on emissions like ULSD, except for HC which showed a 30% reduction.

For the purposes of this paper, the NREL findings about biodiesel emission changes were adopted for evaluation of fleet emissions.

The Modeling Results

Emission Factors for Different Fuels

The results of modeling can be found in Figures 2-9, 2-10 and 2-11. CD and ULSD generate equal amounts of CO, NO_X and HC_S emissions as shown in Figure 2-9. Use of ULSD reduces the exhaust PM_{10} and SO_2 emissions, due to its lower sulfur, which are demonstrated in Figures 2-10 and 2-11 relatively.

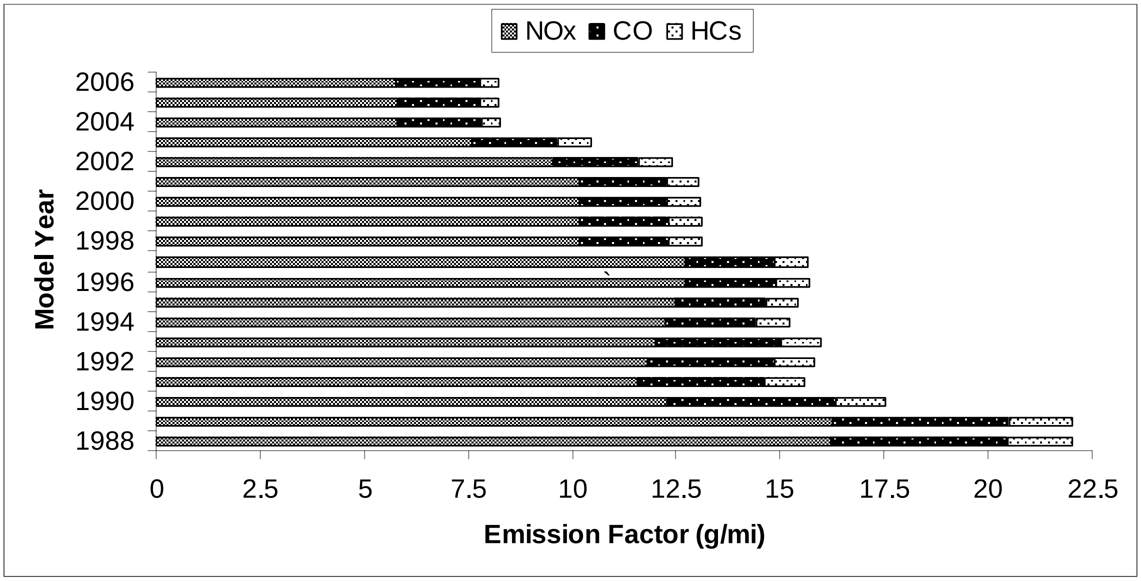

Figure 2-9: The effects of CD and ULSD on NO_X, CO, HC_S emissions (for both CD and ULSD, model has shown the same result)

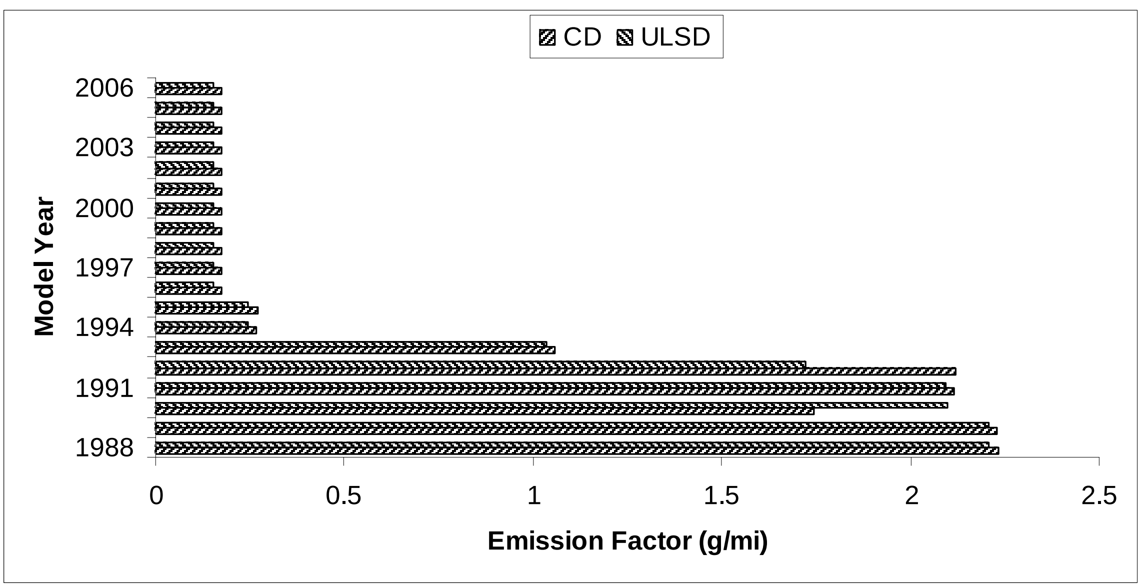

Figure 2-10: The effects of CD and ULSD on PM_{10} emissions

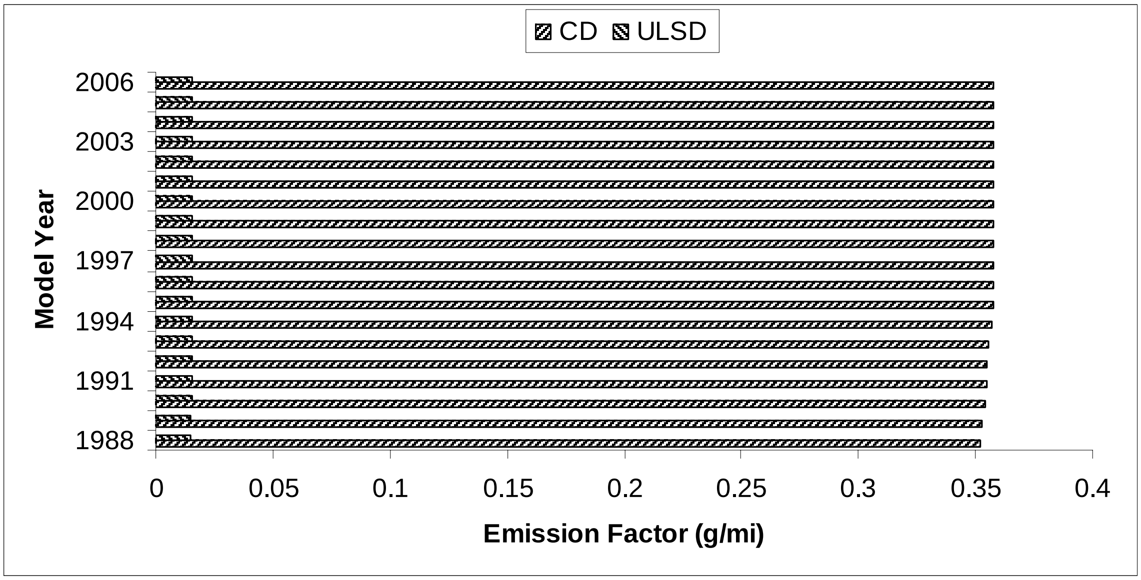

Figure 2-11: The effects of CD and ULSD on SO_2 emissions

Fleet Annual Emissions

The fleet annual emission was estimated based on annual traveled miles. The fleet average age was also estimated to be 8 years[20] which is equally distributed over a range of 0 to 16 years.

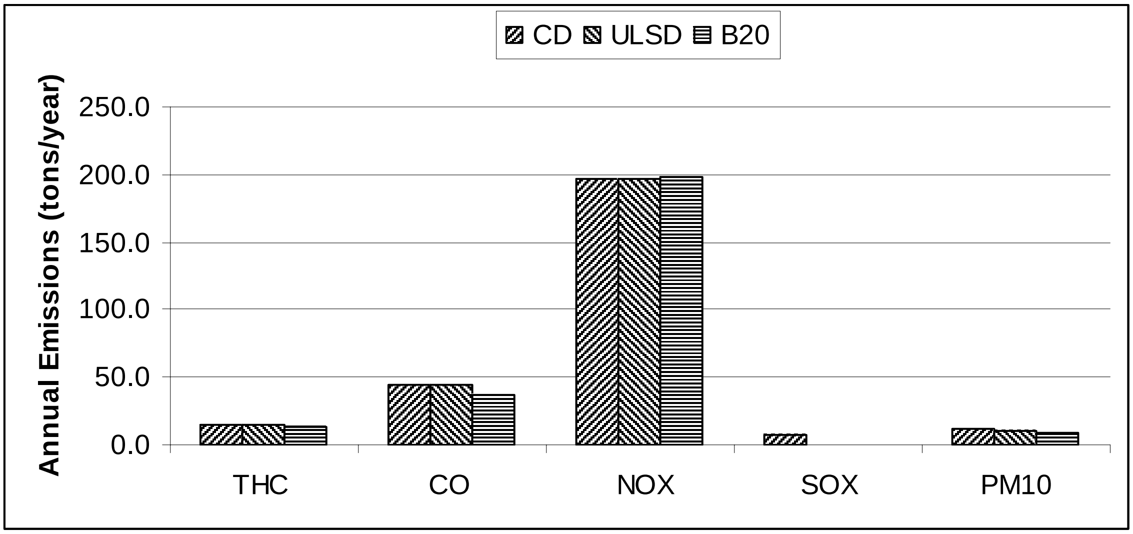

Figure 2-12: The annual emissions from OCPS fleet for different fuels

Table 2-3: The annual emissions from OCPS fleet for different fuels

Fuel Type	Annual Emissions (tons/year)				
	THC	CO	NO_X	SO_X	PM_{10}
CD	14.6	44.9	197.5	6.7	11.3
ULSD	14.6	44.9	197.5	0.3	10.8
B20	12.8	37.5	198.6	0.2	9

Effects of Speed and Idling Time on Annual Emissions

As it is shown previously, increasing speed reduces the emissions per mile traveled for most of the major pollutants. The modeling showed there is an optimum speed which produces the least amount of NO_X. Figure 2-6 illustrates that the speed of 25 to 30 miles per hour release the minimum NO_X. Over or under speeding (<20 or >40 mi/hr) causes the increase of NO_X. It should be mentioned again that MOBILE6.2 does not take account for the effect of speed changes on PM or SO_X.

Reduction of idling time is another important approach that reduces the fleet emissions significantly. The amount of emission saving is depended on the amount of idling time reduction. An emission saving estimation analysis for different idling time saving was conducted. Figures 2-13, 2-14 and 2-15 show the amount of saved emissions for three different idling time reduction. These emission saving estimates were calculated based on having 200 school days per year.

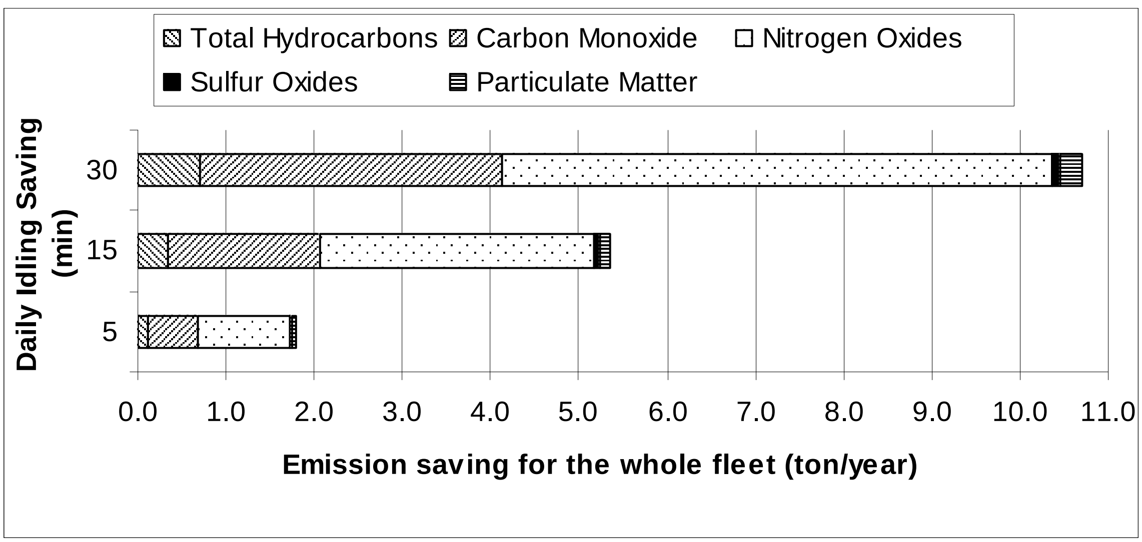

Figure 2-13: The annual emission saving resulted from reduction of school bus fleet idling time for conventional fuel

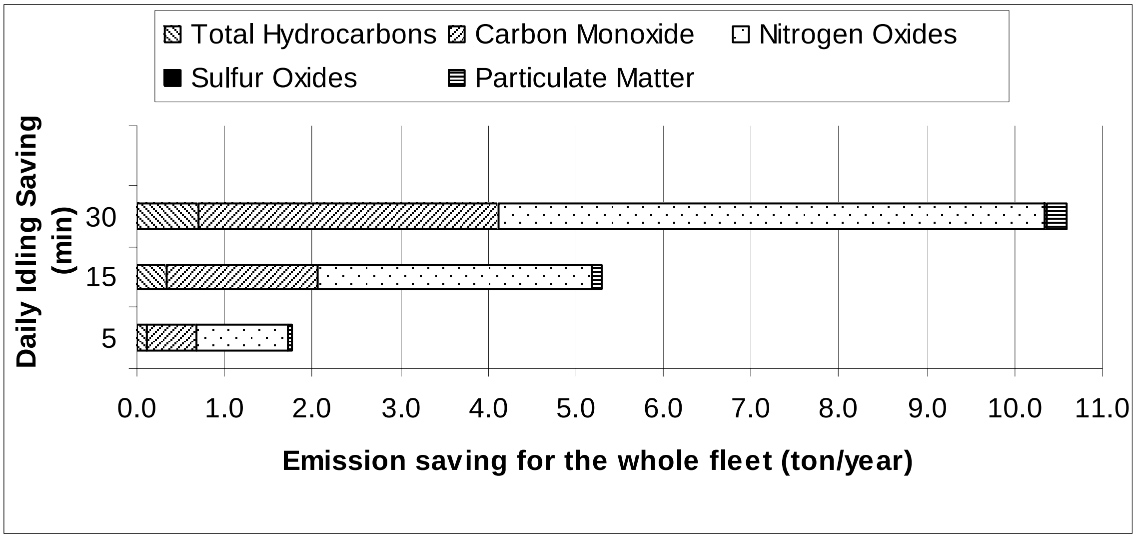

Figure 2-14: The annual emission saving resulted from reduction of school bus fleet idling time for ultra low sulfur diesel fuel

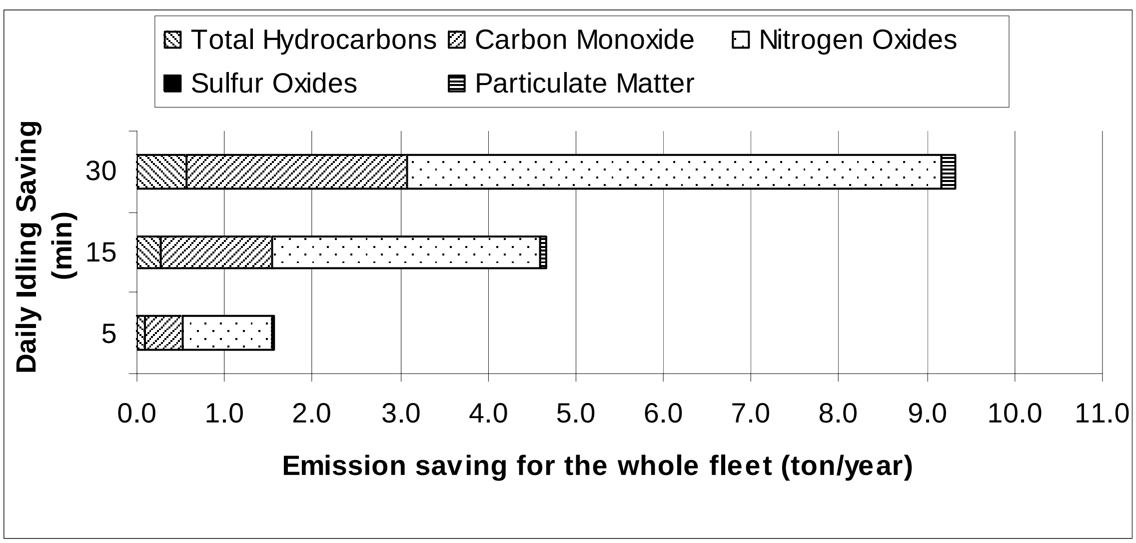

Figure 2-15: The annual emission saving resulted from reduction of school bus fleet idling time for B20

Conclusions & Recommendations

The use of ultra low sulfur diesel fuel can affect the school bus emissions as follows:

- PM_{10} can be reduced by about 10-12% for school bus 1994 model year or newer and about 0.1-2 % for 1993 model year or older (but not older than 1988).
- SO_2 will be decreased by about 95% for all the model years (in range of 1988-2006).

The biodiesel impact on bus emission can be summarized as following:

- There is a good agreement among researchers that biodiesel reduces all emissions, except NO_X, which needs to be investigated more thoroughly.
- Biodiesel should be tested on more advanced and newer engines in order to see whether its emission reductions are still significant.
- The effect of biodiesel on particles of different sizes should be addressed in future studies.

The transportation parameters impact on bus emission can be summarized as following:

- Operating the school buses at the optimum speed, 25-30 (mi/hr), considering the behavior differences of different emissions related to the speed changes, decrease the amount of generated emissions significantly
- Reduction of school buses idling time results in saving large amount of emissions annually
- There is no direct cost for saving emissions by optimizing the transportation parameters

References

1- "Health and Environment." Ground-level Ozone. U.S Environmental Protection Agency. 26 Feb 2007 < http://www.epa.gov/air/ozonepollution/health.html>

2- Attainment Status for 2006." Air. Florida Department of Environmental Protection. 26 Feb 2007 <http://www.dep.state.fl.us/air/flaqs/AttainReport.asp>.

3- ARBRANDT, M, "Emission Inventory for Central Florida." Master Thesis. Orlando: University of Central Florida, 2003.

4- "Statistics." School Bus Fleet Magazine 2006: 38.

5- Clean School Bus USA. Environmental Protection Agency. 26 Feb 2007 <http://www.epa.gov/cleanschoolbus/>.

6- Perrotta, K, "School Buses, Air Pollution & Children's Health." Ontario Public Health Association, 2005.

7- Laughlin, M. United States. Department of Energy. Analysis of U.S. School Bus Populations and Alternative Fuel. Clean Cities, 2004.

8- School bus photos were adapted from: Laughlin, M. Department of Energy. Analysis of U.S. School Bus Populations and Alternative Fuel. Clean Cities, 2004.

9- Wheeler, R. "Information about the School Buses." E-mail to Bayat,A.09/26/2006.

10- Clark, N. "Factors Affecting Heavy Duty Diesel Vehicle Emissions." Air & Waste Management Association 52(2002): 84-94.

11- Wang, W. "Emissions from Nine Heavy Trucks Fueled by Diesel and Biodiesel Blend without Engine Modification." ENVIRONMENTAL SCIENCE & TECHNOLOGY 34(2000): 933-939.

12- "MOBILE6 Technical Documentation Index." Modeling and Inventories. Environmental Protection Agency. 26 Feb 2007 <http://www.epa.gov/otaq/models/mobile6/m6tech.htm>.

13- "Automatic vehicle location." Wikipedia. 26 Feb 2007 <http://en.wikipedia.org/wiki/Automatic_vehicle_location>.

14- United States. Environmental Protection Agency. A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions. 2002.

15- McCormick, R.L. United States. National Renewable Energy Laboratory. Effects of Biodiesel Blends on Vehicle Emissions. NREL, 2006.

16- Holden, B. United States. Department of Defense. Effect of Biodiesel on Diesel Engine Nitrogen Oxides and Other Regulated Emissions. 2006.

17- Frey, H. United States. Department of Transportation. Operational Evaluation of Emissions and Fuel Use of B20 Versus. 2005.

18- Farzaneh, M. Capital Area Council of Governments. School Bus Biodiesel (B20) NO_X Emissions Testing. Texas Transportation Institute, 2006.

19- Hearne, J. "Diesel Emissions Reduction Strategies for School Buses: Mobile Emissions Test Result with Biodiesel, Ultra Low Sulfur Diesel and #2Diesel." Society of Automotive Engineers (2004)

20- Arby Creach, Personal Interview, 2006.

CHAPTER 3 : COSTS & BENEFITS OF USE OF ALTERNATIVE FUELS AND OPTIMIZING THE TRANSPORTATION PARAMETERS FOR ORLANDO METROPLAN AREA

Introduction

In order to choose the most beneficial emission saving strategies, a comparison analysis was conducted among fuel switching and optimization of average speed and idling time. The financial cost and emission saving for each strategy was evaluated and the cost indicator is reported as dollars per tons of pollutants. Table 3-1 shows the number of students that ride school buses for different counties in Central Florida[1].

Table 3-1: Number of students riding school buses

District	2003-04	2004-05	2005-06
Orange	73538	72158	71047
Osceola	22167	22839	23759
Seminole	31881	31952	31253

The annual distance traveled by school buses for all three counties are reported in Table 3-2. As it can be observed in 2005-06 school year, the school buses traveled about 32.7 million miles[1].

Table 3-2: School bus fleet fuel consumption and VMT

District	Number of buses	Annual Fuel Consumption (million gallons/year)	Annual Miles Traveled (million mile)
Orange	1400	2.7	17
Osceola	392	0.8	7.1
Seminole	459	1.1	8.6
Total	2251	4.6	32.7

Costs & Benefits Analysis

Alternative Fuels

Three scenarios were defined, based on fuel type, to show the annual emission saving for all school bus fleets in Central Florida:

1) Use of 100% conventional diesel (CD)

2) Use of 100% ultra low sulfur diesel (ULSD)

3) Use of a mixture of 80% conventional diesel and 20% biodiesel (B20)

The estimated emission factors (EFs) for different fuel type are shown in Table 3-3. It should be mentioned that these EFs were calculated for the observed average speed of 25.2 mi/hr.

Table 3-3: Emission Factors for all fuel types

Fuel Type	THC (g/mi)	CO (g/mi)	NO_X (g/mi)	SO_X (g/mi)	PM_{10} (g/mi)
CD	0.779	2.396	10.537	0.357	0.601
ULSD	0.779	2.396	10.537	0.015	0.577
B20	0.685	2.000	10.600	0.012	0.482

The annual emissions of major pollutants from all three school bus fleets for the school year of 2005-06 are reported in Table 3-4.

Table 3-4: Total annual emissions

Scenario	THC (tons/year)	CO (tons/year)	NO_X (tons/year)	SO_X (tons/year)	PM_{10} (tons/year)
CD	28.07	86.36	379.80	12.86	21.66
ULSD	28.07	86.36	379.80	0.54	20.79
B20	24.69	72.08	382.07	0.43	17.37

By replacing the CD with ULSD, the SO_X emissions can be reduced significantly, about 12 tons/year. Considering ozone precursors, use of B20 cause 2.3 ton/year increase in the annual NO_X emissions and reduce about 3.3 tons of VOC_S emissions per year.

The fuel consumption for all three fleets was estimated to be 4.6 million gallons /year so the annual consumption of biodiesel is about 980,000 gallons/year. Depend on the price differences between biodiesel and regular diesel, the cost of saving 3 tons of VOC_S per year varies. Every 10 cents additional cost for biodiesel, cause about $100,000 increase in annual cost of fuel. Also the cost of some initial engine modifications for biodiesel compatibility needs to be added in order to calculate the total cost.

Transportation Parameters

The affect of speed on different emissions is illustrated in Figure 3-1,

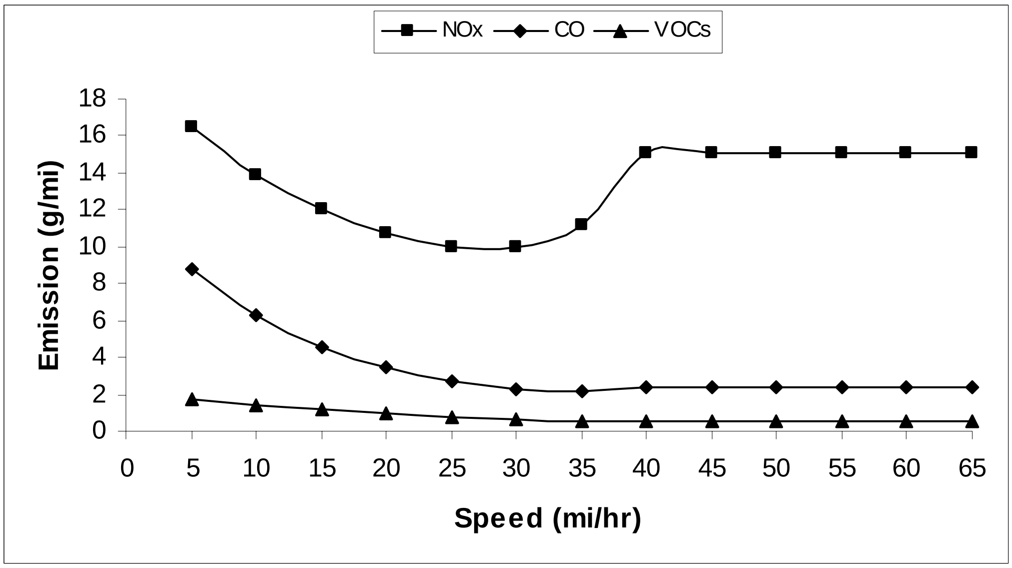

Figure 3-1: Speed sensitivity analysis for school buses, road type arterial

In order to minimize the NO_X emissions the fleet average speed should be around 27 mi/hr. The current estimate of average speed for OCPS fleet is 25.2 mi/hr, which is assumed to be the same for the other two counties. It should be mentioned that the MOBILE6.2 does not take into account the effects of speed changes on SO_X and PM emissions. It is noted that NO_X emissions have a minimum at speed of 27 mi/hr and NO_X increase after and before that speed.

Also reduction of idling time can effect the emissions from school bus fleets, Table 3-5 shows the EFs for idling for different fuel type,

Table 3-5: Emission Factors for different fuels

Fuel Type	THC (g/minute)	CO (g/minute)	NO_X (g/minute)	SO_X (g/minute)	PM_{10} (g/minute)
CD	0.088	0.414	0.832	0.015	0.025
ULSD	0.088	0.414	0.832	0.001	0.024
B20	0.077	0.346	0.837	0.0008	0.020

The annual emission saving by reduction of idling time, based on 200 school days per year for all three counties is shown in Table 3-6.

Table 3-6: Annual emission saving for different fuels, by reduction in daily idling time for15 minutes/day

Fuel Type	THC (tons/year)	CO (tons/year)	NO_X (tons/year)	SO_X (ton/year)	PM_{10} (ton/year)
CD	0.65	3.08	6.19	0.11	0.18
ULSD	0.65	3.08	6.19	0.007	0.18
B20	0.57	2.57	6.23	0.006	0.15

The emission reduction from decreasing the idling time has no cost which makes it the most favorable emission reduction strategies.

The proposed strategy, using the ultra low sulfur diesel or biodiesel can be implemented to reduce most of school bus emissions with NO_X as exception. Use of B20 instead of CD or ULSD for school bus fleets in Central Florida can be highly costly which is also associated with small increase in NO_X emissions. Reduction of idling time or optimizing the fleet average speed brings a significant decrease in all emissions. It is noted that increasing the average speed must be done by increasing the speeds below 27 mi/hr and not by increasing speeds above it. In fact NO_X emissions increase significantly by increasing the speed to the 35 mi/hr and greater. This strategy has no associated cost and can be adapted and implemented by fleets easily. The recommended actions for reducing the NO_X and VOC_S are summarized in Table 3-8. The NO_X and VOC_S emission saving , results of implementation of recommended actions, compared to the total annual all sources emissions and total annual mobile source emissions in Tables 3-9.

Table 3-7: Recommended actions

Action	Pollutant saved (tons/year)					Cost ($/ton)
	THC	CO	NO_X	SO_X	PM_{10}	
Decreasing idling time by 15 minutes/day*	0.65	3.08	6.19	0.007	0.18	0
Switching from ULSD to the B20	3.38	14.28	(2.3)	0.11	3.42	N/A

* Because currently all the buses are using ULSD, the saving for scenario#2 is reported

Table 3-8: Comparing the total annual emissions with saving emissions resulting from recommendation actions

Emissions	NO_X	VOC_S
Total Annual, All Sources, Central Florida (tons/year)*	80389	84586
Total Annual, Mobile Sources, Central Florida (tons/year)*	67690	51677
Saving emissions by decreasing idling time by 15 minutes/day	6.19	0.65
Saving emissions by switching from ULSD to the B20	(2.3)	3.38

* Emission Inventory for Central Florida by Marten Arbrandt, 2003.

References

1- Jacobson, Susan. Get on the Bus." Orlando Sentinel 07 Aug, 2006: B.