Reducing School Bus Emissions in Texas

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ABSTRACT

School bus emissions are of particular concern, not only for their contribution to overall air quality problems, but also for their impact on children, who are highly vulnerable to this health risk. The purpose of this study was threefold: to develop a methodology to estimate the emissions from school buses in nonattainment (NA) and early action compact (EAC) areas in Texas, perform an order of magnitude estimate of school bus emissions, and develop recommendations for reducing such emissions.

Information about school bus fleets was obtained from 65 out of 228 school districts in the NA and EAC areas in Texas. By combining this data with an array of demographic data, such as school district location, population, minority population, and median household income, a model was developed to estimate the number of buses per category per school district. The study results indicate that school buses in the NA and EAC areas in Texas produce more than 2,400 tons of nitrogen oxides (NOx) emissions and almost 150 tons of particulate matter (PM 2.5) emissions per year. Although these emissions represent only 0.8% and 3.1% of the total NOx and PM 2.5 mobile source emissions, respectively, reducing these emissions is important because it can help NA areas reach attainment and reduce health risks to children. Furthermore, school bus emissions can be reduced by using strategies such as engine retrofitting or replacement, replacement of buses with new clean-burning units, and using cleaner fuels.

Key words: emissions—retrofits—school bus

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INTRODUCTION

Approximately 450,000 school buses operate every day in the United States. These buses transport 24 million children to and from school, which equates to almost 10 billion student rides annually (School Transportation News 2004). Of these buses, approximately 90% are diesel fuel-powered, which has been shown to cause or exacerbate a host of health problems, including respiratory ailments such as asthma and even cancer. Children are particularly vulnerable to the harmful impact of air pollution because they breathe at a faster rate than adults and their lungs are still developing (children breathe 50% more air per pound than adults) (US EPA 2002). In addition, children spend much more time outdoors than adults.

School buses expose children to soot (particulate matter) and smog-forming pollutants (NOx) and hydrocarbons (HC). They also add to the problem of global warming by emitting the greenhouse gas carbon dioxide (CO_2). It is estimated that the nation's school buses release 3,000 tons of soot, 95,000 tons of smog-forming pollutants, and 11 million tons of greenhouse gas emissions annually. Older school buses are exempt from today's stronger emissions standards, but buses built before 1991, which constitute around a 1/3 of buses now in operation in the United States, have six times higher particulate matter (PM 2.5) emission rates and three times higher NOx emissions rates than buses built in 2004 (Monahan 2002).

The purpose of this study was threefold: to develop a methodology to estimate the emissions from school buses in the nonattainment (NA) and early action compact (EAC) areas in Texas, perform an order of magnitude estimate of school bus emissions in NA and EAC areas in Texas, and develop recommendations for reducing such emissions.

TEXAS CASE STUDY

Methodology

The methodology in this study can be summarized in the following steps:

- Focus on the NA and EAC areas as defined by the EPA in the new eight-hour ozone standards.
- Identify the school districts within each of the NA and EAC counties.
- Use U.S. Census Bureau data and other sources to obtain demographic information, such as total area of the school district, population, total enrollment, percentage minority population, and median household income, for each school district.
- Develop criteria for selecting samples of school districts within each of the NA and EAC areas.
- Select the sample school districts based on the pre-determined criteria.
- Use personal interviews and mail-out questionnaires to obtain specific information regarding the school bus fleets and usage rates.
- Develop statistical relationships between the demographic information of the sample school districts and the number of buses per category.
- Develop a procedure to predict the average miles driven per bus category.
- Develop the appropriate emissions rates for the categories and model years of the school buses.
- Calculate emissions estimates for NOx and PM 2.5 for school districts in the NA and EAC areas.
- Aggregate the emissions estimates to NA and EAC counties.
- Identify the most productive emissions control strategies and estimate possible emissions reductions.
- Develop conclusions and recommendations.

Data Collection

Demographic Data for School Districts

Data from the U.S. Census Bureau was used to determine the values for relevant independent variables, such as the total area of the school district, population, minority population, and median household income (U.S. Census 2004). The population for each school district was calculated as a proportion based on surrounding population density and the coverage area of the school district. The number of schools and total enrollment in the various school districts were obtained from a study performed by the Galveston-Houston Association for Smog Prevention (GHASP) to investigate the reduction of air pollution from Houston-area school buses (GHASP 2004). This study examined retrofit and fuel technology options and focused on school districts within five of the eight NA counties. Table 1 shows the summarized demographic data for the various NA and EAC areas.

Table 1. 2000 demographic data for the NA and EAC areas

NA or EAC area	Population	% minority population	Average household income	Total enrollment	School districts	Schools
Austin	812,279	31.8	$64,817	187,672	14	276
Beaumont	385,090	31.7	$38,776	70,988	17	126
Dallas/Fort Worth	4,910,758	31.6	$53,706	966,077	98	1403
Houston	4,715,639	37.3	$44,202	948,881	69	1230
Tyler/Longview	111,379	27.3	$36,825	22,030	6	45
San Antonio	1,392,931	31.1	$42,030	298,344	20	438
Total/Average	**12,328,076**	**31.8**	**$46,726**	**2,493,992**	**224**	**3,518**

Emissions Rates

MOBILE6 was used to develop emissions rates for the various school bus categories. Emissions rates were developed for NOx and PM 2.5. In the MOBILE6 model, only one category is specifically dedicated to the larger type C and D school buses: Heavy-Duty Diesel School Buses (HDDBS). In terms of heavy-duty gasoline buses, the closest relevant category is Heavy-Duty Gasoline Buses (HDGB), which includes school, transit, and urban gasoline-fueled buses. There are no specific categories for the smaller (type A and B) school buses. However, these buses are closely related to the two class 2b heavy-duty vehicles. Specifically, in the case of diesel-fueled type A and B school buses, the selected category is Class 2b Heavy-Duty Diesel Vehicles with 8,500–10,000 gross vehicle weight rating (GVWR) (HDDV2b). In the case of gasoline-fueled type A school buses, the selected category is Class 2b Heavy-Duty Gasoline Vehicles with 8,500–10,000 GVWR (HDGV2b).

MOBILE 6 runs were performed to produce the respective emissions rates. An important assumption in emissions estimation with MOBILE 6 is the average speed, because emissions rates are developed based on different drive cycles, and these drive cycles are defined according to average speeds. Questionnaires and interviews were used to determine the average speeds. The average speeds mentioned by the individual school districts varied between 18 mph and 24 mph, with 20 mph being a reasonable average. Therefore, it was decided to use 20 mph as the average speed for emissions modeling purposes.

Table 2 shows the final emissions rates in grams per mile for the 20-mph scenario. MOBILE6 produces emissions rates for individual years over a 25-year period. The model years were grouped into six groups, as shown in Table 2. In addition, the school bus types are grouped into two categories: those that carry less than 20 passengers (types A and B) and those that carry more than 20 passengers (types C and D). As expected, the rates for larger buses are higher than for smaller vehicles, and are higher for diesel-fueled vehicles than for gasoline-fueled vehicles.

Table 2. Emissions rates for school buses

	Diesel				**Gasoline**			
Model years	**< 20 passengers**		**> 20 passengers**		**< 20 passengers**		**> 20 passengers**	
	NOx	**PM 2.5**	**NOx**	**PM 2.5**	**NOx**	**PM 2.5**	**NOx**	**PM 2.5**
1978-1984	7.47	0.60	12.77	2.94	5.40	0.17	7.46	0.17
1985-1989	7.29	0.60	12.81	2.94	7.01	0.07	10.36	0.08
1990-1993	4.87	0.27	12.51	1.97	4.54	0.06	6.34	0.05
1994-1998	4.46	0.11	13.80	0.18	4.07	0.06	6.31	0.05
1999-2000	3.56	0.11	11.04	0.18	3.37	0.06	4.95	0.05
2001-2004	3.56	0.11	10.40	0.18	3.15	0.06	4.75	0.06

Sample Data

A sample set of school districts was selected within each of the NA and EAC areas for detailed analysis to determine information regarding the bus fleets and usage rates. These school districts were selected based on criteria such as geographic location, median household income, and total enrollment.

The objective was to obtain reasonable sample sizes in terms of the number of school districts within the NA and EAC areas and to have a good spread of the above-mentioned criteria. The respective data elements for the various school districts were organized in quartiles to assist in selecting a good distribution for the sample.

In the case of the Houston/Galveston area, the previous GHASP study generated most of the needed information (GHASP 2004). To supplement the GHASP data, personal interviews and written questionnaires emailed and faxed to the selected school districts were used to obtain information regarding the number of buses by size and model year categories, particularly for districts not covered in the GHASP study. In addition, information was obtained regarding the total miles driven per year, retrofit and alternative fuels used, idling policies, and plans for purchasing additional buses. The response rate was good: 46% of the selected school districts provided the required information. Specifically, for Houston/Galveston, 7 out of 22 responded (32%); for Beaumont/Port Arthur, 3 out of 5 responded (60%); for Dallas/Fort Worth, 10 out of 22 responded (45%); for San Antonio, 4 out of 5 responded (80%); for Austin, 3 out of 5 responded (60%); and for Tyler/Longview, 2 out of 3 responded (66%).

A total of 16 of the 28 respondents indicated that they had some type of idling policy or practice, 9 of the 25 respondents reported using ultra-low sulfur diesel (ULSD) fuel, and 2 school districts indicated that they use their older buses more frequently than the newer buses and reserve the new buses for field trips. In most cases, however, the older buses, especially 1978–1984 model years, are used as back-up buses or used in very limited cases.

Rural versus Urban

It was expected that school districts in rural areas would have different bus fleets and mileage accumulation characteristics than those in urban areas. Urban school districts were defined as those located in cities or towns with a population higher than 30,000. The rural school districts were defined as districts located in towns with a population less than 30,000.

Average Speed

An important assumption in emissions estimation is the average speed, because emissions rates are developed based on different drive cycles, and these drive cycles are defined according to average speeds. It was initially assumed that the average speeds of school buses in rural school districts are higher than those in urban school districts. This trend could not be confirmed based on the feedback from the individual school districts. As mentioned above, an average speed of approximately 20 mph was found.

Number of Buses

A sample of the number of buses per category was obtained from the questionnaires. A regression equation was then developed to obtain an estimate of the total number of buses for the school districts that did not provide information. A broad range of independent variables were tested to determine which ones are statistically significant for estimating the number of buses per school district. The significant variables found were number of minorities in the school district area, total enrollment, and number of schools in the district. An equation represented by the negative binomial distribution produced the best fit to the data (Equation 1).

$$\log N = \left[4.0896 - 0.010M / 1000 + 0.0940E / 1000 - 0.0336S\right] - RU \qquad (1)$$

Where

N	=	Number of school buses
M	=	Total minority population in the school district area
E	=	Total enrollment of all the schools in the district
S	=	Total number of schools in the district
RU	=	If in a rural area then RU = 0.4629; otherwise RU = 0

The assessment for the goodness of fit test for a negative binomial regression is the Pearson Chi-Square test, where a result close to 1.00 indicates the model fits the distribution (Social Sciences Teaching and Research Statistics 2004). The Pearson Chi-Square test for this model produced 0.9673, which indicates a good fit for the model. The model was subsequently applied to the remaining school districts in the NA and EAC areas to estimate the number of school buses per district. The total number of buses could then be distributed according to the various categories: age, size, and fuel type (diesel or gasoline). The distributions were based on the information obtained from the questionnaires. Figure 1 shows the age distribution of school buses in the NA and EAC areas in Texas. The figure shows a fairly even distribution of the buses between the different age groups, with the 1994–1998 model year buses representing the largest group.

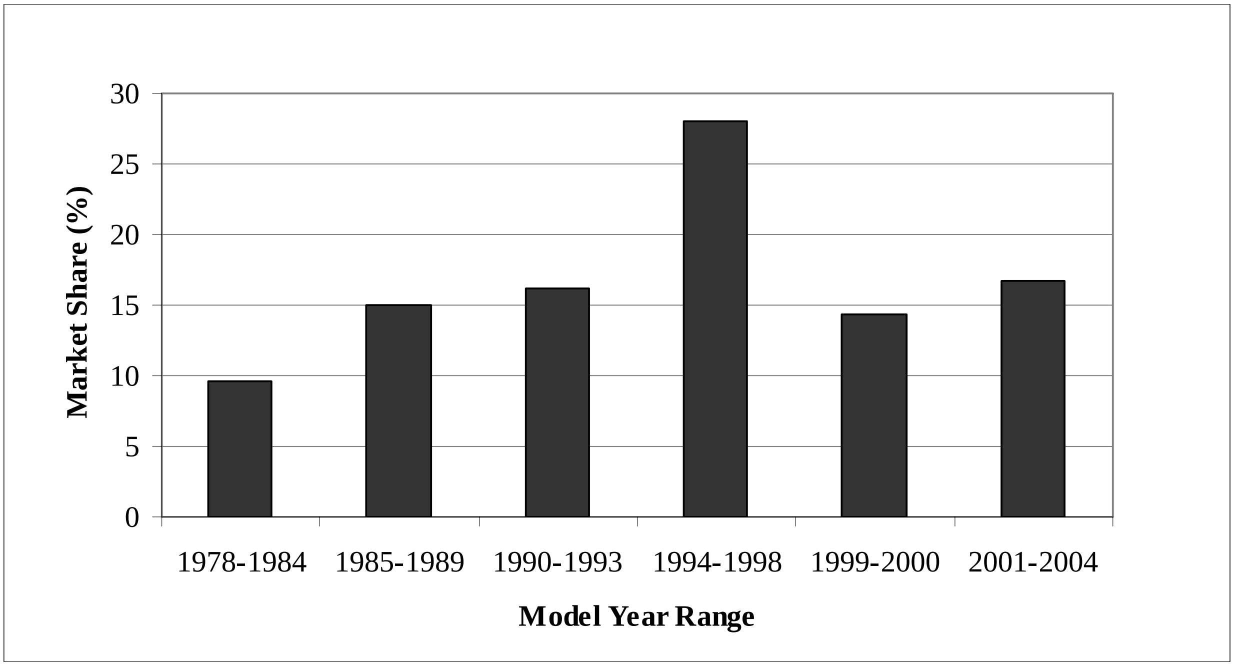

Figure 1. Age distribution of school buses in the NA and EAC areas in Texas

Vehicle Miles of Travel

Another important factor in emissions estimation is the vehicle miles of travel (VMT). Previous research and findings from this study indicate that school districts generally prefer to drive newer buses longer distances than older buses (GHASP 2004). The GHASP study researched the relationship between the model year of school buses and annual miles driven. The study produced a linear relationship between these two parameters. Based on the additional information gathered from the surveys performed for this study, the linear relationship developed through the GHASP study was modified by a factor to define the relationship between the total miles driven per bus per age group.

The total number of buses per school district was estimated using Equation 1. These buses were then distributed according to fractions of the model years, as determined from the sample data. The mid-point of each range was then selected to estimate the annual mileage for that specific range.

Data Analysis

The NOx and PM 2.5 emissions were calculated by multiplying the relevant emission rate for the age and size category with the average annual miles accumulated for that bus category. Emissions were then determined for each school district per model year, school bus category, and rural or urban classification. These emissions were then aggregated to the school district level and then to the NA and EAC county level. Figure 2 illustrates the process followed in this study to estimate the school bus emissions for the various school districts.

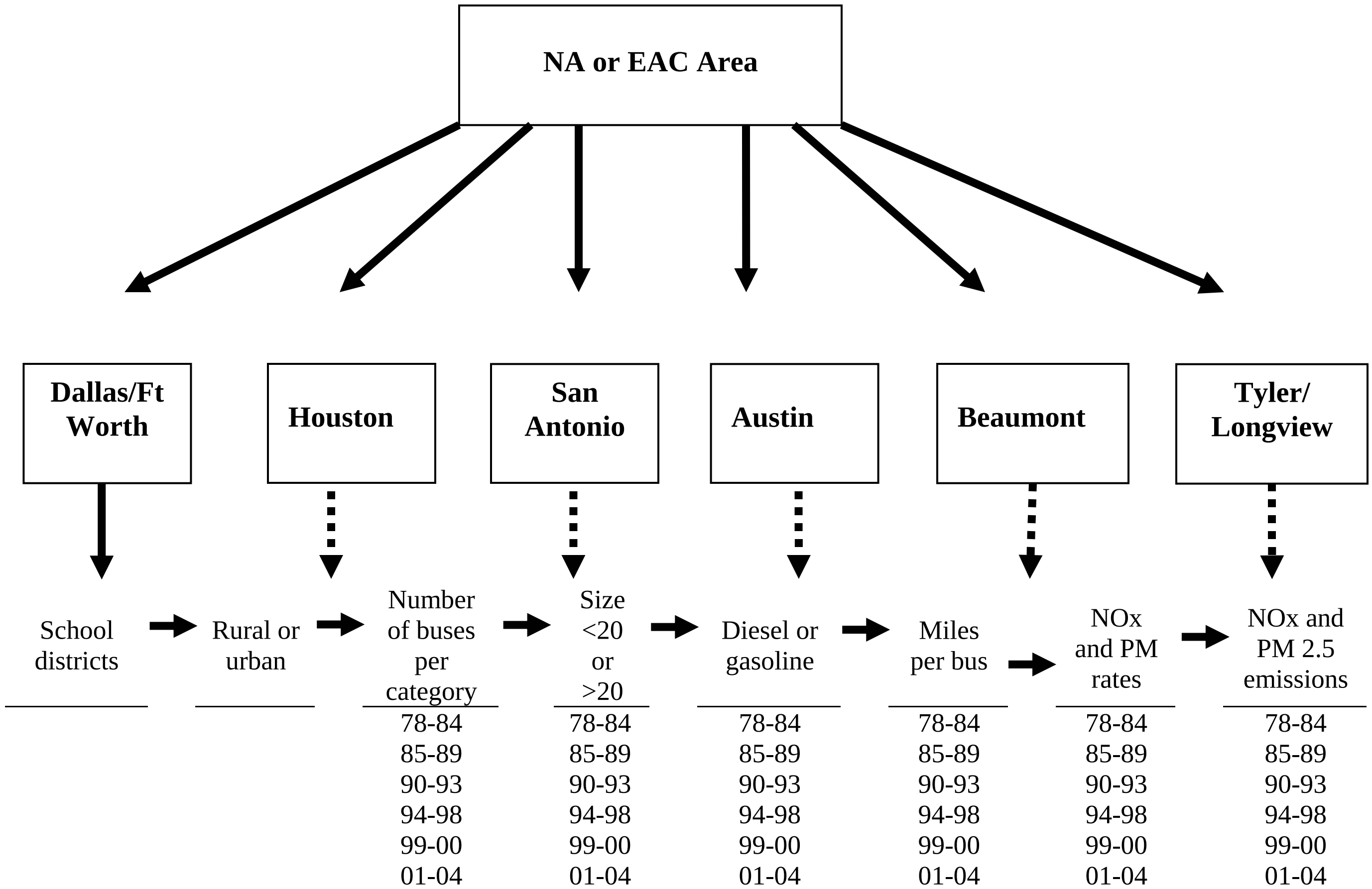

Figure 2. Procedure to estimate school bus emissions

Table 3 shows the results from the analysis by NA and EAC areas. The table shows that school buses in the NA and EAC areas in Texas produce more than 2,400 tons of NOx emissions and almost 150 tons of PM 2.5 emissions per year.

Table 3. School bus emissions for NA or EAC areas

Nonattainment or EAC area	Enrollment	Number of schools	Number of gasoline-fueled buses		Number of diesel-fueled buses		Annual NOx emissions (tons)	Annual PM 2.5 emissions (tons)
			<20	>20	<20	>20		
Austin	187,672	276	9.2	64.1	68.2	791.6	131	9
Beaumont	70,988	126	9.2	64.0	76.1	586.3	84	5
Dallas/Fort Worth	966,077	1403	94.4	660.2	856.2	5510.2	844	52
Houston	948,881	1230	293.4	812.4	645.0	6311.0	1146	64
San Antonio	298,344	438	13.7	95.8	161.5	1243.5	204	16
Tyler/Longview	22,030	45	10.2	22.5	24.6	249.2	36	2
Total	**2,493,992**	**3,518**	**430**	**1,719**	**1,832**	**14,692**	**2,445**	**147**

Table 4 shows the proportion of school bus emissions versus the total on-road mobile source emissions inventory (Texas Transportation Institute 2003). The table shows that the total NOx emissions and PM

2.5 emissions produced by school buses in the NA and EAC areas represent 0.8% and 3.1% of the total on-road emissions, respectively. Although these emissions represent very low percentages of the overall on-road emissions, they are important because reducing these emissions can help NA areas reach conformity and reduce the health risk of a vulnerable sector of the population (school children).

Table 4. Annual school bus emissions vs. total on-road mobile source emissions

NA or EAC area	Total on-road mobile source emissions		Total school bus emissions		% produced by school buses	
	NOx	**PM 2.5**	**NOx**	**PM 2.5**	**NOx**	**PM 2.5**
Austin	33,160	501	131	9	0.4	1.8
Beaumont	16,141	203	84	5	0.5	2.5
Dallas/Fort Worth	104,000	1456	844	52	0.8	3.6
Houston	118,070	1810	1146	64	1.0	3.5
San Antonio	45,050	727	270	16	0.6	2.2
Tyler/Longview	6,990	96	36	2	0.5	2.1
Total/Average	**323,411**	**4,793**	**2,445**	**147**	**0.8**	**3.1**

RECOMMENDED EMISSIONS REDUCTION STRATEGIES

Technologies

Table 5 shows a summary of emissions reduction technologies for heavy-duty diesel vehicles such as school buses. Note that some technologies are only in the development phase, whereas others are already commercially available. Compatibility refers to the extent that the specific technology can be used with commercially available school bus engines.

Table 5 shows that there is a wide range of potential NOx and PM 2.5 emissions reductions strategies as a result of the various fuel and engine technologies. Depending on the specific strategies selected by the various school districts, NOx and PM 2.5 emissions can be reduced from 0% to almost 100%. By only considering the EPA-verified retrofit technologies, NOx emissions can on average be reduced by 10% and PM 2.5 emissions by 35%. By applying these averages to the school bus emissions calculated for the school districts in the NA and EAC areas in Texas, up to 244 tons of NOx emissions and 52 tons of PM 2.5 emissions can be reduced per year.

Table 5. Summary of possible emissions reduction technologies for school buses

Technology	% reduction NOx	% reduction PM 2.5	Status	Compatible engines	Cost over 10 years*
Low sulfur diesel	6	11	Available	Most	Low
Diesel emulsions	14	30	Available	Most	Low
Fuel-borne catalyst	15	40	Available	Most	Low
Diesel oxidation catalyst	0	20	Verified	Most	Low
Particulate traps	0	85	Verified	1994 & newer	Medium
Lean NOx catalyst	25	85	Verified	Select	High
NOx trap	90	0	In development	TBD	TBD
Selective catalyst reduction	85	25	Available	Most	High
Exhaust gas recirculation	30	0	Demonstrations	Most	Medium
Fuel line devices	TBD**	TBD	Available	Most	Low
Natural gas	60	90	Ltd. availability	Most	High
Propane	20	90	Available	Different engine	Low
Ethanol	20	75	Available	Different engine	High
Biodiesel	10	20	Available	Most	Low
Methanol	50	TBD	Available	Different engine	Low
Hybrids	50	TBD	In development	Different engine	High
Fuel cells	100	TBD	In development	Different engine	High
Electric vehicles	90	TBD	In development	Different engine	High

*Low: less than $5,000; Medium: from $5,000 to $10,000; High: more than $10,000
**TBD: to be determined

CONCLUSIONS

Overall Findings

- Information regarding school bus fleets was obtained from 65 of 228 school districts in the NA and EAC areas in Texas. The study showed that in Texas NA and EAC areas school buses emit approximately 2,500 tons of NOx emissions and approximately 150 tons of PM 2.5 emissions per year. Although these emissions represent only 0.8% and 3.1% of the total NOx and PM 2.5 mobile source emissions, respectively, reducing these emissions can help NA areas reach attainment and reduce the health risk to a vulnerable sector of the population (school children).
- Several technological approaches can be used to reduce NOx and PM 2.5 emitted by school buses. By only considering the U.S. EPA-verified retrofit technologies, up to 244 tons of NOx emissions and 52 tons of PM 2.5 emissions can be reduced per year in Texas NA and EAC areas.
- In Texas, 35 school districts use propane to power about 1,600 buses. In addition, several school districts are involved in demonstration projects that use Texas Low-Emissions Diesel (TxLED; ultra low-sulfur diesel) fuel and installing certified PM 2.5 traps. Others do not have the resources to purchase the slightly higher priced propane buses or the necessary fueling facilities.
- Programs used by other school districts across the nation include converting to natural gas, biodiesel, and propane. In addition, limited retrofits are installed that typically involve PM filters.
- A total of 16 of the 28 responding school districts indicated that they had some type of idling policy or practice, 9 of the 25 respondents reported using ULSD fuel, and 2 districts indicated that they use their older buses more frequently than the newer buses and reserve the new buses for field trips. In most cases, however, the older buses, especially 1978–1984 model years, are used as back-up buses and/or used in very limited cases.

Strategies to Reduce Emissions

- School bus fleet emissions can be reduced by using the following broad strategies: (1) retrofitting existing buses; (2) replacing the engines of existing buses; (3) replacing existing buses with new clean burning units; and (4) using cleaner fuels, some of which require engine conversions.
- Retrofits are available for newer buses at a cost of less than $5,000 per unit. However, the retrofits will not work effectively without low-sulfur fuel because the retrofits clog up very quickly. In addition, many buses in the current fleet cannot be retrofitted because of age and model-year configurations.
- There are concerns with the reliability of retrofits as well as the ease with which they can be repaired. The preferred strategy, therefore, would be to replace older buses rather than retrofit them. This alternative becomes even more attractive, considering that 42% of all the buses in the Texas fleet are estimated to be over 10 years old. If bus replacement costs are considered to be prohibitive, engine replacements may be considered (approximately $30,000 for a new engine versus more than $60,000 for a new bus).
- In terms of new buses, clean diesel units are available for approximately $7,000. It is important to note that these buses do not operate effectively without the correct fuel type (mostly ULSD fuel).
- Some school districts make a concerted effort to ensure that their older and higher emitting buses drive the shortest routes, whereas other districts do it more randomly. It would be beneficial from an emissions perspective if the newest buses are used on the longest routes.
- Idling could be a large source of school bus emissions, and various strategies are listed in this report for reducing idling. Approximately 60% of the respondents indicated they already have some type of idling policy or practice. Those with policies indicated they limit idling to less than five minutes.

Future Research

- VMT is an important component of school bus emissions. There is a need to develop more accurate estimates of miles driven by the various school bus fleets, particularly per age group.
- There is a need to determine the actual emissions rates of the various categories of school buses relative to age, size, and fuel type.
- There is a need to develop courses for drivers, maintenance personnel, and transportation managers to train them on improved operational aspects and available clean-burning equipment.
- There is a need to investigate the possibilities and implications of having school buses subjected to an inspection and maintenance program.

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REFERENCES

Galveston-Houston Association for Smog Prevention (GHASP). 2004. *Reducing Air Pollution From Houston-Area School Buses.* Houston, TX.

Monahan, P. 2002. *Pollution report Card: Grading America's School Bus Fleets*. Union of Concerned Scientists.

School Transportation News. 2004. School Bus Operations. fttp://www.stnonline.com/stn/operations/schoolbusmanufacturing.

Social Sciences Teaching and Research Statistics. 2004. Poisson and Negative Binomial Regression. http://www.uky.edu/ComputingCenter/SSTARS/P_NB_3.htm.

Texas Transportation Institute. 2003. *2002 Three-Year Cycle Emissions Inventory Methodology for Texas Nonattainment Areas.* Study No. 402131. College Station, TX: Texas Commission On Environmental Quality, The Texas A&M University System.

U.S. Census Bureau. 2004. http://www.census.gov.

U.S. Environmental Protection Agency. 2002. *What You Should Know About Diesel Exhaust and School Bus Idling.* Region 6.