Reducing Air Pollution From Houston-Area School Buses

Galveston-Houston Association for Smog Prevention

March 2004

Reducing Air Pollution from Houston-Area School Buses

Table of Contents

Appendix: Sources and Methodology

Tables

Figures

The Galveston-Houston Association for Smog Prevention (GHASP) is a community-based environmental organization dedicated to improving the quality of our region's hazardous air through public education, participation in the state and federal planning process, and active advocacy in appropriate venues.

GALVESTON•HOUSTON ASSOCIATION•FOR SMOG•PREVENTION

3015 Richmond, Suite 201
Houston, TX 77098-3013

www.ghasp.org

713.528.3779
info@ghasp.org

Reducing Air Pollution from Houston-Area School Buses

Introduction

Houston-Galveston area school districts operate approximately 7,500 school buses to offer the region's nearly one million students a safe and reliable ride to and from school. Because the region's school districts typically use buses for about twenty years, only about a third of the region's school buses meet recent federal standards for pollution control. New school buses are much cleaner than those offered in years past because of technology improvements spurred by more stringent government standards.

School districts can reduce children's exposure to harmful air pollutants and help improve Houston's overall air quality by replacing or retrofitting old school buses. This report seeks to improve the understanding of how school bus emissions affect Houston's overall air quality and offer school districts assistance in their efforts to reduce their fleets' emissions.

This report begins with an overview of area school bus emissions. This section estimates the current nitrogen oxide (NO_x), particulate matter (PM), and volatile organic compound (VOC) emissions in the fleet, forecasts how those emissions will change over the next several years, and describes the different factors influencing school bus emissions. Next, the report evaluates alternative emission reduction technologies and region-wide strategies to lower school bus emissions. Finally, the report discusses possible sources of funding for emission reduction programs and offers contacts for districts to find more information about technologies that are discussed.

Nitrogen Oxide (NO_x) Emissions: A Regional Crisis

Nitrogen oxides contribute to the formation of ground-level ozone in the Houston area and consequently to serious health problems for residents in the region. Because the region's unhealthy air does not meet national standards set by the Clean Air Act for ground-level ozone, the state's clean air plan calls for extensive reductions in NO_x emissions from nearly all pollution sources in the Houston-Galveston area. If the area does not meet the standard by 2007, the US Environmental Protection Agency is obligated to impose sanctions, including the loss of federal highway dollars.

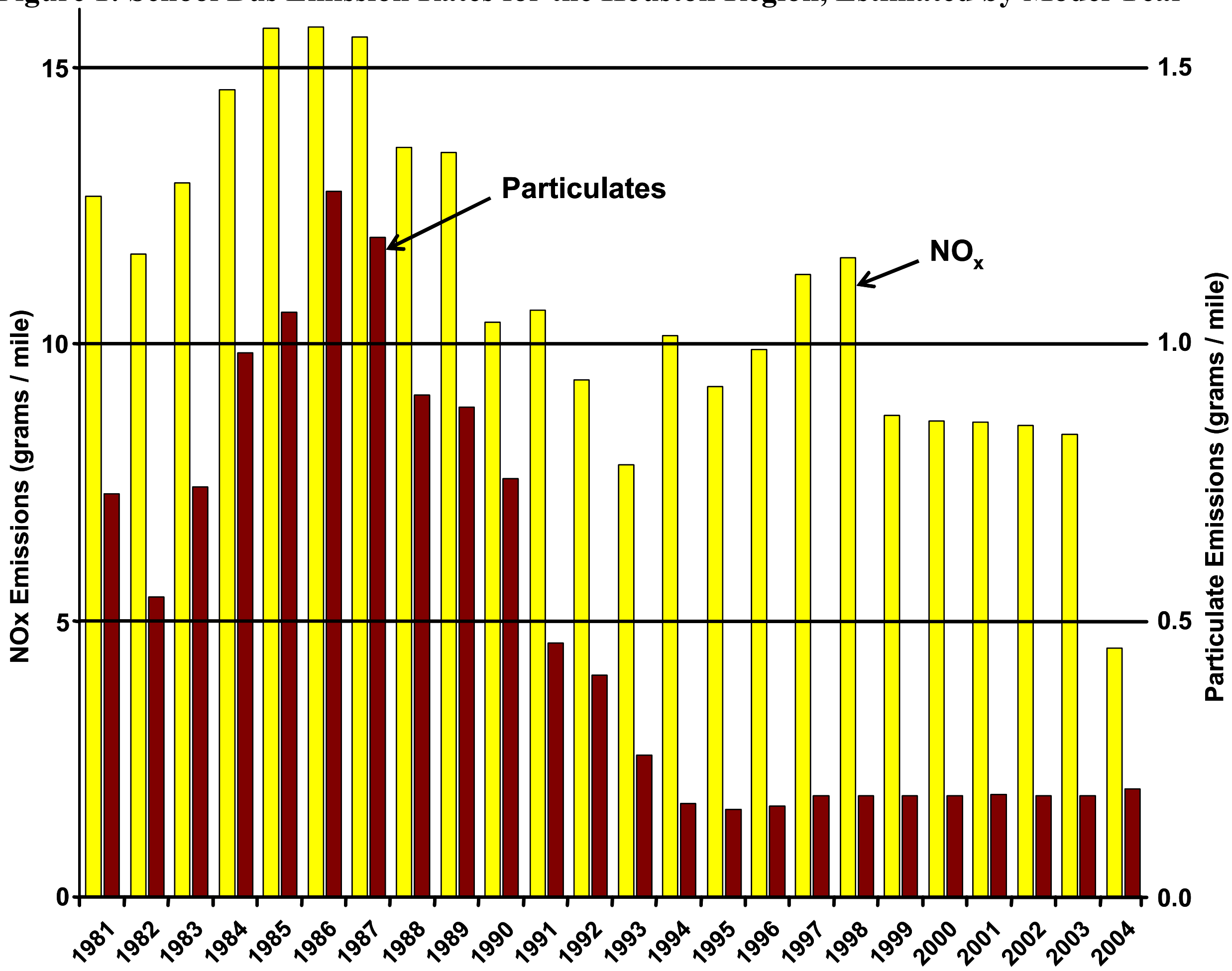
Each school day, school buses in the Houston region emit almost 6 tons of NO_x. Better technology and more stringent government regulations have led to improved NO_x emissions in newer model year buses (see tables 1 and 2, and figure 1).

Table 1: Estimated Air Pollution from Houston Region School Buses **(88% of students in 5 counties)**

	Buses	Annual Miles	NO_x Emission Rate (g/mi)	Annual NO_x Emissions	Particulate Emissions (g/mi)	Annual Particulate Emissions
All Model Years	**6,643**	**84,990,671**	**10.0**	**938 tons**	**0.38**	**36 tons**
1978-84	11%	3%	12.9	4%	0.75	6%
1985-89	15%	10%	14.7	15%	1.07	28%
1990-93	15%	13%	9.8	13%	0.48	17%
1994-98	29%	34%	10.2	35%	0.34	30%
1999-04	30%	39%	8.5	33%	0.18	19%

Note: The higher emission rates in the 1985 to 1989 model year period appear to be caused mainly by an increase in the average size of bus purchased during that period. The slightly raised emission rate in the 1994-98 model year period seems to be due to a number of alternative fuel buses purchased in the proceeding period.
Source: GHASP analysis. See appendix.

Figure 1: School Bus Emission Rates for the Houston Region, Estimated by Model Year



Source: GHASP analysis. See appendix.

To bring the area into attainment with federal health standards for ozone air pollution, the state has adopted a State Implementation Plan, which calls for reducing the region's NO_x emissions by 60%, including a reduction of 55% from heavy-duty mobile sources. The 6 tons of NO_x the region's school buses emit each day represent only 2% of the NO_x emissions from all traffic in the Houston region, but all sources of pollution, including school districts, must do their part to help the community meet federal air quality health standards.

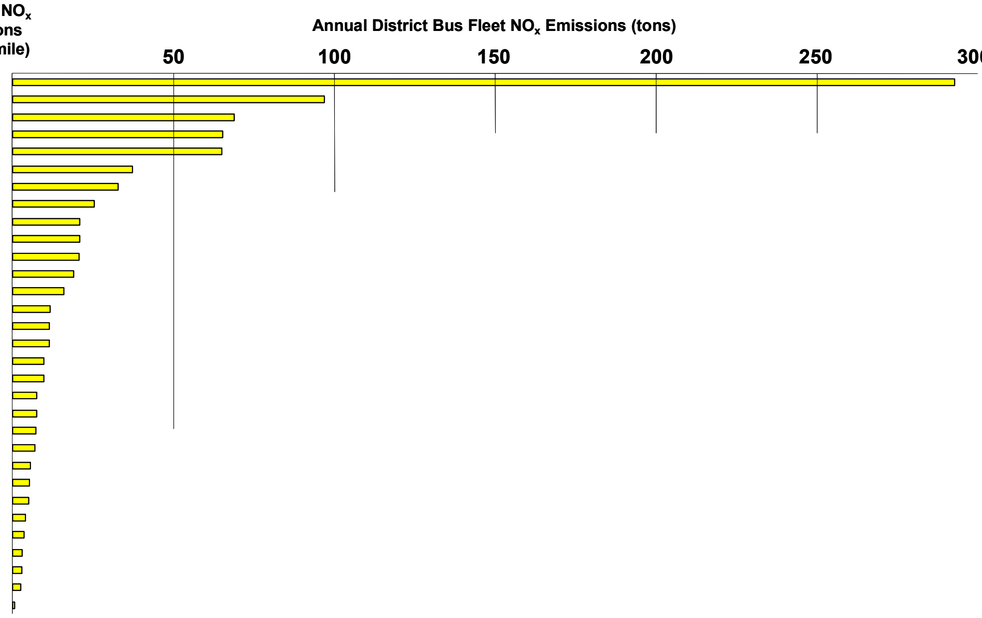
Largely because of their large bus fleets, the five largest school districts emit over half of the NOx from school buses in the Houston region (see figure 2). Taking into consideration each district's unique blend of bus sizes and model years, the average NO_x emission rates of individual school districts vary from as little as 7 grams per mile to as much as 13 grams per mile.

Fortunately, without even taking action, the area's school bus fleet will emit about 20% less NO_x by 2007. First, routine replacement of older (higher pollution) buses will more than compensate for the anticipated growth in student population and the consequential need for a larger overall bus fleet. Second, the state has mandated that diesel in the area meet a new Texas Low Emission Diesel (TxLED) standard by 2005, which will lower NO_x emissions by 5.7% and allow school districts to use new technologies that lower NO_x even more.

If school districts are to go beyond a 20% reduction in NO_x emissions, they will need to consider more aggressive actions. For instance, to achieve a 50% reduction in NO_x emissions, the average NO_x emission rate from school buses would need to drop to about 5 grams per mile, considerably below the rate for the cleanest district in the region.

Figure 2: Estimated Nitrogen Oxide (NO_x) Emissions by School District

District	Student Population	Average NO_x Emissions (grams/mile)
Houston ISD	209,916	10.0
Aldine ISD	50,950	9.9
Cy-Fair ISD	50,491	11.1
Conroe ISD	33,483	10.4
Fort Bend ISD	52,904	9.4
Katy ISD	32,338	12.5
Spring ISD	22,134	11.8
Pasadena ISD	41,953	10.0
Humble ISD	24,221	9.4
Alief ISD	41,839	6.8
Klein ISD	32,331	10.5
Goose Creek ISD	18,148	11.3
Spring Branch ISD	31,628	9.9
Waller ISD	4,074	10.5
Galena Park ISD	18,523	9.0
Brazosport ISD	13,224	12.1
Tomball ISD	7,023	9.8
Sheldon ISD	4,195	10.6
Galveston ISD	9,487	10.3
Crosby ISD	3,952	10.8
LaPorte ISD	7,502	9.6
Willis ISD	4,570	9.8
Santa Fe ISD	4,369	11.3
Stafford MSD	2,870	11.0
Dickinson ISD	6,007	12.0
Sweeny ISD	2,210	13.1
Texas City ISD	5,951	9.6
Needville ISD	2,433	12.8
Huffman ISD	2,443	11.7
Friendswood ISD	4,992	11.9
Damon ISD	141	8.9



District	Student Population	
Clear Creek ISD	28,871	Does not maintain a bus inventory.
Lamar CISD	14,896	Did not respond to public information requests.
North Forest ISD	12,614	Did not respond to public information requests.
Deer Park ISD	11,500	Did not respond to public information requests.
Alvin ISD	11,404	Did not respond to public information requests.
Pearland ISD	10,202	Did not respond to public information requests.
Magnolia ISD	6,501	Did not respond to public information requests.
Angleton ISD	6,481	Did not respond to public information requests.
Channelview ISD	6,474	Did not respond to public information requests.
New Caney ISD	6,170	Did not respond to public information requests.
La Marque ISD	4,146	Did not respond to public information requests.
Montgomery ISD	3,502	Did not respond to public information requests.
Columbia-Brazoria ISD	3,314	Did not respond to public information requests.
Splendora ISD	2,822	Did not respond to public information requests.
Hitchcock ISD	1,237	Did not respond to public information requests.
Danbury ISD	729	Did not respond to public information requests.
High Island ISD	293	Did not respond to public information requests.
Kendleton ISD	111	Did not respond to public information requests.

Source: GHASP analysis. See appendix.

Fine Particulate Matter (PM) Emissions: A Health Issue

Each school day, school buses in the Houston region emit about 381 pounds of fine particulate matter (PM), which is a complex mixture of carbon, sulfate particles, ash, and volatile organic compounds (VOCs). The importance of fine PM pollution depends on the circumstances in which it is emitted. The Houston region meets federal standards for regional particulate levels. Nevertheless, if the particulates from a bus are emitted into a confined space or on a day when levels are already high because of weather or emissions from other sources, they contribute to already unhealthy conditions.

High levels of PM pollution have been associated with adverse respiratory effects, such as asthma, reduced lung function, and acute respiratory illness.[1] Children are especially susceptible to these risks because they inhale 50% more air per pound of body weight than adults.[2] In addition to respiratory problems, a number of studies have begun to associate PM pollution with cardiovascular disease and death.[3] In 1993, a study of over 8,000 adults in six cities found that the death rate in the most polluted city was 26% higher than in the least polluted city, and demonstrated a significant association between fine

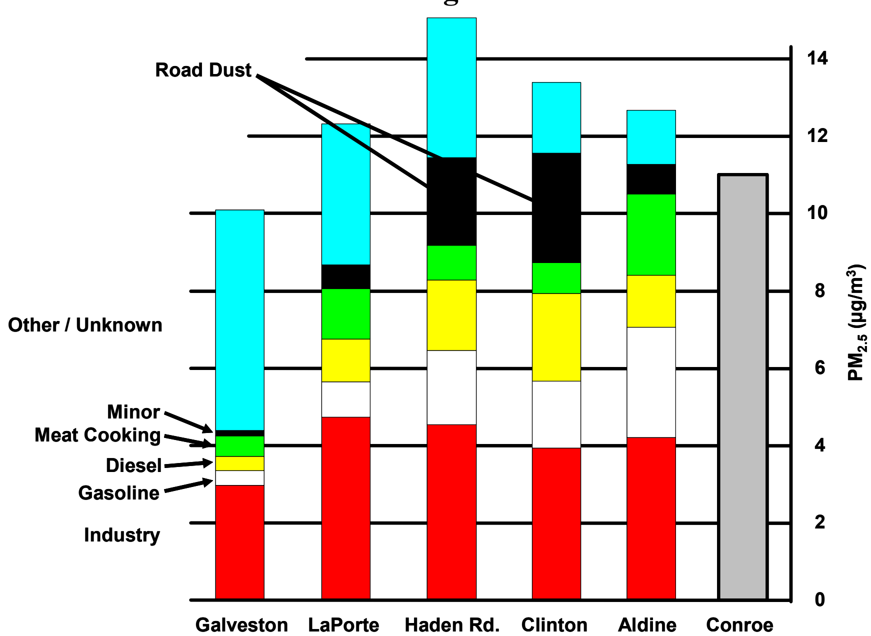
[1] "Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines," EPA. EPA420-R-00-010. Washington, D.C. (July, 2000).
[2] Ibid.
[3] "Cardiovascular Disease and Death," Presentation by Dr. George Delclos, Director, Southwest Center for Occupational and Environmental Health, University of Texas School of Public Health, Houston, TX (June 26, 2003)

PM matter and deaths from cardiopulmonary disease and lung cancer, controlling for other known factors.[4] Since this initial study, the onset of heart attacks has been associated with hourly PM concentrations within the previous three hours.[5] Furthermore, high PM levels have been linked to blood markers of cardiovascular disease such as high white blood cell, platelet, and fibrinogen counts and changes in blood vessel tone.[6]

In Houston, fine PM pollution, the smallest and most hazardous form of PM, is measured at levels just below the federal health standard for annual exposure.[7] While the Houston region is thus not required by federal law to reduce these pollution levels, the current level of fine PM pollution does have serious regional health consequences.

Diesel PM is a major component of Houston's fine PM pollution. Estimates of the specific contribution of diesel PM to total fine PM pollution levels have only been made at five locations in the Houston region, and only over relatively short study periods (see figure 3). At three of the locations, diesel PM was about 10% of total PM; diesel contributed as much as 17% at one site in an industrial area and as little as 4% on Galveston Island. Controlling diesel PM emissions is evidently an important part of reducing fine PM exposure in most parts of the Houston region.

Figure 3: Fine Particulates in the Houston Region



Sources: Synthesis of various data (1997-1998, 2000-2002). Speciation from Matt Fraser, Rice University. Total $PM_{2.5}$ levels from Texas Commission on Environmental Quality.

Using a cancer potency factor published by the California EPA's Office of Environmental Health Hazard Assessment, GHASP estimated that long-term exposure to the current level of fine PM pollution typically found in the Houston region would increase an individual's risk of getting cancer by about 360 in a million, ranging from as little as 120 per million to 690 per million.[8] This means that an individual exposed to current levels of fine PM pollution from diesel faces an increased cancer risk from air

---

4 D.W. Dockery and C.A. Pope, III. "An Association Between Air Pollution and Mortality in Six U.S. Cities," *New England Journal of Medicine*, 329 (24): 1753-9.
5 Delclos presentation.
6 Ibid.
7 "Where Does Houston's Smog Come From?" Galveston-Houston Association for Smog Prevention. (October, 2003). (Hereafter "GHASP report.")
8 Ibid.

pollution that is 360 times higher than the goal expressed in the federal Clean Air Act. For many individuals in the Houston region, diesel particulates may be the single most dangerous type of air pollution, in terms of long-term exposure.

While diesel PM from school buses is a significant regional environmental problem, a greater concern is the micro-environment within and near school buses that children are exposed to every day they ride a school bus. Especially when buses idle at schools, traffic lights, and bus stops, fine PM levels inside and near school buses rises dramatically. Students inside, boarding or walking near a school bus are potentially exposed to very high levels of fine PM pollution from the diesel exhaust. While school buses are a safer transportation choice than many alternatives, the current fleet of school buses in use places children, especially those with respiratory disease, at an unnecessary health risk, and places others exposed to the same emissions in traffic, neighborhoods or the schoolyard at risk as well.

A number of reports have now begun to link the known health risks of PM pollution to the exposure children receive as passengers of school buses. A study by the Natural Resources Defense Council (NRDC) and Coalition for Clean Air (CCA) indicates that a child riding inside a 1988 school bus may be exposed to four times the level of exhaust as a passenger riding in a car directly in front of it.[9] Since that time, another study attached monitors to 15 school children to measure their exposure to PM pollution. It confirmed that high exposure to PM pollution while children are on school buses, but also found high rates when children were walking along high-traffic routes.[10] This study also found a surprising range in exposures – levels rise and fall dramatically over the course of a single ride on the bus. Looking only at the average level of pollution is likely to underestimate the health effects of fine PM, as peak exposures are important from a health standpoint.

There are no studies of PM exposure for students in the Houston area.

Particulate emission rates from school buses and other diesel engines have dropped significantly due to federal regulations. As a result, about half of the particulate emissions from school buses are from buses built before 1994, even though districts use newer buses for about two-thirds of miles traveled (see table 1 and figure 1). Because newer buses emit less PM pollution, routine replacement helps decrease a fleet's overall PM emissions. The implementation of TxLED fuel in 2005 will reduce PM by 10.5% and enable school districts to create further reductions by using new technologies. Combined, our forecasts show that routine replacement and the implementation of TxLED will reduce the area's school bus emissions of PM 33% by 2007.

Largely because of their large bus fleets, the five largest school districts emit over three-fifths of the fine PM pollution from school buses in the Houston region (see figure 4). While the total quantity of fine PM pollution emissions is an important contribution to regional levels of diesel PM, the most important consideration for fine PM emissions is the rate at which the emissions are emitted from individual buses or groups of buses parked together near schoolchildren.

Taking into consideration each district's unique blend of bus sizes and model years, the average fine PM emission rates of individual school districts vary from as little as 0.1 grams per mile to more than 0.7 grams per mile (see figure 4). The two districts with the lowest emission rates, Alief and Columbia-Brazoria, each have a high percentage of gasoline-fueled buses. In addition to the non-diesel fraction of the fleet, the average age of the fleet explains a large amount of the variation among school districts.

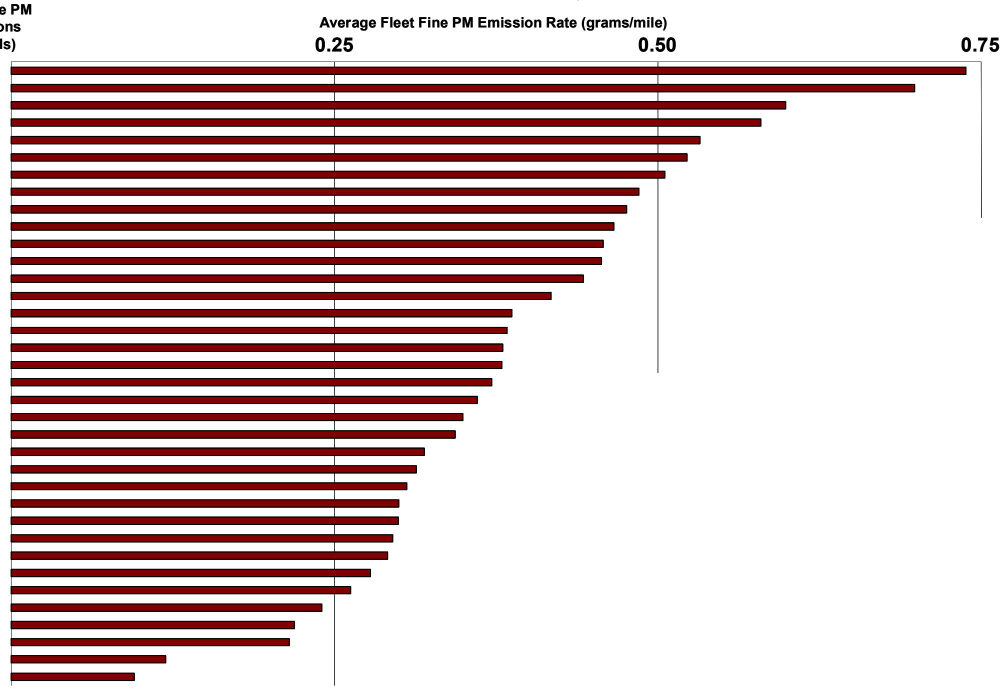
---

[9] "No Breathing in the Aisles: Diesel Exhaust Inside School Buses," Natural Resources Defense Council and Coalition for Clean Air. (January, 2001) (Hereafter "NRDC report")

[10] John Wargo, "Children's Exposure to Diesel Exhaust on School Buses," Environment & Human Health Inc, (February, 2002).

Figure 4: Estimated Fine Particulate (PM) Emission Rates by School District

School District	Student Population	Daily Fine PM Emissions (pounds)
La Marque ISD	4,146	3.3
Sweeny ISD	2,210	2.3
Brazosport ISD	13,224	6.2
Deer Park ISD	11,500	4.4
Spring ISD	22,134	16.4
Friendswood ISD	4,992	1.2
Sheldon ISD	4,195	5.1
Cy-Fair ISD	50,491	33.6
Galveston ISD	9,487	3.9
Goose Creek ISD	18,148	8.7
Huffman ISD	2,443	1.2
LaPorte ISD	7,502	3.8
Needville ISD	2,433	1.2
Santa Fe ISD	4,369	2.3
Damon ISD	141	0.2
Hitchcock ISD	1,237	0.7
Klein ISD	32,331	8.2
Spring Branch ISD	31,628	6.8
Crosby ISD	3,952	2.9
Katy ISD	32,338	11.9
Humble ISD	24,221	8.6
Aldine ISD	50,950	37.6
Waller ISD	4,074	3.9
Tomball ISD	7,023	3.4
Dickinson ISD	6,007	1.4
Stafford MSD	2,870	1.6
Galena Park ISD	18,523	4.2
Conroe ISD	33,483	20.7
Houston ISD	209,916	94.4
Willis ISD	4,570	2.2
Pasadena ISD	41,953	7.3
Fort Bend ISD	52,904	18.4
Texas City ISD	5,951	0.9
Pearland ISD	10,202	3.7
Columbia-Brazoria ISD	3,314	0.8
Alief ISD	41,839	3.2



School District	Student Population	
Clear Creek ISD	28,871	Does not maintain a bus inventory.
Lamar CISD	14,896	Did not respond to public information requests.
North Forest ISD	12,614	
Alvin ISD	11,404	
Magnolia ISD	6,501	
Angleton ISD	6,481	
Channelview ISD	6,474	
New Caney ISD	6,170	
Montgomery ISD	3,502	
Splendora ISD	2,822	
Danbury ISD	729	
High Island ISD	293	
Kendleton ISD	111	

Source: GHASP analysis. See appendix.

Volatile Organic Compounds (VOCs) and Air Toxics

Currently, school buses in the Houston area emit around 1,300 pounds of VOCs each school day. VOCs combine with NOx to form ground level ozone. Some VOCs are directly toxic to people and are associated with cancer as well as adverse neurological, reproductive, and developmental effects.[11] Routine replacement of the oldest buses in the area will reduce school bus VOC emissions 32% by 2007. A number of the emission reduction strategies that are designed to target NOx and PM emissions also reduce VOCs.

In addition to the toxic effects of diesel PM pollution discussed above, bus exhaust contains a number of air toxics such as benzene, acetaldehyde, formaldehyde, polycyclic aromatic hydrocarbons (PAHs), and acrolein. GHASP estimated that long-term exposure to the current levels of these pollutants typically found in the Houston region would increase an individual's risk of getting cancer by about 50 in a million.[12] These pollutants, along with diesel particulates, are also recognized as contributing to the incidence of respiratory, cardiovascular, and other chronic diseases.

Current studies of air toxic sources and exposure levels are not adequate to describe the situation in Houston in detail. We were unable to obtain any information that would assist us in estimating emissions of or exposures to air toxics from school buses in the Houston area. While air toxic emissions

[11] "Health Effects of VOCs," EnviroHealthAction. Available online at www.envirohealthaction.org/pollution/health_effects/.

[12] GHASP report.

from area school buses cannot be accurately estimated, they represent a potential harm to human health that should be further investigated. While all buses emit air toxics, no matter which fuel they use, engine design and new emission control technologies directed at NOx, PM, and VOCs can help control some air toxic emissions as well.

Every person living in the Houston region currently breathes air pollution at unhealthy levels, and school districts have an opportunity to adopt pollution control strategies that help reduce children's exposure to air pollution. While the data needed to precisely predict the amount of improvement in public health that could be expected have not been collected, scientific studies do unambiguously indicate that reduced diesel emissions will help everyone, especially the most vulnerable children and people with respiratory diseases like asthma.

Federal Engine Standards

Newer buses have lower emission rates than older buses because the EPA has required manufacturers to meet increasingly strict emission standards for newer model year engines (see table 2).

Table 2: EPA Engine Certification Standards for Heavy-Duty Vehicles

Years	Smog-Forming Emissions		Soot
	Nitrogen Oxides (NO_x)	Hydrocarbons (HC)	Particulates (PM)
1985-1987	10.7	1.3	Uncontrolled
1988-1989	10.7	1.3	.6
1990	6	1.3	.6
1991-1993	5	1.3	.25
1994-1997	5	1.3	.1
1998-2003	4	1.3	.1
2004-2006	2.5 (combined NO_x & HC)		.1
2007*	.2	.14	.01

Notes: Standards are presented in units of grams emitted per brake horsepower-hour (g/bhp-hr). 2007 standards will be phased in between 2007 and 2010. 50% of diesel sales from 2007 to 2009 must meet the new standard. 50% of gasoline vehicle sales must meet the new standard in 2008. By 2010, all heavy-duty buses and trucks must meet the new standard. Source: EPA Final Rulemaking Documents. Available: www.epa.gov/otaq/diesel.htm

The implementation dates for new federal standards are important in making decisions about bus retirement, purchasing, and retrofitting. Buses built before 1990, which constitute one quarter of the Houston area fleet, are allowed to release six times more soot and almost three times more NO_x than today's average diesel bus. For this reason, districts should make replacing buses built before 1990 a priority. For buses that meet certain standards, it is feasible to apply certain retrofit devices that further reduce emissions. Buses manufactured before 1994 emit too much particulate matter to be compatible with PM filters, while those built in 1994 and after can use a particulate filter to reduce NO_x by an additional 85%.

Buses purchased that meet the 2004 standard emit one half the amount of NO_x pollution and one third the amount of hydrocarbons as the buses manufactured the previous year. This difference becomes even more pronounced in 2007, when new standards require buses to produce one-tenth of the NO_x and PM emissions of their 2004 predecessors. These reductions indicate that a district can drastically lower its emissions by timing its new bus purchases to coincide with more stringent emission standards. In years like 2003, some buses being sold meet 2003 standards, while others meet 2004 standards. Buying the cleanest bus available can make a large difference.

Idling

Table 3: Districts Reporting Idling Policy

- Cypress-Fairbanks I.S.D.
- Friendswood I.S.D.
- Fort Bend I.S.D.
- Galena Park I.S.D.
- Houston I.S.D.
- Katy I.S.D.
- Klein I.S.D.
- Sweeny I.S.D.
- Willis I.S.D.

Diesel idling is perhaps the largest and most easily corrected health hazard associated with school bus emissions. When a large number of diesel school buses are close together with their engines running, particulate matter becomes highly concentrated, posing a large health risk to students and drivers. Breathing diesel exhaust can cause lung damage and respiratory problems.

For these reasons, environmental groups, the EPA, and the National Association of Pupil Transportation (NAPT) have all recommended implementing strict idling provisions that minimize or eliminate school bus idling.

State law places modest restrictions on bus idling in the Houston area as a pollution control measure. However, the state has failed to develop an enforcement strategy for this law. The region's State Implementation Plan (SIP) limits school bus idling to a maximum of 30 minutes between April 1 and October 31 of each year. Besides reducing emissions, idling policies also decrease fuel use, saving districts money.

In spite of these recommendations and the state law, it appears that idling policies are not widely implemented and enforced in the Houston region. In response to GHASP's survey, only about 25% of school districts reported having any idling policy (see table 3) – and details on these policies were rarely provided. For instance, only a few districts reported having any enforcement mechanism. It seems likely that even for those districts that have adopted policies, the difficulty encountered in finding out about those policies is an indication that they are not effectively implemented.

Effective Idling Policies:[13]

- **Minimize Warm-Up Time**
  Morning warm-ups should be limited to the time recommended by the manufacturer, which is usually 3 to 5 minutes.
- **Forbid Idling at Loading and Unloading Areas**
  Zero idling should be allowed at loading and unloading zones where the concentration of buses and people may create a dangerous health condition. Bus operators should turn their ignitions off immediately after parking, and should not restart the bus until they are ready to depart.
- **Provide Climate-Controlled Waiting Spaces for Drivers**
  In loading and unloading areas where drivers may wait for an extended period of time without idling, drivers should be given access to a climate-controlled space within the school to wait.
- **Ensure Equipment Compatibility**
  Fleet managers should make certain that their buses do not require engines to run in order for drivers to power flashing lights. Buses that do not meet this standard should have the circuit configuration changed so that the flashing lights can be powered without the engine running.
- **Educate Operators as to Dangers of Non-Compliance**
  Idling policies work best when those involved understand the health risks that are at issue and are reminded frequently of the policy that is used to prevent unhealthy conditions. To meet this goal, transportation managers should explain the reason for the policy and remind drivers of the policy regularly in newsletters, meetings, and other suitable venues.
- **Include Enforcement Measures**
  Including some enforcement mechanism is the only way to ensure that an idling policy is being effectively executed. Furthermore, the mere existence of enforcement measures will underscore the importance of the policy and encourage compliance.

[13] Ibid.

Evaluating Diesel Retrofit and Fuel Technology Options

Diesel retrofits and fuel technologies vary widely in their emission reduction potential, cost, engine compatibility, and stage of development (see table 4). At the current time, fuel and retrofit technologies to reduce PM emissions from school buses are more widely available than those to reduce NO_x. The information below is intended to provide the best available information about how various technologies compare today and where they are expected to go in the near future.

Table 4: Diesel Retrofit and Fuel Technology Options

Technology or Fuel	Reduction (%)			Stage of Development[c]	Compatible Engines	Cost[b] (10 years)
	NO_x	PM	Source[a]			
Low-NO_x Biodiesel	7-12	20-30	Man	Available	Most	$1,542
Texas Low Emission Diesel	5.7	10.5	TCEQ	Verified	All	$2,892
Emulsified Diesel	12.9	59.2	EPA	Verified	Most	$5,025
Fuel Catalysts	3-15	30	Man	Verified	All	savings
Diesel Oxidation Catalyst	0	20	EPA	Verified	Most	$1,000
Re-Flash ECM & PM Filter	25	85	Man	Certified	Select	$7,500
Exhaust Gas Recirculation	50	0	COH	Demonstrations	NA	---
Fuel Line Devices	TBD	TBD	Man	Available	Most	$500
Lean NOx Catalyst	25	85	CARB	Verified	Select	$17,500
NOx Adsorber	90	0	Bailey	In development	NA	---
Particulate Filter	0	85	CARB	Verified	1994 & newer	$7,500
Selective Catalytic Reduction	85	25	COH	Available.	Most	$28,500

a. TBD means "to be determined."
b. Source refers to the source of the emission reduction estimates. Verified technologies relied upon verification data from either EPA or CARB. "Man" refers to manufacturer claims. "COH" refers to the city of Houston, which has conducted testing on both EGR and SCR technologies in other applications. Predicted reductions from NOx Adsorber technology are from Owen Bailey, "NOx Adsorbers for Diesel Applications," Available online at www.dieselnet.com.
c. To provide a basis for comparing the costs of fuels and retrofits, "cost" is based on our estimates of the cost of operating a technology for ten years. All capital costs were based on manufacturer estimates. In the cases of emulsified diesel and SCR, the cost of the fuel and the ammonia were included as an operational cost. For emulsified diesel, TERP's $0.26/gallon cost was multiplied by 19,328 gallons (7 miles per gallon for 135,000 miles). The figure represents the premium over the cost of regular diesel and takes into account fuel economy loss. For SCR, the manufacturer provided an estimate of $20,000 for the equipment plus $1,000/year for ammonia. Operational costs were discounted using 3%. The cost of PM filters does not include the cost of early implementation of ultra-low sulfur diesel (ULSD) which would be required on any purchase prior to 2005.
d. Retrofit technologies are "verified" by EPA or CARB, while "certification" is a more thorough process usually used for new engines. Often, grant funding is restricted to verified or certified technologies. "Available" indicates that the technology is ready for purchase but is still in the process of verification and may not yet be eligible for some funding sources.

Fuel-Based Technologies

Biodiesel

Most biodiesel formulations are a poor fuel choice for Houston fleets because they increase overall NO_x emissions. However, a new "Low- NO_x" biodiesel formulation might offer the advantages of biodiesel and lower NO_x emissions. Biodiesel is made of waste vegetable oils or soybean sources and contains no petroleum. One of the most common blends of biodiesel contains 20 volume percent biodiesel and 80 volume percent conventional

Low-NOx Biodiesel		
Reduction	NO_x	7-12%
	PM	20-30%
	Source	Man
Stage of Development	Available	
Compatible Engines	Most	
Cost (10 Years)	$1,542	

See table 4 for notes.

diesel. For soybean-based biodiesel at this concentration, the EPA found that it increased NO_x emissions by 2%, but decreased PM emissions by 10% and hydrocarbon emissions by 21%.[14] For this blend, fuel economy appears to increase by 1-2%. The EPA also evaluated the impact of biodiesel on a group of toxic chemicals commonly found in diesel emissions – in general, biodiesel reduced most toxic emissions.

Extengine has introduced a new "Low NO_x" biodiesel, which is in the process of verification by the California Air Resources Board. According to Extengine's claims, the addition of a polymer to the biodiesel produces a net decrease in NO_x emissions of 7-12% and in PM emissions of 20-30%. (The manufacturer did not provide any information about its potential impact on toxic diesel emissions.) An estimated fuel economy benefit of 5% helps offset the fact that the fuel costs on average about $0.08/gallon more than standard diesel.

Cleaner Diesel Fuel

In addition to stricter engine certification standards, state and federal governments are implementing new diesel fuel standards, which allow for new technologies and reduce emissions. Currently, every state outside of California uses the same diesel. Commonly called "49-state diesel," this fuel has a sulfur standard of 500 parts per million (ppm) and is typically sold with a sulfur content of 300-350 ppm. In September 2006, the federal government will require that retailers and wholesalers only sell ultra low-sulfur diesel (ULSD) with a maximum sulfur content of 15 ppm. The 15 ppm sulfur content standard will allow for the use of technologies that are impaired by sulfur, like PM filters and NOx adsorbers.

TxLED		
Reduction	NO_x	5.7%
	PM	10.5%
	Source	TCEQ
Stage of Development	Verified	
Compatible Engines	All	
Cost (10 Years)	$2,892	

See table 4 for notes.

Texas requires further changes to the diesel formula to deal with NO_x emissions in the eastern portion of the state. The Texas low emission diesel (TxLED) standard builds on the federal requirement for a low sulfur content by placing a 10% cap on aromatic hydrocarbons, which reduces NOx from diesel combustion, and a cetane standard that improves the fuel's ignition properties, further reducing the amount of NO_x produced during combustion. TxLED fuel reduces emissions of NOx by 5.7% and PM by 10.5%. While not required until 2005, TxLED is already available in the Houston region from Valero, which has negotiated a contract with the Texas Department of Transportation (TxDOT). Public school districts can use the TxDOT contract to purchase TxLED for $0.1529 per gallon more than the cost of standard diesel, if they should want to begin using it before 2006.[15] The Houston Independent School District (HISD) and the City of Houston have received Texas Emission Reduction Plan (TERP) funds for early implementation of TxLED.

Emulsified Diesel

Emulsified diesel is a verified emission reduction technology, but its application in a school bus fleet could prove challenging. The Lubrizol Corporation's emulsified diesel (PuriNOx) has been EPA-verified for a 12.9% NO_x reduction, a 59.2% PM reduction, and an 87% increase in HC emissions for heavy-duty, urban bus applications.

Emulsified Diesel		
Reduction	NO_x	12.9%
	PM	59.2%
	Source	EPA
Stage of Development	Verified	
Compatible Engines	Most	
Cost (10 Years)	$5,025	

See table 4 for notes.

Emulsified diesel works well with diesel oxidation

[14] US Environmental Protection Agency, "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions," (Draft Technical Report EPA420-P-02-001).
October 2002.

[15] Based on a purchase of at least 7,000 gallons by a school district in the Houston area. Source: "ULSD- TxLED Valero Pricing." Email from Don Lewis, Fleet Manager, TxDOT. June 11, 2003.

catalysts (DOCs) because the two technologies reduce different types of particulate emissions. DOCs reduce soluble organic particulates, while emulsified diesel fuel prevents the formation of elemental carbon. CARB has recognized that combined, the two technologies have almost cumulative benefits.

PuriNO$_x$ (and other forthcoming emulsified diesel fuels) use an additive that essentially adds a fuel soluble tail to water droplets to form an emulsified water-in-diesel fuel. The presence of water in the combustion chamber reduces the formation of NO$_x$ and PM, but also inhibits the complete combustion of hydrocarbons.

In addition to the increased emission of hydrocarbons, there are several technological issues with emulsified diesel that make it particularly challenging for use in a school bus fleet.

- The fuel results in a slight loss of power. While school districts do not tend to purchase engines with much excess power, early school bus demonstrations show the power loss is manageable. Drivers can detect power loss, but they seem to get used to the change and operate as usual.
- The diesel emulsification breaks down during extended periods when the engine is not in use, and that process occurs more quickly in heat. Official operating procedures require that fuel tanks be emptied and cleaned for seasonal use, which would prove cost prohibitive for most school districts. Undoubtedly these procedures are overly cautious, and Lubrizol representatives cite examples of vehicles starting after a couple months of not being used and suggest that tank emptying may be unnecessary. However, no year-long demonstration project has been undertaken, and it cannot be determined what would happen to a large number of buses not being used during a Houston summer.

Because of these technological issues, a pilot demonstration of emulsified diesel seems appropriate before a fleet fully adopts this technology. In addition, research into the effect of diesel emulsification on air toxics is warranted.

Fuel Borne Catalysts

Several fuel borne catalysts have been developed that boast emission reductions and cost savings to end users.

Fuel Borne Catalysts		
Reduction	NO$_x$	3-15%
	PM	30-50%
	Source	Man
Stage of Development	Verified	
Compatible Engines	Most	
Cost (10 Years)	Savings	

See table 4 for notes.

Biofriendly estimates that its Green Plus additive reduces NOx emissions by least 15%, reduces PM emissions by at least 30%, and improves fuel economy by at least 6%. Biofriendly claims that Green Plus allows the tightly clustered hydrocarbons in these fuels to "open up" slightly so that more oxygen can reach the molecules. As a result, the fuel burns more completely, more evenly and at a cooler temperature. Southwest Research Institute certified that the catalyst lowered the burn temperature and slightly increased the cetane (power) index while causing no harm to engines or components. The catalyst is a liquid, which can be added into a bulk fueling tank or individual vehicle tanks.

Clean Diesel Technology's Platinum Plus catalyst additive has recently been verified, but does not achieve as much NO$_x$ reduction as Green Plus. The company recommends that school bus fleets use its product in combination with a lower-cost, lightly catalyzed diesel oxidation catalyst. Together the technologies reduce NO$_x$ by 3-5%, PM by 41% to 50%, and HC by 25-47%, in addition to offering 7-10% improved fuel economy, which produces net cost savings.

Both manufacturers claim that their products result in a net savings to users, and some distributors may be offering these products under a contract that does not require up-front payment.

Diesel Retrofit Technologies

Diesel Oxidation Catalysts (DOC)

Diesel oxidation catalysts are a proven and cost effective way to reduce PM emissions. As exhaust passes through a DOC, a precious-metal catalyst transforms pollutants into carbon dioxide. The catalyst oxidizes carbon monoxide, gaseous hydrocarbons, and liquid hydrocarbons adsorbed on carbon particles. EPA has verified DOCs manufactured by Johnson-Matthey, Engine Control Systems and Engelhard. All of the DOC's reduce emissions of PM by 20%, HC by 50% and CO by 40%. A DOC can be used on almost any diesel school bus, including buses manufactured before 2004 that are not compatible with particulate filters. DOCs do not require the use of ultra low sulfur diesel.

Diesel Oxidation Catalysts		
Reduction	NO_x	0%
	PM	20%
	Source	EPA
Stage of Development	Verified	
Compatible Engines	Most	
Cost (10 Years)	$1,000	

See table 4 for notes.

Engine Recalibration & Particulate Filter Combination

As part of its "Green Diesel" campaign, International Truck and Engine Corporation offers an engine recalibration and a PM filter retrofit for school buses.[16] The recalibration is a re-flashing of the engine control module; it lowers NO_x emissions by 25%, while the PM filter produces an 85% PM reduction and 60% HC and CO reduction. The company is currently only able to provide this package on school buses with T444E and DT466 engines built between 1999 and 2003 for an approximate cost of $7,500. (However, there are few DT466 engines in Houston area bus fleets.) This retrofit combination has the effect of bringing these older bus engines up to the same emission standards as the company's "Green Diesel" school bus.[17]

Engine Recalibration & PM Filter		
Reduction	NO_x	25%
	PM	85%
	Source	Man
Stage of Development	Certified	
Compatible Engines	Select	
Cost (10 Years)	$7,500	

See table 4 for notes.

Exhaust Gas Re-circulation (EGR)

Exhaust gas recirculation (EGR) is a demonstrated technology in new, cleaner diesel engines, but the technology is not yet available for school buses as a retrofit device. By returning a portion of the engine's exhaust to the combustion chamber, EGR systems displace some of the oxygen that would usually be present in the combustion chamber and decrease the amount of NOx formed. The system can be designed to absorb heat from the combustion process, lowering exhaust temperature and further reducing NOx formation. However, EGR may cause a fuel economy penalty of 3 to 5%.

Cummins has used cooled EGR technology to meet 2004 certification standards with its common ISB engine, but the technology is not yet available as a retrofit device for school buses. Engelhard has partnered with STT of Sweden to offer EGR as a retrofit device, and the companies are in the process of obtaining CARB verification for an urban bus application with an expected NO_x reduction of 30-50%. While added maintenance costs have been a concern in the past, Cummins notes that its engine with cooled EGR technology requires fewer oil and fuel filter changes than 2004 engines that don't use the technology. EGR could become available for a school bus application in the next couple of years.

EGR		
Reduction	NO_x	>30%
	PM	0%
	Source	COH
Stage of Development	Demonstrations	
Compatible Engines	Most	
Cost (10 Years)	$5,025	

See table 4 for notes.

[16] Cleaire, a division of Cummins West, markets a similar recalibration and retrofit; however, the CARB verification for the kit's 25% reduction in NOx is limited to the duty cycle of a long haul truck.

[17] The Green Diesel Bus is certified at 3.0 g/bhph for NOx and .01 for PM.

Fuel Line Devices

Fuel Line Devices		
Reduction	NO_x	TBD
	PM	TBD
	Source	Man
Stage of Development	Available	
Compatible Engines	Most	
Cost (10 Years)	$500	

See table 4 for notes.

While primarily used for fuel economy benefits, some tests suggest that emissions may be reduced by fuel line devices that increase vaporization. Eco Fuel Systems claims that the increase in vapor pressure created by its Eco-4 fuel line system causes fuel to burn more completely, producing lower emissions, increased power and improved fuel economy. The manufacturer states that the copper mesh tube catalyzes a reaction that breaks up the hydrocarbon chains in the fuel. The Eco-4 has been used by the Port of Houston and installed in school buses, including some in Austin ISD. While testing is in its early stages, the manufacturer indicates that the system may improve fuel economy by as much as 10% and reduce tailpipe emissions by upwards of 20%, though the manufacturer did not provide pollutant-specific reductions. The company has recently received a grant for additional testing of its emission claims and will pursue verification.

Lean NO_x Catalysts

Lean NOx Catalysts		
Reduction	NO_x	25%
	PM	85%
	Source	CARB
Stage of Development	Verified	
Compatible Engines	Select	
Cost (10 Years)	$17,500	

See table 4 for notes.

Lean NO_x catalysts are one of the only available retrofit technologies to reduce NO_x emissions. Lean NO_x catalysts inject hydrocarbons or diesel fuel directly into the exhaust stream to convert nitrogen oxides into nitrogen gas, carbon dioxide, and water. Recently, the Cleaire Corporation's Longview was verified by CARB for NO_x and PM reduction, becoming the first verified lean NO_x catalyst. The Longview combines a NO_x reduction catalyst and a diesel particulate filter in a single muffler to produce a NO_x reduction of 25% and a PM reduction of at least 85%.

Currently, the technology is verified for the International DT466 and the Cummins ISM engines from 1994 to 2002, which represent nearly 800 school buses in the area. The company is in the process of extending its verification to the Cummins ISB and ISC engines.

NO_x Adsorbers

NOx Adsorber		
Reduction	NO_x	90%
	PM	0%
	Source	Bailey
Stage of Development	In development	
Compatible Engines	---	
Cost (10 Years)	---	

See table 4 for notes.

Nitrogen oxide adsorbers are still in the development stages but show the potential to reduce NO_x by 80% or more in new model year engines. The adsorbers are a further development of the three-way catalyst technology that was developed for gasoline powered vehicles more than 25 years ago to reduce NO_x , HC and CO. Also called "traps," NOx adsorbers capture and store NO_x during oxygen-rich driving conditions and lower NOx emissions using a 3-way catalyst function during fuel-rich driving conditions. NO_x adsorbers do not affect PM, hydrocarbon or air toxic emissions. The traps require periodic injection of a reducing agent like hydrocarbons to regenerate. When it passed the 2007 engine standards in December of 2000, EPA documents determined that "the potential of the NO_x adsorber catalyst is limited only by its need for careful integration with the total vehicle system . . . and by poisoning of the catalyst from sulfur in the fuel." However, no manufacturer, EPA, or other knowledgeable person claims that NO_x adsorbers are likely to be available for school bus retrofits in the foreseeable future.

PM Filters

PM Filter		
Reduction	NO_x	0%
	PM	85%
	Source	CARB
Stage of Development	Verified	
Compatible Engines	1994 and newer	
Cost (10 Years)	7,500	

See table 4 for notes.

Diesel PM filters are widely available and offer the largest PM reductions available by filtering particulates from diesel exhaust. Two filters have been verified by EPA and CARB and reduce PM by 85% and HC and CO by at least 60%.[18] These filters do not affect NOx emissions.

The filters require that the engine produce enough heat to periodically burn (oxidize) the particles off the filter. These filters are usually compatible with all diesel school buses that are model year 1994 and later. Although a retrofit project in New York city ran into a few problems with buses not sustaining a sufficient engine temperature to use the filters, a similar project in Los Angeles did not have problems with compatibility. (Bus stops in Los Angeles are not as closely spaced as those in New York City).[19] According to EPA verification documents, the Johnson-Matthey filter requires that the engine exhaust temperature be at least 275 degrees C for approximately 40 to 50 percent of the duty cycle, while the Engelhard DPX requires that the engine exhaust temperature must be at least 250 degrees C for 30 percent of the duty cycle. As there may be significant variations from application to application, both companies will review actual vehicle operating conditions and perform temperature datalogging prior to retrofitting a vehicle with their PM filter system to ensure compatibility.

PM filters require the use of ultra-low sulfur diesel (ULSD), because sulfur can clog the filter and increase the temperature required for successful regeneration. Districts considering the purchase of PM filters before 2005 would need to use TxLED fuel, and might seek TERP funds to cover the additional costs incurred due to early implementation of TxLED fuel.

Selective Catalytic Reduction (SCR)

Selective Catalytic Reduction (SCR)		
Reduction	NO_x	85%
	PM	25%
	Source	Man
Stage of Development	Available	
Compatible Engines	Most	
Cost (10 Years)	$28,500	

See table 4 for notes.

While not yet verified, SCR technology shows great potential for emission reductions and will likely be the next available NOx reduction retrofit for school buses. SCR uses an anhydrous ammonia injection system upstream of a diesel catalytic converter to remove oxygen from nitrogen oxides. The amount of NOx reduced depends upon the amount of ammonia used.

Two companies hope to have official verification for very similar SCR systems by the end of 2003 and intend to apply the technology to school buses. The City of Houston's demonstration project found that the technology can reduce NO_x emissions by 85% and PM emissions by 25%.[20] Both KleenAir's "NOx Master" and Extengine's SCR system cost around $20,000; a school bus would be expected to use $1,000 to $1,500 worth of ammonia each year. The manufacturers expect the cost of the retrofit and the ammonia to drop as demand increases. As demonstrated in Houston's study, the technology can be used in combination with a particulate filter for additional emission benefits.

There are safety and environmental considerations related to possible ammonia leaks. The systems are constructed to minimize ammonia "slip" (excess ammonia emissions). Manufacturer test data indicates that no slip occurs when the system is functioning properly. In an accident or fire, a small orifice built-in downstream of the manual canister valve would reduce the flow of ammonia by 96%. The canister has an additional shut-off valve for closing down the flow of ammonia through the system. If a leak should occur, it would be easily detected by odor dispersed in the air.

---

[18] EPA has verified both the Engelhard and the Johnson-Matthey CRT for 60% reductions in PM, HC, and CO. While the CARB verification does not include HC or CO emissions, it has verified a 85% PM reduction with both devices.

[19] Information about the Los Angeles and New York City projects based on a phone interview with Kevin Hallstrom, Engelhard Corporation, June 19, 2003.

[20] Environment Canada, "City of Houston Field Demonstration Project." (ERMD Report #01-36.)

Replacement Strategies

Accelerated Replacement

Accelerated Replacement		
Reduction (as modeled for Houston-area fleet)[21]	NO_x	11%
	PM	20%
	Source	Man
Stage of Development	Available	
Compatible Engines	Pre-1990	
Cost (10 Years)	$65,000	

See table 4 for notes.

Accelerated bus replacement is usually the only practical option for reducing emissions for the oldest buses in the fleet. The oldest buses on the road emit the most per mile and have few available retrofits. When retrofits are available, fleet managers must decide whether the bus has enough remaining life to justify the investment in the new technology. In some cases, an inexpensive DOC might be justified, but it is not likely that a district would want to spend the money on a more expensive NO_x reducing technology, like SCR, on a bus that will only be on the road for a few years.

Re-Powers (Engine Replacement)

Re-powers		
Reduction (as modeled for Houston-area fleet)	NO_x	11%
	PM	20%
	Source	Man
Stage of Development	Available	
Compatible Engines	Most	
Cost (10 Years)	$35,000	

See table 4 for notes.

Re-powering existing buses with new, cleaner engines can produce the emission benefits of accelerated replacement at a lower cost. A number of school buses in Sacramento, California have recently been re-powered with the Cummins ISB cooled EGR engine in combination with the Cleaire Longview lean NO_x catalyst for impressive emission reductions. Re-power projects usually cost about $35,000 for the new engine and labor, not including retrofits. The life expectancy of a re-powered bus is less than that of a new bus, although no specific life expectancy values are readily available from any source. Because new diesel buses cost about $65,000, districts may find it more cost-effective to purchase new buses that will have longer lives than re-powered buses.

Deferred Purchasing

Deferred Purchasing		
Reduction (as modeled for Houston-area fleet)	NO_x	8%
	PM	10%
	Source	Man
Stage of Development	In Development	
Compatible Engines	Pre-1990	
Cost (10 Years)	$2,750	

See table 4 for notes.

Because federal emissions standards become considerably more restrictive beginning in 2007, school districts could decide to defer the purchase of new buses until these cleaner buses are available. School districts routinely purchase new buses to meet growth in demand and to replace aging buses; about 960 buses are expected to be purchased by the districts in the study sample. According to EPA estimates, buses meeting the 2007 standard will cost approximately $2,750 more than 2004 model year buses and will reduce the maximum emissions of NO_x and PM by 90%.[22]

One concern with deferring purchases to achieve greater emissions reductions is that school buses meeting the 2007 standard might not become available in 2007. While testing of new technologies indicates that the standards are feasible, further development is needed – and some industry groups are continuing to press for further delay of the standard's implementation. Even if the standard remains in place, there is a loophole that would allow EPA to grant "deficiencies" to manufacturers where compliance with the new requirements would be "infeasible or unreasonable considering such factors as, but not limited to, technical feasibility of the given hardware and lead time and production cycles."

[21] Because districts use new buses for more annual miles than older buses, an accurate estimate of emission reductions from replacement strategies must take into account factors such as routine bus purchases, changes in annual miles for each bus year, and other factors. The modeled emission reductions are a fleet-wide estimate based on accelerated replacement or engine replacement of all Houston are pre-1990 buses after considering normal purchase rates. The deferred replacement strategy assumes that all routine bus purchases after 2004 would be with buses meeting the 2007 emission standard.

[22] Based on an estimate of hard costs by EPA in 2000 when the new standards were proposed. The current cost of new technologies, including PM filters, will need to decrease in cost for this estimate to prove accurate.

Another concern is that while a deferral strategy could reduce emissions in 2007, it would require districts to keep older, higher emission buses on the roads longer. This could temporarily inflate district maintenance costs (or require short-term bus leases) and might require some districts to change capital spending plans to assure adequate funds for the deferred purchases.

A third concern is that the actual cost to buy a bus meeting the 2007 standard is not yet known. Although EPA estimates it will cost only $2,750 more than a 2004 model year bus, the available technology that comes closest to meeting the 2007 standard costs as much as ten times more than this.

A single district on its own might face considerable risk if it chose a deferred purchasing strategy to maximize emission reductions in 2007. However, bus engine manufacturers might respond with more aggressive technology development if several districts adopted a coordinated deferred purchasing strategy by issuing an RFP to purchase a large number of buses meeting the 2007 emission standard.

Finding Cost-Effective Solutions

Reducing school bus emissions is expensive, but some approaches cost more than others. At the current time, cost-effectiveness calculations do not identify one "best" solution for all school buses in the region, but calculating the cost of reducing one ton of NO_x with different strategies is a good way to see which options give the most clean air for the money.[23]

In general, retrofit technologies are more cost-effective than bus replacement, but are limited in their application. Because strategies are usually better at either NO_x reduction or PM reduction, it is most useful to compare the cost effectiveness of strategies that are directed at the same pollutant, while considering other reductions in final decision making.[24]

It appears that school buses are a less cost-effective way to reduce NO_x emissions than reductions from other sources of NO_x in the Houston region. This is because bus engines are used less intensively than many other diesel engines, making the emission-reduction return on a capital investment less productive. (School buses are idle much of the day and much of the year. In contrast, high-use freight equipment may be in use over ten hours a day, virtually every day.) However, several pollution reduction technologies reduce PM and toxic emission exposures for children riding in the school buses as well as those in the vicinity of idling school buses.

Engine recalibration is the most cost-effective option for achieving immediate reducing NO_x emissions (see table 5). Deferring purchases until 2007, when standards should make cleaner buses available, could be the most cost effective NO_x strategy (see table 5). However, as discussed above, there are several concerns with a deferred purchase strategy – considering the uncertainty in the incremental cost for buses meeting the 2007 emission standard, the cost-effectiveness of deferred purchasing could be considerably higher than estimated in table 5.

SCR technologies are not presently cost-effective enough to qualify for major grant programs available for reducing NO_x emissions in the Houston region. Furthermore, they are not yet verified. However, as demand for SCR in other applications increases, costs may decrease enough to make them cost-effective for school buses.

Diesel oxidation catalysts (DOCs) are the most cost effective PM reduction strategy (see table 6). PM filters produce greater reductions for individual buses, but less overall reduction for the price.[25]

---

[23] Because cost effectiveness can vary between buses depending on miles and emission rates, all of the cost estimates in this report are calculated as an average for applying a strategy to compatible buses in the sample collected by GHASP using the formula that is required for funding under the Texas Emission Reduction Plan (TERP).

[24] Cost effectiveness of VOC reductions are difficult to estimate because reductions are not available for all emission control technologies.

[25] While available engine recalibration and lean NO_x catalysts incorporate PM filters, those technologies are evaluated as NOx reduction technologies in table 5.

Table 5: Cost Effectiveness for NO_x Reduction Strategies for Area Fleet

Strategy[a]	Cost Effectiveness (Annualized $/ton)	Availability	Application[b]
(A) Engine Recalibration	23,157	Now	INTL T444E & DT466 ('99-'03)
(B) NOx Catalyst	54,944	Now	INTL DT466 & CUM ISB ('94-'02)
(C) SCR	28,032	Soon	Any (analysis: 1990 and newer buses)
(D) Replacement	65,577	Now	Any (analysis: pre-1990 buses)
(E) Deferral[c]	5,402	2007	New purchases deferred until 2007

Notes:

a. Technologies considered available for widespread school bus application are included. A number of promising fuel-based technologies do not yet meet this standard. More testing is needed on the emission reductions from fuel borne catalysts and "Low-NO_x" Biodiesel, and a full year school bus demonstration of emulsified diesel is needed to determine whether fuel settling or separation would be a problem during summer or winter breaks.

b. Application refers to the compatibility of the strategy to different buses. On technologies like SCR that could presumably be applied a large variety of buses, this column indicates an "ideal" or best-fit application.

c. Routine bus purchases between 2005 and 2007 are assumed to meet the 2007 standard. The incremental cost of the plan was assumed to be $2,750, based on EPA estimates of hard costs when the standard was proposed.

Table 6: Cost Effectiveness for PM Reduction Strategies for Area Fleet

Strategy	Cost Effectiveness (Annualized $/ton)	Availability	Application
(F) DOC	204,298	Now	Any
(G) PM Filters	331,306	Now	1994 & newer

The strategies listed in tables 5 and 6 can be combined in various ways, depending on whether the desired goal is to minimize cost, achieve maximum NOx or PM pollution reductions, or maximum pollution reductions of both NO_x and PM. Table 7 presents summary information on "plans" that include deployment of more than one available technology. The costs are estimated by multiplying the number of suitable buses in the Houston-area fleet times the estimated cost. Emission reductions are calculated in a similar manner, taking into account changes in mileage when fleet mix is adjusted. With costs ranging from $18 million to achieve fairly modest pollution reductions to $270 million for the maximum available pollution control effort,

Table 7: Cost-Effectiveness of Combined Strategies for Area Fleet

Plan[a]	Strategies Used (Tables 6 and 7)	Buses	Cost (millions)	Reductions (tons per year / %)				Cost-Effectiveness (Annualized $/ton)	
				NO_x		PM		NO_x	PM
NO_x Retrofits	A, B	1,345	$ 18	51	7%	3.2	16%	42,000	677,000
PM Retrofits	A, F	6,801	$ 35	20	3%	12.0	60%	204,298	346,000
SCR Strategy	A, C	2,931	$ 84	341	46%	3.2	16%	29,000	3,072,000
Replacement	A, C, D	3,891	$ 147	385	52%	6.3	31%	45,000	2,743,000
Maximum	**A, C, D, F**	**6,799**	**$ 270**	**580**	**78%**	**16.3**	**81%**	**55,000**	**1,943,000**

Notes: While engine recalibration and lean NO_x catalyst plans include every compatible bus, the more versatile SCR technology was only applied to 1990 and newer buses in the five districts with a high number of buses that could be compatible. This limitation was based on the assumption that districts would only invest in the training and equipment to maintain SCR technology if there were a critical mass of buses, and had the ability to take advantage of quantity pricing discounts for the SCR technology and ammonia delivery. In some circumstances, a few buses had two compatible technologies applied in the same plan.

Evaluating Fuels

All of today's school buses—whether powered by diesel or alternative fuel—release smog-forming pollution (nitrogen oxides and hydrocarbons), soot (particulate matter) and greenhouse gas emissions. For many years, alternative fuel school buses have been much cleaner than their diesel counterparts, but most districts have continued to purchase diesel because of its performance and low cost. For model year 2003, compressed natural gas (CNG) school buses remained cleaner than buses powered by other fuels, but CNG buses are also the most expensive (table 8). In the near future, however, stringent new emission standards and improved engine technologies will challenge all previous assumptions about which fuel is "best," and school districts should be prepared to reevaluate their purchasing decisions. A description of issues related to each fuel option is offered below.

Table 8: Comparing Emissions & Cost of Cleanest Available School Buses

Engine	Fuel	Emissions (g/bhph)[a]		Cost of Bus[b]
		NO_x + HC	PM	
John Deere 8.1	CNG	1.5	.01	$110,000 [c]
Cummins B-Gas Plus	CNG or LNG	1.8	.02	$110,000 [c]
Cummins B LPG Plus [d]	Propane	2.2	.1	$80,000
Caterpillar Acert C-7	Diesel	2.5	.1	$65,000
Cummins ISB	Diesel	2.5	.1	$65,000
GM 8.1 [e]	Propane	0.6	.002	$80,000
Mercedes MBE906	Diesel	2.5	.1	$65,000
International "Green Diesel" [f]	ULSD	3	.01	$75,000

Notes:
a. Emissions based on EPA certification, which is still pending for the John Deere 8.1 L.
b. Based on estimates from Capital Bus Sales and engine manufacturers.
c. Would also require investment in expensive fueling station and maintenance facility.
d. Was not made available in school buses in 2003, though it is expected to be available in 2004.
e. Corbeil propane school bus described at www.propaneschoolbus.com.
f. Currently only available in 84 passenger size, common in California.

Compressed Natural Gas (CNG)

While cost prohibitive for many area school districts, CNG school buses remain the cleanest commercially available technology in terms of NO_x emissions. Currently, the cleanest CNG school bus engine emits 40% less NO_x than the cleanest diesel school bus.[26] Furthermore, PM and air toxic emissions from CNG buses are lower than those from traditional diesel buses, though retrofitted diesel buses are sometimes cleaner in this respect.[27] CNG could also provide a stepping stone to hydrogen and eventually hydrogen-powered fuel cell buses because its infrastructure is likely to be adaptable to hydrogen. However, CNG buses cost at least $30,000 more than diesel buses and require large initial investments in infrastructure. Initial infrastructure costs include about $750,000 for a fueling station and $300-400,000 for a maintenance facility. CNG fuel is only widely available in urban areas, so traveling with CNG buses can be difficult.

Diesel

Because of increased government regulation, diesel engine manufacturers are making progress in controlling emissions, and future technologies show promise in bringing emissions to even lower levels. New technologies used for PM reductions may have the added benefit of reducing air toxic emissions to

---

[26]According to Tom Cummins and Glen Crucial at John Deere, the John Deere 8.1 L CNG engine is being certified at 1.5 g/bhph for NOx and HC combined by the end of summer. Both the Cummins ISB and the Caterpillar C-7 Acert engine are certified for 2.5 g/bhph for NO_x and HC combined.

[27] "ARB's Study of Emissions from 'Late Model' Diesel and CNG Heavy-Duty Transit Buses: Toxic Compounds and PM Emissions." Presentation by Albert Ayala, Norman Kado, Paul Rieser, and Robert Okamoto. CARB. (2001).

levels that are below what the latest technologies for CNG buses have been able to achieve.[28] The improved emissions of diesel engines will come at a cost. As discussed above, EPA estimates that buses purchased in 2007 will cost $2,750 more than buses meeting the 2004 standard. However, it is unclear whether the cost differential can be kept that low. For instance, the current cost for a PM filter alone is $7,500. To meet the new NO_x standard, buses will likely require diesel engines to use NO_x adsorbers, SCR or improved cooled EGR systems in their design.

Propane

A number of Texas school districts, including Alvin ISD in the Houston area, operate propane fleets. In fact, Texas has the largest propane fleet in the country, with over 2,000 state school buses using the fuel. Some districts have found propane bus operating costs to be lower than those for diesel, with lower maintenance and reduced overall emissions. Because propane has much lower infrastructure costs than CNG, it is a more cost-effective alternative to diesel. Furthermore, the only available propane bus is considered cleaner than all other buses.

One concern for some school districts is availability of propane school buses. Until 1993, school districts had been able to purchase school buses with gasoline engines that were easily convertible to propane. In 2003, no manufacturer made propane school buses or easily convertible gasoline school buses available. As noted in table 8, however, Corbeil is now selling propane buses again. Furthermore, because it is responsible for promoting the use of alternative fuels in Texas, the Texas Railroad Commission works with manufacturers to help make both propane school buses and easily convertible gasoline school buses available in future years.

Helping School Districts Pay for Emission Reduction

While school districts in the Houston-Galveston area can access a fair amount of state and federal funding to reduce NOx emissions, far less funding is available for retrofits that reduce just PM emissions, despite the health risks posed by high levels of PM pollution.

Adopt-A-School Bus Program www.adopt-a-schoolbus.org

The Adopt-A-School Bus Program, sponsored by the U.S. EPA and the Education Foundation of Harris County, will offer matching grants to help school districts fund new purchases and retrofits. Announced in May 2003, the program has received a federal grant and is seeking corporate sponsors.

Clean School Buses USA www.epa.gov/otaq/schoolbus/funding.htm

Congress included $5 million in EPA's 2003 budget for a cost-shared grant program designed to assist school districts in upgrading their bus fleets. The EPA received applications for over fifty times that much money, including one from Pearland ISD. The Texas State Energy Office received a grant, and will use will use $300,000 in the Houston area to install particulate traps on 22 buses and modify 135 diesel-powered buses to take full advantage of the TxLED fuel. Congress has appropriated $5 million for the program in the 2004 budget.

Congestion Mitigation and Air Quality (CMAQ) Funding www.houston-cleancities.org

[28] CARB found that diesel buses with PM filters have lower overall air toxic emissions than CNG buses. The study detected 1,3 butadiene in CNG exhaust but not diesel exhaust and found that carbonyl emissions, mostly of formaldehyde, were much higher from CNG buses than from diesel buses with PM filters. In a follow-up study, CARB found that oxidation catalysts were successful at decreasing formaldehyde, non-methane hydrocarbons, and some butadiene emissions from CNG buses, but did not decrease heavy polycyclic aromatic hydrocarbon (PAH) emissions, which remained substantially higher than for diesel buses with PM filters. Sources: "ARB's Study of Emissions from 'Late Model' Diesel and CNG Heavy-Duty Transit Buses: Toxic Compounds and PM Emissions," (CARB, 2001) and "Chemical and Bioassay Analyses of Emissions from Two CNG Buses with Oxidation Catalysts" (CARB, 2002 DRAFT).

Fifty million dollars in federal CMAQ funds are available in the Houston-Galveston nonattainment area through the Houston-Galveston Area Council's Clean Cities/ Clean Vehicles program. Under the program, area school districts qualify to receive up to 75% of the cost of replacing, repowering, or retrofitting school buses to help lower NO_x emissions in the area. Only technologies that have been verified qualify, and CMAQ funds cannot be used for the costs of fuel (though they can be used to build clean fuel infrastructure). CMAQ can only fund projects that fall below its cost effectiveness cap of $150,000 per ton of NO_x reduced, which may also be expressed as a cap of $15,000 in annualized costs. To assist applicants calculate emission reductions and cost effectiveness, the Clean Cities/ Clean Vehicles website offers a heavy-duty emissions calculator.

Three school districts have received grant funding under this program, and others have applied (see table 9). It should be noted that the cost-effectiveness calculation by H-GAC differs in three respects from the figures presented above. First, it is a total cost-effectiveness calculation, rather than annualized. Second, the only costs included in the cost-effectiveness calculation are the grant costs; this report considers the full cost of the emission reduction project. Third, the NOx emission reduction estimate may be based on different assumptions about miles traveled than the method used for this report.

Table 9: Approved CMAQ School Bus Emission Reduction Projects

Recipient	Project	Total Cost	CMAQ Grant	NO_x Emission Reduction (tons per year)	Cost-Effectiveness ($ per ton per year)
Alvin ISD	7 propane retrofits 6 propane buses	$74,200	$55,650	0.36	$154,583
Alvin ISD	2 propane retrofits	$9,400	$7,050	0.06	$113,710
Cy-Fair ISD	30 diesel repowers	$1,184,850	$729,000	4.86	$150,000
Houston ISD	80 diesel repowers	$2,493,807	$1,870,355	15.13	$123,660
Houston ISD	2 diesel repowers	$74,442	$55,831	0.51	$109,258
Total	**127 school buses**	**$3,836,699**	**$2,717,886**	**20.92**	**$129,918**

Source: Houston-Galveston Area Council (February 2004).

EPA's Voluntary Diesel Retrofit Grant Program www.epa.gov/otaq/schoolbus/funding.htm

EPA awards grants to retrofit diesel school buses through its Office of Transportation and Air Quality. In previous years, several of these grants have gone to local school districts and government entities.

Texas Emission Reduction Plan (TERP) Grants www.tnrcc.state.tx.us/oprd/sips/terp.html

The Texas Commission on Environmental Quality (TCEQ) awards state TERP funds for NO_x reducing projects in the Houston-Galveston nonattainment area. School districts are eligible for these funds, which can be used to help cover the costs of purchasing or retrofitting school buses, building clean fuel infrastructure, purchasing qualifying fuels, and demonstrating new technologies. TERP pays the entire incremental cost of a new technology up to an annualized cost of $13,000 per ton of NO_x reduced.

Texas Railroad Commission Alternative Fuel Incentive Grants www.rrc.state.tx.us

The Texas Railroad Commission's Alternative Fuels Research and Education Division (AFRDC) has made numerous incentive grants to school districts interested in using alternative fuels. While no funds are available at the time of this publication, AFRDC hopes to offer more grants in the future.

Contacts (provided for information only – no endorsement implied)

Diesel Retrofits
"Eco-4" Fuel Line Device
Wade Thomason
Eco Fuel Systems
(no email address available)
(512) 480-2218

Engelhard PM Filters & DOCs
Kevin Hallstrom
Engelhard Corporation
kevin.hallstrom@engelhard.com
(732) 205-6489

Extengine SCR & "Low-NO_x" Biodiesel
Phillip Roberts, President
Extengine Transport Systems
proberts@extengine.com
(714) 774-3569

International Recalibrations & Retrofits
David Coffee, Sales Manager
International Trucking
dcoffee@intltrucks.com
(713) 933-2376

Johnson Matthey PM Filters & DOCs
Marty Lassen, Market Development
lassen@jmusa.com
(610) 341-3404

"Longview" NO_x Reduction Catalyst
Susan Cleaver, Sales Manager
Cummins Southern Plains
susan.e.cleaver@cummins.com
(817) 640-6981

"NO_x Master" SCR, PM Filters, & DOCs
Daniel Sloan, President/CEO
Emission Reduction Specialists
dsloan@emissionspecialists.com
(832) 485-9016

Fuel-Based Technologies
"PuriNO$_x$" Emulsified Diesel
John Gemmell, Commercial Manager
Lubrizol
jwge@lubrizol.com
(281) 799-5829

"Green Plus" Fuel Catalyst
Jim D'Arezzo, SVP Sales & Marketing
Biofriendly Corporation
jim@biofriendly.com
(626) 303-6000

"Platinum Plus" Fuel Catalyst + DOC
James Valentine, President
Clean Diesel Technologies, Inc.
valcom7@aol.com
(203) 327-7050

Alternative Fuels
Alternative Fuel Engines
Larry Tatorowicz, Sales & Marketing
Cummins Westport
ltatarowicz@cumminswestport.com
(214) 766-4473

Alternative Fueling Infrastructure
David Haradon, General Manager
Clean Energy Fuels
dharadon@cleanenergy.fuels.com
(214) 615-3830

TxLED
Kimberly Murphy
Valero
kimberly.murphy@valero.com
(713) 923-3359

Funding
Adopt-A-School Bus USA
Barbara Schuppener
U.S. EPA, Region 6
schuppener.barbara@epa.gov
(281) 983-2117

Clean Cities/Clean Vehicles (CMAQ)
Beth Whitehead
Houston-Galveston Area Council
bwhitehead@hgac.cog.tx.us
(713) 993-4582

Texas Emission Reduction Program Grants
Steve Dayton, Senior Grants Manager
Texas Commission on Environmental Quality
sdayton@tceq.state.tx.us
(512) 239-6824

Acknowledgements

Many public officials, industry representatives, academics and environmental advocates provided the data, research, and background that made this report possible. GHASP gives a special thank you to the transportation staff and public information officials in each district that responded to open records requests and other questions. The National Association of Pupil Transportation (NAPT) and the staff of several out-of-area school districts including the Elk Grove School District in California shared valuable information as well.

The report includes contact information for many of the industry representatives who provided useful information about different emission reduction strategies. In addition to these distributors, we received useful information and contacts from the staff of the Diesel Technology forum, the Natural Government Vehicle Coalition, the Engine Manufacturer's Association, the Manufacturers of Emission Controls Association, Environ, and Southwest Research Institute.

Many public agencies made an extra effort to help with this project, including the staffs of the US Environmental Protection Agency Region VI, EPA's Clean School Bus USA program, EPA's voluntary diesel retrofit program, EPA's verification program, the California Air Resources Board verification program, CARB's lower emission school bus program, Texas Education Agency's office of transportation, the Texas Commission on Environmental Quality technical analysis division, the City of Houston's environmental office, the Sacramento Metropolitan Air Quality Management District, and the Sacramento School Bus Consortium.

Public interest advocates offering special assistance include the staffs of Natural Resources Defense Council, Union of Concerned Scientists, and Environmental Defense.

Finally, GHASP acknowledges the financial support of its contributors, and the two internship programs that made this project possible. Rachel Krause was supported by the Texas Public Interest Research Group Fellowship and Dustin Rynders was supported by the ECO/EPA Community Intern Program, sponsored by the US Environmental Protection Agency Office of Environmental Justice.

GALVESTON•HOUSTON ASSOCIATION•FOR SMOG•PREVENTION

The Galveston-Houston Association for Smog Prevention (GHASP) is a community-based environmental organization dedicated to improving the quality of our region's hazardous air through public education, participation in the state and federal planning process, and active advocacy in appropriate venues.

3015 Richmond, Suite 201
Houston, TX 77098-3013

www.ghasp.org

713.528.3779
info@ghasp.org

Appendix
Reducing Air Pollution from Houston-Area School Buses
Sources and Methodology

GHASP collected current bus inventory data and fleet operation information from districts in Brazoria, Fort Bend, Galveston, Harris, and Montgomery counties. Districts were contacted at least three times with a public information request; those districts that have not yet responded represent about 12% of the region's student population (see appendix table A). Each district was asked for an inventory including bus model year, engine size, engine manufacturer, capacity, fuel type, and annual miles traveled. Additionally, each district was asked for total fleet miles and students served and information about its idling policies, fueling stations, and purchasing practices.

Few districts provided data on mileage by model year, bus purchasing, or bus replacement. GHASP modeled mileage, bus purchasing, and bus replacement from data provided and student enrollment data from the Department of Education's National Center for Education Statistics.[1] Research about available technology began with a review of current literature in academic, government, and advocacy publications and continued with countless interviews with directors of transportation, engine and retrofit manufacturers, and government officials.

Adjusted Bus Mileage

In most fleets, older buses are driven fewer miles than new buses. Only seven school districts provided specific mileage data by model year. In order to estimate the mileage traveled by each bus in the region, a standard distribution of miles by model year was derived from the seven-district sample, and this distribution was then adjusted for each district by its total fleet mileage. For an example, see appendix table B.

Changing Bus Inventory

Districts' fleets change in size and composition over time. To reflect these changes, bus inventories and student enrollment statistics were used to calculate bus need, purchasing, and replacement.

Each district's bus per student ratio was used to measure its bus need. Growing districts were assumed to purchase new buses to meet their increased need, while districts that were losing students were assumed to be able to retire buses because of their decreasing need. Linear regression was used to forecast student enrollment for the 2003 to 2007 school years. For each forecasted year, the difference in student enrollment from 2003 was multiplied by the bus/student ratio and rounded to the nearest whole number to determine the cumulative change in bus need for that year. The change in bus need for each individual year was the difference between each forecasted year's cumulative change in need and that of the previous year (see appendix table C).

Expected bus replacement was calculated based on assumptions about past purchasing and changing need. Because longitudinal data on bus purchasing were not available, the numbers of buses of each model year were used to indicate bus purchasing during the 1997 to 2002 school years. The difference in the estimated change in bus need and purchasing were assumed to indicate bus replacement.

District replacement rates were adjusted to account for atypical replacement patterns on both extremes of the region's average. Individual district's estimated annual replacement rates ranged from 0% to 10%, with the region's average at 4%. Districts with older fleets tended to replace buses at higher rates, while districts with newer fleets tended to replace buses at slower

---

[1] Department of Education's National Center for Education Statistics, "Common Core of Data" for the 1997 to 2002 school years.

rates. Expecting regression to the mean over time, an adjusted replacement was calculated by taking the average of each district's calculated replacement rate and the region's average.

Accordingly, each district's total bus purchases for a year were calculated according to the following formula:

$$P = \Delta N + R$$

Where,

P = Total number of new buses purchased

Δ N = Change in bus need

R = Expected replacement buses

Whether retiring buses for replacement or decreased need, districts were assumed to retire the oldest buses in their fleet. The size and fuel type of the buses purchased were calculated based on each district's inventory. Buses being replaced were assumed to be replaced with a bus of the same size. To meet the demands of new need, growing districts were assumed to buy buses of different sizes proportional to their representation in the current fleet. However, the inventory data showed a clear trend away from gas, which was confirmed in interviews with district officials and bus sales representatives. The model years with the highest number of gas buses were in the early eighties, and the new gas purchases were mainly for smaller buses. Because of the trend away from purchasing gas buses, all new purchases were assumed to be diesel.

Emission Factors

To the extent possible, this report uses emission factors from the Houston-Galveston Area Council's (HGAC's) heavy-duty emissions calculator.[2] While Mobile 6 has a school bus category, this data was not accessible on the HGAC calculator. Class, year, and fuel type were used to obtain an emission factors in grams per mile from the calculator. The calculator was created by Environ using data and procedures from EPA's MOBILE6 model and its accompanying reports.[3] Engine emission rates were determined from certification data, and an average value from the public EPA reports was included as the default estimate.[4] The emission factors are for 2007 emission rates, not 2003. H-GAC has no estimated emission rates for 2003.

When class was not given by the school district, it was approximated based on bus capacity. Buses with capacities fewer than 19 were classified as 2b, between 35 and 47 were classified as class 6, between 53 and 72 were classified as class 7 and those with more than 72 were classified as 8a.

HGAC emission factors for NOx, PM, and VOCs were used for all current and past model year diesel engines. NOx emission factors were used for gas-powered buses as well. This resource does not include emission estimates for CNG or propane vehicles or PM from gasoline engines.

Calculating PM for Gas Buses

Little information is available on in-use emissions of particulates from heavy-duty gasoline engines. Since emissions have been presumed to be low enough to render standards unnecessary, the U.S. EPA has never imposed standards on PM from heavy-duty gasoline engines. Furthermore, the relatively low number of heavy-duty gasoline engines in operation has made emissions testing for the vehicles a low priority. This report uses data from California's

---

[2] Houston Galveston Area Council (HGAC), "Heavy-Duty Emission Calculator." Online. Available: http://www.houston-cleancities.org/index.html.

[3] U.S. Environmental Protection Agency. MOBIILE6 reports: EPA420-P-98-015 and EPA420-P-99-030, as cited in "Heavy-Duty Emission Reductions Calculations." Memorandum from Chris Lindhjem to Lily Wells on November 19, 2002 ("Lindhjem memo").

[4] Lindhjem memo.

EMFAC 2000 model was used to estimate PM from gasoline school buses.[5] The EMFAC model assumes that gasoline-powered heavy-duty trucks of all model years will emit 0.054 grams per mile, with no deterioration over time. This model may underestimate particulate emissions for two reasons. First, the testing was conducted on newer trucks, which may have lower emissions than the older vehicles because of engine improvements over time. Second, the EMFAC data for particulate emissions were based upon in-use data for light-duty trucks, and it is not clear how closely the emissions profile for medium heavy-duty vehicles such as school buses would compare.[6]

Calculating Emissions for Propane and CNG/Diesel Hybrid Buses

The regional inventory of 6,643 buses included 16 propane buses in LaPorte I.S.D. and 28 CNG/diesel hybrid buses in Katy I.S.D.[7] No reliable emission factors were available for these buses. In the case of the CNG/diesel hybrid buses GHASP assumed an emission factor of 25% less than a diesel bus of the same year and size. Similarly, in the case of the propane bus, GHASP assumed an emission factor, of 25% less than a gas bus of the same year and size. This assumption affects only small number of buses and districts.

Calculating Emissions for Future Model Year Buses

Because engine certification data is not available for engines that have not yet been built, emission factors for future model year buses were estimated using federal emission standards. The ratio of the federal standard to emission factor for 2003 model year buses was used to predict emission factors for future model year buses of the same size and fuel type according to the following formula:

$$E_x = S_x * (S_{2003} / E_{2003})$$

Where,

E = Emission Factor (grams/mile)
X = Year
S = Standard (grams per brake horsepower-hour)

The 2004 standard is combined for NOx and hydrocarbons (HC) at 2.5g/bhph. Based on our conversations with engine manufacturers and the EPA standards office, we used 2.0 as the standard for NOx and 0.5 as the standard for HC. The HC standard was used to forecast VOC emissions.

EPA's planned phase-in of new standards requires that 50% of the engines sold in 2007 must meet the new 2007 standard. To account for this, GHASP used an average of the 2004 and 2007 certification standards to calculate 2007 emission factors.

Conversions Used

To present emission estimates consistently, the following conversions were used:

907,200 grams = 1 ton
and
1 ton = 2,000 pounds

---

[5] California Air Resources Board (CARB). "Technical Support Document," EMFAC 2000. Sacramento, CA. Online. Available: www.arb.ca.gov/msei/doctabletest/doctable_test.html. Accessed: June 23, 2003.

[6] Union of Concerned Scientists (UCS). *Pollution Report Card: Grading America's School Bus Fleets.* Patricia Monahan, (February, 2002). Online. Available: http://www.ucsusa.org/publication.cfm?publicationID=308#vehicles. Accessed: June 26, 2003.

[7] GHASP did not receive a bus inventory from Alvin I.S.D., which operates an almost exclusively propane fleet.

Calculating Emissions by School Day

Because school buses primarily run during the school year, we divided our emission estimates by the number of school days in Texas. Texas schools are required to operate 180 days.[8] While GHASP requested the number of miles driven by a fleet during the school year, we lack certainty in some situations about whether this was the number actually provided or whether districts reported data including summer operation as well.

Extrapolating Regional Estimates from Sample Data

The inventories GHASP collected represent 88% of the student population in the Houston region, so to calculate overall emission figures we increased the sample estimates by 13%.

Calculating Cost Effectiveness of Emission Reduction Strategies

We used the cost effectiveness calculations used by TERP, assuming a discount rate of 3% and a project life of 10 years. TERP stipulates that the cost effectiveness of a project is determined by dividing the total annualized cost by the total annual NOx reduction. Total annual costs are the product of annualized costs and a Capital Recovery Factor (CRF), which is calculated using the following formula.

$$\textit{Capital Recovery Factor (CRF)} = [(1+i)^n]/[(1+i)^n - 1]$$

Where:

n = activity life (10 years)
I = discount rate (3%)

For the early replacement strategy, the price of a new diesel bus ($65,000) was used, because it was more cost effective than an alternative fuel bus. For the deferral strategy, buses purchased during 2005 and 2006 were assumed to be purchased in 2007, meeting the new standard. While our forecasted emissions calculated accounted for the phase-in of the new standard, the deferral strategy assumed that 100% of the buses purchased in 2007 would comply with the new standard. New buses in 2007 are assumed to cost $2,750 more than current 2004 buses. This figure is based on an estimate by EPA in 2000 when the new standards were proposed.

[8] Section 25.081, Texas Education Code

Appendix Table A: Districts Included in Regional Sample

Inventory Included in Sample

District	Enrollment
Houston ISD	209,916
Fort Bend ISD	52,904
Aldine ISD	50,950
Cypress-Fairbanks ISD	50,491
Pasadena ISD	41,953
Alief ISD	41,839
Conroe ISD	33,483
Katy ISD	32,338
Klein ISD	32,331
Spring Branch ISD	31,628
Humble ISD	24,221
Spring ISD	22,134
Galena Park ISD	18,523
Goose Creek ISD	18,148
Brazosport ISD	13,224
Deer Park ISD	11,500
Pearland ISD	10,202
Galveston ISD	9,487
LaPorte ISD	7,502
Tomball ISD	7,023
Dickinson ISD	6,007
Texas City ISD	5,951
Friendswood ISD	4,992
Willis ISD	4,570
Santa Fe ISD	4,369
Sheldon ISD	4,195
La Marque ISD	4,146
Waller ISD	4,074
Crosby ISD	3,952
Columbia-Brazoria ISD	3,314
Stafford MSD	2,870
Huffman ISD	2,443
Needville ISD	2,433
Sweeny ISD	2,210
Hitchcock ISD	1,237
Damon ISD	141
Total	776,701
Percent of Region	**88.5%**

Did Not Provide Inventory

District	Enrollment
Clear Creek ISD	28,871
Lamar Consolidated ISD	14,896
North Forest ISD	12,614
Alvin ISD	11,404
Magnolia ISD	6,501
Angleton ISD	6,481
Channelview ISD	6,474
New Caney ISD	6,170
Montgomery ISD	3,502
Splendora ISD	2,822
Danbury ISD	729
High Island ISD	293
Kendleton ISD	111
Total	100,868
Percent of Region	**11.5%**

Appendix Table B: HISD's Adjusted Miles Traves by Model Year

Year	Buses	Miles	Adjusted Miles	Total Miles
1979	459	2,500	3,994	1,833,231
1981	594	3,250	5,192	3,084,141
1982	1755	4,000	6,390	11,215,059
1983	837	4,750	7,589	6,351,605
1984	81	5,500	8,787	711,725
1985	783	6,250	9,985	7,818,190
1986	2430	7,000	11,183	27,174,950
1987	513	7,750	12,381	6,351,605
1988	1134	8,500	13,579	15,399,138
1989	1053	9,250	14,778	15,560,894
1991	2511	10,500	16,775	42,121,173
1992	1647	11,000	17,573	28,943,479
1994	3969	12,000	19,171	76,089,861
1995	8208	12,500	19,970	163,912,398
1996	405	13,000	20,769	8,411,294
1997	4320	13,500	21,567	93,171,258
1999	3537	14,500	23,165	81,934,632
2000	3267	15,000	23,964	78,289,738
2003	5319	16,500	26,360	140,209,803

Appendix Table C: Predicted Change in Number of Buses in Each Districts Fleet by Year

	Change in Bus Need by Year			
District	**2004**	**2005**	**2006**	**2007**
Aldine ISD	14	14	14	14
Alief ISD	5	6	5	6
Brazosport ISD	-0	0	0	0
Columbia-Brazoria ISD	-1	-1	-1	-1
Conroe ISD	15	15	15	16
Crosby ISD	0	1	0	0
Cypress-Fairbanks ISD	26	26	26	27
Damon ISD	0	0	0	0
Deer Park ISD	-0	-1	0	0
Dickinson ISD	0	1	0	1
Fort Bend ISD	13	13	14	13
Friendswood ISD	1	1	2	1
Galena Park ISD	2	2	2	1
Galveston ISD	-1	-1	-1	-2
Goose Creek ISD	0	1	0	1
Hitchcock ISD	-1	-2	-1	-1
Houston ISD	-1	-2	-1	-1
Huffman ISD	1	1	1	1
Humble ISD	4	5	4	5
Katy ISD	16	16	17	16
Klein ISD	5	5	5	5
La Marque ISD	-0	-1	0	-1
LaPorte ISD	1	1	1	1
Needville ISD	0	0	1	0
Pasadena ISD	3	3	2	3
Pearland ISD	3	3	4	3
Santa Fe ISD	-0	0	0	-1
Sheldon ISD	1	0	1	0
Spring Branch ISD	3	3	3	3
Spring ISD	6	5	6	5
Stafford MSD	1	1	1	1
Sweeny ISD	-0	-1	0	0
Texas City ISD	-0	0	-1	0
Tomball ISD	4	3	4	3
Waller ISD	3	4	3	3
Willis ISD	1	2	1	2