Measuring pollution levels inside Texas school buses

Tests conducted at The Woodlands, Texas, in March 2006

March 2007

A joint project of
Environmental Defense
The Clean Air Task Force
The Conroe Independent School District

Pollution levels are elevated inside Texas school buses; retrofit devices work to reduce risk

In March 2006, Environmental Defense partnered with the Conroe Independent School District and the Clean Air Task Force to investigate the presence of diesel exhaust particles inside school buses and to measure the impact on in-cabin air quality of various pollution control devices installed on school buses.

The results from this project confirm that the bus's own exhaust can enter the bus during the course of a regular school bus route. The tests also showed that an engine filter and a tailpipe filter, used in combination, dramatically reduce the amount of key diesel pollutants inside school buses.

Background

While school buses are the safest way for children to get to school, they present hidden health hazards. More than 90% of Texas' 35,000 school buses emit unhealthy diesel pollution that gets into the bus cabin, where Texas children breathe it in.

Several studies show that air pollution levels inside school buses can be up to five times greater than levels outside the bus. This surprising result is due to emissions from the bus itself that make their way into the bus cabin. The pollution comes from two sources: the tailpipe and the engine crankcase. The crankcase is vented to the air, just a few feet from the bus's front door. Because buses stop frequently and open their doors regularly, a bus's own emissions can enter the cabin. The result is often a significantly elevated level of pollution in the air inside the bus.

Figure 1 (above): **Diesel particulate filter** (Source: Clean Air Task Force)

Figure 2 (left): **Closed crankcase filtration system**

Diesel exhaust is composed of tiny particles of "soot" (particulate matter, or PM), smog-forming oxides of nitrogen, and a complex mixture of gases, many of which are known to cause cancer. Epidemiological studies have shown that it is dangerous to be exposed to the types of pollution found in diesel exhaust, even for short periods. Diesel pollution is linked to dizziness, coughing, increased incidence and severity of asthma attacks, chronic bronchitis, and—over time—heart disease, increased cancer risk and even premature death.

Evidence continues to mount that children, especially those with asthma, are exceptionally sensitive to the effects of fine particulate matter. Diesel pollution puts children at particular risk: Children breathe more rapidly than adults and inhale more pollutants per pound of body weight, and their developing bodies do not have the full range of defenses to battle foreign substances. Exposures during childhood are of special concern because children's developmental processes can easily be disrupted, and the resulting damage may be irreversible. Additionally, exposures that occur early in life appear more likely to lead to disease than do exposures later in life.

Methodology

The purpose of the demonstration project was to investigate the levels of diesel particulate matter (PM) inside school bus cabins and to test the effectiveness of various retrofits in reducing in-cabin PM. The project design included three test scenarios: "Representative Bus Ride", "Idling in a Bus Queue", and "Bus Following" tests. In all runs, the school bus cabins were outfitted with a suite of instruments that test four different parameters of particulate matter. These include; (1) fine particulate matter ($PM_{2.5}$), smaller than 2.5 micrometers in diameter; (2) ultrafine particulate matter ($PM_{1.0}$); (3) black carbon; and (4) particle-bound Polycyclic Aromatic Hydrocarbons[1] (PAH).

Two types of retrofit filters were tested in the study: a diesel particulate filter (DPF) and a closed crankcase filtration system (CCFS). Diesel particulate filters, installed in place of standard mufflers, capture particulate emissions that normally would exit the tailpipe; they can reduce tailpipe particulate emissions by 85%. Closed crankcase filtration systems, installed under the bus's hood, trap oil mists and reroute crankcase emissions back to the engine air intake, effectively eliminating those emissions that normally would vent directly to the outside air.

During the "Bus Ride" scenarios, a control vehicle—kept approximately 50 to 100 feet ahead of the bus—was driven with windows down to measure pollutant levels in the ambient air in front of the bus. The lead vehicle was set up with identical instruments as the test buses, except for the PAH monitor. In this portion of the study, conventional yellow school buses, with the windows closed, followed an actual, typical school bus route designated by the Conroe ISD fleet manager. The bus route was approximately 45 minutes long and traversed a light suburban area in The Woodlands, Texas. This route minimized the number of other vehicles encountered, thereby enhancing the ability to detect bus "self-pollution" and reduce the influence of other diesel sources.[2] Buses whose ages and mileage were typical of the fleet average were picked by the Conroe ISD fleet manager.

At each stop of the bus, one minute in duration, measurements of wind direction relative to the bus were recorded outside the bus. Wind speed and direction were recorded in order to investigate the influence of tailpipe emissions (rear winds) or engine crankcase emissions (front winds) on self-polluting exhaust entering the cabin. PM and black carbon data are reported as "net" concentrations by subtracting from the raw data the average value of outdoor ambient air concentration as measured by the lead van during a bus run. These "net" concentrations represent the contributions of localized sources of diesel pollution, dominated by the bus itself, to the interior bus cabin.

Several different technology configurations tested in the Bus Ride scenario are summarized in Table 1.

In addition to the bus ride scenarios, the "Idling in a Bus Queue" test measured the in-cabin air quality of a bus in the middle of a queue of three conventional buses. All three buses idle for 20 minutes and the middle bus has the front door closed for 10 minutes and then open for 10 minutes.

Table 1:
Scenarios and technology configurations tested

"Bus Ride" tests
- Conventional bus run (two runs)
- Diesel Particulate Filter (DPF)
- Closed Crankcase Filtration System (CCFS)
- The 'Optimal Solution' (Both DPF & CCFS)

"Idling in a Bus Queue" (20 minutes)

"Bus Following" test

Finally, in the "Bus Following" test, we tested the effect of the bus's emissions on ambient air by following a conventional bus with no retrofits.

Findings

The results of these tests indicate that retrofitting with available technologies reduces fine particle and black carbon levels inside the school bus cabin. These technologies, in conjunction with idling reduction programs, can provide significant air quality benefits for children riding in school buses.

Key results from our monitoring campaign are summarized below. All the results can be downloaded from our **www.cleanbuses.org** website.

"Bus Ride" tests

Like other in-cabin school bus air quality studies, we found that diesel particulate matter enters the school bus as the bus proceeds through its normal daily route. We observed frequent increases of $PM_{2.5}$ and black carbon

Figure 3. School bus run 2. Conventional bus with no controls (net $PM_{2.5}$ levels)

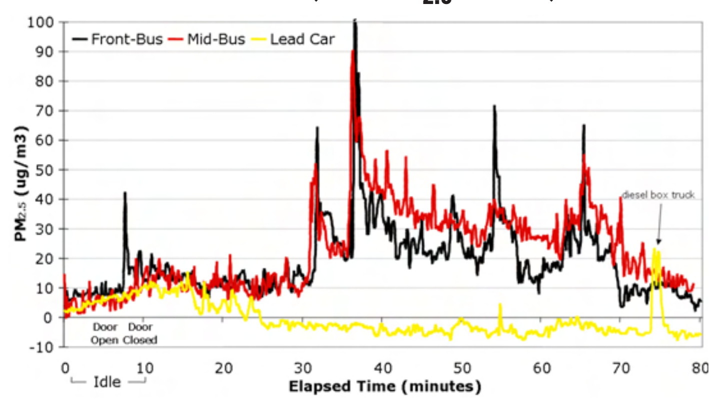
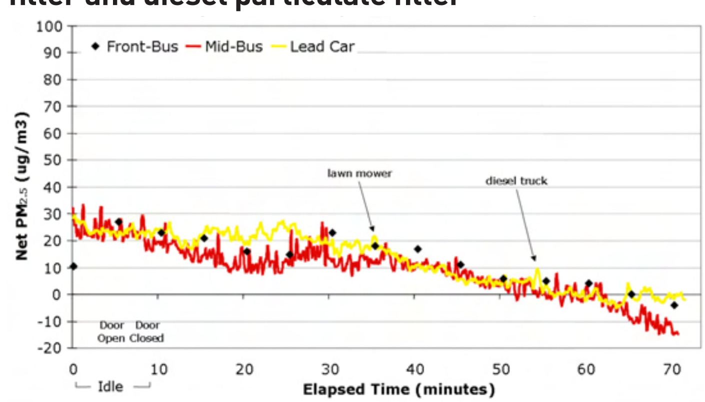


Figure 4. 'Optimal Solution' bus with crankcase filter and diesel particulate filter



when the bus door was opened on the test route. Unlike in similar tests in other cities, we did not observe significant increases in levels of ultrafine particles in the conventional non-retrofitted bus and we were not able to use our PAH data due to technical difficulties with the instrument.

Figure 3 shows that fine particle levels build up and stay elevated inside a school bus with no control devices. Monitors at the front and middle of the bus both show the same pattern of self-pollution from the bus. Throughout the bus ride, the $PM_{2.5}$ levels[3] ranged from 10 to 100 ug/m³. For comparison, the Environmental Protection Agency's health based 24-hour standard for $PM_{2.5}$ exposure is 35 ug/m³.

Figure 5. Black carbon comparison – bus rides

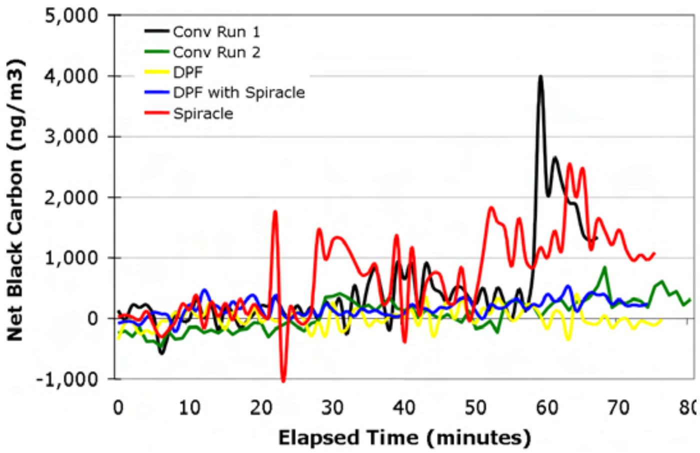
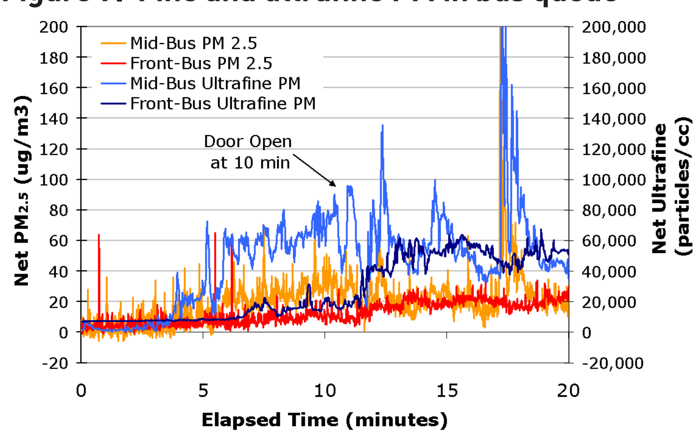


Figure 6. Configuration of bus queue

Figure 7. Fine and ultrafine PM in bus queue



The greatest reduction in pollution levels and increased benefits to in-cabin air quality resulted from using both the crankcase and the tailpipe filter technologies in what we call the "Optimal Solution." Figure 4 shows that fine particle ($PM_{2.5}$) levels inside the bus with both controls are essentially the same as the ambient outside air.[4]

Black carbon was elevated inside the bus in both non-controlled bus runs as well as in the bus outfitted with only a closed-crankcase filtration system. Both bus runs outfitted with diesel particulate filters (DPF) measured very low levels of black carbon in the cabin.

"Idling in a Bus Queue" test

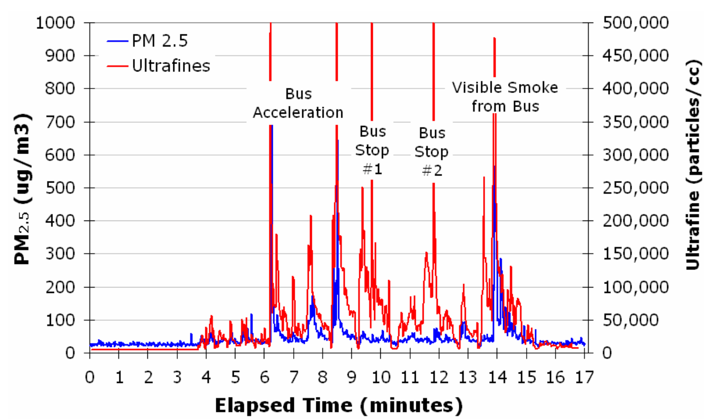
We tested how in-cabin air quality was affected by idling—specifically in school bus queues. In this 20-minute idling test, a bus is sandwiched between two other buses, with front bumpers lined up with the back ends of the buses in front. The particulate monitors were located in the middle bus, which had all windows closed for the duration of the test.

As shown in Figure 7, levels of fine and ultra-fine particles increased even with the front door closed. The highest levels of particulate matter were reached when the door opened after 10 minutes of idling (as it can do in loading and unloading areas at schools).

"Bus Following" test

In this test, the control van followed a conventional bus with no controls on a 20-minute bus ride including simulated bus stops. Levels of ultrafine particles in the minivan were elevated for most of the ride and exceeded the maximum levels of the monitoring instrument five times during the test. Fine particle levels were elevated as well, but not as significantly as ultrafine particles. Consistent with similar tests in other cities, this supports previous findings that tailpipes are the main source of ultrafine particles in diesel exhaust.

Figure 8. "Bus Following" test



Comparison of Conroe ISD to other cities

This study shows that the crankcase is the dominant source of in-cabin levels of $PM_{2.5}$ and that the installation of a closed-crankcase filtration system (CCFS) effectively removes most in-cabin $PM_{2.5}$.

The Clean Air Task Force has provided the following figures depicting results of school buses they have tested in five different cities. The first chart, Figure 9 (below), shows fine particle ($PM_{2.5}$) levels in all uncontrolled buses. The second chart, Figure 10, shows the very low levels of fine particles in all retrofitted buses tested. It is clear that even in buses retrofitted with only a crankcase filter, the $PM_{2.5}$ levels are dramatically reduced.

In our Conroe study, buses retrofitted with diesel particulate filters (DPF) also showed reduced levels of black carbon (BC) inside the bus cabin. However, the effectiveness of DPFs for reducing ultrafine particles ($PM_{1.0}$) and PAH was inconclusive, even though similar studies in other cities have shown DPFs effectively remove ultrafine particles, black carbon and PAH—all originating from the tailpipe.[5]

Figures 11 and 12 (next page) show the reduction in ultrafine particle levels inside bus cabins in five different cities for buses retrofitted with DPFs versus those not retrofitted with DPFs. Some of the buses in Figure 11, in five different cities, have closed crankcase filter systems installed. The fact that ultrafine particle levels are reduced upon addition of a DPF supports the conclusion that DPFs are most effective at reducing ultrafine particles inside the bus.

Although we are unsure why the Conroe data for ultrafine PM differed from other cities' school buses, we believe the differences may be due to the prevalence of intermittent and strong headwinds (vs. winds from rear of bus), turbulent air and high humidity.

The idling/queuing test provided valuable information about how emissions build up inside the bus even if the doors are closed and showed that normal idling practices like opening the door after idling for an extended period of time can significantly increase levels of both fine and ultrafine particles.

Conclusions

- Diesel particle emissions build up inside Texas school buses and can be attributed to the buses' own exhaust.
- The exhaust can be traced to the tailpipe and to the open crankcase, which is vented at the front of the bus.
- In our demonstration project, the fine particle ($PM_{2.5}$) and black carbon levels were the most significantly elevated[6] pollutants in buses without control devices.

Policy implications and recommendations

Texas children are indeed getting an extra dose of diesel pollution when they ride the bus to school, fieldtrips, sporting events and other extracurricular activities. As evidenced in hundreds of studies, diesel exhaust has serious implications for the health and well being of our children. Even though children may spend only a small portion of their day on buses, the high exposures they receive inside the bus can add considerably to their daily and annual exposures.

Children, especially those with asthma, are exceptionally sensitive to the effects of diesel pollution. Across the country, asthma is considered to be the number one childhood disease; in Texas, one in ten people suffer from asthma. The disease is one of the most frequent reasons for hospital admissions of children. While asthma has a strong eco

Figure 9. Composite fine particle ($PM_{2.5}$) data from school buses without crankcase controls

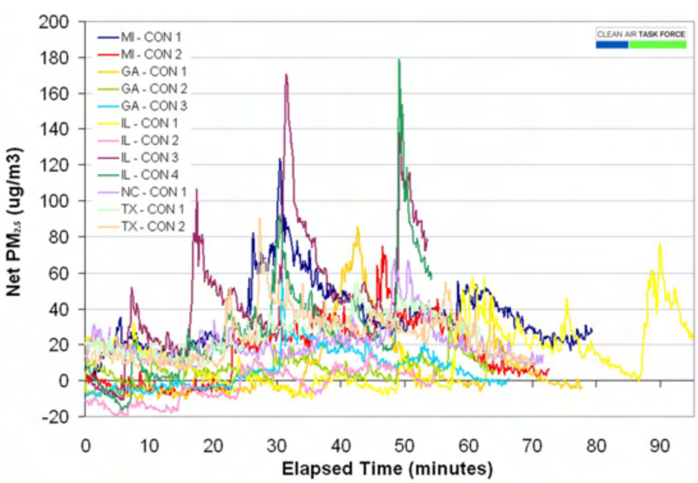


Figure 10. Composite fine particle ($PM_{2.5}$) data from school buses with crankcase controls

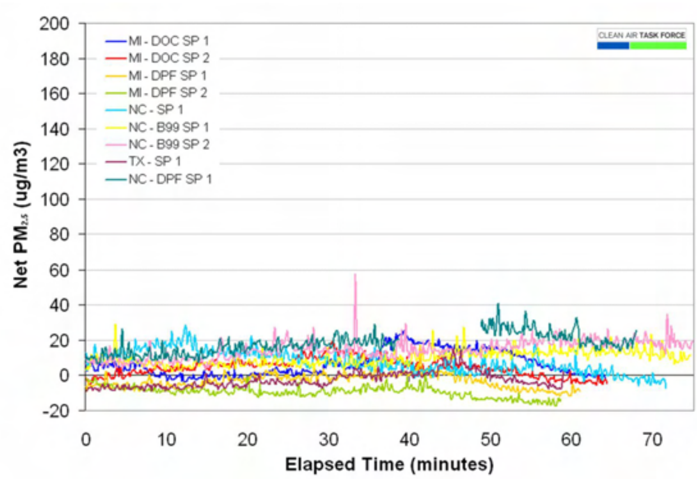


Figure 11. Ultrafine particle data from school buses in 5 cities, without diesel particulate filter

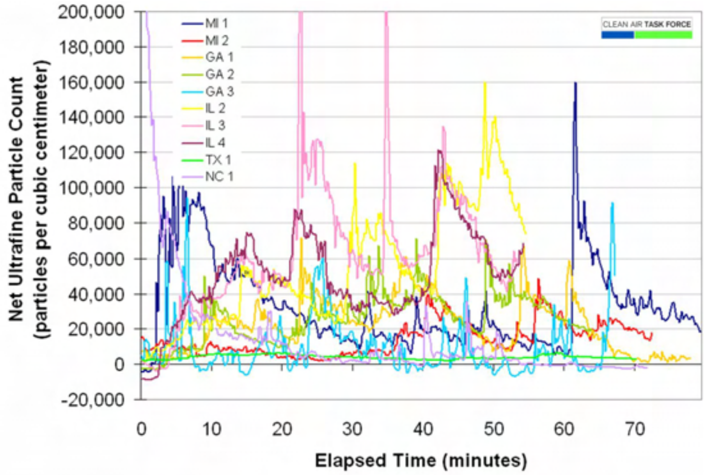
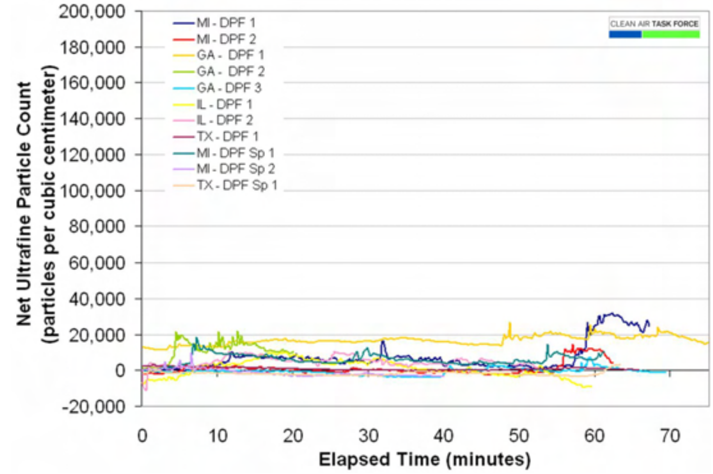


Figure 12. Ultrafine particle data from school buses in 5 cities, with diesel particulate filter



nomic impact in terms of hospital and medication costs, it has immeasurable impacts on children's long-term learning and development. Asthma is one of the leading causes of school absenteeism, nights of interrupted sleep and days of restricted activity.

In addition to needed technological changes, it is clear from the "Idling in a Bus Queue" test that idling reduction is a necessary step for reducing children's and bus drivers' exposure to diesel pollution inside school buses. In addition, those teachers who spend numerous hours on "bus duty" are also exposed to high levels of diesel pollution while making sure our children enter and exit the buses safely.

Added to the health benefits of reduced idling is the lowered fuel consumption that will help school districts save money in a time of tight budgets and increasing needs.

The good news is that affordable technologies exist to significantly reduce these emissions and the health risk to Texas children. Together, a diesel particulate filter and a closed crankcase filtration system reduce diesel pollution by up to 95%, bringing it to the level of a new, clean 2007 diesel bus.

And because of the unique exposures that occur on school buses, reducing diesel emissions from school buses is cost-effective. According to one published analysis, "it is less expensive *per gram inhaled by a student* to reduce emissions from school buses than from an average vehicle" even if emission reductions were many times more expensive *per gram emitted* from school buses than from an average vehicle.[7]

[1] PAHs are a toxic class of chemicals. Diesel exhaust contains 40 toxic chemicals.

[2] Hill, Zimmerman and Gooch, 2005, "A Multi-City Investigation of the effectiveness of Retrofit Emissions Controls in Reducing Exposures to Particulate Matter in School Buses.

[3] Hill, Levy, et al, and others have found that the Dust Trak ($PM_{2.5}$ Monitor) is known to overestimate concentrations sometimes from a factor from 2-3. Please note, however, that a study also shows that fresh PM emissions show a 1-1 correlation and so in this analysis we present the $PM_{2.5}$ measurements minus the ambient constant only.

[4] The sloping baseline is due to a reduction of ambient pollution levels during the bus run.

[5] Hill, Zimmerman and Gooch, 2005, and Fitz, D.R., Winer, A.M., et al., "Characterizing the Range of Children's Pollutant Exposure During School Bus Commutes," Final Report to the California Air Resources Board, 2003.

[6] Note: No data for PAH, so levels could have been elevated as in other in-cabin studies.

[7] Marshall, J.D. and Behrentz, E., "Vehicle Self-Pollution Intake Fraction: Children's Exposure to School Bus Emissions," 2005. Environmental Science & Technology, p. 2559.

For more information

A more detailed discussion about the need to clean up Texas school buses is available at **www.cleanbuses.org**.

This analysis was written by Betin Santos, manager of the Houston Clean Air for Life Campaign. She can be reached at **bsantos@environmentaldefense.org** or **(713) 942-5821**.

Questions can also be directed to Dr. Ramón Alvarez at **ralvarez@environmentaldefense.org** or **(512) 691-3416**.

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Texas Regional Office: 44 East Avenue, Suite 304 • Austin TX 78701 • (512) 478-5161
Houston Office: 2028 Buffalo Terrace • Houston TX 77019-2496 • (713) 942-5821