POLLUTION REPORT CARD

Grading America's School Bus Fleets

Patricia Monahan

Union of Concerned Scientists

February 2002

© 2002 Union of Concerned Scientists
All rights reserved

Patricia Monahan is a senior analyst in the UCS Clean Vehicles Program.
Miriam Shapiro and Joshua Klein provided research assistance for the report.

The Union of Concerned Scientists is a nonprofit partnership of scientists and citizens combining rigorous scientific analysis, innovative policy development, and effective citizen advocacy to achieve practical environmental solutions.

The UCS Clean Vehicles Program develops and promotes strategies to reduce the adverse impacts of the US transportation system.

More information about UCS and the Clean Vehicles Program is available at the UCS site on the World Wide Web, at *www.ucsusa.org.*

The full text of this report is available on the UCS website or may be obtained from

UCS Publications
Two Brattle Square
Cambridge, MA 02238-9105

Or email *pubs@ucsusa.org* or call 617-547-5552.

Cover design by Brent Robie.
Cover photo courtesy of US Environmental Protection Agency,
K.I.C.K. Asthma L.A. Program. Photographer: Andrea Hricko.

Printed on recycled paper

Contents

Figures *v*

Tables *v*

Acknowledgements *vii*

Executive Summary *ix*

1. School Buses and Public Health 1
   Today's School Buses 1
   Public Health Threats 5

2. Grading State Fleets 11
   Calculating Grades 11
   Results 14
   Making the Grade 18

3. Cleaner School Buses 19
   Cleaning Up Diesel 19
   Cleaner Alternative Fuels 25
   Hybrids 26
   Fuel Cells 26

4. Clean Fleet Successes 29
   Natural Gas Buses 29
   Propane Buses 30
   Success Stories 30

5. Government Policies 33
   Research and Development 33
   Standards and Policies 34
   Funding for Cleaner Buses 35

6. Conclusion 37

References *39*

Appendices
   A. Methodology 45
   B. Results, Emission Factors, and Data Sources 54

Figures

ES-1.	School Bus Annual Emissions	*xi*
ES-2.	State Grade Averages	*xii*
1.	Average Annual School Bus Emissions	4
2.	Global Warming Pollution from Fuels	5
3.	Composition of Diesel Particulate Matter	6
4.	Emissions Range Per Grade	13
A-1.	Diesel Conversion Factors	46
A-2.	Comparing Basic Emission Factors for Class 7 and 8a Gasoline Vehicles	47
A-3.	Fuel Economy of Diesel-Powered Transit Bus and School Bus	51
A-4.	Fuel Economy of Gasoline and Diesel Heavy-Duty Vehicles	52

Tables

1.	National School Bus Fleet	2
2.	Certification Standards for School Buses	3
3.	Size Categories for Particulate Matter	7
4.	Cancer Risk Assessments of Diesel Exhaust	8
5.	Estimated Excess Cancers from Diesel	9
6.	Grading Criteria	12
7.	School Bus Report Card	15
8.	Pre-1977 School Buses	18
9.	Diesel Emission Control Opportunities	20
10.	Pollution Reduction Potential from Exhaust Control Technologies	21
11.	State Fleets of Alternative Fuel School Buses	29
A-1.	Particulate Emissions from School Buses	50
B-1.	Annual Pollution from State School Bus Fleets	54
B-2.	Annual Pollution from Average School Bus	56
B-3.	State School Bus Fuel Choice and Age Distribution	58
B-4.	Emission Factors	60
B-5.	Sources of State Data	62

Acknowledgements

The State Directors of Pupil Transportation patiently responded to many questions regarding their state programs and provided key information for this report. Their jobs are dedicated to providing safe, efficient, and reliable transportation for children, and I hope this report helps build support for even stronger state programs.

David Brzezinski and Megan Beardsley from US EPA's Office of Transportation and Air Quality graciously provided EPA's newest emission factors for modeling school bus pollution. Archana Agrawal of the California Air Resources Board's Office of Off-Road Modeling and Assessment also provided helpful information on gasoline school bus emissions.

Jason Mark provided technical assistance and sage advice through all stages of this report. A special thanks goes to Miriam Shapiro, who provided invaluable assistance researching state programs, and to Joshua Klein, for his research support on a wide variety of topics including the health effects of air pollution. Michael Pancook, Michelle Robinson, and Rebecca Cochran reviewed the report and provided helpful comments. The report could not have been completed without the editorial assistance of Beverly Merz, and the layout and graphics support of Anita Spiess and Brent Robie.

Support for this work was provided by The Energy Foundation, W. Alton Jones Foundation, Inc., Oak Foundation, Turner Foundation, Inc., and The Martin Foundation, Inc.

The opinions expressed in this report do not necessarily reflect the opinions of the foundations who supported the work or the individuals who reviewed and commented on it. The Union of Concerned Scientists is solely responsible for the contents of this report.

Executive Summary

Every day, parents watch the trusted yellow bus pull away, taking their children to school. There's no sign on the rear of these buses warning that the exhaust from the tailpipe may be harmful to children's health. But there should be. The exhaust from diesel fuel—which powers nearly 90 percent of the 454,000 school buses on the road today—has been shown to cause or exacerbate a host of health problems, including asthma and other respiratory ailments, and has been linked to cancer and premature death. Children may be particularly vulnerable to the harmful impacts of air pollution because they are outdoors for longer periods and breathe at higher rates than adults (Wiley, 1993). As they wait on the curb, play near idling buses, or even ride safely inside the bus, children may be exposed to this noxious substance every school day.

Health Risks

All of today's school buses, whether powered by diesel, gasoline, natural gas, or other alternative fuels, release pollution from the tailpipe. But conventional diesel school buses, particularly older models, release more smog-forming pollutants and toxic soot than cleaner alternative technologies, and may pose greater risks to children's health.

School buses routinely expose children to soot and smog-forming pollution.

Numerous scientific studies have linked exposure to diesel exhaust with cancer. A study by air pollution control officials and administrators estimates that diesel may be responsible for over 125,000 additional cancers in the United States over a lifetime of exposure (STAPPA/ALAPCO, 2000). In California, the Air Resources Board estimates that diesel pollution is responsible for 70 percent of the state's cancer risk due to airborne pollution (CARB, 2000a).

Air pollution can cause or exacerbate a variety of respiratory ailments, including asthma. The most common chronic disease of childhood, asthma is also a leading cause of disability among children. In 1998, over 3.7 million children—about one in 20—had asthma (Federal Interagency Forum on Child and Family Statistics, 2001). A study of the economic costs of asthma estimated that children with this disease incurred nearly three times more health care expenses per year than did children without asthma (Lozano et al., 1999). This translates to $2.4 billion in additional health costs in the United States for children with asthma.

School Bus Pollution

School buses routinely expose children and communities to soot (particulate matter) and smog-forming pollution (nitrogen oxides and nonmethane hydrocarbons), and also add to the global burden of greenhouse gas emissions. Every year, the nation's fleet of school buses releases 3 thousand tons of soot, 95 thousand tons of smog-forming pollutants, and 11 million tons of greenhouse gas emissions.

Over the last three decades, school bus engine manufacturers have had to meet progressively stronger pollution standards for buses, providing better protection for children's maturing lungs. But older school buses are exempt from today's stronger standards and expose children to greater levels of air pollution. Buses built before 1990 and 1991, which constitute around a third of buses currently in operation, are allowed to release at least six times more toxic soot and nearly three times more smog-forming nitrogen oxides than today's models.

Cleaner Alternatives

There are cleaner alternatives to standard diesel buses. School buses powered by natural gas and other alternative fuels offer the cleanest option commercially available across the country. Natural gas school buses emit 90 percent less toxic soot than conventional new diesel-powered buses, and are over 98 percent cleaner than older diesel buses. Natural gas school buses also reduce smog-forming pollution by more than 30 percent relative to today's diesel, and by over 45 percent relative to diesel buses built in 1990.

Over the last decade, natural gas buses and trucks have moved into the mainstream, with one in five new transit buses on order powered by natural gas (DOE, 2000). These buses have a proven track record of success. School districts in at least 19 states including Indiana (Evansville-Vanderburgh School Corporation), Oklahoma (Tulsa Public Schools), and Texas (Northside Independent School District) currently use natural gas buses. School districts and transit bus operators have turned to alternative fuel buses because of their clean air benefits and lower operating costs. Though the capital cost of a natural gas school bus is about $35,000 greater than that of a diesel school bus, some school districts and transit agencies report that lower operating costs enabled them to quickly recoup the initial investment (SRTD and STA, 1999).

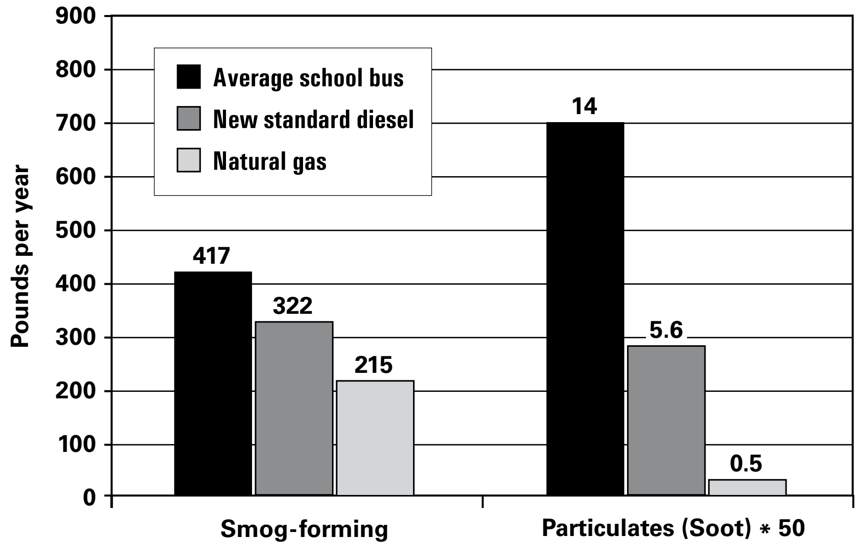
Natural gas school buses emit 90 percent less toxic soot than conventional new diesel-powered buses.

Diesel emission control technologies are evolving and improving, and new low-emission diesel buses are starting to enter the market. Emissions from diesel buses can be reduced through a combination of engine improvements, changes to fuel and oil formulation, and exhaust control equipment. If these clean-up technologies live up to their theoretical potential, they can reduce smog-forming pollutants and toxic soot by 90 percent or more. While clean-up technologies offer hope for a cleaner future for diesel, they have yet to prove effective under a range of real-world conditions. Without government oversight and stricter regulations, diesel clean-up technologies may not be adequate to keep school buses clean over the 20, 30, and even 40 years that they remain on the road.

Grading State Fleets

While school bus fleets across the country differ significantly in terms of age, fuel type, and pollution performance, all states rely to some extent upon high-polluting school buses, primarily those powered by diesel, to transport children. Every year, the average school bus releases twice the amount of smog-forming pollution, 27 times as much soot, and 6,000 pounds more global-warming pollution than a natural gas school bus.

Figure ES-1. School Bus Annual Emissions: National Average Versus Natural Gas



We gave each state fleet grades based on the emissions of particulates, smog-forming pollution, and greenhouse gases from the average state school bus. The level of emissions from a natural gas school bus set the bar for the highest grade, an "A." No state even came close to receiving this highest grade for superior pollution performance. The large gap in environmental performance between today's fleet of school buses and the standard set by natural gas buses shows that even the "cleanest" state fleet has room for improvement.

We allotted grades "B" through "D" based upon relative performance in each pollution category and gave each state an overall grade average. Only six states and the District of Columbia were ranked "ahead of the curve." Twenty-three states received a "middle of the road" ranking, while the remaining 21 states did poorly or flunked out.

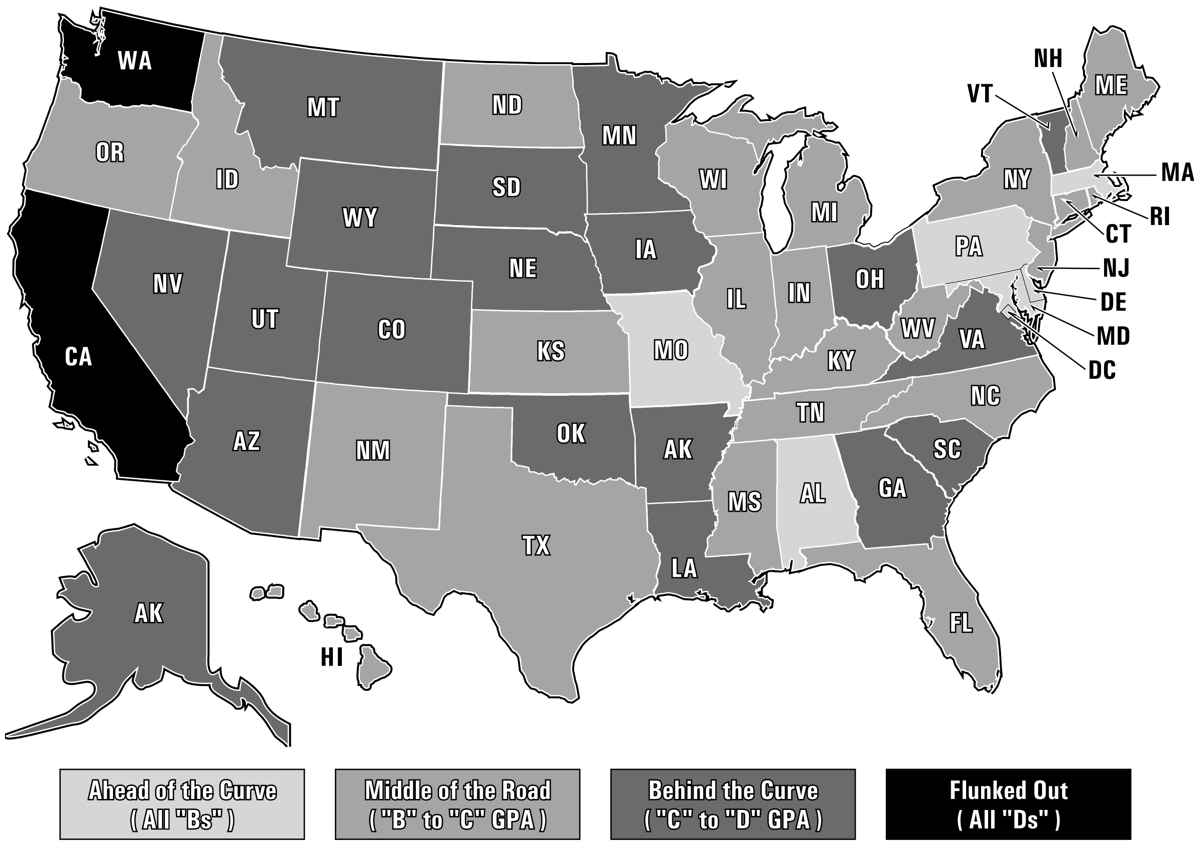
Policy Recommendations

School districts need help—technical, regulatory, and financial—to fund cleaner school buses and to ensure that the buses remain clean over their lifetime on the road. Many school districts do not have the resources to replace older school buses with newer, cleaner models. Some states make school districts choose between new buses and other educational expenses. As long as there remains a trade-off between books and buses, children's health may be compromised. Government action is needed to sponsor and conduct research, set standards and policies to ensure real world emissions reductions, and provide funding to replace and clean up older diesel school buses.

Research and Development

Critical gaps remain in our understanding of school bus clean-up technologies and in the health impacts of air pollution, particularly the role of very small particles. As school buses become cleaner, the average particle size from exhaust

Figure ES-2. State Grade Averages



may become smaller. Research and development can play a critical role in improving our understanding of the health impacts of pollution from low-emission diesel and alternative fuel school buses, getting cleaner buses on the road today, and putting even cleaner technologies—like fuel cells—on the road in the future.

Standards and Policies

Government policies can help narrow the gap between emissions measured in a laboratory setting and real-world emissions. To help keep diesel clean-up equipment effective over the life of the vehicle, the US government needs to develop an inspection and maintenance program. Ultimately, new standards for engines based on in-use performance should replace today's inadequate certification process.

Funding for Cleaner Buses

Children's vulnerability to the harmful impacts of pollution underscores the need for a national school bus replacement program with strict pollution limits. Federal and state funding for cleaner school buses can help meet the dual needs of promoting energy security and protecting children's health and is key to ensuring that children across the country are able to ride in clean and safe school buses.

CHAPTER 1

SCHOOL BUSES AND PUBLIC HEALTH

School buses are considered the safest means for children to get to and from school, at least as far as accidents are concerned (NHTSA, 1998). However, the pollution from older school buses may pose risks to public health that tarnish the reputation of the familiar yellow school bus. Dozens of studies have documented that exposure to air pollution may cause or exacerbate a host of health problems, including cancer and asthma, and may even be linked to premature death. Studies have also indicated that children may be particularly susceptible to the harmful impacts of air pollution.

Today's School Buses

America's school buses transported 25 million children to school last year and logged about 4.5 billion miles (Bobit, 2001). School buses range in size, weight,[1] and passenger occupancy, accommodating as few as 10 to more than 80 children. While school buses were fueled by gasoline[2] in the 1970s, the higher efficiency of diesel engines has made them the popular choice today. Nearly all of the larger, more powerful school buses sold in the United States are powered by diesel. Of the fleet of school buses on the road, about 86 percent use diesel and 13 percent still rely upon gasoline. Less than one percent of school buses are powered by natural gas, propane, and other alternative fuels, but their share is growing.

About 86 percent of the school buses on the road use diesel.

Although school buses are responsible for a small share of vehicle emissions, they routinely expose children and communities to smog-forming pollutants, carbon monoxide, and particulate matter, and also add to the global burden of greenhouse gas emissions (Table 1).

Older Buses Pose Higher Risks

Over the last three decades, engine manufacturers have had to meet progressively stronger pollution standards for school buses, providing better protection for children's maturing lungs. Table 2 provides a history of federal emissions standards for heavy-duty diesel vehicles, which include school buses. Older school buses expose children, whether they are waiting at the bus stop or riding the bus, to greater levels of air pollution. Buses built before 1990 and 1991 are allowed to emit at least six times

[1] Over 95 percent of school buses have a gross vehicle weight between 19,501 and 33,000 pounds and are considered "medium heavy-duty vehicles" under EPA's weight classification (R.L. Polk, 2001).

[2] Many of these older gasoline-powered heavy-duty vehicles did not use the most basic emission control technology, the catalytic converter, to reduce emissions of hydrocarbons, carbon monoxide, and nitrogen oxides.

Table 1. National School Bus Fleet

Total fleet	454 thousand school buses
Children transported	25 million children
Fleet mileage	4.5 billion miles per year
Individual bus mileage	9,939 miles per year
Every year, the nation's fleet of school buses releases:	
Smog-forming pollutants[a]	95 thousand tons
Carbon monoxide	213 thousand tons
Particulate matter (soot)	3,100 tons
Greenhouse gases[b]	10.7 million tons
Every year, the average school bus releases:	
Smog-forming pollutants[a]	417 pounds
Carbon monoxide	939 pounds
Particulate matter (soot)	14 pounds
Greenhouse gases[b]	23.5 tons

a. Smog-forming pollutants include nitrogen oxides (NOx) and non-methane hydrocarbons (NMHC).

b. Greenhouse gases include tailpipe releases of carbon dioxide and methane (from natural gas vehicles only), as well as upstream emissions of greenhouse gases from fuel delivery and processing.

Sources: Data on number of buses, age distribution and fuel choice from R.L. Polk (2001) and interviews with state officials. Average miles traveled per year from EPA (1998). Number of children transported from Bobit (2001). Tailpipe emissions of NMHC, carbon monoxide (CO), and NOx calculated by UCS using modified emission factors from EPA Mobile 6. Particulate matter (PM) emissions from diesel and natural gas based upon in-use data from the DOE's Alternative Fuels Data Center (CTTS, 2001). PM emissions from gasoline based upon California Air Resources Board EMFAC2000 model (CARB, 2001). Greenhouse gas emissions calculated by UCS using GREET Version 1.6 (Wang, 2001). See Appendix A for more detailed explanation.

more toxic soot and nearly three times more smog-forming nitrogen oxides than today's models.

Recognizing the dangers of diesel pollution, the Environmental Protection Agency (EPA) passed new emissions standards for diesel trucks and buses. Disappointingly, the new regulations do not recognize that there are inherently cleaner fuels than standard diesel that are available today. Starting in 2007, these standards require that new buses release 90 percent less particulate matter than today's buses. New standards to reduce smog-causing pollution will be phased in starting in 2007. When these standards are fully implemented in 2010, new buses will emit 95 percent less smog-forming pollutants than today's buses. Unfortunately, the new cleaner buses will be sharing the roads with diesel buses built before 2007, which can continue to release high levels of soot and smog-causing pollution.

Pollution from School Buses

All of today's school buses—whether powered by diesel, gasoline, natural gas, or other alternative fuels—release air pollution and greenhouse gases. However, diesel school buses, particularly older models, release higher levels of pollution than the cleanest commercially available technology, natural gas school buses (Figure 1).

Table 2. Certification Standards for School Buses

Years	Smog-Forming Emissions: Nitrogen Oxides (NOx)	Smog-Forming Emissions: Hydrocarbons (HC)	Soot: Particulates (PM)	Carbon Monoxide (CO)
1985 - 1987	10.7	1.3	uncontrolled	15.5
1988 - 1989	10.7	1.3	0.6	15.5
1990	6	1.3	0.6	15.5
1991-1993	5	1.3	0.25	15.5
1994 - 1997	5	1.3	0.1	15.5
1998 - 2004	4	1.3	0.1	15.5
2004 - 2006	2.5 (combined NOx & HC)[b]		0.1	15.5
2007	0.2[c]	0.14[c]	0.01	15.5

a. Grams per brake-horsepower-hour is a measure of the mass of pollution released per unit energy produced by the engine. This value can be converted into pounds per year through a conversion factor that takes into account fuel density, fuel economy, the amount of fuel required for a specific energy output, and annual miles traveled.

b. Most heavy-duty engine manufacturers are required to meet the 2004 NOx + NMHC standard in October 2002 as a result of a Settlement Agreement with EPA and the California Air Resources Board.

c. Standards for NOx and NMHC will be phased in between 2007 and 2010.

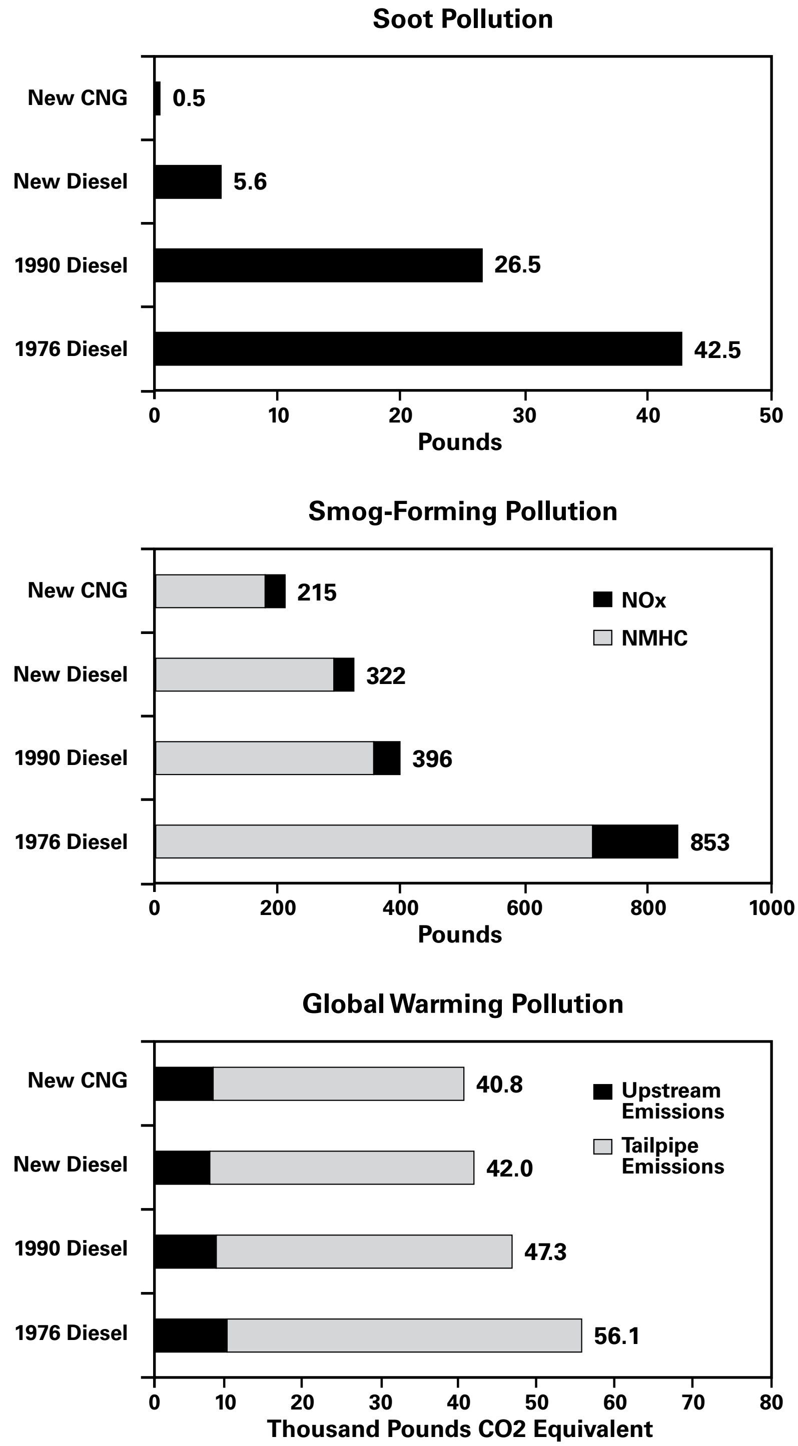
Air Pollution. A new standard diesel school bus releases 11 times more toxic soot and about 50 percent more smog-forming pollutants than a natural gas bus. Older models, which do not have to meet today's stricter emissions standards, produce even more pollution. Replacing a diesel bus built in 1990 with a natural gas bus would reduce soot emissions by over 98 percent and smog-forming pollutants would be nearly halved. Replacing a 25-year-old diesel bus with a natural gas bus would have an even greater effect—a 99 percent reduction in soot and a 75 percent reduction in smog-forming pollutants.

A new standard diesel bus releases 11 times more toxic soot and 50 percent more smog-forming pollution than a natural gas bus.

Global Warming Pollution. Global warming pollutants (also called greenhouse gases or heat-trapping gases) are released both at the vehicle tailpipe through fuel combustion and "upstream" of the vehicle, through fuel production and delivery. Tailpipe emissions of greenhouse gases are a direct function of fuel economy, the fuel's carbon content, and the amount of other greenhouse gases—like methane or nitrous oxide—that are liberated when the fuel is combusted. While carbon dioxide is the largest contributor to global warming, other gases, like methane, have higher global warming potential.

Each gallon of diesel that is combusted releases 27 pounds of carbon dioxide equivalent emissions, while a gallon (in diesel equivalents) of natural gas releases 21 pounds (Figure 2). Although natural gas has a lower carbon level than diesel, the advantage is tempered by the lower fuel economy of natural gas vehicles and by their emissions of methane. Taking those factors into account, a natural gas school bus emits slightly less global warming pollution per mile traveled than a new diesel vehicle (Figure 1). A diesel school bus built in 1990 releases 16 percent more global warming

Figure 1. Average Annual School Bus Emissions Comparing Model Years and Fuel Types



Tailpipe emissions of NMHC and NOx calculated by UCS using modified emission factors from EPA Mobile 6. PM emissions from diesel and natural gas based upon in-use data from the DOE's Alternative Fuels Data Center (CTTS, 2001). PM emissions from gasoline based upon California Air Resources Board EMFAC2000 model (CARB, 2001). Greenhouse gas emissions calculated by UCS using GREET Version 1.6 (Wang, 2001). See Appendix A for more detailed explanation.

pollution than a new natural gas school bus, while a 25-year-old school bus releases 37 percent more global warming pollution.

Public Health Threats

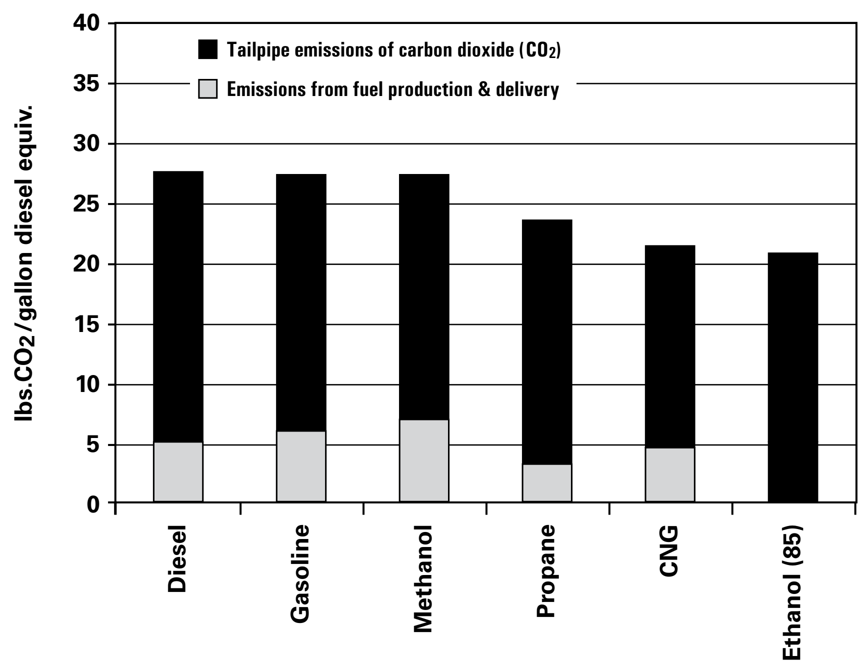
Exhaust from school buses can be inhaled deep into the lungs, where it may cause or exacerbate a wide variety of public health problems. There is overwhelming evidence that air pollution, and particularly diesel exhaust, is potentially harmful to human health in general and may pose even higher risks for children.

Smog-Forming Pollutants

In the presence of sunlight, nitrogen oxides and hydrocarbons can react to form urban ozone, or smog.[3] Smog can irritate the respiratory system, reduce lung function, exacerbate asthma, damage the lining of the lung, and aggravate chronic lung diseases (EPA, 2000a).

Approximately 105 million Americans—37 percent of the nation's population—currently live in areas that exceed the federal ozone standard (EPA, 2001a). Urban

Figure 2. Global Warming Pollution from Fuels



UCS calculation based upon GREET 1.6 model (Wang, 2001)

Ethanol(85) is 85 percent ethanol derived from corn feedstock and 15 percent gasoline-based. CNG is compressed natural gas.

Ethanol is credited with a reduction in tailpipe emissions and no upstream pollution due to carbon adsorption through plant (corn) growth.

Tailpipe emissions only account for carbon dioxide, though natural gas vehicles will also release methane. Emissions from production and delivery account for a variety of greenhouse gases, including nitrous oxide, methane and carbon dioxide.

---

[3] Carbon monoxide can also lead to the formation of smog, though at a slower rate than most hydrocarbons or oxides of nitrogen (EPA, 2000a).

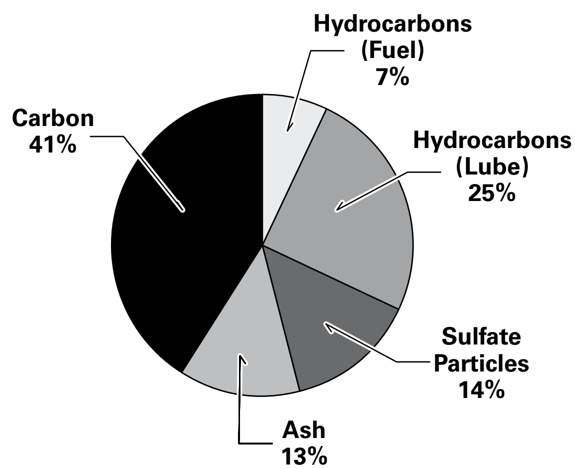
ozone pollution is linked to increased hospital admissions for respiratory problems such as asthma (Koren, 1995; White, 1994), and to higher death rates on smoggy days, even at levels below the current federal standard (ATS, 1996). Ozone air pollution has been associated with as much as 10 to 20 percent of all summertime respiratory hospital visits and admissions (EPA, 2000a). Ozone is also attributed with causing over 1.5 million cases per year of significant respiratory problems in children and adults (EPA, 2000a).

Particulate Matter (Soot)

School buses release soot, technically known as particulate matter, directly from their tailpipes. Nitrogen oxides and hydrocarbons released from the tailpipe can also react in the atmosphere to form secondary particulates.[4] Diesel particulate pollution is a complex mix of carbon, sulfate particles, ash, and hydrocarbons. The exact composition of diesel particulate matter varies depending on the engine technology, test conditions, and the sulfur content in the fuel. Figure 3 presents an example of the mix of particulate pollutants emitted from a standard heavy-duty diesel engine built after 1994.

Inhaling particulate matter can cause or exacerbate a wide variety of respiratory conditions and can even lead to premature death. Sensitive populations, including

Figure 3. Composition of Diesel Particulate Matter



Notes: Represents diesel exhaust from a heavy-duty diesel vehicle manufactured after 1994, using the federal test procedure transient cycle.

Carbon that is not bound with other elements is responsible for the black smoke in diesel exhaust. **Hydrocarbons** are released from lubricating oil and unburned fuel adsorbed onto the surface of carbon particles or present in the form of fine droplets. **Sulfate particles** are derived from sulfur in diesel fuel and formed when sulfuric acid and water react. **Ash** compounds are composed of metals formed from lubricating oil and engine wear.

Source: Kittelson, 1998

[4] EPA has not attempted to quantify the contribution of nitrogen oxides and hydrocarbons released from heavy-duty vehicles to the formation of secondary particles (EPA, 2000a). However, EPA believes the contribution from oxides of nitrogen is "substantial," particularly in areas with high ammonia levels (oxides of nitrogen react with ammonia to form ammonium nitrate particles).

children, the elderly, people with asthma, and people with pre-existing respiratory or cardiovascular diseases, are at greatest risk from exposure to particulates (EPA, 2000a).

Respiratory Impacts. Particulate matter is associated with adverse respiratory effects, such as asthma, reduced lung function, reduced respiratory defense mechanisms, and acute respiratory illness (EPA, 2000a). Numerous studies have reported an association between short-term exposures to particulates and hospital admissions for respiratory-related and cardiac diseases.[5]

Premature Death. Particulate matter has also been directly linked with premature death. A study of more than 1 million adults in 151 US cities found that higher concentrations of fine particles 2.5 micrometers or less, called $PM_{2.5}$, were associated with a 17 percent increase in total mortality between cities with the least and most polluted air (Pope et al., 1995). In another study of more than 8,000 people living in six cities in the eastern United States, $PM_{2.5}$ was associated with even higher rates of mortality (Dockery et al., 1993). This study found a 26 percent increase in mortality between the cities with the highest and lowest levels of air pollution. Based on these studies and other research, the EPA estimates that new standards regulating emissions of $PM_{2.5}$ will save 15,000 lives per year (EPA, 1997).

Particle Size and Regulatory Gaps. Historically, EPA only regulated particles that were 10 microns in diameter and smaller, known as PM_{10}.[6] EPA's particulate emissions standards for heavy-duty vehicles are based on the weight of the PM_{10} released directly from the tailpipe. EPA's recent rulemaking establishing National Ambient Air Quality Standards for $PM_{2.5}$ has not yet resulted in changes to vehicle emissions standards.

There is increasing evidence that particle size plays a key role in potential health effects. Fine particles may contain more of the reactive substances linked to health impacts than coarse particles (EPA, 2000a). These particles are small enough to bypass respiratory defenses and lodge deep in the lungs. From 80 percent to 95 percent of diesel particle mass is in the ultrafine size range from .05–1.0 microns (EPA, 2000a).

Table 3. Size Categories for Particulate Matter

	Diameter in microns[a]
PM_{10}	Less than 10
Fine ($PM_{2.5}$)	Less than 2.5
Ultrafine	Less than 0.1
Nanoparticles	Less than 0.05

a. Size range is based on the aerodynamic diameter of the particle in microns, equal to one millionth of a meter.

The current regulations for particulates do not address growing concerns about the health effects of ultrafine particles and nanoparticles, which are difficult to measure with today's technology. These smaller particles may penetrate more deeply into the respiratory tract, and their large surface-to-volume ratio could allow for more biological interaction. There is no accepted testing method to ensure that these particles are measured accurately and consistently, confounding comparisons between different studies (Andersson, 2001). In addition, different transient cycles, operating conditions, and exhaust temperatures may affect generation of these very small particles.

5 For a list of these studies and a table of results, see EPA (1997) p. V20-a.

6 For comparison, a human hair is about 70 microns in diameter.

As diesel engines become cleaner and more natural gas vehicles penetrate the market, these smaller particles may comprise a larger share of emissions from vehicles. More research is needed into the health impacts and emissions of ultrafine and nanoparticles from light- and heavy-duty vehicles powered by gasoline, diesel, natural gas, and other alternative fuels. Since EPA's current regulations governing particulates from heavy-duty vehicles are based on particle mass and not size distribution, stricter regulations may not proportionally reduce public health risks.

Air Toxics

The health impacts of air toxics vary from pollutant to pollutant, but all are serious, including cancer risk, immune system disorders, and reproductive problems. The California Air Resources Board has listed diesel exhaust, and its 41 constituent chemicals, as "toxic air contaminants" that may cause or contribute to serious illness and even to death (CARB, 1998). Of the many potential health risks from exposure to air toxics, cancer risks are the most studied and best understood.

Cancer Risks. According to over 30 epidemiologic studies, people who are routinely exposed to diesel exhaust through their work on railroads, docks, trucks, or buses have a greater risk of lung cancer (CARB, 1998). On average, these studies found that long-term occupational exposure to diesel exhaust was associated with a 40 percent increase in the relative risk of lung cancer.

Numerous scientific bodies and agencies have linked exposure to diesel exhaust with potential cancer risk (Table 4). The California Air Resources Board (2000) estimates that diesel exhaust causes 70 percent of the state's airborne cancer risk. This translates to 540 additional cancers per million people exposed to current outdoor levels of diesel pollution over a 70-year lifetime. The results in California raised concerns about the risks from diesel pollution to the entire nation. The State and Territorial Air Pollution Program Administrators (STAPPA) and the Association of Local Air Pollution Control Officials (ALAPCO) conducted an analysis of the national risks from diesel, applying similar methodology and risk factors as California. The study found

Table 4. Cancer Risk Assessments of Diesel Exhaust

Year	Organization	Conclusion
2001	US Department of Health and Human Services	Reasonably anticipated to be a human carcinogen
1998	California Air Resources Board	Toxic air contaminant
1998	US Environmental Protection Agency (Draft)	Highly likely to be human carcinogen
1990	State of California	Known to cause cancer
1989	International Agency for Research on Cancer (IARC)	Probable human carcinogen
1988	National Institute for Occupational Safety & Health (NIOSH)	Potential occupational carcinogen

Table 5. Estimated Excess Cancers from Diesel

Major Metropolitan Areas	Excess Cancers
Los Angeles	16,250
New York	10,360
Chicago	4,535
Washington/Baltimore	3,750
San Francisco	3,510
Philadelphia	3,085
Boston	2,900
Detroit	2,810
Dallas/Fort Worth	2,470
Houston	2,270
Atlanta	1,930
Miami/Fort Lauderdale	1,880
Seattle	1,765
Phoenix	1,510
Cleveland	1,500
Minneapolis	1,460
San Diego	1,430
St. Louis	1,320
Denver	1,220
Pittsburgh	1,210
United States	**125,000**

Note: Based on 70-year lifetime of exposure
Source: STAPPA/ALAPCO, 2000.

that diesel may be responsible for over 125,000 additional cancers in the United States over a 70-year lifetime of exposure (STAPPA/ALAPCO, 2000).

Greater Risks for Children

Children may be particularly susceptible to the harmful impacts of air pollution. Because they spend more time outdoors and breathe at higher rates than adults, children may experience greater exposure to harmful air pollutants (Wiley, 1993). Even riding inside of a school bus poses potential risks. A recent study indicates that a child riding a diesel school bus built in 1988 may be exposed to four times the level of toxic diesel exhaust as a person in a car directly in front of it (NRDC and CCA, 2001).[7]

Researchers at the University of Southern California (Gauderman, 2000) found that children exposed to ambient levels of particulates, nitrogen dioxide, and other pollutants in Los Angeles air experienced over four times more lung damage than children who were exposed to second-hand cigarette smoke. That study also found that children who spent more time outdoors had greater lung damage than other children.

Studies suggest that children, especially those with asthma, may be more susceptible to the harmful respiratory impacts of particulate pollution than adults (Pope et al., 1991; Ostro, 1995). The link between particles and asthma is of particular concern because asthma is the most common chronic disease of childhood and a leading cause of disability among children. Approximately 3.7 million children, or about one child in 20, had asthma in 1998, according to the National Health Interview Survey (Federal Interagency Forum on Child and Family Statistics, 2001). A study on the economic costs of asthma estimated that children with asthma incurred nearly three times more health care expenses per year than did children without asthma (Lozano et al., 1999). In the United States, this translates to $2.4 billion in additional health costs for children with asthma.

[7] About one in four school buses on the road today were built in 1988 or earlier.

Global Warming Impacts

School bus pollution not only harms public health directly, it also contributes to global warming, which carries longer-term public health and social consequences. All fossil fuels, including diesel, gasoline, natural gas and propane, contribute global-warming pollution to the earth's atmosphere.

Since the Industrial Revolution, levels of atmospheric carbon dioxide—a primary global warming gas—have increased by more than 30 percent, reaching concentrations higher than any observed in the last 420,000 years (Petit, 1999). The global average surface temperature has increased by 1°F since 1860, and scientific evidence suggests that the rapid flux in global temperature is largely due to human activities (IPCC, 2001). Greenhouse gases and other heat-trapping gases that are released into the air from factories, power plants, and automobiles are primarily responsible for the recent increase in the Earth's surface temperature. Diesel exhaust in the form of carbon soot may also be contributing to global warming. One study estimates that black carbon may be responsible for 15 to 30 percent of global warming, second only to carbon dioxide (Jacobson, 2001). Unless emissions of global warming pollution are drastically reduced, the average temperature could rise 2.5 to 10.4°F by the end of the 21st Century (IPCC, 2001).

School bus pollution also contributes to global warming, which carries long-term public health and social consequences.

Some of the projected consequences of global warming would have drastic effects on the global ecosystem. Rising sea levels, an increase in frequency and intensity of extreme weather conditions, vegetation shifts and altered ranges of both plant and animal species across the world are some of the broader implications associated with global climate change (Field, 1997; Twilley, 2001). The large-scale effects set the stage for more localized hazards, such as increased chances of floods along coast lines and flood plains, wild fires in forest regions and grasslands, and landslides and avalanches in mountainous regions.

CHAPTER 2

GRADING STATE FLEETS

Nearly all states have directors of pupil transportation who are responsible for ensuring the smooth operation of student transportation services. State school bus programs strive to provide efficient, safe, economical, and high quality transport for children. However, no state programs monitor the amount of pollution released from the tailpipe of school buses, or require that school districts purchase low-emission school buses. The age distribution and fuel choice of school bus fleets varies across the country, and as a result, pollution performance also varies.

This report analyzes the amount of pollution released annually from the "average" state school bus. Each state received grades, from outstanding to failure, for smog-forming emissions, particulates and greenhouse gases, as well as an overall grade average.

Calculating Grades

We contacted the State Directors of Pupil Transportation from every state to collect information on state school bus fleets. With the exception of Connecticut, every state responded to our survey. Twenty-six states and the District of Columbia provided general information on the share of buses in the state fleet that were built within the last ten years, and a few states could provide an annual breakdown of their fleet by model year and fuel. Information provided by the states was supplemented and integrated with data from R.L. Polk & Company, which collects and summarizes annual data on school buses from each state's Department of Motor Vehicles.[8]

No state programs monitor the amount of pollution released from school bus tailpipes or require school districts to purchase low-emission buses.

Calculating Emissions

The emissions analysis includes only tailpipe emissions of smog-forming pollutants, particulates, and greenhouse gases, as well as "upstream" emissions of greenhouse gases from fuel production and delivery. Appendix A describes in greater detail how emissions for each state were calculated. This analysis does not account for upstream emissions of smog-forming pollutants and soot, which account for only a small fraction of the tailpipe releases. In addition, emissions of toxic pollutants either from the tailpipe or through fuel production were not evaluated. Ideally, these pollutants would be included in the analysis, but there is not enough information available to develop a common metric to evaluate toxic emissions. Emissions from vehicle manufacturing were also

[8] The data quality varied for different states, since state Departments of Motor Vehicles do not consistently track school bus populations, age distribution and fuel choice.

ignored, assuming that each school bus would be penalized similarly for vehicle manufacturing.

Tailpipe emissions of smog-forming nitrogen oxides and non-methane hydrocarbons were calculated by applying EPA's highway emission factor model, MOBILE6. The model provides emission factors at the beginning of the vehicle's life, as well as deterioration factors to account for vehicle aging and degradation. Emissions are expressed in grams of pollutant released per mile traveled. Combining emission factors with annual vehicle miles traveled provides the amount of air pollution released by school buses over a given year.[9] Tailpipe emissions of particulates from natural gas and diesel school buses were estimated using in-use data on heavy-duty vehicles (CTTS, 2001). For gasoline school buses, particulate emissions were based upon analysis by the California Air Resources Board (CARB, 2000b)

Emissions of greenhouse gases were calculated using the Department of Energy's Greenhouse Gases, Regulated Emissions and Energy Use in Transportation (GREET) model. The model evaluates carbon dioxide releases from the vehicle tailpipe, as well as greenhouse gas emissions from processing and distributing fuels. Integrating these data with vehicle fuel economy and with annual miles traveled provides the amount of greenhouse gases released over a given year. In general, tailpipe emissions of greenhouse gases are dominated by carbon dioxide, with one notable exception: methane, a potent greenhouse gas, has 21 times more global warming potential than carbon dioxide. Recent studies indicate that natural gas transit buses release 10 to 15 grams of methane per mile (NAVC, 2000; Clark et al., 2000). Methane was thus included in the analysis of tailpipe greenhouse gas emissions from natural gas engines.

Distributing Grades

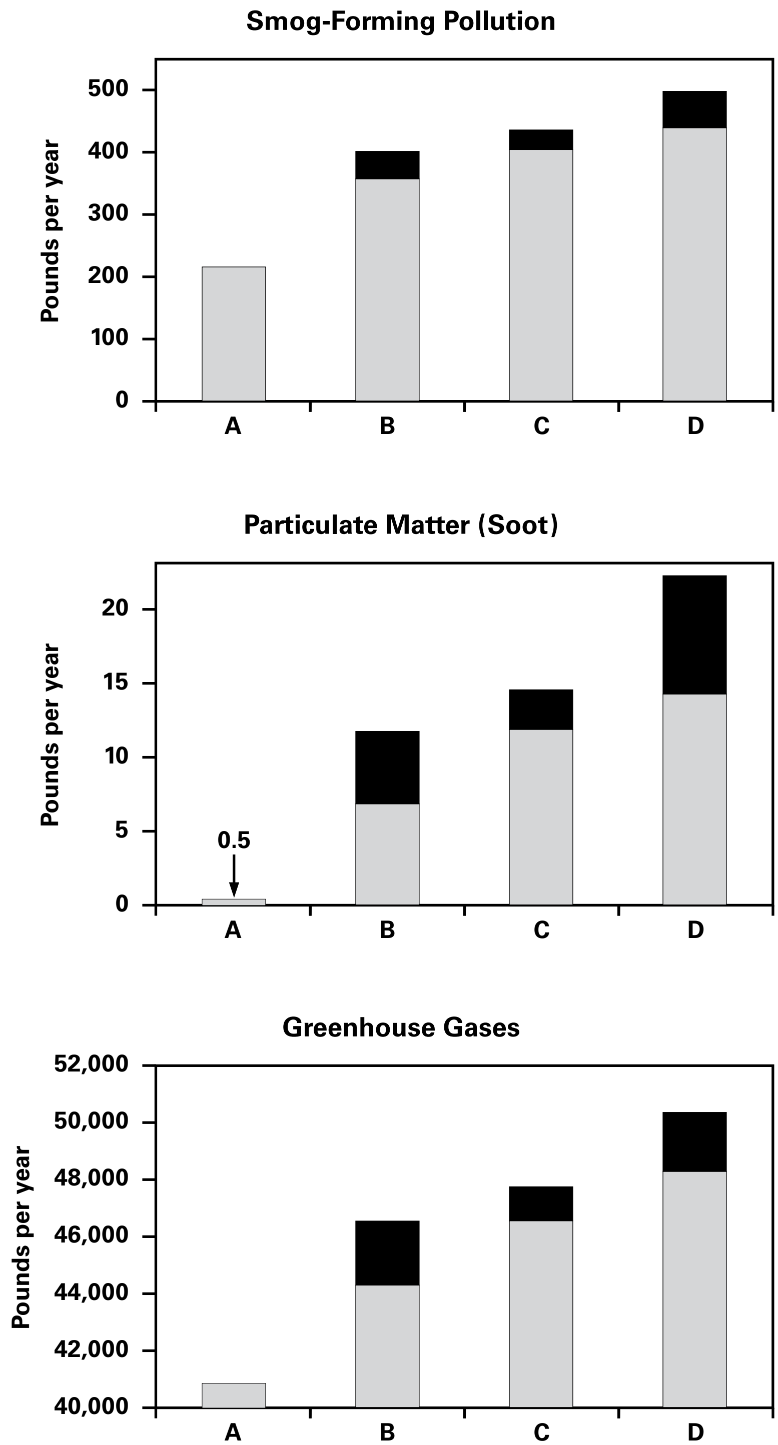
States received individual grades for each of the three pollutant categories. Table 6 presents the criteria we applied for grading state fleets. The highest grade, an "A," was reserved for fleets meeting the emissions of a natural gas school bus. The remaining grades were distributed on a "curve," with approximately 30 percent of the states receiving an above average grade ("B"), 40 percent receiving an average grade ("C"), and the remaining states falling below average ("D"). Generally, the top 15 states received

Table 6. Grading Criteria

	A Superior	B Above Average	C Average	D Below Average
Smog-Forming (lbs/year/bus)	215	358 to 400	>400 to 435	>435
Particulates (lbs/year/bus)	0.5	7 to 12	>12 to 14.4	>14.4
Greenhouse Gases (tons/year/bus)	40.84	44.46 to 46.54	>46.54 to 47.80	>47.80

[9] According to EPA's model, the average school bus travels 9,939 miles per year (EPA, 1999a).

Figure 4. Emissions Range Per Grade



Note: The black region represents the range of values for each grade category.

above average grades, while the bottom 15 were scored below average. However, grade categories were also determined by natural breaks in the emissions data, to ensure that two states with very similar emissions profiles received the same grade. Each state then received an overall grade average, equal to the average of the individual grades for smog-forming emissions, particulates, and greenhouse gases.

All pollutant categories were weighted equally in the overall grade average, although their impacts on human health and the environment might differ. Ideally, grades would be weighted to account for the relative social impacts of different pollutants. Even within the same pollutant category, there should be a difference in weighting based on the type of fuel used and any emission control technologies employed. For example, the level and type of toxics adsorbed onto particulate pollution will vary depending upon whether the pollution is emitted by a standard diesel engine, a diesel engine with a particulate trap, or a natural gas engine. Theoretically, each of these particulate categories should carry different weighting factors.

Only six states and the District of Columbia were "ahead of the curve."

Recent studies have attempted to quantify the costs to human health and the environment from different pollutants released by motor vehicles (DeCicco and Kliesch, 2001; Delucchi, 1996–1998). While such studies have given policymakers better tools for evaluating the true costs imposed on society by motor vehicles, there is currently no widely accepted methodology for calculating these costs. There is little agreement about the human health and environmental impacts of vehicle use, the relative impact of different types of vehicles and different fuels, and the proper methodology for cost accounting. Nor is there a consensus on how to account for the future, possibly catastrophic, impacts of global warming. Given the uncertainties, this analysis gives each pollutant category the same weight.

Results

This study revealed that state school bus fleets differ significantly in age, fuel type, and pollution performance. Despite these differences, there is one fundamental similarity between all of the states: they continue to rely upon high-polluting school buses—primarily powered by diesel—to transport children. Key findings from this study are:

- The amount of pollution the average school bus releases varies greatly from state to state.
- No state received an "A," or even came close to a superior grade.
- Only six states and the District of Columbia, most of which have policies to fund the replacement of older school buses, were "ahead of the curve."
- The 23 states that were ranked in the "middle of the road," with "B-," "C+," or "C" grade averages, maintain older, polluting school buses in their fleet.
- 19 states were "behind the curve," with "C-" to "D+" averages, and two states, California and Washington, flunked out.
- 19 states maintain buses built before 1977, which are not required to meet more protective federal safety and pollution standards.

Table 7. School Bus Report Card

State	Smog-Forming	Soot	Global Warming	Overall Grade Average
Alabama	B	B	B	B
Alaska	D	C	D	D+
Arizona	D	D	C	D+
Arkansas	D	B	D	C-
California	D	D	D	D
Colorado	D	C	D	D+
Connecticut	B	C	C	C+
Delaware*	B	B	B	B
District of Columbia*	B	B	B	B
Florida	B	C	B	B-
Georgia	C	D	C	C-
Hawaii	B	D	B	C+
Idaho	C	C	C	C
Illinois	B	B	C	B-
Indiana	B	C	B	B-
Iowa	C	C	D	C-
Kansas	B	B	C	B-
Kentucky	C	B	D	C
Louisiana	D	C	D	D+
Maine	C	C	C	C
Maryland*	B	B	B	B
Massachusetts	B	B	B	B
Michigan	C	C	B	C+
Minnesota	C	D	C	C-
Mississippi	B	B	C	B-
Missouri	B	B	B	B
Montana	D	C	D	D+
Nebraska	D	B	D	C-
Nevada	D	D	C	D+
New Hampshire	C	C	B	C+
New Jersey	C	C	C	C
New Mexico	C	C	C	C

* States with strong and effective bus replacement policies

Table 7. School Bus Report Card (continued)

State	Smog-Forming	Soot	Global Warming	Overall Grade Average
New York	C	D	B	C
North Carolina	C	D	B	C
North Dakota	B	B	D	C+
Ohio	D	D	C	D+
Oklahoma	D	B	D	C-
Oregon	C	B	C	C+
Pennsylvania	B	B	B	B
Rhode Island	C	D	B	C
South Carolina	D	D	C	D+
South Dakota	D	C	D	D+
Tennessee	B	C	C	C+
Texas	C	C	C	C
Utah	C	D	C	C-
Vermont	C	D	C	C-
Virginia	C	D	C	C-
Washington	D	D	D	D
West Virginia	C	C	C	C
Wisconson	C	C	C	C
Wyoming	D	C	D	D+
National Average	**C**	**C**	**C**	**C**

State Fleets Vary

Across the country, emissions from the average state bus vary considerably.[10] The diversity of grades received by states reflects the diversity of our nation's school bus fleets. For example, the amount of smog-forming pollutants from the average school bus varied from a low of 358 pounds per year (Tennessee) to a high of 498 pounds per year (South Carolina). Particulate releases varied from a low of 7 pounds per year (North Dakota) to a high of 22 pounds per year (South Carolina). For greenhouse gases, there was a 6,000 pounds per year difference between the state with the lowest emissions (Delaware) and the state with the highest emissions (Oklahoma).

No Superior Achievers

No states received an "A" grade, or even came close to it. Average school bus emissions in states with a "B" average were still far higher than the average emissions

[10] For a complete list of results for each state, see Appendix B.

from a natural gas bus. For example, the "cleanest" state bus releases 14 times more soot than a natural gas school bus. The large gap in environmental performance between today's fleet of school buses and natural gas buses shows that no state deserves to receive highest marks for pollution performance.

Ahead of the Curve

Seven states received above average grades in all three pollutant categories. Ranking "ahead of the curve," these states all have relatively new fleets of buses, with 80 to 100 percent built within the last 10 years.

Three of these top seven, Delaware, Maryland, and District of Columbia, have policies to ensure that older buses are removed from the road. Delaware and Maryland require that school buses be retired in the twelfth or fourteenth year of operation and provide state funds for bus replacement. Washington, D.C., which hires contractors to supply its school bus services, will only contract for buses that are 1997 models or newer. Missouri, another of the top seven, does not have an official state bus retirement policy, but it does provide financial incentives to retire older buses. Missouri will refund school districts the full costs of a new replacement school bus, but only if the bus to be replaced is 10 years old or newer.

These policies stand in stark contrast to those of the majority of states, which have no bus retirement policies and require school districts to contribute to bus replacement out of local funds. By providing funds to replace older school buses, these states help ensure children are traveling in cleaner buses.

Middle of the Road

Twenty-three states scored an overall grade average of "B-" to "C," and ranked in the "middle of the road" relative to the other states. These states maintain significant numbers of older school buses in their fleets. From 17 to 40 percent of school buses in these states are more than 10 years old. In addition, school buses in these "middle of the road" states expose children to much higher levels of pollution than do buses employing natural gas—the cleanest available technology. Compared with a natural gas bus, the average school bus releases 27 times more soot, two times more smog-forming pollutants, and more than three tons more greenhouse gases.

The 19 states that ranked "behind the curve" have some of the oldest fleets in the nation, with 30 to 60 percent built before 1991.

Behind the Curve and Flunking Out

Nineteen states had a grade average of "C-," or "D+," and two states "flunked out." States that ranked "behind the curve" have some of the oldest fleets in the nation, with 30 to 60 percent built before 1991.

California and Washington, both of which received all "D"s for pollution performance, had the lowest grade averages in the country. California, with the nation's third largest fleet, maintains some of the dirtiest school buses on the road. Part of the reason for California's poor pollution scores is that school districts must choose between funding for new school buses and other educational expenses. California school districts must contribute part of the cost of replacement buses, and many maintain older buses due to fiscal constraints. Washington has better school bus replacement policies than California, but it still received lowest marks in all three pollutant categories. One of the few states that reimburses school districts for replacement buses, Washington's

Director of Pupil Transportation actively tracks the age and type of school buses in the state fleet. Unfortunately, school bus funding competes with other budget priorities in the legislature, often unsuccessfully.

Special Demotion: Pre-1977 Buses

There are nearly 2,900 buses built before 1977 that are still part of the nation's fleet (Table 8). These buses do not have to meet federal safety standards for crash and rollover protection, nor do they have to meet today's stricter emissions standards for soot and smog-forming pollutants. Of the 19 states reporting that they maintain these older buses in their fleets, California has the dubious distinction of having the highest percentage—about one in 20 of its buses was built before 1977. Louisiana and Washington trail closely, with over 3 percent of their fleets composed of old, potentially unsafe buses. The good news is that 31 states and the District of Columbia report that they have no pre-1977 buses in their fleets. Removing school buses built before 1977 from the roads should be a national priority.

Table 8. Pre-1977 School Buses

	Number of Buses	Percent of Fleet
Arizona	63	0.9%
California	1342	5.5%
Connecticut	52	1.0%
Idaho	1	0.04%
Illinois	130	0.7%
Louisiana	301	4.0%
Missouri	10	0.1%
Montana	54	2.5%
Nebraska	32	1.3%
Nevada	34	1.9%
New York	1	0.002%
North Dakota	10	0.5%
Ohio	180	1.0%
Oklahoma	12	0.2%
Oregon	109	1.8%
South Dakota	25	1.5%
Texas	221	0.7%
Utah	11	0.5%
Washington	279	3.1%
Total	2867	0.6%

Making the Grade

The State Directors of Pupil Transportation are not to blame for their states' aging school buses. Many do not have the resources or legislative authority to replace older school buses with newer, cleaner models. School districts across the country must often choose between new buses and other educational expenses. Funds for a newer, cleaner fleet of buses are directly deducted from the school districts' general funds, potentially reducing the amount of monies available for other educational expenses. As long as there remains a trade-off between books and buses, children's health may be compromised. School districts need financial help to achieve both educational and public health goals.

CHAPTER 3

CLEANER SCHOOL BUSES

Fortunately, there are cleaner alternatives to the standard diesel bus, which allow school districts to provide transportation that is both safe and clean for our nation's children. Evolving diesel emission reduction technologies hold the promise to reduce pollution significantly. To reach their full potential, these control technologies must prove effective over the two-, three-, or even four-decade lifetime of school buses. School buses powered by natural gas and other alternative fuels, which are the cleanest option commercially available today, could become even cleaner. Engine modifications to improve fuel economy and the application of emission-control technologies originally developed for diesel engines could further reduce emissions from alternative fuel vehicles. In the near future, hybrid electric school buses may offer fuel-efficient emissions reductions. In the longer term, fuel cell buses powered by hydrogen can provide pollution free transport for children.

Cleaning Up Diesel

Diesel engines employ compression ignition in which diesel fuel and oxygen are compressed by the engine's cylinders until they spontaneously ignite. Compared to spark-ignited gasoline and natural gas engines, diesel engines typically operate more efficiently over a wider range of conditions, particularly at lower speeds. Instead of using a throttle and suffering efficiency losses as a result, a diesel engine reduces its energy output by reducing fuel input, resulting in less heat loss than gasoline engines. Diesel engines operate at higher pressures and have more horsepower output than spark-ignited engines. As a result, diesel vehicles can haul heavier loads than those powered by gasoline.

Diesel bus emissions can be reduced by reformulating the fuel and oil, improving the engine, and adding exhaust control equipment.

Diesel's enhanced efficiencies come at the cost of toxic soot and smog-forming pollutants. The fuel and air mixture in diesel combustion chambers does not simultaneously ignite, and pockets of excess fuel cause soot to form. Soot formation is enhanced by the presence of sulfur in diesel fuel and certain additives in lubricating oil. Compression ignition also produces high engine temperatures, which promote the formation of smog-forming nitrogen oxides. Engineers are forced to make a trade-off between toxic soot and smog-forming pollutants. Lowering the engine temperature decreases emissions of nitrogen oxides, but increases the amount of fuel that is not combusted and is instead released in the form of soot particulates.

Emissions from diesel buses can be reduced through a combination of changes in fuel and oil formulations, engine improvements, and the addition of exhaust control equipment. These rapidly evolving technologies have the potential to dramatically reduce pollution from diesel vehicles. To realize this potential, the technologies need to prove effective under a range of real-world conditions.

Table 9. Diesel Emission Control Opportunities

	Pollutants Controlled
Engine Improvements	
Fuel injections systems	NOx & PM
Exhaust gas recirculation	NOx
Combustion chamber	NOx & PM
Charge air cooling	NOx
Homogenous charge compression ignition	PM
In-cylinder coatings	PM
Fuel & Oil Specifications	
Fuel formulation	NOx & PM
Lubrication oil	PM
Exhaust Control Equipment	
Oxidation catalyst	PM
Particulate traps	PM
NOx adsorbers	NOx
Lean NOx catalysts	NOx
Selective catalytic reduction	NOx & PM
Plasma-assisted catalysts	NOx

Low-Sulfur Fuel

Low-sulfur diesel fuel offers two key advantages over today's higher-sulfur diesel fuel. First, it will benefit air quality directly by reducing sulfate emissions. Second, it will provide significant indirect benefits by allowing emission control technologies that are sensitive to sulfur contamination to function.

Reducing the amount of sulfur from the current standard of 500 parts per million to 15 parts per million will reduce sulfate particulates and sulfur oxide emissions by 97 percent (EPA, 1995). In December 2000, President Clinton signed a rule that required most retail stations and wholesalers to sell only low-sulfur diesel fuel starting in September 2006.

Many emission control systems require low-sulfur fuel to function. Control technologies like oxidation catalysts, particulate traps, nitrogen oxide catalysts and exhaust gas recirculation are intolerant to sulfur. Their performance is either impaired or totally compromised by the presence of sulfur. Until required by federal law, low-sulfur fuel may be available only in limited locations and quantities, restricting the usage of sulfur-sensitive emission control technologies until the fall of 2006.

Lubricating Oils

Lubricating oils, which can contribute to emissions of particulates, are not regulated under federal law. Lubricating oils can generate soot emissions in two ways. First, ash is generated through the metallic portion of the oils that cannot be combusted. Second, lubricating oils may evaporate in the crankcase and diffuse into the combustion chamber, causing particulate emissions (DieselNet, 1998). Replacing the metal additives with nonmetallic compounds should thus reduce the amount of ash generated. The use of synthetic oils, which can be formulated to evaporate only over a narrow, high-temperature range, also may reduce soot emissions.

Engine Design and Exhaust Gas Recirculation

Engine design improvements can help reduce emissions and can enhance performance of exhaust emission controls. One of the most effective engine design improvements for reducing nitrogen oxides is exhaust gas recirculation (EGR). By returning a portion of the engine's exhaust to the combustion chamber, inert gases displace some of the oxygen that would otherwise be entering the engine, reducing the amount of nitrogen oxides formed. In addition, the system can be designed to absorb heat from the combustion process, lowering exhaust temperature and reducing the amount of nitrogen oxides formed. Cooling the exhaust gas before it enters the combustion chambers could provide greater benefits. However, exhaust gas recirculation also leads to an increase in particulates, to lower fuel economy, and possibly to premature engine wear (DieselNet, 2000a). In addition, sulfur from the diesel fuel poses a corrosive threat to the system. Exhaust gas recirculation is a key strategy that manufacturers are relying upon to meet EPA's stricter standards, which come into effect in 2004. However, additional nitrogen oxide control technologies are needed to meet EPA's 2007 standards. Other possible engine improvements include advanced fuel injection, improved fuel ignition, combustion chamber redesign, turbocharging during acceleration, and charge air cooling.

Table 10. Pollution-Reduction Potential from Exhaust Control Technologies

Technology or Fuel	Particulates	Nitrogen Oxides	Stage of Development
Continuously Regenerating Particulate Trap[a]	85% or more		Currently available
Active Particulate Trap	85% or more		Available in Europe No commercial availability in U.S.
Oxidation Catalyst[b]	20% to 50%		Currently available
Exhaust Gas Recirculation[c]		Up to 50%	Available, but needs improvement to reach potential
Selective Catalytic Reduction[d]	25% or more	55% to 90%	Under development
Lean NOx Catalyst[e]		10% to 20%	Under development
NOx Adsorber or "Trap"[f]		80% or more	Under development

Note: All of these technologies require low sulfur fuel at or below 15 ppm for optimal performance.

Sources:

a. Based on certification data from the California Air Resources Board for the Johnson Matthey and Engelhard continuously regenerating, passive systems

b. Based on EPA certification data (EPA, 2001b)

c. From DieselNet (2000)

d. From Miller (2000) and MECA (2000)

e. From Majewski (2001)

f. From Brogan (1998)

Exhaust Control Technologies

Exhaust control technologies, which are also called "aftertreatment" devices, can potentially cut tailpipe emissions of particulate soot and nitrogen oxides by 90 percent or more. But these technologies are either new or under development, and have not yet proven effective under real-world conditions. Technologies to reduce particulates, like oxidation catalysts and particulate traps, are commercially available today, but there is little information about their long-term performance. Technologies to reduce oxides of nitrogen, such as selective catalytic reduction and nitrogen oxide adsorbers, are still in the development phase and far from realizing their pollution-reduction potential.

Oxidation Catalysts. As exhaust passes through an oxidation catalyst, the precious-metal catalyst transforms pollutants into carbon dioxide. The catalyst oxidizes carbon monoxide, gaseous hydrocarbons, and liquid hydrocarbons adsorbed on carbon particles. According to EPA tests, oxidation catalysts can reduce particulates 20 to 50 percent on older engines (EPA, 2001b). Oxidation catalysts may be most appropriate for older engines that cannot be retrofitted with particulate traps.

Particulate Traps. Particulate traps, which filter particles from diesel exhaust, can reduce soot emissions by 85 percent or more. Recent tests indicate that traps may reduce particulate levels to the point where they are below detectable limits (LeTavec, 2000). In 2001, two particulate traps were certified for use on engines built in 1994 and after.[11] These traps have a certified durability of 150,000 miles. Since school bus engines may run for 300,000 miles or more, these traps would need to be replaced at least once in the vehicle's life. One manufacturer, International, has installed soot traps and is marketing a cleaner diesel school bus. This bus is certified to emit very low particulate levels, though emissions of nitrogen oxides and carbon monoxide remain higher than those of natural gas buses.[12]

Particle traps may reduce particulate levels to below detectable limits.

In order to regenerate or clean the filter, the particles must periodically ignite and burn (oxidize) off of the filter. Particles will normally burn at around 500°C—far higher than the typical temperature range of diesel exhaust. To clean the filter, manufacturers may adopt either active or passive systems. An active system uses a heating device like a microwave to heat the particles to the temperature needed for ignition and will thus require energy to fuel the heating device. A passive system uses catalysts or additives to lower the temperatures required for oxidation. Passive regeneration is often preferred because it is less complex, less fuel-intensive, and less costly than active regeneration.

In a passive system, metals may be added to the fuel, the filter itself may be coated in a catalyst, or a catalyst may be used upstream of the filter. The only system currently on the market is a continuously regenerating trap, in which exhaust gases flow through the catalyst, to convert nitric oxide and other nitrogen oxides into nitrogen

[11] The two traps are Johnson-Matthey Continuously Regenerating Trap (CRT) and Engelhard DPX.

[12] According to certification data from the California Air Resources Board, International's low emission school bus releases three times more carbon monoxide and 35 percent more smog-forming pollutants than the average natural gas school bus. For particulates, International certifies to 0.01 grams of particulates per brake-horsepower-hour (g/bhp-hr), or one-tenth the current standard. Today's natural gas school buses certify to 0.02 g/bhp-hr for particulates. As discussed later in the chapter, diesel buses have traditionally released more particulates under real world conditions than certification values indicate, while natural gas buses have retained their emissions performance over time.

dioxide. The catalyst also oxidizes carbon monoxide and hydrocarbons to form carbon dioxide and water. The gases then pass through the filter, where the soot particles are trapped. Through a chemical reaction between the soot and the nitrogen dioxide, the combustion temperature is lowered to 250°C, which is well within the normal temperature range of diesel exhaust. Thus, the trap continuously self-regenerates during the vehicle's normal operation.

Early data from the California Air Resources Board indicate that the use of traps could lead to greater smog formation (McNerny, 2001). While the current-generation traps do not change the total mass of nitrogen oxides from diesel engines, they do appear to increase the relative share of nitrogen dioxide, which is more reactive in the formation of smog (ozone), nitric acid, and nitric-acid-derived particulates than the other oxides of nitrogen.

Nitrogen oxide adsorbers show the potential to reduce nitrogen oxides 80 percent or more.

Passively regenerating traps will not function properly if high-sulfur fuel is used. Sulfur in the exhaust can impair trap performance in two ways. First, sulfur oxides compete for catalyst sites required for the critical conversion of nitrogen oxide to nitrogen dioxide, increasing the temperature required for successful regeneration and making regeneration less effective. Second, sulfur can be oxidized over the particulate filter itself, clogging the filter. The Department of Energy found that sulfur in diesel fuel significantly harmed particulate trap performance and could even cause emissions to increase (DOE, 2001b).[13]

Lean Nitrogen Oxide (NOx) Catalyst. Lean nitrogen oxide catalysts, which are still in the developmental phase, show the potential to reduce nitrogen oxide emissions by as much as 30 percent, though 10 to 20 percent is a more realistic target. Such systems reduce nitrogen oxide emissions in the presence of diesel engines' typically oxygen-rich exhaust streams. Lean nitrogen oxide catalysts use hydrocarbons to convert nitrogen oxides into nitrogen gas, carbon dioxide, and water. Because there is not a sufficient concentration of hydrocarbons in the exhaust stream, hydrocarbons or diesel fuel are injected directly into the exhaust to provide a hydrocarbon rich environment necessary for greater nitrogen oxide reduction. However, doing so exacts a penalty in fuel-economy. Current-generation lean nitrogen oxide catalysts only perform effectively in a narrow temperature window and are intolerant to high sulfur levels (Majewski, 2001).

Nitrogen Oxide Adsorber or "Trap." Nitrogen oxide adsorbers show the potential to reduce nitrogen oxides 80 percent or more. These traps, which capture nitrogen oxides in a catalyst washcoat during oxygen-rich driving conditions, require the periodic injection of a reducing agent like hydrocarbons to regenerate. Significant technical hurdles still need to be overcome to make this technology available. So far, the systems developed are not durable over the exhaust-temperature profile typical of diesel engines (Duo and Bailey, 1998). In addition, these "traps" are very intolerant to sulfur contamination.

[13] At a sulfur level of 350 parts per million, which is significantly below today's current standard of 500 parts per million, passive particulate traps actually led to an increase in particulates. When the sulfur level dropped to 150 parts per million, particulate reductions were near zero. At 30 parts per million, particulate reductions dropped between 72 and 74 percent over the baseline, and at 3 parts per million, passive catalyst filters reduced particulate emissions 95 percent. This highlights the importance of using ultralow sulfur fuel to assure that particulate traps live up to their potential emissions reductions.

Selective Catalytic Reduction. Selective catalytic reduction has been used for years in stationary engines and some marine applications, but its use in vehicles is still in the development phase. This process, which theoretically could reduce nitrogen oxides over 90 percent, uses a reductant like urea or ammonia to convert oxides of nitrogen to gaseous nitrogen and water vapor. Hydrocarbons and particulate matter are also reduced from this process. Selective catalytic reduction is sensitive to the timing and amount of reductant, variations in exhaust temperature, exhaust gas flow, and concentration of nitrogen oxides in the exhaust. Toxic pollution in the form of ammonium nitrate particulates and ammonia can result if the reductant is injected at the wrong time or in the wrong amount (DieselNet, 2000b).

Much work is focusing on the development of selective catalytic reduction, which may offer the highest level of control of nitrogen oxides. However, modifying the technology from the steady-state conditions of stationary sources to the transient cycles of heavy-duty vehicles poses significant technical challenges. In addition, selective catalytic reduction is more complex, larger in size, and more costly than other catalyst systems. Finally, for selective catalytic reduction to function, users must periodically replenish the reductant. Currently, there is neither an incentive for the vehicle operator to invest in the additional cost of the reductant, nor an established distribution network for the reductant.

Ensuring Long-Term Pollution Reduction

The real-world performance of selective catalytic reduction, particulate traps, and other exhaust-control technologies—which are new and relatively untried—remains to be seen. Our experience with automotive-emission controls indicates that it may take decades for the technology to realize its potential. The eventual success of automotive-emission controls was predicated on two key factors. First, emission control equipment must be effective over the vehicle's lifetime. Second, vehicle emissions must be monitored periodically through an inspection and maintenance program.

Unlike the engines in passenger cars and trucks, heavy-duty engines are not tested for real-world emissions.

Unlike those in passenger cars and trucks, heavy-duty engines are not tested for real-world emissions. To comply with emissions standards, engine manufacturers are required to use a dynamometer to test their engines in operation. The test measures the total mass of particles emitted per unit energy (grams of pollutant per brake horsepower-hour). The dynamometer test does not measure the actual "in-use" emissions, which will vary based on actual driving conditions, engine deterioration, and vehicle maintenance. In-use tests more closely approximate the actual levels of air pollution released from school buses and other heavy-duty vehicles and provide a more accurate picture of human exposures to pollution from heavy-duty vehicles.

The limited data available from real-world tests suggest that standard diesel buses may release more pollutants—especially particulates—than certification standards indicate. Studies have indicated that diesel trucks and buses released two to six times more particulate pollution than indicated by the certification standards, while natural gas vehicles have maintained their emissions performance (Turner, 2000; West Virginia University, 1997). If experience is a guide, the real-world emissions from diesel aftertreatment technologies also may be higher than certification tests indicate. Some of the more complicated systems that need more maintenance, like active particulate traps or selective catalytic reduction, may have higher rates of degradation and failure.

In addition, aftertreatment technologies, particularly those that require maintenance and upkeep or that reduce a vehicle's fuel economy, may be vulnerable to tampering or misuse. In the 1990s, diesel engine manufacturers responsible for the majority of heavy-duty engine sales were allegedly using defeat devices to bypass air-pollution regulations for control of nitrogen oxides. Trucks and buses using these defeat devices released up to 70 percent more pollution than "legal" vehicles (Mark and Morey, 2000). In a 1998 legal settlement with the US Environmental Protection Agency and the California Air Resources Board, the manufacturers agreed to stop using defeat devices.

An inspection and maintenance program is needed to ensure that exhaust control technologies deliver on their environmental promise.

Diesel clean-up technologies may struggle to stay clean over the 20, 30, and even 40 years that school buses remain on the road. Certification alone is not sufficient to ensure that new diesel aftertreatment technology will be effective over the useful life of a truck. The efficacy of exhaust control technologies depends upon a variety of factors, including engine design, fuel sulfur content, and vehicle maintenance. An in-use inspection and maintenance program is needed to ensure that exhaust control technologies deliver on their environmental promise. Such a program could include on-board diagnostic systems designed to detect malfunctions in the exhaust control technologies, chassis-based testing, and fuel auditing and special nozzle applicators to prevent misfueling. In addition, the aftertreatment devices must last the useful life of the vehicles. Without such safeguards in place, there is no guarantee that emission-control technologies will continue to provide emissions benefits over the lifetime of the vehicles.

Cleaner Alternative Fuels

Alternative fuel buses can be powered by natural gas, liquefied petroleum gas (propane), ethanol, methanol, electricity, liquids from natural gas, and hydrogen. Currently, the cleanest alternative fuel used in the United States is natural gas, most often in compressed form.[14] Natural gas is a fossil fuel like gasoline or diesel, but because it is inherently cleaner than oil, it does not require significant refining to remove contaminants. Natural gas engines do have toxic emissions, but the trace amount of toxic particulates is generally attributed to crankcase lubricating oil and not the fuel itself (DOE, 2000). Reducing the metallic portion of lubricating oils, using synthetic oils that offer improved performance, and ensuring that the engine is properly sealed to prevent leaks could reduce toxic emissions from natural gas engines.

Like gasoline engines, natural gas engines are generally spark-ignited and use a throttle to control fuel input, resulting in a lower fuel economy relative to diesel.[15] New generation natural gas engines using high-pressure direct-injection can take

[14]Compared to a conventional diesel fuel tank, the compressed natural gas storage system uses three to four times the space and weighs two to three times more (INFORM, 2000). Fuel tanks carry the gas at pressures of 3,000 to 3,600 pounds per square inch. These tanks take up between three and four times the space of a gasoline fuel tank and weigh two or three times more.

[15]Natural gas engines can achieve ten percent or higher fuel economy compared with gasoline engines because their compression ratios are adjusted to take advantage of the higher octane rating of natural gas. Regular unleaded gasoline has an octane rating of 87, while the octane rating of natural gas is 130.

advantage of diesel's attributes—high efficiency, relatively low heat loss, and high energy output. However, the fuel-efficiency gains for natural gas engines that employ high-pressure, direct-injection may come at the cost of increased particulate emissions.[16]

Until recently, studies comparing emissions of soot and smog-forming pollutants from natural gas and diesel engines have consistently found natural gas to be the significantly cleaner fuel. The advent of emission control technologies, especially particulate traps, has rendered diesel more competitive with natural gas for lower emissions, in terms of both mass and toxicity (Ahlvik, 2000; LeTavec, 2000).

Natural gas provides a stepping stone to hydrogen-powered fuel cell vehicles.

Despite substantial concern about the long-term performance of diesel-exhaust controls, these technologies can make engines powered by alternative fuels even cleaner. Particulate traps, oxidation catalysts, and nitrogen oxide catalysts can be modified for use on alternative fuel vehicles to further reduce their emissions. Because natural gas is inherently cleaner than diesel and is not contaminated by sulfur, exhaust-emission controls could prove more effective. If similar technologies are applied to natural gas and diesel engines, natural gas engines should retain their emissions advantages and remain cleaner over the vehicles' lifetime.

Natural gas provides a stepping stone to another gaseous fuel—hydrogen—and the eventual penetration of hydrogen-powered fuel cell vehicles. Most of today's commercial hydrogen is reformed from natural gas, which is currently the lowest-cost source of hydrogen fuel. Building an infrastructure for natural gas should support longer-term development of zero-emission fuel cell vehicles.

Hybrids

Hybrid school buses, which combine the advantages of internal combustion and electricity, can run on either diesel or alternative fuels. A conventional internal-combustion engine is mechanically attached to the drive wheels through the transmission and driveshaft in conventional cars and buses, while hybrid vehicles rely on electric motors to turn the wheels. Hybrid vehicles recover part of the energy otherwise lost as heat through "regenerative" braking, which entails storing that energy for later use during rapid acceleration. In addition, the engine turns off while at rest, eliminating both tailpipe emissions and noise.

This drive system offers several advantages over a standard internal combustion engine. The increased efficiency of the engine can translate into higher fuel economy (as long as the increased power is used to improve fuel economy rather than supplement vehicle amenities). Vehicle emissions can also be reduced, since the electric energy adds no tailpipe emissions. Finally like natural gas vehicles, hybrids move us closer to another electricity-based technology—fuel cells.

Fuel Cells

Fuel cells produce electricity through a chemical reaction between hydrogen and oxygen rather than through combustion. They can convert fuel into electricity more efficiently than internal combustion engines, without producing tailpipe emissions. The

---

[16]While natural gas engines that are spark-ignited can reduce toxic soot by 90 percent relative to conventional diesel engines, natural gas engines using high-pressure, direct-injection reduce soot emissions by only 70 percent (Ouliette, 2000).

hydrogen needed to power fuel cells can be derived from renewable sources, such as solar energy, or from traditional energy feedstocks like gasoline, methanol, and natural gas. For now, natural gas is the least expensive source of hydrogen.

The promise of pollution-free, cost-effective transportation is driving research into fuel cell vehicles, which may ultimately replace internal combustion engines and revolutionize vehicle technology. Fuel cell vehicles are in the prototype phase of development, and it may be several years before they become reliable and cost-effective commercial products. However, every auto maker is deeply engaged in fuel cell research and development, and several transit agencies in the United States are experimenting with fuel cell buses.

CLEAN FLEET SUCCESSES

School districts across the country have turned to alternative fuels and low-emission diesel to solve problems ranging from air quality to tight budgets. At least 130 school districts in 19 states transport children to and from school in buses powered by alternative fuels and low-sulfur diesel. Of the nearly 4,000 alternative fuel school buses on the road today, about half are powered by natural gas, and the other half are fueled by propane (liquefied petroleum gas).

Natural Gas Buses

Natural gas buses have been on the road for over a decade and have a long track record of success. Approximately one in five transit buses currently on order in the United States is powered by natural gas (DOE, 2000). Natural gas transit buses are used in cities throughout the country, including Los Angeles, New York, Tacoma, Phoenix, State College of Pennsylvania, Cleveland, Dallas, and Atlanta. School districts across America are also turning to the low emissions, high-quality performance, and cost competitiveness of natural gas school buses.

Fleet managers report that natural gas buses can be cheaper to operate and maintain than diesel buses. The Sacramento Regional Transit Agency achieved a 38 percent cost reduction, while Sunline Transit reported 27 percent lower costs (SRTD and STA, 1999). Lower fueling costs and reduced maintenance costs—both for parts and labor—contributed to the savings from natural gas. While the capital cost of a natural gas school bus is approximately $35,000 higher than that of a diesel bus, fleet managers can recoup the difference through reduced operating expenses and maintenance costs.

Replacing diesel with natural gas also helps promote energy security. Ninety percent of the natural gas consumed in the United States is

Table 11. State Fleets of Alternative Fuel School Buses

State	Approximate number of alternative fuel school buses
Alaska	2
Arizona	223
California	624
Colorado	10
Connecticut	9
Florida	5
Georgia	2
Indiana	141
Massachusetts	4
Nevada	7
New York	39
North Carolina	14
North Dakota	6
Oklahoma	240
Oregon	362
Pennsylvania	130
Texas	2000
Utah	20
Washington	8
West Virginia	9
Wisconsin	63
GRAND TOTAL	**3918**

produced domestically (DOE, 2001a). The price of natural gas has historically been lower than the price of diesel, although prices in 2000 and 2001 were higher than usual. Today's prices are back down to the level in 1999. The US Energy Information Agency reports that drilling for gas is at an all-time high, which will lead to greater supplies and lower prices of natural gas in the near term (DOE, 2001b).

The US Department of Energy (DOE, 2001a) considers natural gas buses to be as safe on the road as their diesel and possibly even safer during maintenance and refueling. Although both natural gas and diesel fuels are flammable and require special precautions and fire protection equipment, there are fewer risks associated with natural gas. DOE reports that natural gas fuel tanks are much stronger and safer than either diesel or gasoline fuel tanks.

Propane Buses

Propane powers nearly half of the alternative fuel school buses in the United States today. A by-product of natural gas processing and crude oil refining, propane offers somewhat lower smog-forming and toxics emissions than diesel. It also produces less carbon build-up than gasoline or diesel vehicles, allowing for reduced maintenance costs. Unlike natural gas, propane requires neither cryogenic or compression storage, and it is thus easier to store and distribute. However, octane ratings and fuel prices for propane vary widely. Propane school buses are most common in Texas, which has up to 2,000 on the road.

Success Stories

School districts nationwide have found that alternative fuel school buses can provide transportation for children that is safe, reliable, and clean. The following are a few examples of the positive experiences that school districts have had with alternative fuel buses.

Lower Merion School District (Pa.)

In response to community concerns about diesel engine noise and air pollution, the Lower Merion School District began purchasing natural gas buses in the mid-1990s. The district currently operates a fleet of 68 natural gas buses, for which it recently received the National Clean Cities Award. The reliability and durability of the fleet, which has logged 3.3 million miles, has reinforced the district's commitment to purchasing natural gas buses exclusively.

The reliability of Lower Merion's school bus fleet has reinforced the district's commitment to purchase only natural gas buses.

The school district has received funding and technical support from the DOE, the Pennsylvania Department of Environmental Protection, and the local natural gas supplier, PECO Energy Company. Mike Andre, Supervisor of Transportation for the district, is a strong advocate for the switch: "We really need…to change our perspectives about fuel. The US government needs to start supporting alternative fuel," he says.

Tulsa Public Schools (Okla.)

Tulsa Public School District, the largest in Oklahoma, began investing in natural gas school buses over 10 years ago, well before natural gas vehicles had hit prime time. Of the district's 850 buses, 202 have been converted to natural gas. To raise funds for the higher costs of these buses, Tulsa Public Schools partnered with the Oklahoma Department of Commerce and the US Department of Energy. Despite increases in natural gas prices during 2000 and 2001, fuel savings for each bus averaged around $1,000 per year.

According to Larry Rodriguez, Alternative Fuel Technician at the Tulsa Public School District, "the switch has probably saved the district around $1.6 million over the last 10 years if one considers the fuel differential, engine longevity, and other matters. It has definitely been worth it."

Northside Independent School District (Tex.)

Northside Independent School District has the second-largest fleet of propane school buses in the country and is committed to maintaining its alternative fuel fleet. Northside employs about 472 propane buses to transport 33,000 students to and from school every day, and the district plans to increase the fleet to 550 buses by 2005.

Motivated by the cheaper price of propane, Northside made the switch from gasoline and diesel 20 years ago. Since propane comes from local sources, it is not subject to the price fluctuations of other fuels. Northside has found that maintenance costs are low, gas mileage is good, and drivers are happy with the buses' performance.

Evansville-Vanderburgh School Corporation (Ind.)

The Evansville-Vanderburgh School Corporation has one of the largest natural gas school bus fleets in the nation, with 120 natural gas buses on the road. In response to the instability of gasoline and diesel prices, the district started converting its gasoline buses to natural gas in 1986. Savings from reduced fuel and maintenance expenses enabled the district to recover the costs of converting the buses within the first year of operation.

Savings from reduced fuel and maintenance expenses enabled the Evansville-Vanderburgh district to recover the costs of converting to natural gas within the first year of operation.

The chief garage group leader, Curtis Fritz, is very pleased with his natural gas fleet, reporting that drivers like the way the buses handle. Maintenance and fuel costs are lower, and the distance between oil changes has doubled. "The drivers who were initially hesitant about switching to natural gas now love these buses. When they have to drive other [gasoline or diesel] buses, they scream that they want their natural gas buses back," Fritz reports.

The Safe School Bus Demonstration Program (Calif.)

The California Energy Commission's "Safe School Bus Demonstration Program" is responsible for increasing the percentage of alternative fuel vehicles in the state's school bus fleet. As a result of the program, 826 school buses built before 1977 have been replaced with cleaner buses, more than half of which are alternatively fueled. Nearly 270 are powered by natural gas and 150 are fueled by methanol. Moreover, all are equipped with advanced safety features. The final phase of this program ended December 2001.

CHAPTER 5

GOVERNMENT POLICIES

Children's heightened sensitivity to the harmful impacts of diesel pollution—including an increased risk of premature death, cancer, and respiratory ailments, such as asthma—argues for strong policies to ensure cleaner school buses on the road. By employing technologies and fuels that will eventually be used to clean up all heavy-duty trucks and buses, school buses can help lead the nation to a clean transportation future. In addition, cleaner buses powered by alternative fuels can help to improve the nation's energy security. By displacing petroleum fuels, alternative fuels can reduce our dependence on petroleum imports and promote stability in our energy markets.

Strong government policies can help assure that pollution from dirty school buses no longer puts children's health at risk.

But school districts need help—technical, regulatory, and financial—to fund cleaner school buses and to ensure that the buses remain clean over their lifetime on the road. Government action is needed to sponsor and conduct research and development programs, set standards and policies to ensure real-world emissions reductions, and provide funding to replace and retrofit older diesel school buses. Strong government policies and programs can help assure that toxic pollution from older, dirty school buses no longer puts children's health at risk.

Research and Development

Critical gaps remain in our understanding of school bus clean-up technologies. There are insufficient data on the health impacts of air pollution, and particularly of very fine particles. Research and development can play a critical role in furthering our understanding of the health impacts of pollution from heavy duty vehicles, in getting cleaner school buses on the road today, and in putting even cleaner technologies on the road in the future.

Health-Based Emissions Research

As engine technologies reduce the total mass of pollution released from school buses, ultrafine particles and nanoparticles may figure more prominently as health risks. For example, a recent study found that both natural gas engines and diesel engines with particulate traps released a greater number of nanoparticles than standard diesel vehicles (Andersson, 2001). However, measurement techniques for these very small particles are still being developed, and there are no standards to assure these particles are consistently and accurately measured. We also need additional research into how emissions of nanoparticles vary with operating conditions, transient cycles, and the age and condition of both engines and emission control equipment.

In addition, we need to better understand how particle size impacts human health: whether small particles are more respirable and travel deeper into the lungs, and whether the greater surface-to-volume ratio of smaller particles impacts toxicity. If ultrafine or nanoparticles carry greater health risks than larger particles, standards and regulations should be revised from strictly a mass basis to one that considers size distributions or concentrations.

Particulates are composed of both solids and liquid droplets. Thus far, studies on the impact of particles on human health have focused on the solid fraction. More research needs to be conducted into the toxicity of liquids and vapors, particularly since their share in exhaust may be higher for natural gas engines and diesel engines with particulate traps than for conventional diesel engines. One study found that diesel particulate traps changed the percent of volatiles in exhaust from 20 percent by mass to nearly 100 percent (Andersson, 2001).

Technology R&D

While technologies to clean up diesel are evolving and improving, research and development is key to getting these technologies off the shelf and on the road. Particulate traps need to be tested over the lifetime of vehicles and over a wide variety of transient cycles and operating conditions. New technologies like selective catalytic reduction and lean nitrogen oxide catalysts need further development before they can be taken out of the laboratory and placed onto vehicles. And alternative fuel school buses need to be made even cleaner by taking advantage of clean up technologies developed for control of diesel emissions. Particulate traps and other aftertreatment technologies that were developed for diesel may pose fewer contamination risks and perform even better with alternative fuels. Research into the role that lubricating oils play in creating particulates, especially for natural gas engines, is also needed. In addition, government research into next generation fuel cell school buses can help pave the way for the zero-pollution school buses of the future.

Research remains to be done before technologies to clean up diesel can be considered reliable and cost-effective.

Standards and Policies

Government policies can help narrow the gap between emissions as measured in a laboratory setting versus real world conditions. To keep exhaust control technologies effective over the life of the vehicle, an inspection and maintenance program is critical. Key components of such a program would include:

- On-board diagnostic systems designed to detect malfunctions in the exhaust control technologies
- Periodic chassis-based testing
- Fuel auditing and special nozzle applicators to ensure no misfueling occurs
- Requirement that aftertreatment devices last the useful life of the vehicles

Ultimately, new standards for engines based on in-use performance should replace today's certification process. In addition, new standards for lubricating oil, particle size, or particle toxicity can help keep school buses cleaner and reduce the public health risks from exposure to exhaust.

States can also play a role in protecting children's developing lungs from the harmful impacts of diesel pollution. Policies adopted by states like Delaware and

Maryland, which require buses to be retired after a certain age, can ensure that the oldest and dirtiest buses are removed from the road. State and local air pollution control districts could also require that new school buses meet specific pollution criteria. For example, in California, the South Coast Air Quality Management District has required that school districts purchase only cleaner alternative fuel buses.

Funding for Cleaner Buses

School districts that are strapped for funds should not have to make a trade-off between books and cleaner buses. Both the federal government and states can play key roles in funding cleaner school buses by providing grants for cleaner school buses, offering incentives for replacing or retrofitting older buses, and conducting demonstration programs for advanced technologies like fuel cell buses.

Federal Funding

Federal funds for cleaner school buses can meet the dual goals of protecting children's health and promoting energy security. Alternative fuels like natural gas help diversify America's energy sources and enhance national security. US reliance on oil products and on imported oil, which now accounts for over half of all oil products, has steadily increased over the last several decades. Approximately one-quarter of these imports are supplied by politically unstable countries in the Middle East (Friedman, 2001), leaving the country vulnerable to price shocks. US natural gas supplies, which come from North American sources, can help diversify our energy supplies and protect the economy.

Children's vulnerability to pollution highlights the need for a national school bus replacement program with strict pollution limits.

Children's vulnerability to the harmful impacts of pollution highlights the need for a national school bus replacement program with strict pollution limits. The Clean Cities Program, sponsored by the US Department of Energy, provides funds through the State Energy Program (SEP) for alternative fuel vehicles, including school buses. However, the program is not targeted specifically to school districts, and it only provides for the incremental cost difference between a conventional diesel vehicle and an alternative fuel vehicle, including fueling infrastructure. School districts that cannot afford the capital costs of a standard school bus are excluded from the program. Nevertheless, the program drew interest from school districts across the country, which were awarded nearly $490,000 for alternative fuel school bus projects in 2001 (DOE, 2001c).

Recognizing the need for targeted legislation specific to cleaner school buses, both the House and the Senate sponsored draft legislation in 2001. The legislation passed the House as part of the House Energy Bill, and was still pending in the Senate at the end of 2001. The legislation earmarked $300 million for a five-year grant program that would replace older school buses with new low-emission models. Seventy-five to 80 percent of the funds would be used for alternative fuel buses, while the remaining funds would go to low-emission diesel buses. This program could fund the replacement of over 2,000 school buses across the country. In addition, the legislation earmarked $25 million for demonstration projects of fuel cell school buses. Federal funding is key to ensuring that children across the country are able to ride in clean and safe school buses.

State Funding

While several states offer incentive programs to encourage the use of alternative fuel vehicles, most are not targeted specifically to school bus replacement. California is an exception, with a grant program specifically designed to put cleaner school buses on the road.

The California Governor's budget provided $66 million over the last two years to replace or retrofit older school buses. Though far short of the roughly $200 million needed to replace every California bus built before 1977 with a clean, natural gas vehicle, this investment was an important first step in cleaning up that state's oldest and dirtiest buses. Of the total funding available, half was reserved for alternative fuel vehicles and infrastructure, 25 percent for low-emission diesel buses, and the remaining 25 percent for retrofitting diesel buses with particulate traps. By the end of 2001, nearly 400 older school buses had been replaced with new, clean buses powered by alternative fuels or low-sulfur fuel.

CHAPTER 6

CONCLUSIONS

Children, whose lungs are still developing, deserve the highest level of protection from harmful diesel exhaust. Although numerous studies have linked diesel pollution with asthma and other respiratory illnesses, cancer, and premature death, all states still rely heavily upon diesel to power their fleet of school buses. The accelerated replacement of older and high-polluting diesel school buses with new, cleaner models should be a top public policy priority.

Today's natural gas school buses provide the cleanest commercially available alternative, offering reductions in toxic soot by 90 percent and in smog-forming emissions by 30 percent compared to conventional new diesel buses. Cleaner fuels like natural gas and stricter emissions regulations have spurred diesel-bus manufacturers to reduce tailpipe pollution. Diesel clean-up technologies are rapidly evolving and show the potential to dramatically reduce harmful pollution. Low-emission diesel school buses that rely upon particulate traps promise to reduce toxic soot emissions to the level of emissions from natural gas engines. However, diesel clean-up technologies, which are just beginning to penetrate the market, have not yet proven to be effective under real-world driving conditions. To assure these technologies remain effective over the lifetime of school buses, an inspection and maintenance program that evaluates in-use performance is critical. Without such safeguards, diesel engines may continue to pollute at higher levels than certification standards indicate.

Research on the health effects of air pollution from school buses is largely based upon data on older diesel engines. However, as school bus technologies evolve and become cleaner, the "average" emissions from the tailpipe will change. Vapors and smaller particles—like ultrafine and nanoparticles—may play a larger role in the emissions profile. Additional research is needed into the emissions and health effects of pollution released by low-emission diesel engines, natural gas engines, and natural gas engines with pollution aftertreatment technologies, like particulate traps.

The use of cleaner school buses today can help pave the way for the adoption of cleaner technologies tomorrow. Natural gas provides a stepping stone to hydrogen-powered fuel cells, which hold the potential for pollution-free transportation for children. In the nearer term, hybrid-electric drivetrains can improve engine efficiency and reduce emissions, particularly for the stop-and-go applications characteristic of school buses.

Our nation's most precious resource deserves the highest level of protection. America's children should be riding on the buses of the future, powered by the cleanest fuels and technologies available.

References

Ahlvik, P.J.E., and A.R.L. Brandberg. 2000. Relative Impact on Environment and Health from the Introduction of Low Emission City Buses in Sweden. Society of Automotive Engineers. 2000-01-1882. Warrendale, Pa.

American Thoracic Society (ATS). 1996. Health Effects of Outdoor Air Pollution. *American Journal of Respiratory & Critical Care Medicine,* 153:3–50.

Andersson, J., and B. Wedekind. 2001. Particulate Research Programme: Summary Report." Ricardo Consulting Engineers. May.

Bobit Publishing. 2001. Fact Book Issue. In *School Bus Fleet.* Online at *www.schoolbusfleet.com.*

Brogan, M., A.D. Clark, R. J. Brisley. 1998. Recent Progress in NOx Trap Technology. Society for Automotive Engineers. SAE 980933.

California Air Resources Board (CARB). 2000a. Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles. October.

California Air Resources Board (CARB). 2000b. Technical Support Document. EMFAC2000. Sacramento, Calif.: CARB. Online at *www.arb.ca.gov/msei/doctabletest/doctable_test.html.*

California Air Resources Board (CARB). 1998. Initial Statement of Reasons for Rulemaking: Proposed Identification of Diesel Exhaust as a Toxic Air Contaminant. Staff Report. Sacramento, Calif.: CARB. June.

California Air Resources Board (CARB). 1996. Mobile Source Emission Reduction Credits. Stationary Source Division, Mobile Source Division. Sacramento, Calif.: CARB. February.

California Energy Commission (CEC). 1999. Safe School Bus Clean Fuel Efficiency Demonstration Program. Second Interim Status Report. P500-99-001. Sacramento, Calif.: CEC. May.

Cannon, J.S., and C. Sun. 2000. *Bus Futures: New Technologies for Cleaner Cities.* New York: INFORM. ISBN 918790-74-8.

Center for Transportation Technologies and Systems (CTTS). 2001. Bus emissions test data accessed by querying a database on the DOE's Alternative Fuels Data Center from the website of the DOE's Center for Transportation Technologies and Systems *www.ctts.nrel.gov/heavy_vehicle/emissions.html.* Links to query forms are listed under the heading "Bus Emissions Database Queries." Data accessed during December 2001.

Clark, N., D. Lyons, M. Gautam, J. Kopako, and W. Xie. 2000. Emissions Performance Testing of Eight Transit Buses with Different Fuels and Technologies. Prepared by West Virginia University for the Massachusetts Bay Transportation Authority, Boston.

DeCicco, J., and J. Kliesch. 2001. Rating the Environmental Impacts of Motor Vehicles: ACEEE's Green Book Methodology. May. Washington, D.C.: ACEEE.

Delucchi, M.A. 1996–1998. Social Costs of Transportation. A series of 20 reports published by Institute for Transportation Studies. University of California, Davis.

Department of Energy (DOE). 2001a. Natural Gas School Buses; Driving our Kids to a Cleaner Tomorrow. Fact Sheet. March. Online at *www.ott.doe.gov/pdfs/natural_gas_school_buses_mar_2001.pdf.*

Department of Energy (DOE) 2001b. DECSE Phase I: Evaluating the Effects of Sulfur on Diesel Particulate Filters. January. Online at *www.trucks.doe.gov/research/fuel/decse-filterphase1.html.*

Department of Energy (DOE). 2001c. Alternative Fuel School Buses Earn High Marks. *Alternative Fuel News* 5(3). November. Online at *www.afdc.doe.gov/documents/altfuelnews/5_3cover.html.*

Department of Energy (DOE). 2000. Natural Gas Buses: Separating Myth from Fact. Alternative Fuel Information Series. NREL/FS-540-28377. Office of Energy Efficiency and Renewable Energy. May.

DieselNet. 2000a. Effects of EGR on Engine and Emissions. *DieselNet Technology Guide.* Revision 2000.08. Online at *www.DieselNet.com.*

DieselNet. 2000b. Selective Catalytic Reduction. Online at *www.DieselNet.com.*

DieselNet. 1998. Emission Control Technologies. Revision 6. Online at *www.DieselNet.com.*

Dockery, D.W., and C.A. Pope, III. 1993. An Association Between Air Pollution and Mortality in Six US Cities. *New England Journal of Medicine,* 329(24): 1753–9.

Duo, D., and O. Bailey. 1998. Investigation of NOx Adsorber Catalyst Deactivation. SAE 982594. Warrendale, Pa.: Society of Automotive Engineers. October.

Environmental Protection Agency (EPA). 2001a. Ozone Nonattainment Area Summary as of August 02, 2001. Online at *www.epa.gov/oar/oaqps/greenbk/onsum.html.*

Environmental Protection Agency (EPA). 2001b. Urban Bus Retrofit Program. Online at *www.epa.gov/otaq/retrofit/retroverifiedlist.htm.*

Environmental Protection Agency (EPA). 2001c. MOBILE6 Emission Factors for Natural Gas Vehicles. EPA420-R-01-033. Washington, D.C.: EPA. April.

Environmental Protection Agency (EPA). 2000a. Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines. EPA420-R-00-010. Washington, D.C.: EPA. July.

Environmental Protection Agency (EPA). 2000b. AP-42, Compilation of Air Pollutant Emission Factors. Volume II. Mobile Sources. Updated November 24, 2000. Online at *www.epa.gov/otaq/ap42.htm.*

Environmental Protection Agency (EPA). 1999a. Fleet Characterization Data for MOBILE6: Development and Use of Age Distributions, Average Annual Mileage

Accumulation Rates and Projected Vehicle Counts for Use in MOBILE6. EPA420-P-99-011. Washington, D.C.: EPA. April.

Environmental Protection Agency (EPA). 1999b. Update Heavy-Duty Engine Emission Conversion Factors for MOBILE6: Analysis of Fuel Economy, Non-Engine Fuel Economy Improvements, and Fuel Densities. EPA420-P-98-014. Washington, D.C.: EPA. May.

Environmental Protection Agency (EPA). 1997. Health and Environmental Effects of Particulate Matter. Fact sheet. Online at *www.epa.gov/ttn/oarpg/naaqsfin/pmhealth.html.*

Environmental Protection Agency (EPA). 1995. Human Health Benefits from Sulfate Reduction Under Title IV of the 1990 Clean Air Act Amendments. Washington, D.C.: Office of Air and Radiation, Acid Rain Division. November.

Federal Interagency Forum on Child and Family Statistics. 2001. America's Children: Key National Indicators of Well-Being. 2001. Washington, D.C.: US Government Printing Office. Online at *www.childstats.gov.*

Field, C.B., G.C. Daily, F.W. Davis, S. Gaines, P.A. Matson, J. Melack, and N.L. Miller. 1999. Confronting Climate Change in California. Cambridge, Mass.: Union of Concerned Scientists.

Frailey, M., P. Norton, N.N. Clark, and D.W. Lyons. 2000. An Evaluation of Natural Gas versus Diesel in Medium-Duty Buses. SAE 2000-01-2922. Warrendale, Pa.: Society of Automotive Engineers.

Friedman, D., J. Mark, P. Monahan, C. Nash, and C. Ditlow. 2001. Drilling in Detroit. Cambridge, Mass.: Union of Concerned Scientists.

Gauderman, W.J., R. McConnell, F. Gilliland, S. London, D. Thomas, E. Avol, H. Vora, K. Berhane, E.B. Rappaport, F. Lurmann, H.G. Margolis, and J. Peters. 2000. Association Between Air Pollution and Lung Function Growth in Southern California Children. *American Journal of Respiratory & Critical Care Medicine,* 162:1384–1390.

Intergovernmental Panel on Climate Change. 2001. *Climate Change 2001: Impacts, Adaptation and Vulnerability. Summary for Policymakers.* Cambridge, U.K.: Cambridge University Press.

Jacobson, M.Z. 2001. Strong radiative heating due to the mixing state of black carbon in atmospheric aerosols. *Nature,* 409: 695–697.

Kittelson, D.B. 1998. Engines and Nanoparticles: A Review. *Journal of Aerosol Science,* 29(5): 575–588.

Koren, H.S. 1995. Associations between Criteria Air Pollutants and Asthma. US EPA's Health Effects Research Laboratory. Presented at the Workshop on Air Toxics and Asthma-Impacts and End Points, Houston, Texas, February 4.

LeTavec, C., J. Uihlein, J. Segal, and K. Vertin. 2000. EC-Diesel Technology Validation. Program Interim Report. SAE 2000-01-1854. Warrendale, Pa.: Society of Automotive Engineers.

Lozano, P., S.D. Sullivan, D.H. Smith, and K.B. Weiss. 1999. The Economic Burden of Asthma in US Children: Estimates from the National Medical Expenditure Survey. *Journal of Allergy & Clinical Immunology,* 104(5): 957–963.

Majewski, W.A. 2001. Lean NOx Catalyst. Revision 2001-04. Online at *www.DieselNet.com/tech/cat_lean-nox.html.*

Majewski, W.A. 2000. Diesel Particulate Matter. *DieselNet Technology Guide.* Revision 2000.03a. Online at *www.dieselnet.com /tech/dpm.html.*

McNerny, Don. 2001. Effects of Trap-Related Emissions on Air Quality. Presentation by the California Air Resources Board. October.

Mark, J., and C. Morey. 2000. Rolling Smokestacks. Union of Concerned Scientists. Cambridge, Mass.: Union of Concerned Scientists.

McKinley, T. 1997. Modeling Sulfuric Acid Condensation in Diesel Engine EGR Coolers. SAE 970636. Warrendale, Pa.: Society of Automotive Engineers.

Manufacturers of Emissions Control Association (MECA). 2000. Emission Control Retrofit of Diesel-Fueled Vehicles. March.

Miller, W.R. 2000. The Development of Urea-SCR Technology for US Heavy Duty Trucks—Demonstration Update. Presented at the Diesel Engine Emission Reduction Conference, 2000.

Natural Resources Defense Council (NRDC) and Coalition for Clean Air (CCA). 2001. No Breathing in the Aisles: Diesel Exhaust Inside School Buses. New York: NRDC. January.

National Highway Traffic Safety Administration. 1998. School Bus Safety—Safe Passage for America's Children. HS 808 755. Washington, D.C.: US Department of Transportation. August. Online at *www.nhtsa.dot.gov/people/injury/buses/schbus/schbussafe.html.*

Northeast Advanced Vehicle Consortium (NAVC). 2000. Hybrid-Electric Drive Heavy-Duty Vehicle Testing Project: Final Emissions Report. Prepared by M.J. Bradley & Associates, Inc. Boston, Mass.: NAVC.

Ostro, B.D., M.J. Lipsett, J.K. Mann, H. Braxton-Owens, M.C. White. 1995. Air Pollution and Asthma Exacerbations among African American Children in Los Angeles. *Inhalation Toxicology,* 7:711–722.

Oueliette, Patric. 2000. High Pressure Direct Injection of Natural Gas in Diesel Engines. Westport Innovations, Inc. Natural Gas Vehicle Conference, Yokohama, Japan, October 17–19.

Patten, J.W. 1997. Diesel Engine Emissions Reduction History and Future Prospects. Cummins Engine Company, Inc. In *Proceedings of the 1997 Diesel Engine Emissions Reduction Workshop.* CONF-970799. Springfield, Va.: US Department of Energy, Office of Transportation Technologies.

Petit, J.R., J. Jouzel, D. Raynaud, N.I. Barkov, J.M. Barnola, I. Basile, M. Bender, J. Chappelaz, M. Davis, G. Delaygue, M. Delmotte, V.M. Kotlyakov, M. Legrand, V.Y. Lipenkov, C. Lorius, L. Pepin, C. Ritz, E. Saltzman, and M. Stievenard. 1999. Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature,* 399:429–436.

Pope, C.A., M.J. Thun, M.M. Namboodiri, D.W. Dockery, J.S. Evans, F.E. Speizer, and C.W. Heath. 1995. Particulate Air Pollution as a Predictor of Mortality in a Prospective Study of US Adults. *American Journal of Respiratory & Critical Care Medicine,* 151:669–674.

Pope, C.A., III. 1991. Respiratory Hospital Admissions Associated with PM_{10} Pollution in Utah, Salt Lake, and Cache Valleys. *Archives of Environmental Health,* 46:90–97.

R.L. Polk. 2001. US Vehicles in Operation, School Buses. Provided by Sandra Bogart, Account Executive, to UCS in September.

Sacramento Regional Transit District (SRTD) and SunLine Transit Agency (STA). 1999. Three Year Comparison of Natural Gas and Diesel Transit Buses. Revised August. Thousand Palms, Calif.: SunLine Transit Agency.

State and Territorial Air Pollution Program Administrators (STAPPA) and the Association of Local Air Pollution Control Officials (ALAPCO). 2000. Cancer Risk from Diesel Particulate: National and Metropolitan Area Estimates for the United States. March 15. Online at *www.4cleanair.org/comments/Cancerriskreport.PDF.*

Turner, S.H., C. Weaver, M. Balam, and R. Gable. 2000. Comparison of In-Use Emissions from Diesel and Natural Gas Trucks and Buses. SAE 2000-01-3473. Warrendale, Pa.: Society of Automotive Engineers.

Twilley, R.R., E.J. Barron, H.L. Gholz, M.A. Harwell, R.L. Miller, D.J. Reed, J.B. Rose, E.H. Siemann, R.G. Wetzel, R.J. Zimmerman. 2001. Confronting Climate Change in the Gulf Coast: Prospects for Sustaining Our Ecological Heritage. Cambridge, Mass.: Union of Concerned Scientists.

Wang, M.Q. 2001. GREET 1.6.—Transportation Fuel-Cycle Model. Argonne, Ill.: Argonne National Laboratory. Online at *http://greet.anl.gov:80/pdfs/greet1-6summary.pdf.*

West Virginia University Transportable Heavy-Duty Vehicle Emissions Testing Laboratory. 1997. Exhaust Emissions Test Results Report of Raley's Distribution Center Tractors. In Gas Research Institute (GRI). 1999. Final Report: The Cleaner Choice: Natural Gas as a Substitute for Diesel. GRI-99/0261. Batavia, Ill.: GRI.

White, M.C., R.A. Etzel, W.D. Wilcox, and C. Lloyd. 1994. Exacerbations of Childhood Asthma and Ozone Pollution in Atlanta. *Environmental Research,* 65:56–68.

Wiley, J., J. Robinson, T. Piazza, L. Stork, and K. Pladsen. 1993. Final Report—Study of Children's Activity Patterns. Cited in Gauderman, W.J., R. McConnell, F. Gilliland, S. London, D. Thomas, E. Avol, H. Vora, K. Berhane, E.B. Rappaport, F. Lurmann, H.G. Margolis, and J. Peters. 2000. Association Between Air Pollution and Lung Function Growth in Southern California Children. *American Journal of Respiratory & Critical Care Medicine,* 162:1384–1390.

APPENDIX A

Methodology

State School Bus Fleets

We contacted the State Directors of Pupil Transportation and other school bus officials from every state to collect information on the model years and fuel choices for school buses. All of the states except Connecticut responded to the survey. Twenty-six states and the District of Columbia were able to provide the percentage of buses that had been built within the last decade in each state fleet. Only a few states could provide a year-by-year breakdown of their fleet by model age and fuel.

We supplemented state-reported information with data from R.L. Polk & Company, the only centralized source of school bus registration data from each state's Department of Motor Vehicles (R.L. Polk, 2001). Polk provided information on model year, fuel type, and gross vehicle weight for each state school bus. Where Polk data conflicted with information provided by the State Directors of Pupil Transportation, we revised the Polk data to reflect the state-reported statistics. We also used the School Bus Fleet "Fact Book Issue" (Bobit, 2001) for general statistics on state school bus fleets. For a list of the sources of school bus data for each state, see Appendix B.

Our review of the Polk data indicated that there were apparent errors in some of the vehicle registration data for state school bus fleets. The Polk data indicated that there were significant numbers of medium heavy-duty gasoline-powered school buses that were manufactured from 1990 through 2001. In discussions with school bus distributors and manufacturers, it appears that nearly all of the heavy-duty school buses manufactured in the last decade were fueled by diesel or natural gas. Since less than one percent of the nation's school buses are fueled by natural gas, we assumed that all post-1990 gasoline buses should have been apportioned to diesel.

Calculating NOx, HC, and CO Emissions

We used factors developed for US EPA's highway emissions factor model, MOBILE6—the first EPA emissions model to incorporate emission factors specific to school buses—to estimate emissions of NOx, HC, and CO. For a list of the emission factors for diesel, gasoline and natural gas school buses, see Appendix B. The final version of MOBILE6 has not yet been released by EPA, but EPA staff provided the most recent emission factors for use in our model. MOBILE6 includes data on vehicle population and applies emission factors specific to vehicle type, model year, and on-road operating characteristics. EPA assumes that the average school bus is a medium heavy-duty vehicle with a gross vehicle weight of 19,501 to 33,000 pounds.

The model assumes that

$$E = CF * SCF * [ZML + DF * (VMT / 10,000 \text{ miles})]$$

where

E = emissions in grams per mile (g/m)
CF = conversion factor in brakehorsepower-hour per mile (bhp-hr)/m
SCF = speed correction factor (unitless)
ZML = zero mile level in g/bhp-hr
DF = deterioration factor in g/bhp-hr per 10,000 miles
VMT = vehicle miles traveled

The model also assumes that:

$$CF = FD / (BSFC*FE)$$

where

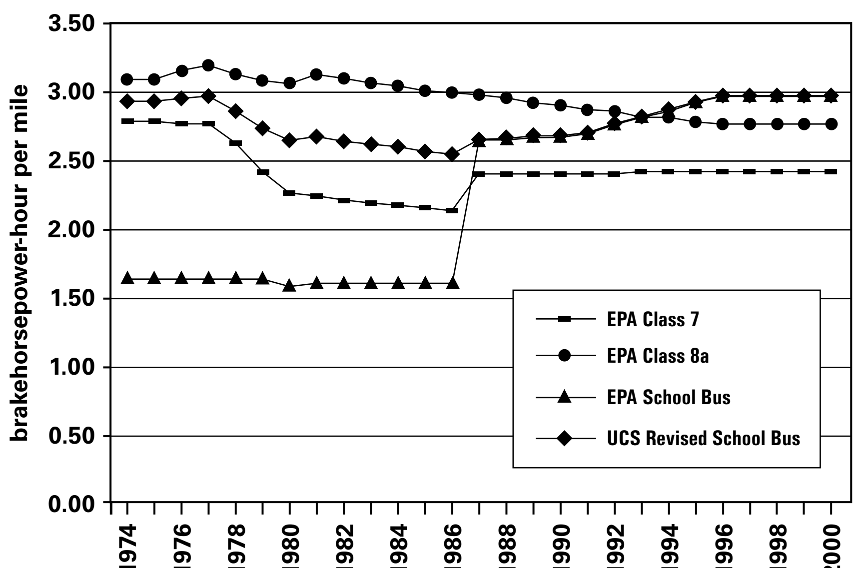
FD = fuel density in lb/gal
BSFC = brake specific fuel consumption in lb/bhp-hr
FE = fuel economy in m/gal

Diesel NOx, HC, and CO Emissions

Our analysis of EPA's emission factors for diesel school buses detected some inconsistencies in the emission factors. We revised the diesel school bus emission factors to address the apparent discrepancies. Specifically:

- EPA assumes that the conversion factor for 1986 diesel school buses and older are 40 percent below the 1987 level, even though the conversion factors for other medium heavy-duty vehicles did not change as noticeably (Figure A-1). We would expect school buses to have a conversion factor higher than other Class 7 vehicles, since their stop-and-go drive cycle may result in lower fuel economy. There was no apparent reason for the school bus conversion factors for pre-1987 model years to deviate so significantly from other Class 7 vehicles. We thus modified the school

Figure A-1. Diesel Conversion Factors



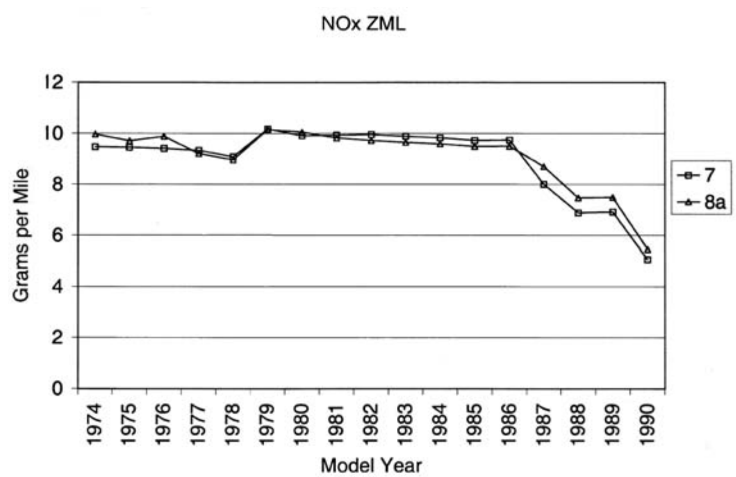
Source: EPA MOBILE6 conversion factors provided by EPA staff bus conversion factors to reflect the average of Class 7 and Class 8a vehicles for all model years before 1987.

- According to EPA, the ZML and DF for school buses and other medium heavy-duty diesel vehicles should be the same. However, a few of the values for school buses deviated from the values for other medium heavy-duty vehicles. In those instances, we applied the ZML and DF for medium heavy-duty vehicles rather than the values specific to school buses.

Gasoline NOx, HC, and CO Emissions

MOBILE6 did not provide basic emission factors for school buses powered by gasoline. The basic emission factors for gasoline-powered school buses should be higher than the factors for Class 7 vehicles. EPA's basic emission factors for Class 7 and Class 8a heavy-duty gasoline engines were similar (Figure A-2), and we applied the Class 8a basic emission factors for gasoline-powered school buses.

Figure A-2. Comparing Basic Emission Factors for Class 7 and 8a Gasoline Vehicles



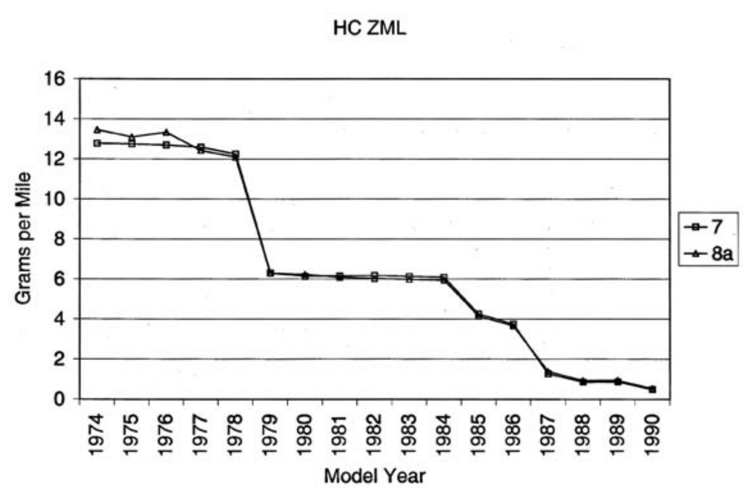
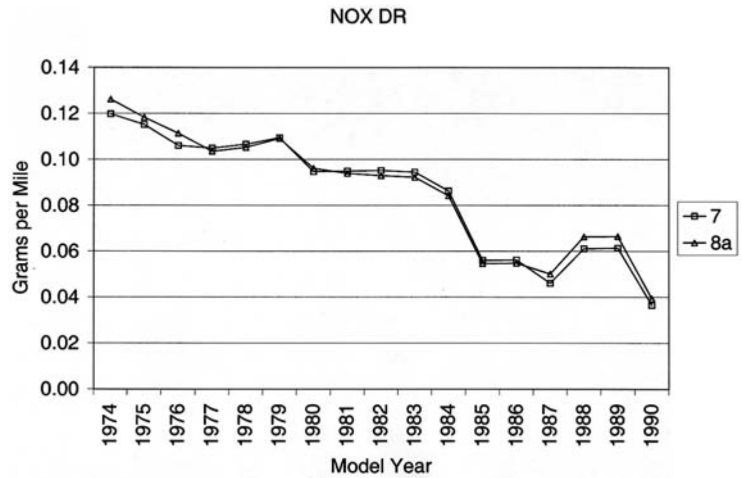
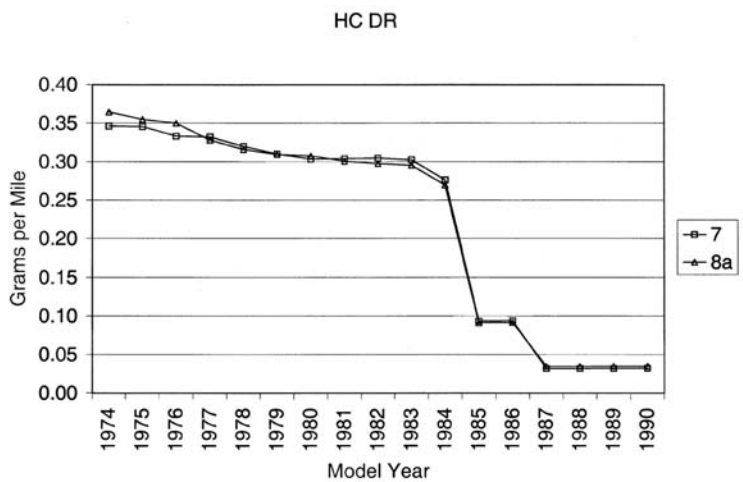


Figure A-2. Comparing Basic Emission Factors for Class 7 and 8a Gasoline Vehicles (continued)





Natural Gas NOx, HC, and CO Emissions

For natural gas school buses, we integrated school bus certification data from the California Air Resources Board with EPA deterioration factors for medium heavy-duty natural gas engines (EPA, 2001c). EPA assumes that the conversion factors for diesel school buses also apply to natural gas school buses. Ideally, the conversion factors for natural gas vehicles would be based upon their brake-specific fuel economy, fuel density, and fuel economy. The California Air Resources Board has calculated the conversion factors for diesel and natural gas transit buses to be 4.3 and 4.1 bhp-hr/mile respectively (CARB, 1996). Thus, EPA's assumption that natural gas and diesel school buses would have similar conversion factors is compatible with the California Air Resources Board's analysis of transit buses. We thus followed EPA's guidance and used the diesel school bus conversion factors for natural gas vehicles.

Drive Cycle

We assumed that school buses would operate on the central business district drive cycle. For NOx, HC, and CO calculations from diesel and gasoline school buses, we applied EPA's speed correction factors specific to those fuels (EPA, 2000b). EPA assumes that same speed correction factor for diesel would also apply to natural gas engines.

Calculating PM Emissions

PM from Natural Gas and Diesel School Buses

The limited data available from in-use testing indicates that real world emissions may be much higher than certification values indicate, particularly for diesel vehicles. To estimate PM emissions from natural gas and diesel school buses, we relied upon in-use data from the DOE's Alternative Fuels Data Center (CTTS, 2001). We focused only on emissions data for the central business district. Our statistical analysis of emissions data from in-use tests for different model years showed no clear deterioration factor. As such, we are assuming no deterioration over time in emissions performance for natural gas or diesel vehicles.

Because there were not sufficient data to enable us to develop emission factors for every model year, we developed emission factors only for the following model year ranges: pre-1988 models, 1988–1990, 1991–1993, and 1994 and newer. We selected these age ranges because models manufactured in these years were subject to specific PM_{10} certification standards. The first soot regulations were established in 1988, and the standards were strengthened in 1991 and 1994.

Most of the data on in-use emissions for model years 1988 through today were for transit buses or refuse vehicles. These Class 8a and 8b vehicles are heavier and more powerful than school buses and would likely have higher particulate emissions. We assumed that PM emissions from different types of heavy-duty vehicles would be scaled to their conversion factors. For example:

ESB = ETB * [CFSB / CFTB]

where

ESB = Emissions from school buses in g/m
ETB = Emissions from transit buses in g/m
CFSB = Conversion factor for school buses
CFTB = Conversion factor for transit buses

There were no in-use data available on diesel school buses built before 1988, which did not have to meet any particulate standards for soot. To estimate emissions from these older vehicles, we assumed that PM emissions from different types of heavy-duty vehicles would be scaled to their certification values[1] according to the following formula:

---

[1] Pre-1988 school buses certify at 1.0 g/bhp-hr (Patten, 1997), while buses built from 1988 through 1990 certify at 0.6 g/bhp-hr.

Table A-1. Particulate Emissions from School Buses

Model Year	Diesel	CNG	Gasoline
Pre-88	1.939	N/A	0.054
1988-1990	1.211	N/A	0.054
1991-1993	1.067	N/A	N/A
1994 and newer	0.256	0.022	N/A

ESB(Pre1988) = ETB(1988–1990) * [CERTSB(Pre1988) / CERTTB(1988–1990)]

where

ESB(Pre1988) = Emissions from pre-1988 school buses in g/m
ETB(1988–1990) = Emissions from transit buses built 1988 through 1990 in g/m
CERTSB(Pre1988) = Certification for school buses in g/bhp-hr
CERTTB(1988–1990) = Certification for school buses in g/bhp-hr

PM from Gasoline School Buses

Unfortunately, there is scant information available on in-use emissions of particulates from gasoline engines, particularly in the heavy-duty sector. US EPA has never imposed standards on PM from heavy-duty gasoline engines, since emissions have been presumed to be low enough to render standards unnecessary. Recently, there have been mounting concerns that gasoline engines release particulates that could be harmful to human health. Measuring soot emissions from gasoline engines raises technical challenges because the particles are so small that accuracy may be compromised. Because there are relatively few medium heavy-duty gasoline engines on today's market, emissions testing for these vehicles is a lower priority than for the light-duty sector.

To estimate particulate emissions from gasoline school buses, we used data from California's EMFAC 2000 model (CARB, 2000b). EMFAC relied upon emissions testing from light-duty trucks to extrapolate potential emissions from heavy-duty vehicles. The EMFAC model assumes that gasoline-powered medium heavy-duty trucks of all model years will emit 0.054 grams per mile, with no deterioration over time. It is possible that EMFAC underestimates particulate releases from gasoline-powered school buses for two reasons. First, newer gasoline heavy-duty vehicles may have a lower ZML than older models, reflecting engineering improvements over time. Most gasoline school buses were built over ten years ago, and some are two, three and even four decades old. Second, the EMFAC data for particulate emissions were based upon in-use data for a limited sample of light-duty trucks. It is not clear how closely the emissions profile from the heavy-duty sector would mirror the light duty sector. Lacking real world data on emissions from gasoline-powered medium heavy-duty vehicles, however, we relied upon the particulates emission factor from EMFAC.

Calculating Global Warming Emissions

Per Gallon Emissions

We applied a model developed by Argonne National Laboratory, which estimates per gallon emissions of greenhouse gases from fuel combustion and from the production and distribution of fuels (so called "upstream" emissions). The model, Greenhouse

Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Version 1.6 (Wang, 2001), is periodically revised to reflect the author's best estimate of upstream and downstream pollution from the use of a gallon of fuel.[2] Linking per-gallon emission rates from GREET with vehicle fuel economy provides an estimate of average greenhouse gas emissions per mile traveled.

The model accounts for upstream emissions of methane, nitrous oxide, and carbon dioxide, as well as tailpipe releases of carbon dioxide. It does not account for tailpipe releases of methane from heavy-duty engines. Today's natural gas transit buses and other heavy-duty engines emit 10 to 15 grams of methane per mile (NAVC, 2000; Clark et al., 2000). We assumed the average transit bus would release 12.5 grams of methane per mile, and that releases are scaled to vehicle fuel economy. School buses emissions are thus estimated to be 7.7 grams of methane per mile according to the following formula:

MethaneSB = MethaneTB* FETB / FESB

where

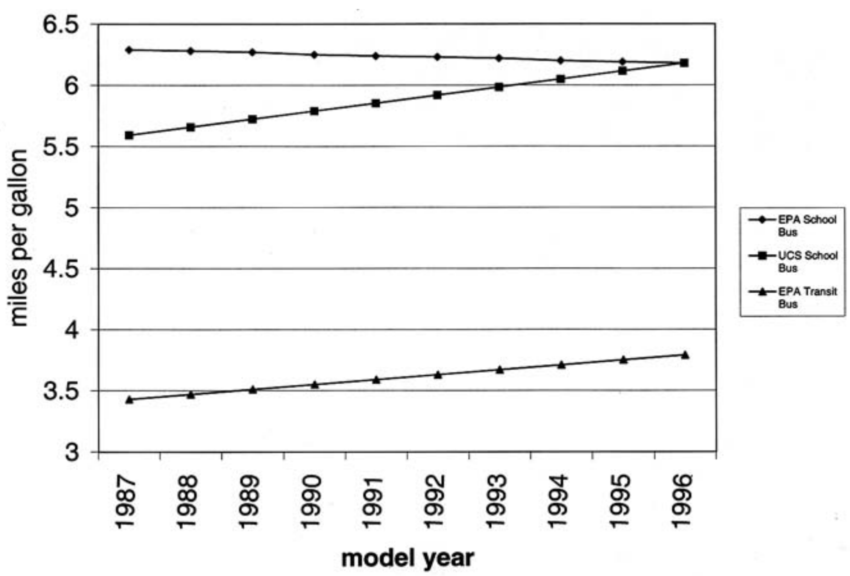
MethaneTB = Methane releases from transit buses (estimated at 12.5 grams/mile)

FETB / FESB = Ratio of the fuel economy of transit to school buses (estimated to be 0.6)

Vehicle Fuel Economy

Diesel Fuel Economy. In MOBILE6, EPA assumes that fuel economy for diesel school buses declines over time, while transit buses become more fuel efficient (EPA, 1998). We assume that diesel school buses would improve in fuel efficiency over time at the same rate as transit buses (a linear rate of .065 miles per gallon per year).

Figure A-3. Fuel Economy of Diesel-Powered Transit Bus and School Bus

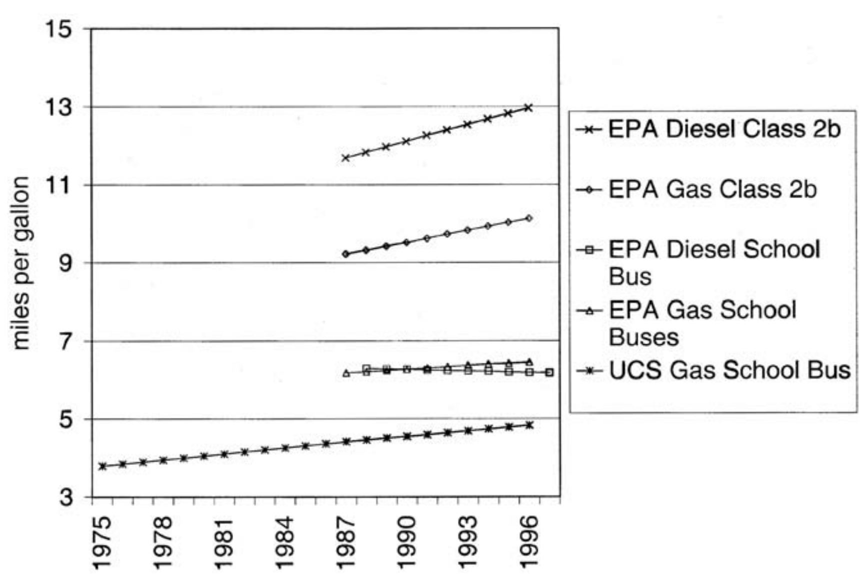


[2] The version of the model that we used is still in the beta testing phase.

Natural Gas Fuel Economy. We would expect the fuel economy of school buses powered by natural gas to be lower than their diesel counterparts due to the inherent efficiency gains of compression ignition. There have been several studies comparing the fuel economy of natural gas and diesel engines, with varying results. The California Energy Commission conducted a school bus demonstration program and found that the newest alternative fuel school buses approached the fuel economy (6 miles per gallon), on an energy-equivalent basis, of the newest diesel engines (CEC, 1999). A recent evaluation of transit buses reported that natural gas averaged 17 percent lower fuel economy than diesel (Frailey et al., 2000). A DOE study on refuse haulers found that the fuel economy of natural gas vehicles was 5 to 20 percent lower than comparable diesel vehicles, with a median of 12.5 percent (DOE, 1997). We applied the results of the DOE refuse study, which represented the mid-range estimate of natural gas fuel economy relative to diesel, and assumed that the fuel economy of natural gas vehicles would be 12.5 percent lower than diesel school buses.

Gasoline Fuel Economy. In MOBILE6, EPA assumes that gasoline school buses would have about the same fuel economy as diesel vehicles (EPA, 1998). However, diesel engines should have higher fuel economy for two reasons. First, diesel compression ignition engines are inherently more fuel efficient than spark-ignited gasoline engines, and second, diesel has a higher energy content per gallon. We assume that EPA's fuel economy data for the lightest heavy-duty vehicles, Class 2b vehicles (which include pick-ups), is more reliable than the data for other heavy-duty vehicles. We compared the difference in fuel economy between Class 2b gasoline and diesel vehicles, and assumed that their relative difference would also be reflected in the fuel economy of school buses (Figure A-4). Using this formula, gasoline engines have about 21 percent lower fuel economy than diesel engines on a miles per gallon basis.

Figure A-4. Fuel Economy of Gasoline and Diesel Heavy-Duty Vehicles



APPENDIX B

Results, Emission Factors, and Data Sources

Table B-1. Annual Pollution from State School Bus Fleets

State	# School Buses	Tons Released in 2001					
		NMHC	NOx	Smog	CO	PM	GHG
Alabama	6,963	185	1,126	1,311	2,077	31	157,285
Alaska	1,052	71	173	244	1,130	7	25,947
Arizona	6,676	329	1,145	1,473	4,699	49	159,409
Arkansas	6,338	468	962	1,430	7,990	26	159,045
California	24,190	1,162	4,697	5,859	14,186	225	584,819
Colorado	5,798	370	982	1,352	5,724	41	143,336
Connecticut	5,232	132	893	1,025	1,363	38	124,315
Delaware	1,559	22	259	281	82	8	34,656
District of Columbia	652	9	113	122	34	4	14,706
Florida	20,292	518	3,506	4,024	5,160	134	463,187
Georgia	14,879	514	2,613	3,127	6,142	114	348,051
Hawaii	794	14	142	157	61	8	18,325
Idaho	2,738	115	460	575	1,592	18	64,787
Illinois	18,001	614	2,948	3,562	7,696	106	424,464
Indiana	13,164	261	2,251	2,512	1,780	90	302,243
Iowa	5,831	245	961	1,206	3,357	39	140,883
Kansas	6,470	270	1,022	1,292	3,942	30	153,680
Kentucky	9,469	581	1,476	2,057	9,489	48	229,566
Louisiana	7,510	540	1,210	1,750	8,924	46	185,940
Maine	2,642	109	447	556	1,482	18	63,034
Maryland	7,179	107	1,195	1,302	421	40	160,494
Massachusetts	8,497	174	1,437	1,611	1,303	47	191,760
Michigan	15,787	514	2,744	3,259	5,996	109	366,479
Minnesota	10,608	423	1,875	2,298	5,448	82	251,079
Mississippi	5,534	182	875	1,056	2,354	29	129,929
Missouri	12,082	287	2,003	2,290	2,879	66	275,991

Table B-1. Annual Pollution from State School Bus Fleets (continued)

State	# School Buses	Tons Released in 2001					
		NMHC	NOx	Smog	CO	PM	GHG
Montana	2,166	137	368	505	2,148	15	53,141
Nebraska	2,554	148	411	559	2,348	15	61,940
Nevada	1,832	85	327	412	1,156	15	43,458
New Hampshire	2,443	80	425	506	943	17	56,818
New Jersey	19,281	704	3,306	4,010	8,807	138	455,431
New Mexico	3,039	130	517	647	1,785	21	72,080
New York	45,495	1,179	8,321	9,500	10,192	375	1,049,069
North Carolina	13,120	242	2,402	2,644	1,072	95	297,251
North Dakota	1,854	77	276	353	1,152	7	44,815
Ohio	18,042	885	3,169	4,054	12,592	130	429,897
Oklahoma	7,460	503	1,132	1,636	8,322	42	187,734
Oregon	6,046	261	980	1,241	3,662	36	141,111
Pennsylvania	19,274	514	3,216	3,729	5,422	112	439,586
Rhode Island	1,638	41	290	331	373	12	37,515
South Carolina	5,589	194	1,197	1,391	1,808	62	133,577
South Dakota	1,620	106	268	373	1,686	10	39,752
Tennessee	7,367	137	1,182	1,319	973	45	171,456
Texas	33,335	1,367	5,416	6,783	18,755	208	787,964
Utah	2,051	72	361	433	840	16	48,057
Vermont	1,346	46	232	278	539	10	31,695
Virgina	11,809	425	2,068	2,493	5,149	92	278,606
Washington	8,916	548	1,540	2,088	8,536	66	215,884
West Virginia	3,602	136	628	764	1,742	26	84,773
Wisconsin	12,581	473	2,117	2,591	6,161	82	294,675
Wyoming	1,757	118	297	414	1,872	12	43,283
US Total	454,154	16,825	77,959	94,784	213,342	3,112	10,672,975

Table B-2. Annual Pollution from Average School Bus

State	Pounds Released in 2001					
	NMHC	NOx	Smog	CO	PM	GHG
Alabama	53	323	377	596	9	45,177
Alaska	134	330	464	2,148	12	49,329
Arizona	98	343	441	1,408	15	47,756
Arkansas	148	304	451	2,521	8	50,188
California	96	388	484	1,173	19	48,352
Colorado	128	339	466	1,975	14	49,443
Connecticut	51	341	392	521	14	47,521
Delaware	29	333	361	105	11	44,460
District of Columbia	28	346	374	103	11	45,110
Florida	51	346	397	509	13	45,652
Georgia	69	351	420	826	15	46,784
Hawaii	36	359	395	154	19	46,158
Idaho	84	336	420	1,163	13	47,324
Illinois	68	328	396	855	12	47,160
Indiana	40	342	382	270	14	45,920
Iowa	84	330	414	1,151	13	48,322
Kansas	83	316	399	1,219	9	47,505
Kentucky	123	312	434	2,004	10	48,488
Louisiana	144	322	466	2,377	12	49,518
Maine	83	338	421	1,122	13	47,717
Maryland	30	333	363	117	11	44,712
Massachusetts	41	338	379	307	11	45,136
Michigan	65	348	413	760	14	46,428
Minnesota	80	353	433	1,027	16	47,338
Mississippi	66	316	382	851	10	46,957
Missouri	48	332	379	477	11	45,686

Table B-2. Annual Pollution from Average School Bus (continued)

State	Pounds Released in 2001					
	NMHC	NOx	Smog	CO	PM	GHG
Montana	126	340	466	1,983	14	49,068
Nebraska	116	322	438	1,838	12	48,504
Nevada	92	357	449	1,262	16	47,443
New Hampshire	66	348	414	772	14	46,515
New Jersey	73	343	416	914	14	47,241
New Mexico	86	340	426	1,175	14	47,437
New York	52	366	418	448	16	46,118
North Carolina	37	366	403	163	14	45,313
North Dakota	83	297	381	1,243	7	48,344
Ohio	98	351	449	1,396	14	47,655
Oklahoma	135	304	438	2,231	11	50,331
Oregon	86	324	411	1,211	12	46,679
Pennsylvania	53	334	387	563	12	45,614
Rhode Island	50	354	405	455	14	45,805
South Carolina	70	428	498	647	22	47,800
South Dakota	130	331	461	2,082	13	49,076
Tennessee	37	320	358	263	12	46,556
Texas	82	325	407	1,125	12	47,275
Utah	70	352	422	819	16	46,862
Vermont	68	345	413	801	15	47,095
Virgina	72	350	422	872	16	47,185
Washington	123	345	468	1,915	15	48,426
West Virginia	75	349	424	967	14	47,070
Wisconsin	75	337	412	979	13	46,844
Wyoming	134	338	472	2,131	14	49,269
US Total	74	343	417	939	14	47,002

Table B-3. State School Bus Fuel Choice and Age Distribution

State	Bus Age Distribution			Fuel Choice		
	Before 1977	1977 to 1990	After 1990	Diesel	Gasoline	Other
Alabama	0.0%	15.1%	84.9%	92%	8%	0.0%
Alaska	0.0%	47.5%	52.5%	71%	29%	0.0%
Arizona	0.9%	40.5%	58.5%	80%	17%	3.34%
Arkansas	0.0%	46.9%	53.1%	60%	40%	0.0%
California	5.5%	42.7%	51.8%	85%	12%	2.58%
Colorado	0.0%	52.9%	47.1%	72%	28%	0.17%
Connecticut	1.0%	22.7%	76.3%	93%	6%	0.17%
Delaware	0.0%	0.6%	99.4%	100%	0%	0.0%
District of Columbia	0.0%	0.0%	100.0%	100%	0%	0.0%
Florida	0.0%	17.3%	82.7%	95%	5%	0.02%
Georgia	0.0%	36.1%	63.9%	89%	11%	0.01%
Hawaii	0.0%	30.2%	69.8%	98%	2%	0.0%
Idaho	0.04%	33.2%	66.8%	84%	16%	0.0%
Illinois	0.7%	33.5%	65.8%	82%	18%	0.0%
Indiana	0.0%	17.3%	82.7%	93%	6%	1.07%
Iowa	0.0%	43.6%	56.4%	76%	24%	0.0%
Kansas	0.0%	32.5%	67.5%	78%	22%	0.0%
Kentucky	0.0%	30.9%	69.1%	73%	27%	0.0%
Louisiana	4.0%	43.9%	52.1%	70%	30%	0.0%
Maine	0.0%	41.4%	58.6%	81%	19%	0.0%
Maryland	0.0%	10.9%	89.1%	98%	2%	0.0%
Massachusetts	0.0%	18.8%	81.2%	95%	5%	0.05%
Michigan	0.0%	30.7%	69.3%	90%	10%	0.0%
Minnesota	0.0%	39.8%	60.2%	87%	13%	0.0%
Mississippi	0.0%	24.6%	75.4%	81%	19%	0.0%
Missouri	0.1 %	13.9%	86.0%	92%	8%	0.0%

Table B-3. State School Bus Fuel Choice and Age Distribution (continued)

State	Bus Age Distribution			Fuel Choice		
	Before 1977	1977 to 1990	After 1990	Diesel	Gasoline	Other
Montana	2.5%	42.2%	55.3%	75%	25%	0.0%
Nebraska	1.3%	40.1%	58.7%	75%	25%	0.0%
Nevada	1.9%	41.4%	56.8%	88%	11%	0.38%
New Hampshire	0.0%	30.8%	69.2%	90%	10%	0.0%
New Jersey	0.0%	38.9%	61.1%	85%	15%	0.0%
New Mexico	0.0%	40.4%	59.6%	84%	16%	0.0%
New York	0..0%	33.2%	66.8%	95%	5%	0.09%
North Carolina	0.0%	30.9%	69.1%	99%	1%	0.11%
North Dakota	0.5%	31.9%	67.6%	69%	31%	0.32%
Ohio	1.0%	45.4%	53.6%	83%	17%	0.0%
Oklahoma	0.2%	54.0%	45.8%	58%	39%	3.22%
Oregon	1.8%	22.9%	75.3%	81%	13%	5.99%
Pennsylvania	0.0%	19.9%	80.1%	92%	7%	0.67%
Rhode Island	0.0%	28.3%	71.7%	95%	5%	0.0%
South Carolina	0.0%	59.9%	40.1%	95%	5%	0.0%
South Dakota	1.5%	43.2%	55.2%	73%	27%	0.0%
Tennessee	0.0%	30.1%	69.9%	85%	15%	0.0%
Texas	0.7%	34.5%	64.8%	77%	17%	6.00%
Utah	0.5%	37.4%	62.1%	89%	10%	0.98%
Vermont	0.0%	39.2%	60.8%	86%	14%	0.0%
Virgina	0.0%	42.8%	57.2%	86%	14%	0.0%
Washington	3.1%	37.9%	59.0%	81%	19%	0.09%
West Virginia	0.0%	38.7%	61.3%	87%	13%	0.25%
Wisconsin	0.0%	33.0%	67.0%	86%	14%	0.50%
Wyoming	0.0%	50.1%	49.9%	73%	27%	0.0%
US Total	0.6%	33.1%	66.3%	86%	13%	1.0%

Table B-4. Emission Factors (in grams per mile released during 2001)

Model Year	Diesel School Buses					
	NMHC	NOx	Smog	CO	PM	GHG
1975	7.04	34.10	41.13	22.50	1.94	2,595
1976	7.00	34.11	41.10	22.42	1.94	2,561
1977	6.93	33.99	40.93	22.26	1.94	2,527
1978	6.63	32.69	39.32	21.33	1.94	2,494
1979	4.24	26.38	30.62	24.03	1.94	2,462
1980	4.10	25.51	29.61	23.13	1.94	2,430
1981	4.11	25.60	29.71	23.17	1.94	2,400
1982	4.10	25.34	29.44	22.56	1.94	2,370
1983	4.06	25.12	29.18	22.35	1.94	2,341
1984	4.03	24.92	28.95	21.97	1.94	2,313
1985	4.00	24.73	28.72	21.62	1.94	2,285
1986	3.48	24.54	28.02	21.34	1.94	2,258
1987	3.40	24.01	27.40	20.87	1.94	2,232
1988	2.39	21.21	23.60	8.15	1.21	2,206
1989	2.40	21.27	23.67	8.11	1.21	2,181
1990	1.87	16.07	17.93	7.98	1.21	2,157
1991	1.45	15.10	16.55	5.80	1.07	2,133
1992	1.48	15.43	16.90	5.89	1.07	2,109
1993	1.50	15.69	17.19	5.95	1.07	2,086
1994	1.19	16.08	17.27	4.14	0.26	2,064
1995	1.21	16.38	17.59	4.18	0.26	2,042
1996	1.23	16.70	17.93	4.22	0.26	2,020
1997	1.23	16.70	17.92	4.18	0.26	1,999
1998	1.22	13.36	14.59	4.14	0.26	1,978
1999	1.22	13.36	14.58	4.10	0.26	1,958
2000	1.21	13.36	14.57	4.05	0.26	1,938
2001	1.21	13.35	14.56	4.01	0.26	1,919

Table B-4. Emission Factors (continued)

Model Year	Gasoline School Buses					
	NMHC	NOx	Smog	CO	PM	GHG
1975	38.04	12.02	50.06	742.65	0.05	2,941
1976	37.62	11.91	49.53	741.39	0.05	2,902
1977	34.55	11.00	45.55	677.41	0.05	2,863
1978	32.93	10.71	43.64	645.73	0.05	2,826
1979	22.22	11.80	34.01	452.68	0.05	2,790
1980	21.91	11.34	33.25	438.51	0.05	2,754
1981	20.89	10.99	31.88	415.74	0.05	2,720
1982	20.17	10.80	30.97	399.04	0.05	2,686
1983	19.52	10.63	30.15	383.76	0.05	2,653
1984	18.16	10.35	28.51	348.83	0.05	2,621
1985	9.48	9.71	19.20	145.92	0.05	2,590
1986	8.51	9.68	18.19	121.39	0.05	2,559
1987	3.02	8.81	11.83	55.00	0.05	2,529
1988	2.32	7.83	10.16	41.24	0.05	2,503
1989	2.27	7.79	10.06	40.74	0.05	2,477
1990	1.52	5.53	7.05	22.62	0.05	2,452

Model Year	Natural Gas School Buses					
	NMHC	NOx	Smog	CO	PM	GHG
1996	1.53	8.13	9.66	8.74	0.022	1,953
1997	1.52	8.13	9.65	8.72	0.022	1,935
1998	1.51	8.12	9.64	8.70	0.022	1,916
1999	1.51	8.12	9.62	8.68	0.022	1,898
2000	1.50	8.12	9.61	8.66	0.022	1,881
2001	1.49	8.11	9.60	8.64	0.022	1,864

Table B-5. Sources of State Data

State	Total # buses in state fleet	Age distribution by model year range (% built 1991-2001)	Age distribution by model year	Fuel choice	Pre-77 buses	Policies for bus replacement
Alabama	Joe Lightsey Admin of Pupil Transportation AL Dept of Ed	Joe Lightsey Admin of Pupil Transportation AL Dept of Ed	R.L. Polk	R.L. Polk	Joe Lightsey Admin of Pupil Transportation AL Dept of Ed	Joe Lightsey Admin of Pupil Transportation AL Dept of Ed
Alaska	Joe Precourt Admin of Pupil Transportation AK Dept of Ed	N/A	R.L. Polk	R.L. Polk	Joe Precourt Admin of Pupil Transportation AK Dept of Ed	Joe Precourt Admin of Pupil Transportation AK Dept of Ed
Arizona	Vickie Barnett School Transportation AZ Dept of Public Safety	N/A	R.L. Polk	R.L. Polk	Vickie Barnett School Transportation AZ Dept of Public Safety	Vickie Barnett School Transportation AZ Dept of Public Safety
Arkansas	Mike Simmons Coord. School Transportation AR Dept of Ed	N/A	R.L. Polk	R.L. Polk	Mike Simmons Coord. School Transportation AR Dept of Ed	Mike Simmons Coord. School Transportation AR Dept of Ed
California	Each of the 8 divisions of the CA Highway Patrol: Northern, Valley, Golden Gate, Central, Southern, Border, Coastal, Inland	Archana Agrawal, Off-Road Modeling & Assessment, CA Air Resources Board	Archana Agrawal, Off-Road Modeling & Assessment, CA Air Resources Board	Archana Agrawal, Off-Road Modeling & Assessment, CA Air Resources Board	Each of the 8 divisions of the CA Highway Patrol: Northern, Valley, Golden Gate, Central, Southern, Border, Coastal, Inland	John Green, Supervisor Office of School Transportation CA Dept of Ed
Colorado	Bruce Little, Sr. Transportation Consultant CO Dept of Ed	N/A	R.L. Polk	R.L. Polk	Bruce Little, Sr. Transportation Consultant CO Dept of Ed	Bruce Little, Sr. Transportation Consultant CO Dept of Ed
Connecticut	www.schoolbusfleet.com	N/A	R.L. Polk	R.L. Polk	www.schoolbusfleet.com	N/A. School Pupil Transportation Director did not respond to survey or repeated calls
Delaware	Ronald H. Love, Supervisor Pupil Transportation DE Dept of Ed	Ronald H. Love, Supervisor Pupil Transportation DE Dept of Ed	R.L. Polk	R.L. Polk	Ronald H. Love, Supervisor Pupil Transportation DE Dept of Ed	Ronald H. Love, Supervisor Pupil Transportation DE Dept of Ed
District of Columbia	Alfred Winder General Mgr of Transportation DC Public Schools	Alfred Winder General Mgr of Transportation DC Public Schools	R.L. Polk	Alfred Winder General Mgr of Transportation DC Public Schools	Alfred Winder General Mgr of Transportation DC Public Schools	Alfred Winder General Mgr of Transportation DC Public Schools

Table B-5. Sources of State Data (continued)

State	Total # buses in state fleet	Age distribution by model year range (% built 1991-2001)	Age distribution by model year	Fuel choice	Pre-77 buses	Policies for bus replacement
Florida	Terri Egler School Transportation FL Dept of Ed	Terri Egler School Transportation FL Dept of Ed	R.L. Polk	R.L. Polk	Terri Egler School Transportation FL Dept of Ed	Charles Hood Director, Student Transportation FL Dept of Ed
Georgia	www.school busfleet.com	N/A	R.L. Polk	R.L. Polk	Bill Bonnett Research & Evaluation Specialist Pupil Transportation GA Dept of Ed	Bill Bonnett Research & Evaluation Specialist Pupil Transportation GA Dept of Ed
Hawaii	George Okano, Mgr, Student Transportation Services HI Dept of Ed	N/A	R.L. Polk	R.L. Polk	George Okano, Mgr, Student Transportation Services HI Dept of Ed	George Okano, Mgr, Student Transportation Services HI Dept of Ed
Idaho	Lynette Daw Pupil Transportation Specialist ID Dept of Ed	Lynette Daw Pupil Transportation Specialist ID Dept of Ed	R.L. Polk	R.L. Polk	Lynette Daw Pupil Transportation Specialist ID Dept of Ed	Lynette Daw Pupil Transportation Specialist ID Dept of Ed
Illinois	Alvida Petro, Prin Fiscal Consultant, Div Funding & Disburs Svcs IL State Board of Education	N/A	R.L. Polk	R.L. Polk	Alvida Petro, Prin Fiscal Consultant, Div Funding & Disburs Svcs IL State Board of Education	Alvida Petro, Prin Fiscal Consultant, Div Funding & Disburs Svcs IL State Board of Education
Indiana	www.doe.state.-in.us/safety/ pupilrpt.html	www.doe.state.-in.us/safety/ pupilrpt.html"	R.L. Polk	R.L. Polk	Pete Baxter, Director Div of School Traffic Safety IN Dept of Ed	Pete Baxter, Director Div of School Traffic Safety IN Dept of Ed
Iowa	Terry Voy, Consultant Student Transportation IA Dept of Ed	Terry Voy, Consultant Student Transportation IA Dept of Ed	R.L. Polk	R.L. Polk	Terry Voy, Consultant Student Transportation IA Dept of Ed	Terry Voy, Consultant Student Transportation IA Dept of Ed
Kansas	Larry Bluthardt, Director School Bus Safety Education Unit KS Dept of Ed	N/A	R.L. Polk	R.L. Polk	Larry Bluthardt, Director School Bus Safety Education Unit KS Dept of Ed	Larry Bluthardt, Director School Bus Safety Education Unit KS Dept of Ed
Kentucky	MichaelRoscoe Director of Pupil Transportation KY Dept of Ed	Michael Roscoe Director of Pupil Transportation KY Dept of Ed	R.L. Polk	R.L. Polk	Michael Roscoe Director of Pupil Transportation KY Dept of Ed	Dave Magnum KY Dep. of Ed

Table B-5. Sources of State Data (continued)

State	Total # buses in state fleet	Age distribution by model year range (% built 1991-2001)	Age distribution by model year	Fuel choice	Pre-77 buses	Policies for bus replacement
Louisiana	Larry Ourso School Transportation Supervisor LA Dept of Ed	Larry Ourso School Transportation Supervisor LA Dept of Ed	R.L. Polk	R.L. Polk	Larry Ourso School Transportation Supervisor LA Dept of Ed	Beth Scioneaux Div of Ed Finance LA Dept of Ed
Maine	Harvey Boatman Director of Transportation ME Dept of Ed	For district owned buses: Harvey Boatman Director of Transportation ME Dept of Ed	R.L. Polk	R.L. Polk	Harvey Boatman Director of Transportation ME Dept of Ed	Harvey Boatman Director of Transportation ME Dept of Ed
Maryland	Patricia Askew Pupil Transportation MD Dept of Ed	Patricia Askew Pupil Transportation MD Dept of Ed	R.L. Polk	R.L. Polk	Patricia Askew Pupil Transportation MD Dept of Ed	Patricia Askew Pupil Transportation MD Dept of Ed
Massa-chusetts	Michael Devaney Office Manager Vehicle Inspection Services MA Registry of Motor Vehicles	N/A	R.L. Polk	R.L. Polk	Michael Devaney Office Manager Vehicle Inspection Services MA Registry of Motor Vehicles	Jay Sullivan Director, School Business Services MA Dept of Ed
Michigan	www.schoolbusfleet.com	N/A	R.L. Polk	R.L. Polk	www.schoolbusfleet.com	Susan Anderson, Dir, School Support Services MI Dept of Ed
Minnesota	Bob Fischer MN Dept of Public Safety	N/A	R.L. Polk	R.L. Polk	Bob Fischer MN Dept of Public Safety	Bob Fischer MN Dept of Public Safety
Mississippi	Leonard Swilley, Director, Pupil Transportation MS Dept of Ed	Leonard Swilley, Director, Pupil Transportation MS Dept of Ed	R.L. Polk	R.L. Polk	Leonard Swilley, Director, Pupil Transportation MS Dept of Ed	Leonard Swilley, Director, Pupil Transportation MS Dept of Ed
Missouri	Debra Clink School Services Dept of Elem & Sec Education	Debra Clink School Services Dept of Elem & Sec Education	R.L. Polk	R.L. Polk	Debra Clink School Services Dept of Elem & Sec Education	Debra Clink School Services Dept of Elem & Sec Education
Montana	Maxine Mougeout MT Office of Public Instruction	Maxine Mougeout MT Office of Public Instruction	Buses built after 1989: Maxine Mougeout, MT Office of Public Instruction. For pre-1990 buses, R.L. Polk	R.L. Polk	Maxine Mougeout MT Office of Public Instruction	Maxine Mougeout MT Office of Public Instruction
Nebraska	Russ Inbody, Dir, Pupil Transportation NE Dept of Ed	N/A	R.L. Polk	R.L. Polk	Russ Inbody, Dir, Pupil Transportation NE Dept of Ed	Russ Inbody, Dir, Pupil Transportation NE Dept of Ed

Table B-5. Sources of State Data (continued)

State	Total # buses in state fleet	Age distribution by model year range (% built 1991-2001)	Age distribution by model year	Fuel choice	Pre-77 buses	Policies for bus replacement
Nevada	Diana Hollander Secretary, State Superintendent NV Dept of Ed	N/A	R.L. Polk	R.L. Polk	Diana Hollander Secretary, State Superintendent NV Dept of Ed	Diana Hollander Secretary, State Superintendent NV Dept of Ed
New Hampshire	Beth R. LaMarca, Supervisor Pupil Transportation NH Div Motor Vehicles	N/A	R.L. Polk	R.L. Polk	Inspector Jim Curran Dept of Safety Division of State Police	Beth R. LaMarca, Supervisor Pupil Transportation NH Div Motor Vehicles
New Jersey	William Reed Supervisor of Operations NJ Dept of Motor Vehicles	N/A	R.L. Polk	R.L. Polk	www.schoolbus fleet.com	Linda Wells, Dir, Ofc of Student Transportation NJ Dept of Ed
New Mexico	Tito Ortiz Transportation NM Dept of Ed	N/A	R.L. Polk	R.L. Polk	Tito Ortiz Transportation NM Dept of Ed	Tito Ortiz Transportation NM Dept of Ed
New York	www.school busfleet.com	For district owned buses: Karen Corbin State Aid NY Dept of Ed	R.L. Polk	R.L. Polk	# buses: www.schoolbus fleet.com Pre-77 buses: Karen Corbin, State Aid NY Dept of Ed	Marion Edick State Director NY Dept of Ed
North Carolina	Derek Graham Section Chief, Transportation NC Dept of Public Instruction	Derek Graham Section Chief, Transportation NC Dept of Public Instruction	Derek Graham Section Chief, Transportation NC Dept of Public Instruction	R.L. Polk	Derek Graham Section Chief, Transportation NC Dept of Public Instruction	Derek Graham Section Chief, Transportation NC Dept of Public Instruction
North Dakota	Tom Decker, Dir, School Bus Transportation ND Dept of Public Instruction	Tom Decker, Dir, School Bus Transportation ND Dept of Public Instruction	Some annual data from Tom Decker, Dir, School Bus Transportation, ND Dept of Public Instruction Remainder of data from R.L. Polk	Tom Decker, Dir, School Bus Transportation ND Dept of Public Instruction	Tom Decker, Dir, School Bus Transportation ND Dept of Public Instruction	Tom Decker, Dir, School Bus Transportation ND Dept of Public Instruction
Ohio	Carol Brandel Student Transportation Div of School Finance OH Dept of Ed	N/A	R.L. Polk	R.L. Polk	Carol Brandel Student Transportation Div of School Finance OH Dept of Ed	Carol Brandel Student Transportation Div of School Finance OH Dept of Ed

Table B-5. Sources of State Data (continued)

State	Total # buses in state fleet	Age distribution by model year range (% built 1991-2001)	Age distribution by model year	Fuel choice	Pre-77 buses	Policies for bus replacement
Oklahoma	Randy McLerran Transportation Director OK Dept of Ed	Randy McLerran Transportation Director OK Dept of Ed	From 1990 to 1999: Randy McLerran, Transportation Director, OK Dept of Ed Remainder of data from R.L. Polk	R.L. Polk	Randy McLerran Transportation Director OK Dept of Ed	Randy McLerran Transportation Director OK Dept of Ed
Oregon	Deborah Lincoln Director of Pupil Transportation OR Dept of Ed	Deborah Lincoln Director of Pupil Transportation OR Dept of Ed	R.L. Polk	R.L. Polk	Deborah Lincoln Director of Pupil Transportation OR Dept of Ed	Deborah Lincoln Director of Pupil Transportation OR Dept of Ed
Pennsylvania	James P. Dorwart Coord, Pupil Transportation PN Dept of Ed	For contractor buses only: James P. Dorwart Coord, Pupil Transportation PN Dept of Ed	R.L. Polk	R.L. Polk	www.school busfleet.com	James P. Dorwart Coord, Pupil Transportation PN Dept of Ed
Rhode Island	Charles Dolan Administrator RI Division of Motor Vehicles	Charles Dolan Administrator RI Division of Motor Vehicles	R.L. Polk	R.L. Polk	Charles Dolan Administrator RI Division of Motor Vehicles	Steve Nardelli Special Asst to Commissioner for Legislative Relations RI Dept of Ed
South Carolina	Donald Tudor Director of Transportation SC Dept of Ed	Donald Tudor Director of Transportation SC Dept of Ed	Donald Tudor Director of Transportation SC Dept of Ed	Donald Tudor Director of Transportation SC Dept of Ed	Donald Tudor Director of Transportation SC Dept of Ed	Donald Tudor Director of Transportation SC Dept of Ed
South Dakota	Bonnie Glodt SD Dept. of Motor Vehicles	Bonnie Glodt SD Dept. of Motor Vehicles	R.L. Polk	Bonnie Glodt SD Dept. of Motor Vehicles	Bonnie Glodt SD Dept. of Motor Vehicles	Janelle Toman Director of Pupil Transportation SD Div of Ed
Tennessee	Melissa Brown Dir of Research Pupil Transportation TN Dept of Ed	Melissa Brown Dir of Research Pupil Transportation TN Dept of Ed	Melissa Brown Dir of Research Pupil Transportation TN Dept of Ed	R.L. Polk	Melissa Brown Dir of Research Pupil Transportation TN Dept of Ed	Melissa Brown Dir of Research Pupil Transportation TN Dept of Ed
Texas	Sam Dixon School Transportation Unit TX Education Agency	Sam Dixon School Transportation Unit TX Education Agency	R.L. Polk	R.L. Polk	Sam Dixon School Transportation Unit TX Education Agency	Sam Dixon School Transportation Unit TX Education Agency

Table B-5. Sources of State Data (continued)

State	Total # buses in state fleet	Age distribution by model year range (% built 1991-2001)	Age distribution by model year	Fuel choice	Pre-77 buses	Policies for bus replacement
Utah	Brent Huffman Pupil Transportation Specialist UT State Office of Education	N/A	R.L. Polk	Brent Huffman Pupil Transportation Specialist UT State Office of Education	Brent Huffman Pupil Transportation Specialist UT State Office of Education	Brent Huffman Pupil Transportation Specialist UT State Office of Education
Vermont	Ron Richer VT Dept of Motor Vehicles	N/A	R.L. Polk	R.L. Polk	www.schoolbus fleet.com	Ron Richer VT Dept of Motor Vehicles
Virginia	June Eanes Dir, Support Services VA Dept of Ed	N/A	R.L. Polk	R.L. Polk	June Eanes Dir, Support Services VA Dept of Ed	June Eanes Dir, Support Services VA Dept of Ed
Washington	Allan J. Jones WA Office of Superintendent of Public Instruction	Allan J. Jones WA Office of Superintendent of Public Instruction	Allan J. Jones WA Office of Superintendent of Public Instruction	R.L. Polk	Allan J. Jones WA Office of Superintendent of Public Instruction	Allan J. Jones WA Office of Superintendent of Public Instruction
West Virginia	Wayne Clutter Dir, School Transportation WV Dept of Ed	N/A	R.L. Polk	R.L. Polk	Wayne Clutter Dir, School Transportation WV Dept of Ed	Wayne Clutter Dir, School Transportation WV Dept of Ed
Wisconson	Russ White DMV statistics WI Dept of Motor Vehicles	N/A	R.L. Polk	R.L. Polk	www.school busfleet.com for pre-77 data; Jeff Lorentz, State Patrol, for # of buses	Mary Larson Dept of Public Instruction
Wyoming	D. Leeds Pickering Program Mgr Pupil Transportation WY Dept of Ed	N/A	R.L. Polk	R.L. Polk	www.schoolbus fleet.com	D. Leeds Pickering Program Mgr Pupil Transportation WY Dept of Ed