ROLLING SMOKESTACKS

Cleaning Up America's Trucks and Buses

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Union of Concerned Scientists
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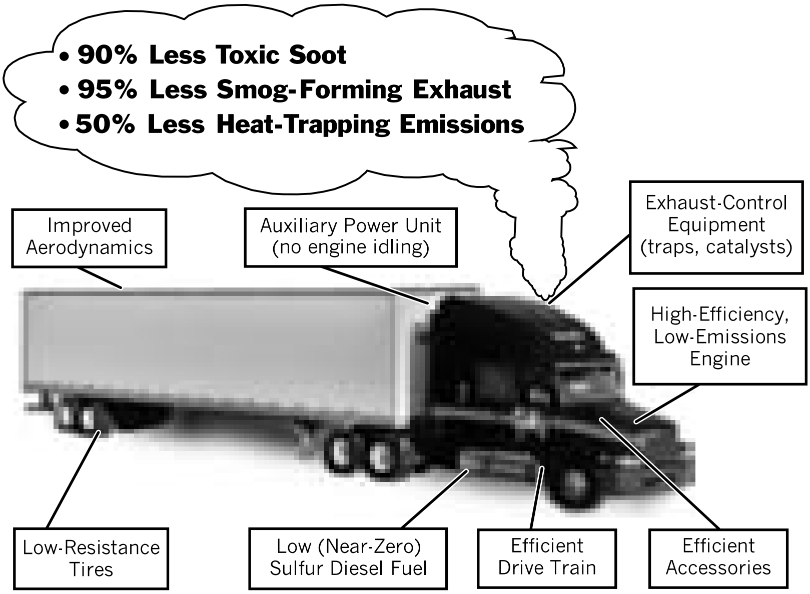
BLUEPRINT FOR A CLEANER BIG RIG



Executive Summary

If you have ever stood on a street corner as a large truck or bus accelerates from a stop, you are acutely aware of diesel pollution. Like passenger cars, trucks have become cleaner since pollution controls were first required in the 1970s. But the degree of cleanup has been a fraction of what regulators have asked of cars. As a result, trucks are now a substantial source of air pollution and other environmental problems. Although trucks account for under 6 percent of the miles driven by highway vehicles in the United States, they are responsible for

- one-quarter of smog-causing pollution from highway vehicles
- over half the soot from highway vehicles
- the majority of the cancer threat posed by air pollution in some urban areas
- 6 percent of the nation's global warming pollution
- over one-tenth of America's oil consumption

Improvements to conventional diesel trucks are an absolute priority, but cleaner alternative fuels and advanced technologies are the ultimate solution.

Cleaner Diesel: Improvements to Today's Trucks

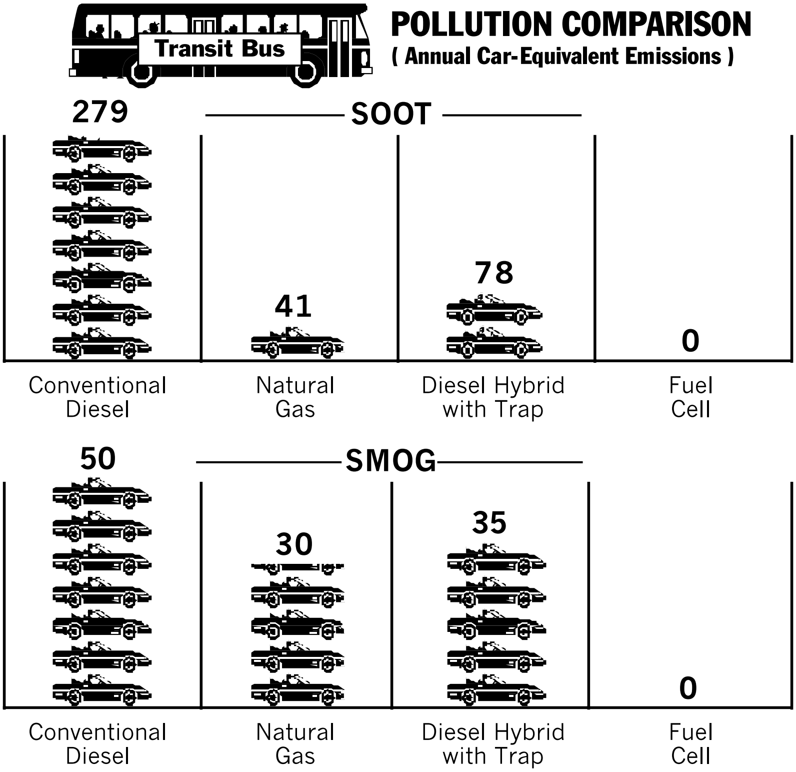
Advances in pollution-control technologies will make it possible to slash truck pollution almost as quickly as oil refiners can—or are required to—supply cleaner diesel fuel. The figure on the opposite page indicates some of the technologies that could be applied to clean up big diesels. With strong regulatory guarantees that ensure these cleaner trucks stay clean over their million-mile lives, truck pollution can be reduced by over 90 percent. Advances in engines and truck designs can also increase truck fuel efficiency, which will save truckers money and reduce global warming emissions as trucks travel farther on each gallon of diesel fuel.

Green Technologies: Alternative Fuels and Advanced Technologies

Cleaner diesel engines can go a long way toward reducing air pollution and global warming emissions from trucks. But moving beyond diesel to cleaner alternative fuels (such as natural gas) is essential for polluted urban areas where health protection is a priority today. And advanced technologies, such as fuel cells, are a vital part of the long-term solution. Transit buses, school buses, and urban delivery vehicles are particularly well suited to these green technologies and are the logical launch point for broader introduction.

Vehicles powered by alternative fuels and advanced technologies have inherently low emissions, both of smog-forming pollutants and of soot. In addition, they emit fewer of the heat-trapping gases that cause global warming. The figures below illustrate just how much difference these technologies can make. They show how many cars-worth of emissions a model year 2000 transit or school bus would produce, if powered by various technologies.

Although diesel engines will become cleaner, these alternatives will retain their advantage in curbing pollution because the cleanup technologies developed for diesel engines can also be used with natural gas or hybrid engines. But the ultimate solution to combustion is fuel cells: high-efficiency engines that emit no pollution.

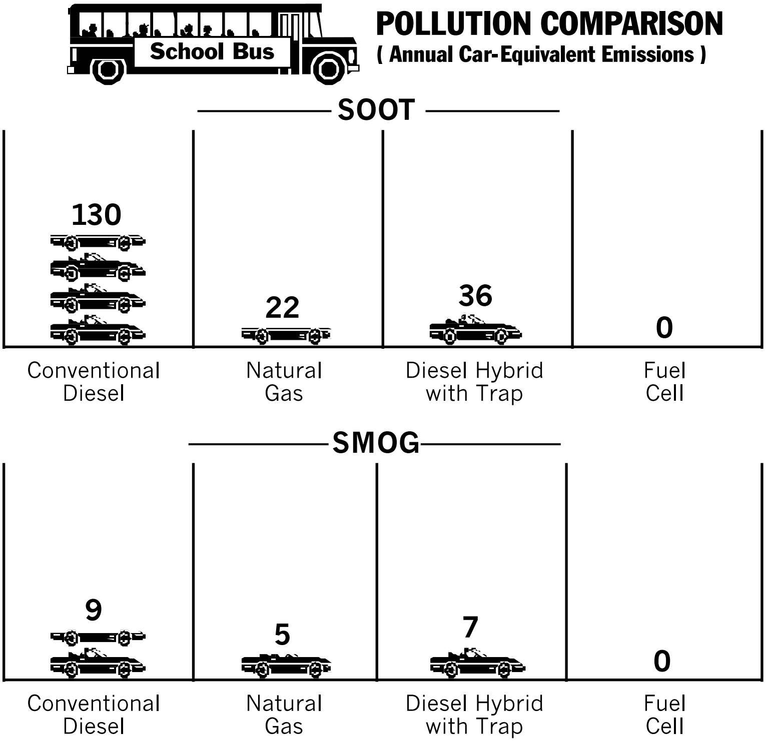


Annual emissions estimates for model year 2000 transit bus compared with a model year 2000 passenger car fueled by gasoline. See text for details of per-mile emission rates.

Assumed annual mileage rates: 11,400 (car), 35,800 (transit bus).

Policies for Progress: Regulations, Incentives, and Research

Realizing the potential of cleaner diesel and green technologies requires strong policies to move trucking onto a greener path. The Environmental Protection Agency's recently proposed diesel engine regulations are an excellent first step, requiring that emissions from new trucks show a 95 percent reduction of smog-causing nitrogen oxides over current levels and a 90 percent reduction of soot. The same regulations would also require oil companies to remove 97 percent of the sulfur currently present in diesel fuel, an essential step for enabling exhaust-control equipment to achieve and retain high levels of pollution reduction. But tighter tailpipe standards alone are not enough. Regulators must ensure that vehicles are as clean on the highway as they are during certification testing—and that they stay clean over their million-mile lifetimes. And they should require cleanup of existing fleets of dirty trucks and buses.



Annual emissions estimates for model year 2000 school bus compared with a model year 2000 passenger car fueled by gasoline. See text for details of per-mile emission rates.

Assumed annual mileage rates: 11,400 (car), 13,300 (school bus).

Cleaning up diesel is an absolute necessity. But policymakers also need to recognize the special benefits of intrinsically clean vehicles: those powered by alternative fuels or advanced technologies. These green trucks and buses offer an extra measure of public health protection in urban areas, and many can also help reduce global warming pollutants. Regulations, incentives, and research are all needed to push these technologies onto the road as soon as possible. The place to start is high-priority markets like transit buses, school buses, and urban trucks.

Although not a replacement for strong regulations and incentives, public research is the foundation for environmental gains in trucks and buses. Reducing emissions of the heat-trapping gases responsible for global warming is a particularly challenging task that should be addressed through research to boost truck efficiency and to find suitable fuels that contain less carbon, the primary global-warming pollutant.

Green Truck Path: National Benefits

The benefits of cleaner and more efficient diesel, alternative fuel, and advanced technology trucks could be substantial, allowing trucks to remain at the heart of America's commerce while curbing their impact on public health and the environment. We constructed a detailed model of the US truck sector to evaluate the potential energy and environmental benefits of a national green truck strategy. By the time cleaner trucks permeate the truck population in 2030, we estimate that the gains over a "business-as-usual" base case could include

- Preventing emission of one-quarter of a million tons of toxic soot
- Keeping over 60 million cars-worth of smog-forming exhaust out of the air*
- Doubling truck travel without increasing oil use
- Reducing global warming pollutants by 26 percent

Today's diesel trucks emit more soot and smog-forming pollution than even a coal-fired power plant, for every unit of energy they burn. But new technologies and fuels can clean up America's rolling smokestacks, allowing trucks and buses to finally pull their weight in protecting the planet.

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* Based on the pollutants emitted by the average passenger vehicle on the road today.

CHAPTER 1
DIESEL TODAY

From the school buses picking up our children to the freight trucks delivering groceries to our supermarkets, the 3.3 million diesel trucks and buses on American roads are the workhorse of the transportation economy. They are used in applications that require power, efficiency, and longevity, and many engines last over one million miles. Unfortunately, these same durable trucks come with a price tag in the form of air pollution, threats to public health, and contribution to global warming.

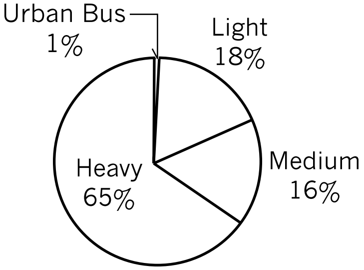
Diesel trucks come in a wide variety of weights and sizes, ranging from "lighter" diesel trucks like parcel delivery vans, to transit buses, to the heavy big-rigs that transport goods around the country. Table 1 shows the range of vehicles and how they are classified. The heaviest vehicles account for the majority of the miles traveled by trucks each year (Figure 1, next page) and therefore account for the majority of pollution and energy use. But light and medium trucks, as well as urban buses, are significant contributors to pollution, especially in cities where people and diesel pollution are concentrated.

Table 1. Types of Heavy-Duty Diesel Trucks

Heavy	Classes 8b (60,001+ lb. gross vehicle weight, or GVW) 8a (33,001–60,000 lb GVW)	long-haul tractor-trailers transit and school buses
Medium	Classes 7 (26,001–33,000 lb GVW) 6 (19,501–26,000 lb GVW)	school buses large delivery trucks
Light	Classes 5 (16,001–19,500 lb GVW) 4 (14,001–16,000 lb GVW) 3 (10,001–14,000 lb GVW) 2B (8,500–10,000 lb GVW)	parcel delivery trucks smaller freight trucks super-duty pickups

The study reported here examines how current and emerging technologies could be employed to limit diesel exhaust, thereby decreasing the public health threat it poses. In this section, we discuss the impacts on public health and global warming of exhaust from today's diesel trucks and buses. The second section describes technologies that could make diesel engines run cleaner. The third section looks at how truly green technologies—alternative

Figure 1. Travel Distribution for Diesel Trucks & Buses



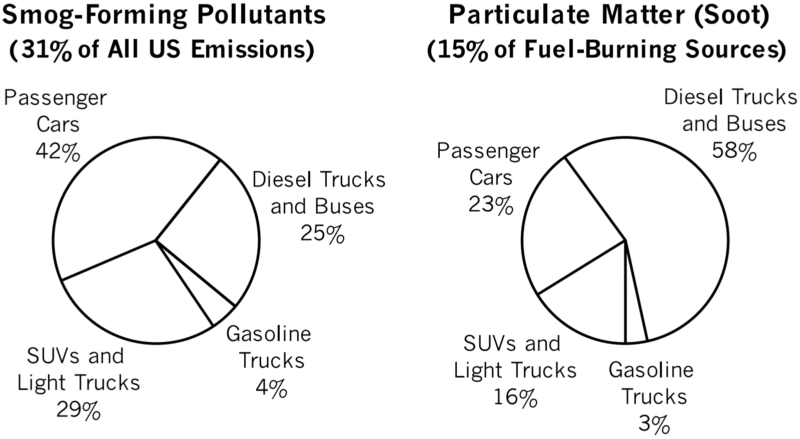
Source: EPA 2000

fuels such as natural gas and advanced technologies such as hybrids and fuel cells—are now or could soon replace diesel in various niches. The fourth section discusses which technology might best be employed for each type of vehicle and what national benefits might be expected from conversion to these technologies. The final section suggests how government regulation might help put these technologies on the street.

The Need for Cleaner Trucks

Today's big-rigs are like rolling smokestacks, emitting three times more soot and smog-forming pollution than a coal-fired power plant, for every unit of energy they burn.[1] Trucks and buses make up less than 2 percent of highway vehicles, and they travel less than 6 percent of the total miles driven each year. Yet they are the source of a quarter of the smog-forming pollutants and over half of the soot from all highway vehicles (Figure 2).

Figure 2. Highway Sources of Pollution



Source: EPA 1997b, adjusted to reflect extra emissions due to defeat devices (based on EPA 1999b)

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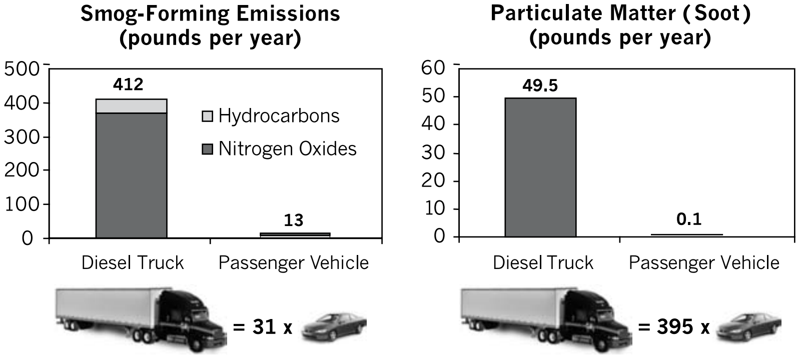
[1] National average emissions rate, measured in pollution per unit of energy consumed. UCS calculation based on (a) national emissions inventory (EPA 1997b), adjusted to reflect extra emissions due to defeat devices, and (b) national energy use (EIA 2000).

While big trucks have faced tougher tailpipe rules over time, these regulations are far more lenient than those imposed on cars, so that much less progress has been made in controlling pollution from big diesel. For example, a car purchased today must emit 23 times less smog-forming pollutants (hydrocarbons plus nitrogen oxides) during emissions testing than an unregulated car did in the 1960s (Hwang 1997). A new big-rig must be only 3 times cleaner for these pollutants than before emission controls were required.

New standards already on the books will force both cars and heavy trucks to become cleaner starting in 2004. But these rules will once again require more of cars than trucks. As a result, even the cleanest diesel trucks will still emit nearly 10 times more smog-forming pollutants per mile and over 100 times more soot than new passenger vehicles. And because trucks average nearly 4 times more miles per year than do cars, annual emissions from a new truck will continue to be much larger than from a car in the future (Figure 3).

Figure 3.
Annual Emissions from a New Truck and Car under 2004 Standards



Source: UCS calculation based on EPA models (EPA 1999a,b) and average annual mileage data (DOC 2000).

The leniency of regulations on diesel trucks and buses comes at a price. Diesel exhaust takes a toll on public health, particularly in cities where the concentration of people and diesel fumes is greatest. And we are all beginning to feel the effects as carbon emissions fuel climate change, bringing heat waves, droughts, floods, and other severe weather in its wake.

Public Health Risks

Diesel exhaust poses a substantial threat to public health. It can cause or aggravate a variety of respiratory diseases, and it has been linked to cancer.

Urban Ozone (Smog)

Diesel trucks and other motor vehicles emit nitrogen oxides (NO_x) and hydrocarbons, which contribute to ozone, the major ingredient in the smog engulfing major cities. High up in the stratosphere, ozone shields us from harmful ultraviolet (UV) rays. But at ground level, it irritates the respiratory system, causing coughing, choking, and reduced lung capacity. Children and the elderly are especially sensitive to smog. Urban ozone pollution has been linked to increased hospital admissions for respiratory problems such as asthma and to higher death rates on smoggy days, even at levels below the current standard (ATS 1996). Some studies suggest that long-term exposure to ozone may have chronic, irreversible impacts on lung function (Tashkin et al. 1994; Kunzli et al. 1997). Emphysema, chronic bronchitis, and chronic asthma may result from the permanent lung damage associated with repeated exposure to ozone (EPA 2000).

Particulates (Soot)

Diesel trucks and other motor vehicles emit particles (also known as *particulates, particulate matter*, or *soot* and abbreviated *PM*) directly from their tailpipes. They also release pollutants, notably nitrogen oxides and hydrocarbons, that form secondary particles in the atmosphere. Particulates irritate the eyes and nose and aggravate respiratory problems. Children, the elderly, asthmatics, and people with heart or lung disease are particularly at risk from exposure to particulates (EPA 1997a).

Fine particles, those smaller than 2.5 microns[2] in diameter ($PM_{2.5}$), have also been directly associated with an increased risk of premature death (EPA 1996; ATS 1996). In one recent study, researchers followed more than 8,000 people in six different locations for 17 years. They found that the risk of premature death in areas with high levels of fine particles was 26 percent greater than in areas with lower levels (Dockery et al. 1993). Based on extrapolations from a larger study of premature mortality and particulates, the Environmental Protection Agency (EPA) estimates that its new health standards for $PM_{2.5}$, which will go into effect within the decade, will save 15,000 lives each year (EPA 1997a).

At present, the specific mechanism by which fine particles increase the risk of death is unknown (EPA 1996). As a result, while regulations are based on the total mass of particles less than 10 or 2.5 microns, other characteristics such as particle size, surface area, number, chemical composition, or physical shape may also be important (Sawyer and Costantini 1997). For example, smaller particles—especially ultrafines and nanoparticles (Table 2)—more readily evade the body's physical defenses, penetrating further into the lungs, and are thought to cause more health

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[2] A micron, or micrometer, is one-millionth of a meter. The average human hair is about 100 microns thick.

Table 2. Size of Diesel Particles

SIZE DESCRIPTION	SIZE RANGE
Nanoparticles	0 – 0.05 µm
Ultrafine	0.05 – 0.1 µm
Fine	0.1 – 2.5 µm
PM-10	2.5 – 10 µm

Size range based on the aerodynamic diameter of the particle.
A micron or micrometer (µm) is one-millionth of a meter ($1/10^6$ meters).

Source: Kittleson 1998

damage (ATS 1996). As a result, control strategies that focus solely on reducing the total mass of particles may not reduce public health risks proportionally.

Carcinogenesis

Public health agencies consider diesel exhaust a potential human carcinogen (Table 3).[3] Studies of people routinely exposed to diesel exhaust indicate

Table 3.
Cancer Risk Assessments of Diesel Exhaust

Organization	Year	Conclusion
National Institute for Occupational Safety & Health	1988	potential occupational carcinogen
International Agency for Research on Cancer (WHO)	1989	probable human carcinogen
State of California	1990	known to cause cancer
US Environmental Protection Agency (Draft)	1998	"highly likely" human carcinogen
California EPA (Staff Recommendation)	1998	"may cause an increase in the likelihood of cancer"
California Air Resources Board	1998	diesel particulate emissions are toxic air contaminant

Sources: NIOSH and IARC: HEI 1995, p.19; State of California: listing under the Safe Drinking Water and Toxic Enforcement Act of 1986 (Proposition 65); US EPA: EPA 1998b, p.12-29; Cal EPA: CalEPA 1998a, p. ES-27; CARB: CARB 1998

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[3] Although diesel exhaust contains over 40 compounds thought to cause cancer (CalEPA 1998a), most public health studies of diesel exhaust have focused on the aggregate emissions rather than on specific compounds. In its recent ruling, however, the California Air Resources Board voted to list only diesel exhaust particulates as toxic, rather than whole diesel exhaust, which contains both particulates and vapor-phase emissions (CARB 1998).

a greater risk of lung cancer. For example, occupational health studies of workers exposed to high levels of diesel exhaust over many years, such as those in the railroad, dock, trucking, and busing industries, consistently demonstrate a 20 to 50 percent increase in the risk of lung cancer or death (HEI 1995; Bhatia et al. 1998).

Even at the average rates of exposure most people experience, diesel exhaust poses a potential cancer risk. Estimates that extrapolate from epidemiological studies suggest that, at current exposure levels, as many as 450 of every million Californians (i.e., over 14,000 residents) are at risk of contracting lung cancer as a result of lifetime exposure to diesel exhaust.[4] One estimate suggests that 125,000 people may be at risk nationwide (STAPPA/ALAPCO 2000). Risk from diesel exhaust may be particularly high in cities, where large numbers of people are exposed to truck and bus pollution. In the Los Angeles region, for example, diesel particles account for an estimated 71 percent of total cancer risk (SCAQMD 1999).

Global Warming

Diesel exhaust not only threatens public health, it contributes substantially to global warming through emissions of carbon and other heat-trapping gases. Transportation is the source of roughly one-third of all heat-trapping gases released in the United States. This is more than most countries release from all sources combined.[5] Each gallon of diesel fuel burned in a diesel truck engine results in emissions of 22.8 pounds of carbon and other heat-trapping gases.[6] An additional 5.4 pounds of heat-trapping gases result from the production and delivery of each gallon (Wang and Huang 1999). Nationally, heavy trucks emit nearly 400 million metric tons of heat-trapping gases annually, accounting for about 6 percent of US carbon emissions.[7]

Heat-trapping emissions from transportation and other sources—primarily those that burn fossil fuels—have led to an increase in the earth's temperature. The global average surface temperature has increased by 0.5°F to 1.1°F since the last half of the nineteenth century, and all of the 10 warmest years on record have occurred in the last 15 years (UCS 1997). Over the next century, further unchecked increases in the atmospheric concentrations of carbon dioxide and other heat-trapping gases (such as methane and nitrous oxide) will cause more

[4] The independent Scientific Review Panel of the California EPA has proposed a reasonable estimate of cancer risk from diesel exhaust to be 0.0003 for every microgram of diesel exhaust per cubic meter of air (3×10^{-4} $(\mu g/m^3)^{-1}$) (CalEPA 1998b). The current average exposure rate is 1.5 $\mu g/m^3$, resulting in an average lifetime risk of 4.5×10^{-4}.

[5] Only China, Russia, and Japan have higher total emissions (based on Marland et al. 1996).

[6] Measured as carbon dioxide-equivalent emissions. Emissions of nitrous oxide and methane are added to carbon dioxide emissions based on the global warming potential of those gases.

[7] UCS estimate based on energy use for freight trucks and total carbon estimate from the Annual Energy Outlook (EIA 2000).

extreme changes in global climate patterns. Scientists project a further increase in global average surface temperature of about 1.8°F to 6.3°F by the year 2100 (UCS 1997).

Global warming will not mean more pleasant temperatures. Even within the next 20 years, different regions of the world will likely see longer droughts, more coastal flooding, and more frequent extreme weather events (UCS 1997). And if global warming continues, we could well see increased risk to human health, severe stress on large areas of forest, a loss of mountain and coastal-wetland habitats—and the plants and animals that live there—the expansion of deserts, the disruption of agriculture, and a rise in sea level of anywhere from 6 to 37.5 inches above the current level with persistent coastal flooding. Increased global warming will also affect fisheries, water resources, and all natural habitats. Human well-being, including commerce and economic development, could well be at risk. The most serious impacts will most likely include human health, agriculture, and natural habitats (UCS 1997). Higher surface temperatures could also increase the frequency of ozone-conducive meteorological conditions (Deul et al. 1999), making it more difficult and expensive to achieve and maintain clean and healthy air.

CHAPTER 2

CLEANER DIESEL: IMPROVING TODAY'S TRUCKS AND BUSES

The modern diesel truck or bus is a relatively efficient vehicle, but it has by no means reached the pinnacle of its technical potential. The fuel economy of new diesel highway trucks continues to improve even after decades of development. For example, new truck efficiency has increased nearly one mile per gallon over the past ten years (EPA 2000). And diesel trucks and buses, like passenger vehicles, have faced more stringent tailpipe pollution standards over the past few decades. But unlike cars, trucks have satisfied exhaust standards primarily through better engine designs rather than by installing exhaust-control technologies like the catalysts found on modern automobiles (Dickey et al. 1998).

Diesel vehicles use compression-ignition engines in which the fuel and air mixture begins burning spontaneously as the engine's cylinders compress it. In contrast, gasoline vehicles use a spark to initiate combustion. Diesel engines are more efficient than gasoline engines for several reasons. First, their peak efficiency is higher because they operate at higher pressures and because heat loss is typically lower. Second, in real-world driving their fuel economy is higher because they are efficient even when operating at low speeds. In a compression-ignition engine, lowering engine output merely means cutting back on fuel input. In contrast, a gasoline vehicle uses a throttle to restrict both fuel and air at lower engine output, creating losses that hurt fuel economy.

The fundamental characteristics that make diesel engines more efficient than gasoline engines can also make them worse polluters. In particular, the higher pressures and temperatures that boost peak efficiency produce more nitrogen oxides. Diesel engines also produce more particles because, unlike gasoline engines where the fuel and air are well mixed and ignited all at once, diesel combustion creates pockets of excess fuel that generate particles. Fortunately, technologies abound to help clean up diesel technology and, in the future, boost fuel economy even further.

Technologies to Reduce Emissions

A history of underregulation means that many technical solutions for cleaning up trucks are available. Emission standards already on the books call for modest reductions of smog-causing emissions (nitrogen oxides and hydrocarbons), starting in 2004 (see Table 4, next page). These near-term reductions

Table 4. Truck Emission Standards

Years	Smog-Forming Emissions (g/bhp-hr)[a] HC	Smog-Forming Emissions (g/bhp-hr)[a] NO_x	Particles (g/bhp-hr)[a] PM
uncontrolled (pre-1974)		15–16	1.0
1985–1987	1.3	10.7	uncontrolled
1988–1989	1.3	10.7	0.6
1990	1.3	6.0	0.6
1991–1993	1.3	5.0	0.25
1994–1997	1.3	5.0	0.1
1998–2003	1.3	4.0	0.1
2004+	2.5 (combined HC + NO_x)[b]		0.1

a. The EPA measures truck pollution in grams per brake-horsepower-hour (g/bhp-hr), which is the weight of pollutant emitted per unit of energy produced by the engine. Emissions expressed in g/bhp-hr can be converted into grams per mile (the way car pollutants are measured). For example, under the 2004 standard above, trucks will emit 4.5 grams per mile of smog-forming pollution and 0.55 grams per mile of soot on average.

b. Under a recent legal settlement, several manufacturers will meet these standards beginning in October 2002.

are likely to be achieved primarily through recirculation of cooled exhaust gases rather than through exhaust-control technologies. Then, starting in 2007, the pollution standards the EPA has proposed would require that emissions of nitrogen oxides be reduced to 95 percent below today's standards[8] and that particulates be reduced by 90 percent. In addition, oil companies will be required to reduce, by 2006, the amount of sulfur contained in diesel fuel by 97 percent, to a maximum of 15 parts per million (ppm).[9] Achieving these substantial, long-term emission reductions will require a combination of engine improvements, exhaust-control technologies, and cleaner diesel fuel (Tables 5 and 6, opposite).

Engine Improvements

Changes to the engine that will help reduce emissions include refinements of current systems for recirculating exhaust gases and for fuel injection.

Exhaust gas recirculation (EGR) consists of recycling some of the exhaust gas back to the engine intake system. The recycled gases dilute the intake air, which in turn inhibits formation of nitrogen oxides (Heywood 1988).

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[8] 90 percent below the 2004 standards.

[9] Parts per million (ppm) represents one part sulfur in one million parts of diesel fuel. For example, 500 ppm indicates that sulfur makes up 0.05 percent of the fuel by weight.

Table 5. NO_x-Reducing Technologies

Engine Improvements	**Exhaust-Control Technologies**
• Fuel-injection systems: ◆ *High pressures* ◆ *Injection rate shaping* ◆ *Pilot & post injections* ◆ *Timing retard* • Exhaust gas recirculation: ◆ *Cooled* ◆ *Faster response* ◆ *Increased levels* • Combustion chamber: ◆ *4-valve cylinders* ◆ *Increased swirl* ◆ *Bowl geometry* • Charge air cooling	• Lean NO_x catalysts • Selective catalytic reduction • NO_x adsorbers • Plasma-assisted catalysis **Fuel Reformulations** • Diesel fuel changes: ◆ *Lower sulfur content* [a] ◆ *Increased cetane* ◆ *Decreased aromatics* • Diesel fuel additives: ◆ *Water emulsifications* ◆ *Surfactants/cosurfactants*

a. Lower fuel sulfur levels may be required for some NO_x treatment strategies to function.

Source: Mark and Morey, 1999

Cooling the exhaust gases (called *cooled EGR*) provides even greater benefits. Today's diesel engines already use exhaust gas recirculation, but cooled systems and the amount of gases that are recirculated will provide additional reductions of nitrogen oxides (Kreiger et al. 1997).

Advanced fuel-injection systems, such as common rail-injection systems which create a reservoir of pressurized fuel ready for delivery to each cylinder,

Table 6. Particle-Reducing Technologies

Engine Improvements	**Exhaust-Control Technologies**
• Fuel-injection systems: ◆ *High pressures* ◆ *Increased rate* • Turbocharging during acceleration • Homogenous charge compression ignition **Fuel Reformulations** • Diesel fuel changes: ◆ *Lower sulfur content* • Diesel fuel additives:[a] ◆ *Cerium, sodium, copper, iron, other metals*	• Diesel oxidation catalysts • Particle traps ◆ *Passive regeneration* ❍ *Fuel additives* ❍ *Catalyst loaded* ◆ *Active regeneration* ❍ *Electric burner* ❍ *Microwave regeneration* ❍ *Exhaust gas throttling*

a. Metal-based fuel additives are one strategy for particulate trap regeneration

Source: Mark and Morey, 1999

will also yield near-term emissions reductions. These technologies allow for higher injection pressures and flexible fuel-injection timing, which can reduce emissions of particulates and nitrogen oxides.

Increased recirculation, advanced fuel-injection systems, and other engine design improvements could reduce emissions below the 2004 standards. But they will not, alone, be sufficient to meet the proposed 2007 standards. However, decreasing the emissions exiting the engine will give manufacturers additional flexibility in designing exhaust controls that are effective over the entire range of operating conditions encountered by diesel trucks.

Exhaust-Control Technologies

Meeting the proposed emission standards for 2007 and beyond will require exhaust-control technologies capable of reducing nitrogen oxides and particulates in the exhaust exiting the engine by 90 percent. Particulate traps appear to be the most promising strategy for reducing particles, while selective catalytic reduction and nitrogen oxide adsorbers both hold the potential for achieving the required reduction of nitrogen oxides.

Particulate Traps Particulate traps physically capture individual particles with a filter. Over time, the particles build up, clogging the trap. Clearing the trap requires what is called *regeneration* to remove the soot. Regeneration consists of literally burning (oxidizing) the particles off the trap. The trap itself is made of materials capable of withstanding the high oxidation temperatures.

Particles normally ignite around 500 degrees Celsius (°C), a temperature rarely encountered in diesel exhaust. A variety of strategies are available to initiate regeneration. Active filters use microwaves or other heating devices to periodically increase exhaust temperatures to ignite the soot particles. Passive systems lower the temperature at which the particles burn, using catalyst-coated filters, metal fuel additives,[10] or oxidation catalysts upstream of the filter. This third type, called a continuously regenerating trap, takes advantage of the nitrogen oxides in the exhaust stream to facilitate continuous oxidation of the particulates.

In the past, problems with regeneration and durability prevented particulate traps from being put to use. Recent development has mitigated these problems, and traps are now over 90 percent efficient and have proven durable when operated on low-sulfur fuel. In California, new transit bus regulations will likely require the use of traps on all new diesel buses by late 2002.

Some passively regenerating traps become less efficient as a result of the sulfur in diesel fuel. In these traps, the catalysts used to induce regeneration convert sulfur dioxide in the exhaust gas to sulfate particles. Because these

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[10] Metal-based fuel additives may affect human health. Thus, any particular additive must be investigated thoroughly before it is widely adopted.

particles increase the vehicle's total particulate emissions, trucks equipped with such traps might not meet the EPA's proposed emission standard, even if the fuel's sulfur content was as low as 15 to 30 ppm (EPA 2000). This underscores the importance limiting fuel sulfur levels to 15 ppm *maximum*, which corresponds to about 7 ppm on average.

In addition to reducing the efficiency of passive traps, sulfur can actually increase the temperature required for successful regeneration in continuously regenerating traps. This would inhibit proper regeneration, causing increased fuel consumption and potentially elevating the risk of trap failure, especially in colder climates (EPA 2000).

Selective Catalytic Reduction Another exhaust-control technology with potential is selective catalytic reduction (SCR). In this process, the catalyst—ammonia—reacts with the nitrogen oxides in the exhaust gas, producing nitrogen and water as a byproduct. Since ammonia is hazardous in raw form, solutions of urea (ammonia bonded to carbon monoxide) are stored on board the vehicle and injected into the exhaust upstream of the catalyst. These systems have been shown to reduce nitrogen oxides by 65 to 99 percent over a range of diesel operating conditions (Bunting 1998; MECA 1999).

Selective catalytic reduction has been employed on stationary sources such as power plants for over 15 years, but applying the technology to motor vehicles poses important challenges. Mobile catalytic reduction applications must achieve smaller packaging, be durable, and work over the diverse operating range of a truck engine. Systems must be designed to prevent "ammonia slip," in which unreacted ammonia escapes out the tailpipe. This may be solved by carefully tailoring the amount of urea injected into the catalyst and adding a diesel oxidation catalyst to the system.

An additional challenge is the requirement for a urea-refueling infrastructure. Consumers may not accept having to purchase a second "fuel" (urea). Since the vehicles will operate whether or not there is urea available to reduce emissions, it may be difficult to ensure that the catalysts operate properly. If these secondary issues can be adequately addressed, selective catalytic reduction should enable vehicles to meet the stringent nitrogen oxide standards the EPA has proposed.

While some selective catalytic reduction systems are not as sensitive to sulfur as particulate traps, maximizing emission reductions will require fuel with a low sulfur content. Furthermore, the extra catalysts needed to prevent ammonia slip could increase sulfate emissions and hinder efforts to meet the particulate standards.

Nitrogen Oxide Adsorbers Adsorbers reduce nitrogen oxides in two steps. First, the catalyst chemically traps and stores the nitrogen oxides. Eventually the catalyst's active sites "fill up," setting off the second step: regeneration. Diesel fuel or other hydrocarbons are injected directly into the exhaust gas. This artificial hydrocarbon-rich (reducing) environment triggers the release of oxygen and the conversion of nitrogen oxides to nitrogen and water. Regeneration exacts a small penalty in fuel economy, projected at 2 to 5 percent, as a result of the injection of fuel into the exhaust gas.

Adsorbers decrease emissions of nitrogen oxides by more than 90 percent under some operating conditions (Duo and Bailey 1998). While their efficiency during tests is currently only 60 to 70 percent (EPA 2000), the technology shows substantial promise for achieving average reductions of over 90 percent.

Adsorbers are quickly poisoned by sulfur, and their efficiency drops substantially even when exposed to very low levels (Duo and Bailey 1998).[11] This may be reversed through desulfurization, which involves periodically raising the exhaust temperature to above 650°C for a short time. However, desulfurization uses fuel, and the frequency with which desulfurization is required increases as the fuel's sulfur content rises. This fuel-consumption penalty is small but noticeable (less than 1 percent) at 15 ppm but increases rapidly as sulfur levels rise, reaching about 2 percent at 50 ppm (EPA 2000).

Another option for protecting adsorbers from sulfur poisoning may be to use a sulfur-reducing catalyst upstream of the adsorber. However, the size, complexity, and cost of the additional catalyst would scale with the amount of sulfur in the fuel, requiring a larger system to clean up higher sulfur levels.

Cleaner Diesel Fuel

Regulations currently limit sulfur levels in diesel fuel to 500 ppm, resulting in fuel that contains 300 to 350 ppm sulfur on average (Table 7). Because

Table 7. Diesel Fuel Sulfur Levels

	Sulfur Content (ppm, by weight)
uncontrolled (pre-1993)	5,000
current standard	500
current US average	300–350
2002 California transit fuel	15
current Swedish Class I	10

Parts per million (ppm) represents one part sulfur in one million parts of diesel fuel. For example, 500 ppm indicates that sulfur makes up 0.05 percent of the fuel's weight.

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[11] Duo and Bailey reported that average nitrogen oxide conversion declined to less than 50 percent when exposed to fuel sulfur levels as low as 10 ppm.

sulfur adversely affects exhaust-control technologies and directly increases particle emissions (as discussed above), the EPA is proposing to cap sulfur levels at 15 ppm starting in 2006.

As a counteroffer to the EPA's proposal, the oil industry has suggested instead reducing the sulfur in fuel by 90 percent to 50 ppm. While 90 percent is significant, it is simply not enough to ensure that engine manufacturers will be able to meet the new emission standards. Even at 50 ppm, sulfur reduces the efficiency of particulate traps enough that the proposed standards might not be met. In addition, at 50 ppm traps must reach a higher temperature to regenerate, which increases the likelihood that they will fail during winter in the northern states (EPA 2000).

Nitrogen oxide adsorbers are also significantly impaired by sulfur levels of 50 ppm. While this technology is relatively new and technological advances may improve sulfur tolerance, minimizing fuel sulfur levels is currently the best strategy for maintaining high reduction efficiencies in adsorbers.

Modeling Pollutant-Reduction Potential

To evaluate how these technologies could improve the environmental performance of diesel trucks, we estimated emissions for three groups of model years:

- 1998 to 2003 to find out where emissions stand today
- 2004 to 2006 to determine what emissions are likely to be once trucks are being held to the regulations currently on the books
- 2007 to 2030 to project what emissions might be if trucks are modified with exhaust-control technologies to meet the standards the EPA has recently proposed

The results of these estimates are presented later in this report, in the section on the benefits of greener trucks and buses. Here we lay out our assumptions and methodology.

We used traditional emission-modeling methods for estimating smog-causing emissions (nitrogen oxides and hydrocarbons), relying on the EPA's data and methods (EPA 1998b; EPA 1999a, b; EPA 2000).[12] However, we did not follow the EPA's methodology for estimating particulate emissions, as we believe that

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[12] The EPA assumes that 2004 and later vehicles meet emission standards with an 8 percent compliance margin at the regulatory useful life (the 400,000+ miles over which vehicles must meet the standard), then calculates the required zero-mile-level emissions rate (emissions before the engine deteriorates) based on the assumed deterioration. Deterioration, emissions, and conversion factors for model years 2004 and later are listed in the Regulatory Impact Analysis (EPA 2000). Zero-mile-level emission rates and deterioration factors for pre-2004 model years are taken from EPA 1999a. The conversion factors used to compare vehicles of different size classes (i.e., 3 or 8B) are from EPA 1998b.

method does not accurately predict real-world emission levels.[13] Instead, we calculated baseline particulate emissions based on real-world testing data from the Alternative Fuels Data Center (AFDC, n. d.).

In the near term, improved engine designs can reduce smog-causing emissions by 40 percent below today's levels. These modest controls are required for model year 2004 and later trucks under already-adopted standards. They define the baseline for measuring the emissions benefits of the proposed new rules.[14]

Long-term emission reductions for diesel trucks require maximizing the emissions benefits of engine modifications, applying two exhaust-control systems (one to control nitrogen oxides, the other to control particulates), and using virtually sulfur-free fuel. We assumed that particulate traps will be the preferred technology for meeting the particulate standards and that they will achieve an average reduction efficiency of 90 percent. We assumed that the nitrogen oxide standards will be met using adsorbers or selective catalytic reduction, either of which will yield the 91 percent reduction necessary for compliance. The EPA believes that adsorbers will be the preferred technology due to the issues regarding urea infrastructure and compliance associated with selective catalytic reduction (EPA 2000). While other technologies under development could eventually prove more cost effective, easier to operate, or superior from a fuel-economy standpoint, these technologies appear to be the most promising today (EPA 2000).

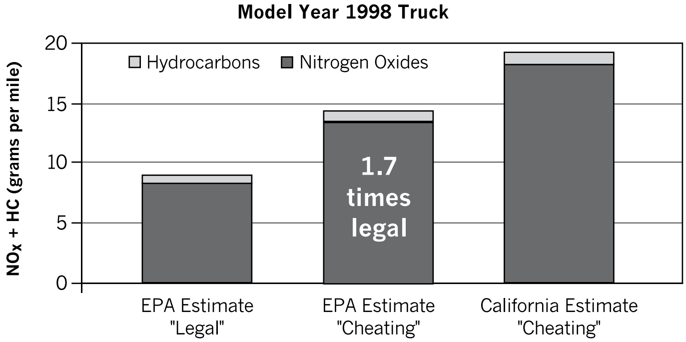
Real-World Emissions

Historically, stricter standards have not yielded equivalent real-world emission reductions. In 1998, several diesel engine manufacturers reached a legal settlement with the EPA over the alleged use of devices to bypass air pollution laws. Engine controls that were used to meet the emission standards during certification tests were allegedly turned off during highway driving to boost fuel economy. This resulted in as much as 70 percent more pollution per truck than if the trucks had been meeting legal emission limits (Figure 4, next page). In 1998 alone, these devices may have released an additional 1.3 million tons of nitrogen oxides, or 28 million cars-worth

[13] The EPA estimates emissions of nitrogen oxides, hydrocarbons, and particulates by applying a bhp-hr/mi conversion factor to the g/bhp-hr emissions (one constant factor for each vehicle class). These conversion factors are reasonable for in-use nitrogen oxide emissions but may not be as accurate for particulate and hydrocarbon emissions because these pollutants appear to be more a function of changes in driving conditions (transients) that are not captured in the average conversion factors used here (EPA 1998b). Our comparison of particulate estimates modeled in this way with real-world emissions data (AFDC n.d.) suggests that using these conversion factors greatly underestimates particulate emissions. Thus, we chose to use real-world emissions values instead of modeled estimates for particulates. However, we used the modeled estimates for hydrocarbons, for lack of sufficient real-world data.

[14] For nitrogen oxides plus hydrocarbons only. We assume that the particulate emissions will not change from the levels emitted by today's new trucks

Figure 4.
Effect of Defeat Devices on Smog-Forming Emissions



Source: UCS calculation based on the EPA's Mobile 6 spreadsheet model (EPA 1999a, b) and California's EMFAC2000 model.

of pollutants. While manufacturers have agreed to stop using such defeat devices in some instances, the experience highlights the fact that the EPA must develop an effective in-use compliance program to ensure that trucks are as clean on the highway as they are during certification tests.

In estimating emissions, the EPA assumes the exhaust-control technologies used on trucks will not deteriorate. This runs counter to experience with catalytic converters on gasoline vehicles, which do become less efficient as mileage increases. Thus, we also evaluated emissions under a scenario in which the exhaust-control technologies of model year 2007 to 2030 trucks deteriorate.[15]

Cost

The EPA estimates that the long-term costs for trucks meeting the rule will range from $1,396 for light heavy-duty trucks such as large pickups to $4,838 for class 8 trucks such as transit buses or long-haul tractor-trailers. This assumes all trucks are equipped with nitrogen oxide adsorbers and particulate traps. The estimate also takes into account the higher operating costs resulting from the exhaust-control technologies, an additional 4.4 cents per gallon for low-sulfur diesel fuel, and reduced maintenance costs resulting from the use of low-sulfur fuel. For a heavy-duty class 8 truck, these additional hardware costs will add less than 2 percent to the total lifetime cost of the vehicle (EPA 2000).[16]

[15] We assumed deterioration factors equal to those assumed for model year 2004 vehicles for nitrogen oxides and hydrocarbons (EPA 2000). For particulates, we used a deterioration rate of 0.001 g/bhp-hr per 10,000 mi for all vehicle classes (i.e., equal to hydrocarbon deterioration). The EPA assumes particulate deterioration is zero for all post-1990 model year trucks.

[16] Vehicle purchase price will increase approximately 1.2 percent and operating costs will increase about 2.8 percent (EPA 2000).

Fuel-Saving Technologies

Much of the emphasis on fuel savings for conventional diesel vehicles has appropriately focused on the large (Class 8), long-haul vehicles that account for the majority of truck energy use. The US government launched a 21st Century Truck Initiative in April 2000 with the stated goal of developing a production-ready prototype of an 18-wheel, long-haul truck by 2010 with twice the fuel economy of today's vehicles (Eberhardt 2000). The exact technical pathway for achieving the goal has not yet been articulated, but it is likely to rely heavily on conventional technology improvements.

Engine efficiency has steadily improved since the early 1900s, with modern diesel engines converting 40 to 45 percent of the fuel to useful energy. Continued improvements can be achieved through a number of techniques (see Table 8).

Table 8. Fuel-Saving Technologies

Engine Efficiency

- High peak cylinder pressure
- Increased turbocharger efficiency
- Improved heat management
- Reduced engine friction

Aerodynamics

- Rounded exteriors
- Air dams
- Gap seals
- Trailer streamlining

Low-Resistance Tires

- Design improvements
- Super singles

Drive Train

- Improved lubricants
- Optimized gearing
- Non-driven axle (tag axle)

Efficient Accessories

Weight Reduction

Idling Energy

- Auxiliary power units
- Truck stop electrification

Sources: DOE 200; Sachs et al. 1992

Achieving large gains in engine efficiency will be a substantial technical challenge given the simultaneous need to reduce pollutant emissions because many of the emission-control technologies under development reduce, rather than improve, fuel economy. Fortunately, with low-sulfur fuel the penalty can be small compared with the large efficiency gains available through the engine improvements and load-reducing strategies envisioned here.

Although substantial gains have already been made, continued aerodynamic improvements are vital to improving the fuel economy of the large trucks that spend most of their time on the open road, since over half of the engine's power can go into overcoming wind resistance at highway speeds (Sachs et al. 1992). Better tires are also important, as the friction they create can consume 40 percent of the power produced in freeway driving (DOE 2000). Additional savings will come through incrementally improving the drive train, decreasing the amount of energy accessories like air conditioning consume, and reducing weight.

Another opportunity for reducing a truck's energy use is to decrease the amount of energy expended idling. The average large freight truck may idle as many as 6 hours per day to heat, cool, and provide power to the cab (ANL n.d.). Auxiliary devices for that purpose—such as cab heaters, dedicated generators, or fuel cells—or plugging in to electrical outlets at a truck stop are 80 to 90 percent more efficient than idling the engine. These strategies also reduce pollution.

Modeling Fuel-Saving Potential

Detailed analyses of the fuel-economy gains achievable in long-haul trucks project potential increases of 40 to 65 percent in the short term (DOE 2000; Sachs et al. 1992; DeCicco and Mark 1998). To evaluate the national benefits of fuel-saving technologies, we assumed that the Department of Energy's target for a 2004 prototype truck achieving a 43 percent fuel-economy gain at highway speeds will be attained by all new long-haul trucks by 2015. We further assumed that all new long-haul trucks will achieve the 21st Century Truck Initiative's goal of double fuel economy by 2030, which translates into a 50 percent reduction in per-mile emissions of heat-trapping gases. Smaller diesel trucks used for urban delivery or other freight uses are likely to improve as well, but we assumed that the substantial environmental gains for these vehicles will come about through alternative fuel use and advanced technologies, as discussed below, rather than through the more conventional technologies evaluated for long-haul trucks.

CHAPTER 3

THE GREEN TECHNOLOGIES: ALTERNATIVE FUELS, HYBRIDS, AND FUEL CELLS

While diesel engines can be made substantially cleaner, truly green technologies hold greater promise of benefits for public health. Alternative fuels and hybrid vehicles have already been demonstrated in a number of diesel niches. Natural gas transit buses, in particular, are already on the road. Fuel cells—which will do the most to clean up the air—are still a few years from market.

Alternative Fuels

Alternative fuels provide an extra measure of health protection in urban regions. A variety of alternative fuels have been demonstrated in heavy trucks and buses, including natural gas, propane, electricity, hydrogen, methanol, ethanol, biodiesel, and natural gas-derived liquids. And these fuels are gaining momentum, especially in the market for urban vehicles. One in four transit buses currently on order in the United States will be powered by alternative fuels. Most of these will run on natural gas (DOE 2000), which has gained the largest market share for alternatives today. Over 1,000 natural gas transit buses now operate in cities around the country (Larson 1997). Other attractive applications for such fuels include garbage trucks, school buses, and local delivery vehicles—both large trucks, such as the tractor-trailer distribution trucks used by grocery store chains, and small trucks, such as those used for parcel delivery. Given its market success, we focused our analysis of alternative fuels on natural gas; however, future technical and economic progress could well create markets for other fuels.

Costs for natural gas trucks and buses are higher than for diesel vehicles, but operators can make up some or all of the additional price through lower fuel costs, since natural gas is typically cheaper than diesel fuel (Mark and Davis 1998). Infrastructure and range have posed the greatest challenge to widespread natural gas use. Currently, vehicles that run on natural gas are most often centrally fueled and typically travel less than a few hundred miles before refueling, although this range can be extended if the fuel is cooled and stored as a liquid. Technology advances and an expanding refueling infrastructure will eventually overcome these hurdles, but the short-range, centrally fueled market is in itself large enough that natural gas trucks can yield a major environmental improvement even in the near term. Today, 23 percent of all truck miles are traveled by vehicles that are refueled in central locations and that typically travel fewer than 200 miles before refueling.[17]

Two broad categories of natural gas engines are available today. The dominant option uses spark plugs like those found in gasoline engines to initiate combustion. These spark-ignited engines are very clean, but suffer, at lower driving speeds, some of the fuel-economy penalties experienced by gasoline vehicles.

Another technology beginning to enter the market is the pilot-injection natural gas engine, sometimes called a dual-fuel engine. Several technologies are being tested, but all use a small amount of diesel fuel to initiate combustion and then inject natural gas to the engine's cylinders. In most recent designs, roughly 85 percent of the fuel used to power the vehicle during driving is natural gas (Arcadis 1998; Westport 2000). Future versions may further increase the natural gas fraction, perhaps closer to 95 percent (DOE 2000). Pilot-injection engines have the benefit of operating much closer to the efficiency of diesel engines, but have not yet been able to fully match the emissions benefits of spark-ignited engines, although they deliver substantial gains over diesel engines.

Potential to Reduce Pollutant Emissions

Natural gas engines are the cleanest commercial option for trucks and buses today. Particulate emissions from natural gas vehicles during real-world testing have been shown to be 80 to 90 percent lower than diesel (AFDC n.d.; NAVC 2000). Natural gas is also much cleaner than diesel for nitrogen oxides, reducing emissions by 35 to 50 percent (CARB 2000b). However, non-methane hydrocarbon emissions are higher for natural gas than for diesel. Taking these higher NMHC emissions into account, natural gas vehicles still reduce smog-causing emissions by as much as 40 percent over conventional diesel.[18]

In the near term, the same types of engine changes that will reduce diesel emissions (particularly increasing the amount of exhaust gas recirculation) can also reduce natural gas emissions. Transit bus regulations passed by the state of California in February 2000 provide a strong incentive for manufacturers of natural gas engines to meet the state's optional low-emission standard, which is 1.8 g/bhp-hr for nitrogen oxides and hydrocarbons combined (CARB 1999). This standard, which represents a 40 percent reduction

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[17] UCS calculation based on DOC (2000).

[18] Per-mile emissions estimates for today's natural gas vehicles are based on certification testing data for model year 2000 trucks and buses (CARB 2000b) and chassis testing data (NAVC 2000; AFDC n.d.). We applied these emission reductions (or increases, for hydrocarbons) to the modeled emission rates for diesel vehicles in 2000. We used the same nitrogen oxide and hydrocarbon conversion factors (bhp-hr/mi) as for diesels. In-use particulate rates were based on average AFDC results for model year 1994 and later trucks and model year 1996 and later buses.

in smog-forming emissions over the average new natural gas engine, should not prove challenging for industry to meet. In fact, some engine models are nearly that clean today.[19] Natural gas buses meeting the optional standard will be about 30 percent cleaner than diesel vehicles for smog-forming exhaust and will retain their 80 to 90 percent advantage in reducing particulates.

Meeting the long-term diesel standards proposed by the EPA should pose no problem for natural gas vehicles. There are no technical reasons why particulate traps, nitrogen oxide adsorbers, and selective catalytic reduction cannot also be used to clean up the exhaust from natural gas engines. The different chemistry of the exhaust gas may require optimizing catalysts specifically for natural gas systems, but because the fuel is naturally sulfur-free, it may prove easier to achieve higher control efficiencies over the lifetime of the vehicle. Hydrocarbon reductions should also be possible to the same degree as for diesel trucks, through better engine designs, particulate traps (which can remove some hydrocarbons), or the use of oxidation catalysts. Ultimately, natural gas vehicles that employ the same exhaust-control technologies as diesel vehicles should easily retain their emissions advantages.[20]

Potential to Reduce Heat-Trapping Emissions

Natural gas fuel contains less carbon than diesel fuel. If all emissions of heat-trapping gases associated with the production and delivery of fuel plus the carbon contained in the fuel are taken into account, compressed or liquefied natural gas offers a 22 percent reduction over diesel in emissions of heat-trapping gases per equivalent gallon (Figure 5, next page). However, two factors counteract this inherent advantage:

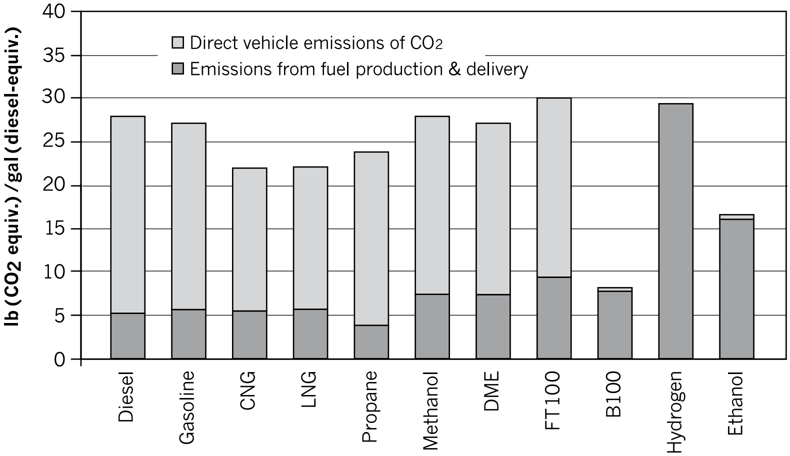
- Natural gas engines are less efficient than diesel engines.
- Natural gas engines emit methane, a potent heat-trapping gas.

Natural gas engine efficiency depends on engine design, drive cycle, fuel quality, and other factors. For example, real-world testing data on nearly 200

[19] Per-mile emissions estimates for near-term natural gas vehicles were based on an assumption that natural gas vehicles meet the 1.8 g/bhp-hr standard with the same relative hydrocarbon and nitrogen oxide proportions as natural gas in 2000, with an 8 percent compliance margin. Deterioration rates were assumed to be proportional to vehicle emissions. In other words, we adjusted the deterioration factors for natural gas down by the same proportion as the emission benefits relative to diesel (or disbenefits, in the case of hydrocarbons). This is consistent with data from the California Air Resources Board showing that deterioration rates for heavy trucks have decreased with time as those vehicles meet cleaner standards (but without exhaust-control technologies) (CARB 2000a, chapter 10).

[20] We based our per-mile emission estimates for long-term natural gas vehicles on the assumption that hydrocarbons are reduced 88 percent and nitrogen oxides are reduced 91 percent in natural gas vehicles using exhaust-control technologies. These are the same zero-mile-level reductions the EPA assumes for diesel vehicles. However, it is likely that catalysts would be more than 88 percent efficient at removing hydrocarbons from natural gas exhaust.

Figure 5.
Emissions of Heat-Trapping Gases



Notes: 1. UCS calculation based on GREET 1.5 model (Wang 1999).

2. CNG=compressed natural gas; LNG=liquified natural gas; DME=dimethyl ether; FT100=100% Fischer-Tropsch fuel; B100=100% biodiesel.

3. B100 and ethanol are credited with carbon absorbed from the atmosphere during the growth of the plant feetstocks (e.g., soy or corn).

buses indicates that natural gas transit buses are 85 percent as efficient as diesel buses.[21] The relative efficiency of natural gas garbage trucks can range from 0.74 to 0.83, while that of spark-ignited natural gas tractor-trailers can be 0.70 to 0.74.[22] Limited data on lighter trucks, such as UPS delivery vehicles, suggests similar relative efficiencies of around 75 percent.[23] In evaluating the carbon impacts of alternative fuel use nationwide, we assumed that modern natural gas tractor trailers and delivery vans will be 75 percent as efficient as diesel, improving to 85 percent in the future as the technology develops.[24] If more efficient pilot-injection technology were to gain market share, the relative efficiency would be over 95 percent (DOE 2000).

[21] Based on carbon dioxide measurements for transit buses operating over the Central Business District (AFDC n.d.). To derive relative efficiency, we adjusted tailpipe emissions of CO_2 by the ratio of carbon in natural gas fuel to that in diesel fuel.

[22] Garbage truck values based on New York Garbage Truck Cycle (0.78) and Central Business District cycle (0.83), which are standard tests used for emissions evaluation of heavy vehicles in urban operations. Tractor-trailer values based on liquified natural gas (LNG) and compressed natural gas (CNG) vehicles over the 5-mile truck route (AFDC n.d.).

[23] Based on DOE (1999), which reports CNG UPS trucks in one recent demonstration were 9 to 15 percent more efficient than their gasoline counterparts. We adjusted these values by assuming that diesel light-duty trucks are 50 to 60 percent more efficient than gasoline (Mark and Morey 1999).

[24] These are efficiency changes relative to a conventional diesel engine, which does not assume aggressive fuel economy advances. The 85 percent estimate is from DOE (2000) for a modern engine today; we used this as a future value, since current testing data suggests that real-world efficiencies are currently lower.

Data from testing today's natural gas engines indicate that methane emissions are 10 to 15 grams per mile (NAVC 2000; Clark et al. 2000). Each gram of methane is estimated to have an impact on global warming equal to that of 21 grams of carbon dioxide (Wang and Huang 2000). Thus, a natural gas engine's average—12 grams per mile of methane—has the same potency as over 250 grams of carbon dioxide. This is relatively small compared with a natural gas transit bus's 2,400 grams per mile of direct carbon dioxide emissions, but it is not insignificant. In the future, methane emissions from natural gas are likely to decline as better engine controls and emission-control equipment do a better job of combusting all carbon in the fuel to carbon dioxide. We assumed that methane emissions will drop in the future along with other hydrocarbon emissions as exhaust-control equipment is applied (see section above on reducing pollutant emissions). Thus, methane emissions might be only 1.2 grams per mile in 2007 when new cleanup technology is installed to reduce hydrocarbon emissions from truck engines.

Taking tailpipe methane and the efficiency penalty of spark-ignited natural gas engines into account, the "well-to-wheels" heat-trapping emissions from natural gas vehicles and fuel production could be as much as 25 percent higher per mile than diesel for some applications. But urban buses (such as transit and school buses) are already roughly equivalent, if not slightly better, than diesel engines when it comes to heat-trapping gases. In the future, technological advances will narrow the efficiency gap between diesel and spark-ignited natural gas, so that eventually natural gas use might result in global warming benefits on the order of 5 to 10 percent. The higher efficiency pilot-injection natural gas engines entering the market today already match the heat-trapping emissions performance of the majority of today's diesel engines and even provide a 10 percent benefit in applications such as transit and school buses.

Hybrids

Hybrid vehicles combine two power sources: a conventional combustion engine and an energy-storage device such as a battery. The combination offers opportunities to boost vehicle fuel economy and reduce emissions by

- using its engine more efficiently
- turning off the engine at rest
- relying on a more efficient electric motor to drive the wheels
- capturing energy normally lost during braking

As a hybrid truck or bus pulls away from the curb, it typically uses a combination of power from the engine and batteries. As it decelerates, the wheel motors become generators, storing energy in batteries that is normally lost during braking (called *regenerative braking*). And at rest, the engine may be turned off altogether. As with traditional trucks and buses, the engine in a hybrid vehicle can be built to run on either diesel or an alternative fuel such as natural gas.

Hybrid vehicles are in the early stages of commercialization. Demonstrations have proven the technology in transit bus applications. However, this market may not be the most attractive for diesel hybrids, since cleaner natural gas buses are already available and zero-emission fuel cell buses are just around the corner. A more promising niche is with urban vehicles that are not centrally refueled and that make lots of starts and stops, such as delivery vans and trucks.

The complexity of the combined system and the use of batteries increase the purchase price of hybrid vehicles. But lower fuel costs resulting from these vehicles' higher efficiency will offset a portion of the price. One recent analysis estimates that fuel savings will pay a hybrid truck owner back in 4 to 7 years, but cost reductions over the coming decades may reduce the time till payback to 2 or 3 years (An et al. 2000).

Potential to Reduce Pollutant Emissions

Data from testing prototype diesel hybrid-electric buses equipped with particulate filters demonstrate that this technology can emit about 70 percent less particulate matter and 30 percent less smog-forming pollutants than a new diesel bus (NAVC 2000).[25] A portion of the particulate reductions comes from the hybrid configuration, but most derives from the use of particulate filters. In the near term, requirements to produce cleaner diesel engines by 2004 will enable hybrid manufacturers to produce even cleaner vehicles. We assumed that hybrids will be able to meet California's optional standard for nitrogen oxides plus hydrocarbons.[26]

In 2007 and beyond, hybrids should be able to employ the same exhaust-control technologies as diesel for reducing nitrogen oxide emissions, allowing hybrids to maintain an emissions edge over conventional diesels. Since hybrid buses being demonstrated today already use particulate filters, additional particulate reductions of 90 percent will not be likely. We assumed that low-sulfur fuel will be the primary factor enabling further particulate reductions from hybrids and estimated those additional benefits to be about 80 percent.[27]

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[25] Results for the Central Business District test cycle.

[26] We estimated hybrid emissions in 2004 the same way as we did for compressed natural gas trucks meeting the optional 1.8 g/bhp-hr standard. But rather than proportioning hydrocarbon emissions based on model year 2000, we assumed that hybrid hydrocarbon emissions equal hydrocarbon emissions from model year 2004 diesel trucks.

[27] This is based on comparing test results from the Northeast Advanced Vehicle Consortium (NAVC) for hybrid buses running on conventional fuels with those running on sulfur-free synthetic diesel fuels. Alternatively, we could estimate the particulate benefits of hybridizing diesel trucks (i.e., the impacts of reducing fast changes in engine output that lead to particulate formation). However, since testing data compares hybrids *with* particulate filters to diesel trucks with oxidation catalysts, we could not clearly

Potential to Reduce Heat-Trapping Emissions

Diesel hybrid transit buses have demonstrated an ability to boost fuel economy by roughly 25 percent in city driving, although limited testing suggests higher fuel savings may be possible.[28] Other real-world data is relatively limited. Engineering models of vehicle efficiency have predicted a 90 percent boost, on average, to fuel economy from hybridization of smaller delivery vans and trucks (such as UPS trucks), with increases tripling during driving with lots of starts and stops.[29] In modeling national benefits of diesel hybrid vehicles, we assumed that the near-term gain of 90 percent for light-heavy vehicles gives way to the 200 percent target of the 21st Century Truck Initiative for all new vehicles by 2030 (Eberhardt 2000), leaving ample time for the initiative's 2010 prototype vehicle to penetrate the entire new vehicle fleet. Such a super-efficient hybrid would cut emissions of heat-trapping gases by two-thirds compared with a conventional diesel vehicle.

Vehicle efficiency modeling by the Argonne National Laboratory has predicted that medium-heavy trucks, such as Class 6–7 school buses or large delivery trucks, could average a 70 percent fuel economy gain (An et al. 2000). In higher speed driving, the gain may be lower, closer to 45 percent.[30] The Department of Energy has established a target of a 100 percent increase in fuel economy for a prototype delivery vehicle by 2004 (DOE 2000). For our modeling, we assumed that hybridization yields a 50 percent gain in fuel economy for medium-heavy trucks in the near term, giving way to a 100 percent improvement by 2015 for all new hybrid trucks—effectively cutting heat-trapping emissions in half.

Fuel Cells

A fuel cell is an electrochemical device that produces electricity directly from the reaction of hydrogen and oxygen. The only by-product is water. The oxygen for the reaction is taken from outdoor air. Hydrogen can be stored directly on the vehicle, which is the cleanest and simplest way to power a fuel cell vehicle, or it can be extracted from other "carrier" fuels such as methanol with the addition of fuel-processing equipment.

separate the reductions due to the filter from the benefits due to hybridization. Similarly, comparing the test results for hybrid buses with and without regenerative braking showed no clear particulate benefit. Barring a clear method for estimating the benefits of hybridization, we felt it was more accurate to estimate potential improvements to filter efficiency with low-sulfur fuel.

[28] Recent testing in New York City of two diesel hybrid prototypes indicated increases of 23 to 27 percent over the Central Business District cycle, and 21 to 64 percent over the New York Bus Cycle (NAVC 2000).

[29] Average of results for all drive cycles for Class 3–4 truck was a 93 percent gain (An et al. 2000). New York Garbage Truck Cycle results indicated a 172 percent increase in fuel economy.

[30] Based on the Central Business District cycle (An et al. 2000).

Fuel cells were invented as far back as 1839, but they were primarily a laboratory curiosity until NASA found extensive use for them in space applications. In the past decade, major technical improvements and cost reductions have brought fuel cells down to earth. As with hybrids, fuel cells have found their first heavy-vehicle application in transit buses, with the first fuel cell bus debuting in 1993. Since that time, several fuel cell buses have been demonstrated, and commercial buses are expected to reach the market in 2002.

Fuel cells offer large efficiency gains over combustion engines, especially at lower speeds. This makes them particularly attractive for urban trucks and buses. Whether they are a good choice for powering long-haul trucks is not currently clear, because the base diesel engine is already operating at very high efficiencies. However, fuel cells are an excellent candidate for powering the electrical needs of long-haul trucks, reducing the fuel use and emissions from several hours of idling each day.

Costs for fuel cells are currently high, but future improvements and mass production offer the potential for cheap and clean energy—not only for heavy vehicles such as transit buses, but also for automobiles and electricity production. Every major automaker in the world is aggressively pursuing fuel cell technology, which is often thought of as the ultimate replacement for combustion engines because of its high efficiency, zero emissions, and potential for cost competitiveness.

Potential to Reduce Pollutant Emissions

A fuel cell vehicle powered by hydrogen emits only water from the tailpipe. It is otherwise a truly zero-emission vehicle.[31] Fuel cell vehicles that carry a secondary fuel such as methanol from which to generate hydrogen will release pollutants, although these are likely to be at near-zero levels in a well-designed, properly operating fuel cell system (Mark and Davis 1998).

Potential to Reduce Heat-Trapping Emissions

Fuel cell vehicles are inherently more efficient than combustion vehicles. Data from testing early fuel cell buses indicates that they can achieve double the fuel economy of diesel vehicles (Mark and Davis 1998). In modeling national benefits, we assumed that fuel cells will be twice as efficient as the base diesel vehicle in each year for most applications. For the heaviest vehicles, we assumed that the fuel economy gain grows to double that of a model year 2000 vehicle, beginning at 50 percent in the early years. Fuel cells for light-heavy trucks are a prime option for meeting the three times efficiency gain targeted by the 21st Century Truck Initiative for heavy pickups and large

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[31] While the production and delivery of hydrogen does result in some emissions, they appear to be similar to the relatively small amount of pollutants associated with manufacturing and distributing diesel fuel (Mark and Davis 1998).

delivery vans. As with diesel hybrids, we assumed that new trucks will meet this target by 2030.

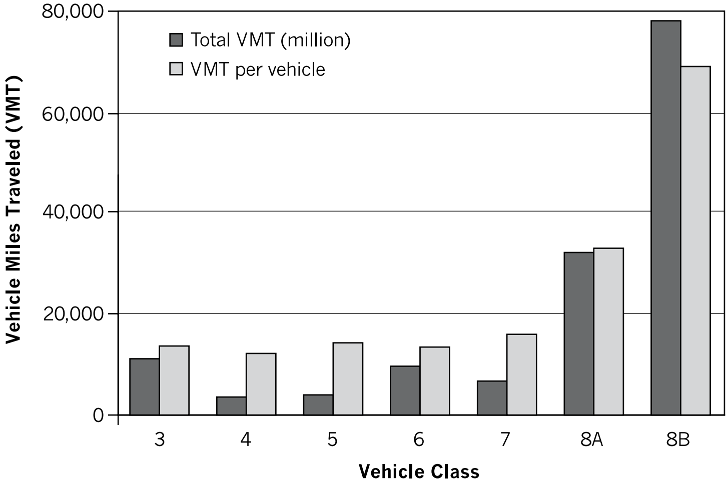
The hydrogen used in fuel cells does not contain any carbon, so a hydrogen fuel cell truck or bus will emit no carbon dioxide. However, the production of hydrogen does generate heat-trapping gases, particularly if fossil fuels are the source from which the hydrogen is produced. Today, most commercial hydrogen is manufactured from natural gas. In the near term, we expect natural gas to be the dominant source of hydrogen, with renewable sources coming on line in the future. The production and delivery of compressed hydrogen for vehicles emits just about as many heat-trapping gases as the production of diesel fuel added to the carbon released when the diesel fuel is burned (see Figure 5, p. 24). As a result, fuel cell trucks and buses that are two to three times more efficient than their diesel counterparts will reduce heat-trapping emissions by one-half to two-thirds.

CHAPTER 4

BENEFITS OF GREENER TRUCKS AND BUSES

The truck market today is extremely diverse, ranging from garbage trucks that may travel less than 5,000 miles per year in dense cities to tractor-trailer trucks that travel over 100,000 miles in a year on the open road (Figure 6).

Figure 6. Mileage of Heavy Trucks



Source: DOC 2000

This creates opportunities for technology and fuel solutions tailored to the specific needs of the user, the truck's driving pattern, and the local environment. For example, cleaner alternative fuels are a priority for densely populated urban areas and applications where users, such as school children, are particularly sensitive to pollution. Hybrid and fuel cell trucks are likely to offer their largest benefits in stop-and-go driving. And conventional diesel improvements may make most sense for long-haul trucks operating at constant, high speeds over the open road.

To illustrate the per-vehicle benefits that can accrue through cleaner and more efficient technologies and fuels, we constructed four case studies: a transit bus, school bus, parcel delivery truck, and long-haul truck.[32] For each

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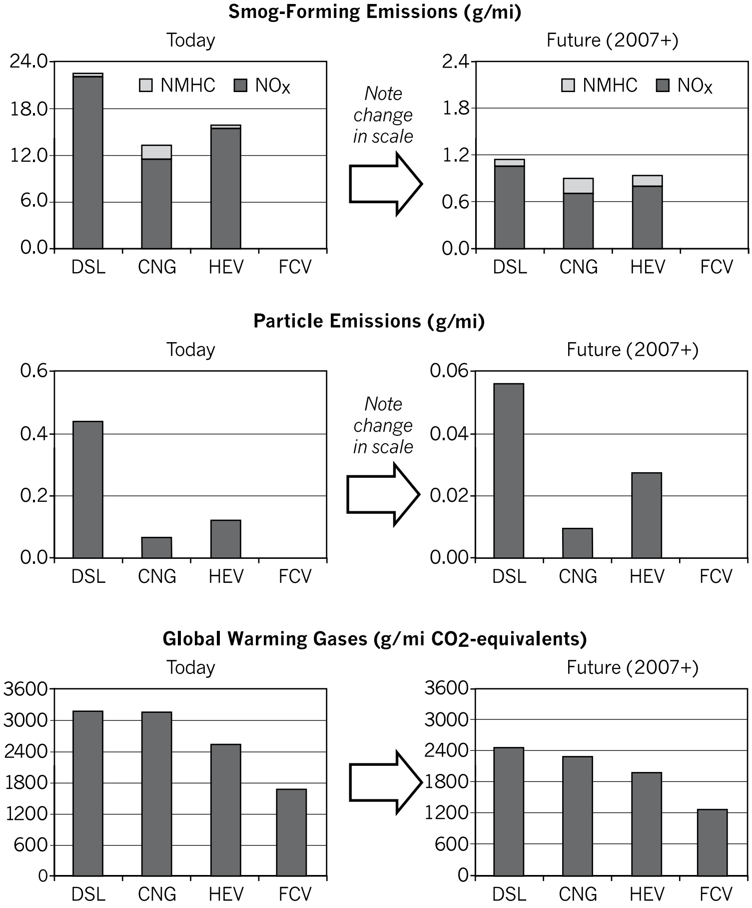
[32] See Table A-1 for detailed values.

of these, we determined what the emissions would be if it were powered by diesel, compressed natural gas, hybrid electric drive, or fuel cells. And we examined how emissions could change in the future as the industry adopts more advanced technologies in order to meet the proposed regulations discussed above. We also modeled the national benefits of reduced emissions brought about by conversion to cleaner technologies.

Figure 7. Urban Bus Emissions

Class 8, 33,000+ lb gross vehicle weight (GVW)



DSL= diesel bus; CNG = compressed natural gas bus;
HEV = hybrid electric bus *with particulate trap*; FCV = fuel cell bus.

Estimates based on UCS modeling (Mobile 6 analysis of NO_X and HC and real-world data for PM) and AFDC n.d.; CARB 2000b; EPA 1998b, EPA 1999a, EPA 2000; NAVC 2000. See text for discussion.

Case Study 1: Transit Bus

Because transit buses often operate in cities, where public exposure to smog and diesel particles is highest, transit agencies should purchase the cleanest buses possible. Buses fueled by natural gas are the best commercial choice today. Demonstration programs show that prototype diesel hybrid-electric buses have yet to match the low smog-forming emissions of compressed natural gas buses. Diesel hybrid buses can decrease emissions of particles (especially when using traps) and heat-trapping gases compared with conventional diesel buses, as Figure 7 shows, but more testing is needed to evaluate their ability to reduce toxic emissions.

Zero emissions make hydrogen fuel cells the natural choice for transit buses as soon as they become commercially available, which will be within the next few years. In addition, these offer the potential for large reductions in heat-trapping emissions. Even when the hydrogen is produced from fossil fuels, heat-trapping emissions decrease by half compared with future diesel and by 35 percent compared with diesel hybrids. Transit agencies that start down the natural gas path today are building an infrastructure for future fuel cell buses, because many of the changes in facilities necessary to accommodate natural gas fuel will be useful for hydrogen.

Case Study 2: School Bus

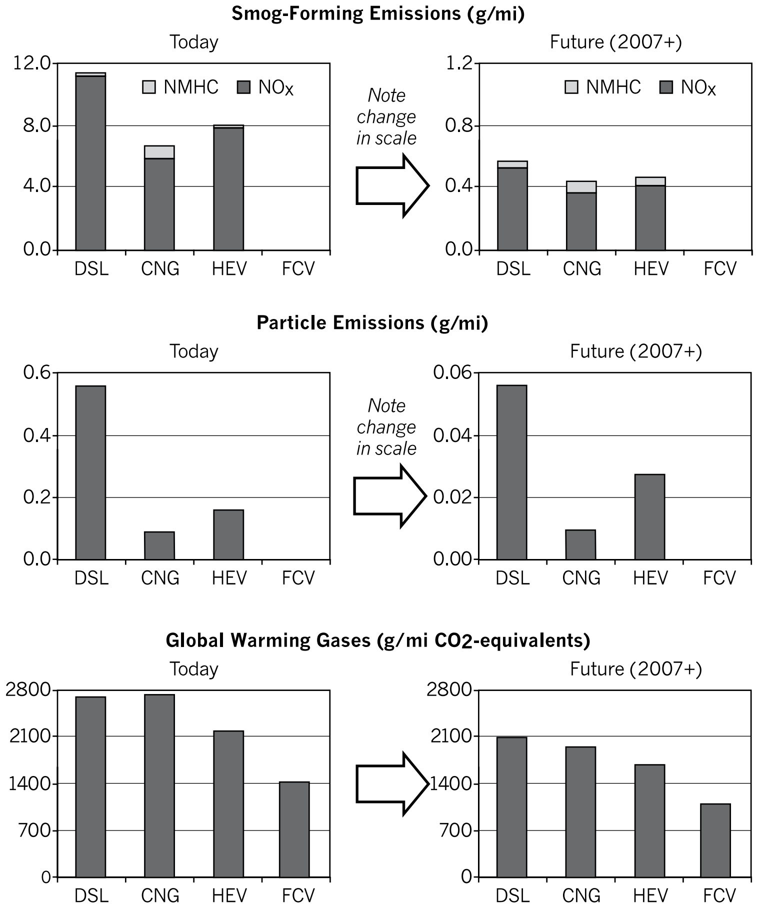
Children, and their sensitive lungs, deserve the absolute cleanest buses. Natural gas buses, with their dramatically low particle emissions (85 percent lower than conventional diesel and 46 percent lower than hybrids equipped with traps), are the safest choice for transporting children today. These buses also emit 42 percent less smog-forming pollutants than diesel buses, as Figure 8 (next page) illustrates.

While diesel hybrid buses are, from a global warming standpoint, slightly better than buses running on compressed natural gas, they do not provide the same level of protection from toxic diesel soot—and lessening children's exposure to toxic soot takes precedence in school bus applications. Future diesel hybrid school buses could eventually emit almost as few smog-forming pollutants as natural gas buses, but if their particle emissions are three times higher (as we projected), they will continue to be a less prudent choice for school buses.

Eventually, zero-pollution fuel cell buses will become the cleanest option for school buses, as well as the lowest contributors to global warming. Schools that invest in natural gas refueling infrastructure today will be well positioned to make the transition to fuel cell buses, because hydrogen refueling systems use many of the same components as are needed for compressed natural gas.

Figure 8. School Bus Emissions

Class 8, 33,000+ lb gross vehicle weight (GVW)



DSL= diesel bus; CNG = compressed natural gas bus;
HEV = hybrid electric bus *with particulate trap*; FCV = fuel cell bus.

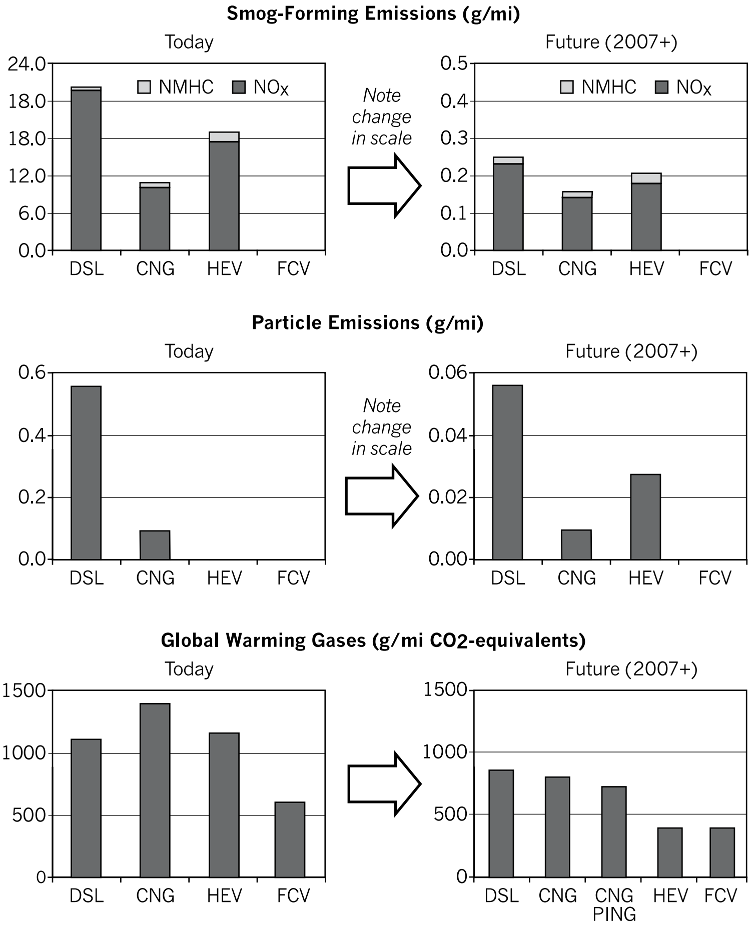
Estimates based on UCS modeling (Mobile 6 analysis of NO_x and HC and real-world data for PM) and AFDC n.d.; CARB 2000b; EPA 1998b, EPA 1999a, EPA 2000; NAVC 2000. See text for discussion.

Case Study 3: Parcel Delivery Truck

Parcel delivery trucks, such as those operated by UPS, FedEx, or the Postal Service, are an important target for cleanup, since they operate in densely populated urban centers and in residential neighborhoods. Zero-polluting hydrogen fuel cells are the best long-term option for such urban delivery vehicles. As Figure 9 (next page) shows, they will emit 50 percent less heat-trapping gases than delivery trucks powered by diesel or natural gas. While

Figure 9. Parcel Delivery Truck Emissions

Class 3, 10,001 – 14,000 lb gross vehicle weight (GVW)



DSL= diesel bus; CNG = compressed natural gas bus;
HEV = hybrid electric bus *with particulate trap*; FCV = fuel cell bus.

Estimates based on UCS modeling (Mobile 6 analysis of NO_X and HC and real-world data for PM) and AFDC n.d.; CARB 2000b; EPA 1998b, EPA 1999a, EPA 2000; NAVC 2000. See text for discussion.

hybrids may match the global warming benefit of fuel cells in the long term, they cannot compete on smog-forming or particle emissions.

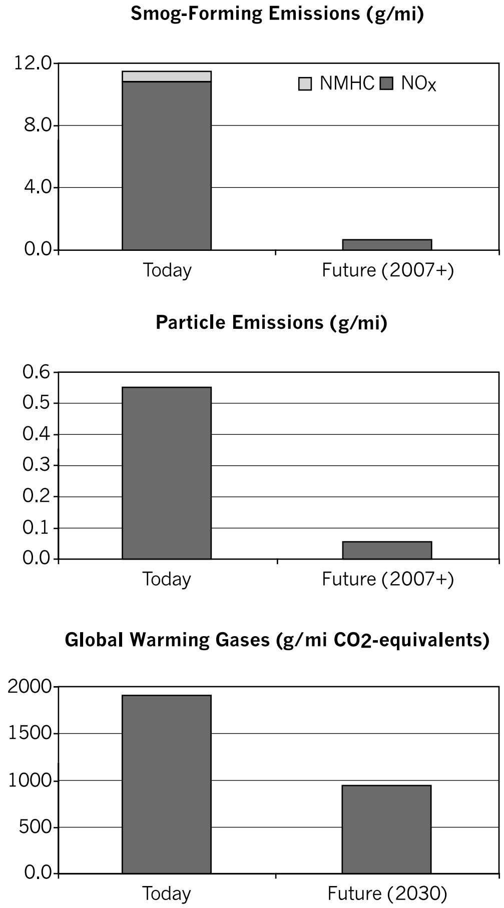
Until fuel cells become widely available, a mix of technologies can reduce the environmental impacts of urban delivery vehicles. Natural gas, which is available for centrally refueled vehicles, offers the greatest public health benefits, but may have a slight global warming penalty compared with diesel vehicles. Natural gas engines that use diesel fuel to initiate combustion (so-called pilot-injection natural gas engines) are more efficient and would reduce global warming emissions, but have yet to match the pollution performance of pure natural gas engines. Hybrid vehicles are not as clean as natural gas, but emit over 50 percent less heat-trapping gases.

Case Study 4: Long-Haul Tractor-Trailer

Forthcoming cleaner diesel technologies will substantially reduce emissions of smog-forming pollutants, particles, and heat-trapping gases from class 8 long-haul trucks. Long daily driving ranges makes natural gas less suitable for

Figure 10. Long-Haul Tractor-Trailer Emissions

Class 8B, 60,000+ lb gross vehicle weight (GVW)



Smog-Forming Emissions (g/mi)

Particle Emissions (g/mi)

Global Warming Gases (g/mi CO_2-equivalents)

Estimates based on UCS modeling (Mobile 6 analysis of NO_x and HC and real-world data for PM) and AFDC n.d; CARB 2000b; EPA 1998b, EPA 1999a, EPA 2000; NAVC 2000. See text for discussion.

these trucks (although this would be less of a problem for liquefied natural gas trucks). And the long periods of highway driving at high speeds means that hybrids or fuel cells may not significantly improve fuel economy or reduce pollutant emissions. However, using fuel cells for auxiliary power sources could eliminate idling emissions.

Pollution savings through new diesel technologies are well within reach, offering the potential to reduce smog-causing emissions by 95 percent over conventional diesel and particulates by 90 percent, as Figure 10 (opposite) indicates. Reducing heat-trapping emissions from diesel trucks is a greater challenge, since they are efficient vehicles today, but if technical targets can be achieved, these gases can be cut to half of today's levels from long-haul trucks.

National Benefits

To evaluate the benefits of greener trucks and buses, we constructed a model to estimate the national savings in energy, heat-trapping gases, and key air pollutants that might result from aggressive policies to improve or replace diesel truck technology and fuels. We developed a snapshot of what the diesel truck market could look like in 2030.

Base Case

We derived a baseline for comparison from the travel and fuel-economy projections collected in the EPA's draft rule for heavy-duty diesel engines and fuels (EPA 2000). These projections suggest that US diesel trucks will travel a total of 475 billion miles in 2030, more than double the total today. The EPA also assumes that, as in the past, truck fuel economy will continue to improve, slightly offsetting the impact of increased travel miles.[33] Nonetheless, under the EPA scenario total energy use by diesel trucks increases nearly 75 percent by 2030 compared with today's usage (Davis 1999).[34]

Green Scenario

In developing scenarios of future technology and fuel penetration, we considered a variety of factors, including commercial readiness, cost, and market characteristics (e.g., drive cycle, range, and power requirements). Our expectation is that successful research and development programs, coupled with aggressive policies, will deliver technologies and fuels that do

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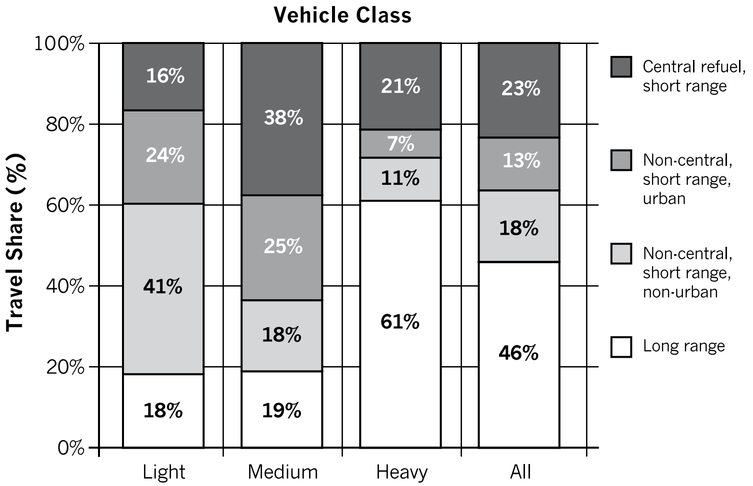
[33] The EPA assumes the following fuel-economy increases for new heavy-duty trucks by 2030 (vs. model year 2000): 28 percent (light heavy), 8 percent (medium heavy), 36 percent (heavy heavy), and 30 percent (urban bus). For our base case, we assume a lower increase in heavy-heavy fuel economy, only 28 percent, the increase projected by the recent Annual Energy Outlook forecast (EIA 2000). We also adjusted the EPA's base case by accounting for increasing sales of trucks as predicted by the Energy Information Administration (EIA). This adjustment increases the fraction of miles traveled by newer vehicles compared with the EPA's base case, which assumes static travel fractions regardless of calendar year.

[34] The EPA's estimate projects that trucks will consume slightly more than 25 percent more energy in 2030 than projections in the Annual Energy Outlook (EIA 2000). The EPA projects higher vehicle miles traveled but also higher fuel economy than the EIA.

not face substantial cost hurdles to entering the market.[35] Rather, we see the characteristics of individual vehicle use as determining the market potential of various technologies.

Figure 11 presents an overview of current travel data for the US truck fleet, based on data from the Vehicle Inventory and Use Survey (DOC 2000). Nationwide, over 20 percent of all truck miles are traveled by vehicles fueled in central locations that typically travel less than 200 miles from their home base.

Figure 11. Heavy Truck Mileage by Major Use



1. UCS analysis of Commerce Department's Vehicle Inventory and Use Survey (DOC 2000).
2. Short-range vehicles typically have a range of 200 miles or less.
3. Urban/nonurban fraction for noncentral, short-range vehicles based on the EPA's analysis of vehicle miles traveled for urban vs. rural roadways (EPA 1999a).
4. Long-range vehicles typically have a range of more than 200 miles.

Alternative fuels that rely on a unique fuel infrastructure are ideally suited to this market.[36] Nearly 15 percent of all miles are traveled by short-range trucks operating largely in urban areas that are not centrally refueled. Short driving range and urban travel suggests that average speeds are low and vehicles are operating in congested areas. Diesel hybrid vehicles might be

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[35] This assumption is supported by recent analyses of potential future vehicle and fuel costs of alternative fuels, hybrids, and fuel cells for heavy-duty applications (DOE 2000; DeCicco and Mark 1998; An et al. 2000; Mark and Davis 1998).

[36] Clearly, technical advances that allow more fuel to be stored on board alternative fuel trucks could change this assumption. Such advances might include better compressed or liquefied gas storage or the widespread use of liquid alternative fuels.

good candidates for this type of driving pattern, since hybridization offers the greatest benefits in stop-and-go driving. Finally, over 45 percent of all miles are traveled by vehicles with a range greater than 200 miles. We assumed that these will largely be advanced diesel vehicles. Our assumptions about the market penetration of each technology are sketched out below, for each size class of trucks. In the appendix, Table A-2 summarizes these assumptions.

Light-Heavy Trucks Light-heavy trucks include vehicles such as super-duty pickups, urban delivery vans (e.g., UPS trucks), and smaller freight trucks that are rated at between 8,500 and 19,500 pounds gross vehicle weight.[37] For these vehicles, we assumed that technologies like alternative fuel engines, hybrids, and fuel cells that are envisioned for their smaller cousins—large pickups, sport-utility vehicles, and vans—will be available. Roughly 15 percent of the miles in this size category are traveled by short-range, centrally fueled vehicles. We assumed that natural gas delivery vehicles, such as those already being used by some fleets, will fully capture this portion of the market by 2030.

Another 20 percent of miles are driven by long-range vehicles; this category is likely to continue to consist of conventional diesel trucks. The remaining 65 percent of short-range vehicles that are not centrally fueled offer large opportunities for both diesel hybrids and fuel cells. We assumed that diesel hybrids will enter the market first, with their share of sales growing rapidly from introduction in the 2005–2010 timeframe. We assumed that fuel cells will begin to enter this size class around 2010, building off the market success of fuel cell passenger vehicles and the resulting infrastructure. Under our scenario, fuel cells would eventually eclipse diesel hybrids as the urban delivery vehicle of choice by 2030.

Medium-Heavy Trucks Trucks and buses between 19,500 and 33,000 pounds gross vehicle weight offer the largest market for short-range, centrally fueled vehicles, as they account for over 35 percent of miles traveled in this category. We assumed that natural gas vehicles will dominate in the early years, but that fuel cells will eventually work their way into this segment of the market. Hybrid vehicles will account for the majority of short-range trips for vehicles that are not centrally fueled, accounting for over 35 percent of miles by 2030.

Heavy-Heavy Trucks Trucks over 33,000 pounds gross vehicle weight account for the majority of miles traveled by all trucks. And nearly 75 percent of the miles in this weight category are traveled by vehicles with a range greater than 200 miles or in rural areas without central refueling. This is the target market for advanced diesels with improved fuel economy and emissions performance. The remainder of the market will be split, under our scenario, among alternative fuels, diesel hybrids, and fuel cells.

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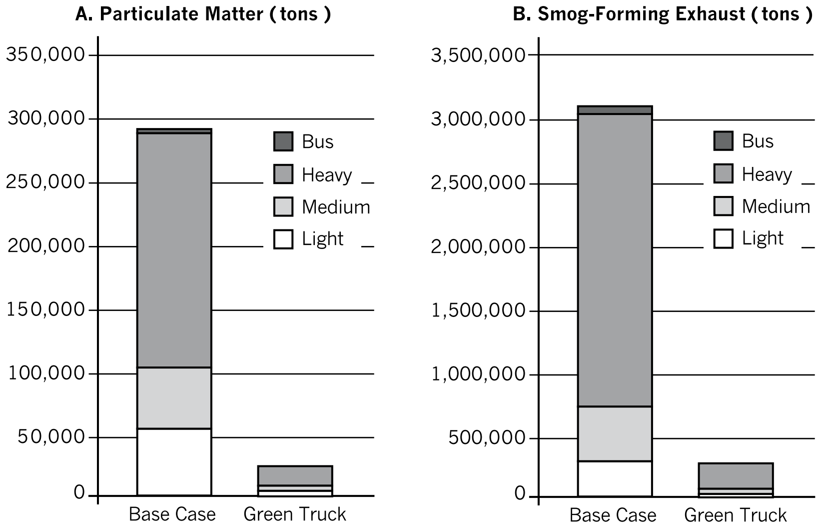
[37] Gross vehicle weight is the weight of a vehicle including its maximum payload.

Urban Buses Natural gas buses are already making their way into the urban bus market, and we assumed that this trend will continue until the fuel cell technology being demonstrated today begins to take over the bus market in the next decade. By 2030, we assumed that all new urban buses will be powered by fuel cell engines.

Results

The technologies and fuels available for heavy trucks could transform the transportation sector—protecting public health, the environment, and the economy even as truck miles double over the next 30 years. Nationwide, we estimated that pollutant emissions from diesel trucks can be cut by 91 to 92 percent in 2030 over the base case, if aggressive, real-world reductions in emissions are achieved (Figure 12 A & B). The smog-forming exhaust savings alone are equivalent to removing over 60 million of today's cars from the road.[38] Tighter standards for diesel trucks would form the backbone of the air pollution savings, but alternative fuels and advanced technologies such as hybrids and fuel cells offer additional emissions benefits—especially in urban areas where large populations are exposed to harmful diesel exhaust.

Figure 12. National Benefits of Greener Trucks and Buses in 2030



A. Particulate Matter (tons)

B. Smog-Forming Exhaust (tons)

1. See Table A-3 for details.
2. Light = Class 2B–5; Medium = Class 6–7; Heavy = Class 8; Bus = Urban Bus.

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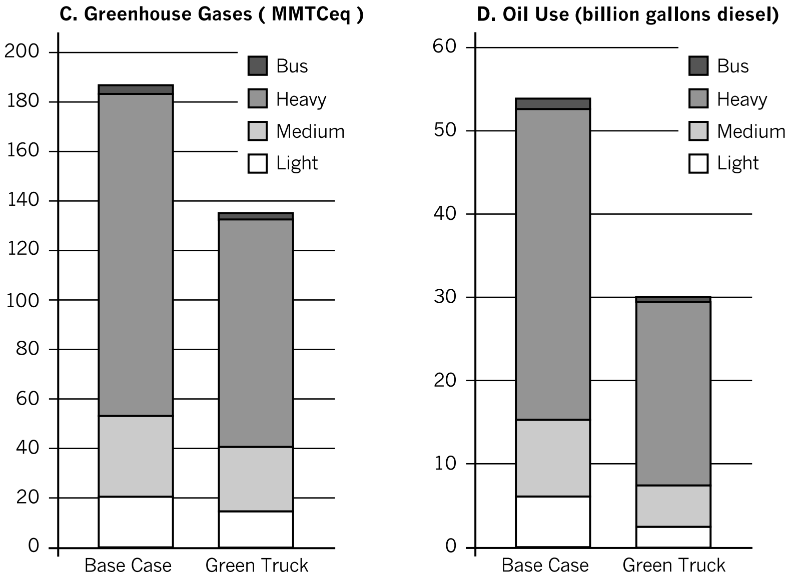
[38] We estimated 3.69 grams/mile for the average passenger vehicle in calendar year 2000, based on total national emissions inventory (EPA 1997b), total national automobile travel, and annual average per-vehicle travel rate of 11,400 miles (Davis 1999).

We estimated that heat-trapping emissions from US diesel trucks can be cut 26 percent (Figure 12 C), a substantial reduction given that today's diesel engines are already relatively efficient. These benefits will grow if low-carbon fuels, such as hydrogen produced from solar energy or biomass-derived ethanol, are used. For this analysis, we assumed that all fuels are produced from fossil fuels, but renewable fuels can provide significant benefits beyond those estimated here. This is an important area for further study.

In addition to the gains in reducing air pollution and contributions to global warming, our green scenario has the added advantage of cutting petroleum use. We estimated that the amount of oil used by diesel trucks can be cut by 45 percent over the base case (Figure 12 D), keeping petroleum use for highway trucks in 2030 at about today's levels. These savings will help insulate truckers from the price volatility of oil, as well as protecting the US economy by reducing oil imports. Slightly over half of these oil savings accrue from gains in efficiency, while the remainder come from switching from diesel fuel to alternatives such as natural gas or hydrogen.

Figure 12 (continued).



C. Greenhouse Gases (MMTCeq)

D. Oil Use (billion gallons diesel)

1. See Table A-3 for details.
2. Light = Class 2B–5; Medium = Class 6–7; Heavy = Class 8; Bus = Urban Bus.

Our estimates suggest that fuel cells can virtually eliminate urban buses from the pollution picture. Fuel cells also play a major role in delivering large reductions in the light-heavy truck segment, as do diesel hybrids. Because these smaller delivery vehicles and large vans are close cousins to passenger vehicles (especially SUVs, pickups, and vans), fuel cells and hybrids developed for the passenger vehicle market will pay off for light-heavy trucks as well. But our results show that long-haul heavy trucks continue to be the dominant polluters in 2030, indicating that this market segment should be a priority for efforts to further reduce emissions, heat-trapping gases, and oil use.

CHAPTER 5

POLICIES TO PUT GREENER TRUCKS AND BUSES ON THE ROAD

Realizing the potential of greener fuels and technologies will require engine, truck, and fuel companies to be much more aggressive in bringing about change in a century-old industry. And customers—from businesses that use parcel delivery, to grocery store chains, to parents who put their kids on a school bus five days a week—also need to signal that they are ready for change. Aggressive policies are the catalyst that can bring about the transition, giving industry the necessary nudge to invest in cleaner options and consumers the incentive to buy them. A coordinated package of regulations, incentives, and voluntary actions can yield a robust strategy for creating an environment of change.

Regulations

Emission Standards

It is time to ask trucks to pull their own weight in cleaning the air. With new technologies coming to the fore, cutting nitrogen oxide and particulate emissions by a factor of ten is well within reach. The EPA's recently proposed standards, which would begin in 2007, could do just that. But the EPA could secure more gains for public health by encouraging early introduction of cleaner engines and setting optional low-emission standards that encourage manufacturers whose engines go beyond the requirements.

Real-World Emissions

Tighter standards are only part of the solution. Ensuring real-world emission reductions becomes even more critical as engine makers install pollution-control devices on all diesel engines for the first time. Twenty-five years of experience with automotive emission controls have highlighted the clear need for catalysts that last the entire life of the vehicle and operate efficiently under all driving conditions. The EPA must develop testing methods and requirements—such as in-use tests, onboard diagnostic technology as is found on new cars today, and limits on high-power pollution levels—to ensure that cleaner trucks are clean in real-world driving situations and that they stay clean over the vehicle's life.

Should the EPA fail to establish an effective real-world testing and compliance program and trucks fail to stay clean, the loss to air quality would be staggering. In modeling the benefits of tighter truck and fuel standards, the EPA assumes that emissions from future trucks will not deteriorate or malfunction. In the real world, both truck engines and control technology are likely to do so over time. We analyzed the impact on national emissions in 2030, assuming historic deterioration rates prevail in the future or even double (assuming new exhaust-control technology malfunctions much as today's automotive catalysts sometimes do). Under this scenario, particulate emissions in 2030 would be 2.5 to 4 times higher than in the base case, and smog-forming exhaust 1.7 to 2.3 times higher (Figure 13, opposite). This would substantially cut the benefits of the EPA's proposed rule: trucks that do not deteriorate can cut particulate emissions by over 90 percent by 2030, but the reduction would only be 56 percent if trucks with sophisticated pollution-control technology deteriorate at twice historic rates.

Intrinsically Clean Vehicles

Alternative fuel engines and advanced technologies such as hybrids and fuel cells can provide greater air quality benefits than diesel because they are intrinsically cleaner. As the EPA struggles to ensure that new diesels stay clean over their million-mile lifetimes, alternatives offer a reliable option that the agency must encourage. Figure 13 demonstrates that intrinsically clean vehicles can help offset the impact of diesel deterioration on a national scale. These cleaner options also offer important reductions in heat-trapping emissions, which, although not regulated today, are a clear environmental priority.

Retrofit Requirements

As clean new vehicles move onto the road the air will gradually become cleaner, but cleaning up the fleet of conventional diesel trucks currently on the road can deliver large benefits in the short term. Because these older engines were built to less stringent standards, they are much dirtier than today's new models.

Opportunities to improve the environmental performance of a diesel truck occur every time it is brought in for a major engine overhaul. The engine can be

- rebuilt to a cleaner standard using modern equipment
- replaced with a newer engine (called *repowering*)
- retrofitted with cleanup technologies

Retrofits can offer large benefits at a modest cost. For example, particulate traps installed on an older engine can reduce particle emissions by over 90 percent at a cost of just a few thousand dollars (CARB 1999).[39] Substantial nitrogen oxide reductions may also be achievable through mandatory retrofits, repowers, or rebuilds.

The EPA currently requires that older transit buses to be retrofitted with particulate controls. Regulators in California recently passed a similar rule that

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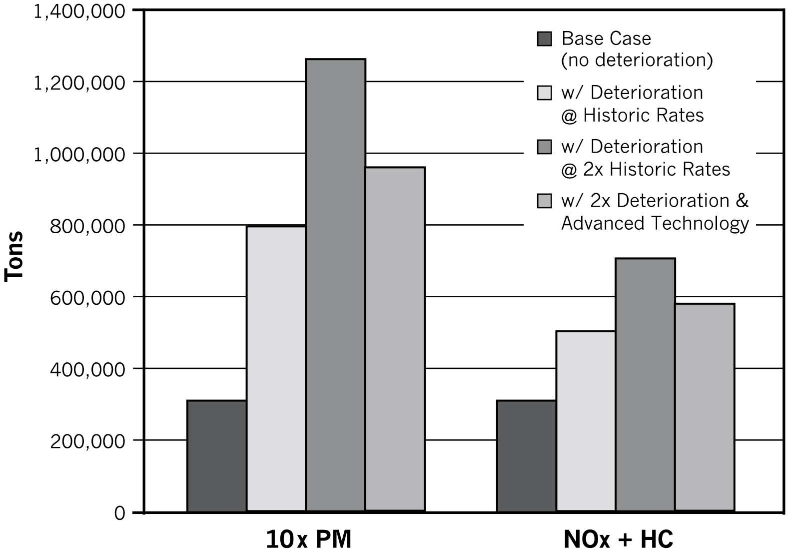
[39] If low-sulfur fuel is also required, drivers may pay a bit more over the vehicle's life for fuel.

Figure 13. Emissions from US Trucks in 2030 Under Various Scenarios of Deterioration



Notes:

1. UCS calculation based on national model for emission levels for engines meeting the EPA's proposed emission standards with and without deterioration.
2. "Historic" deterioration rates based on MY2004 values (EPA 1999a), measured in g/bhp-hr per 10,000 miles.
3. Advanced technology scenario assumes penetration of alternative fuel and advanced technology vehicles with no deterioration, as assumed in the "green truck" scenario (Table A-2).

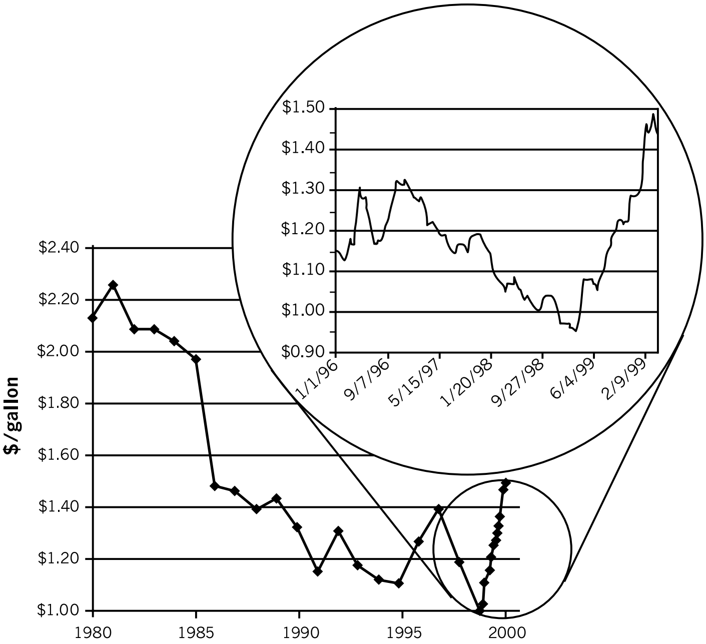
will require even larger reductions, building on recent advances in particulate cleanup technology. Ultimately, all older diesel vehicles should be cleaned up. If new pollution-control technology proves as cheap and effective as both industry and regulators suggest, regulations to require their use on all diesel trucks and buses nationwide will deliver large public health benefits in the near term.

Fuel Standards

To achieve the types of pollution reductions that are technically possible from future diesel engines, the fuel they burn will have to become much cleaner. In particular, data from testing advanced emission-control equipment demonstrates a direct relationship between the sulfur content of diesel fuel and the efficiency and durability of the pollution cleanup technology. Nitrogen oxide traps, the technology that may offer the greatest potential for large gains in control, appear the most sensitive to sulfur. Similarly, particulate traps work best when sulfur levels are low.

Reducing fuel sulfur levels is not free, but the cost increase projected by the EPA to meet their proposed 15 ppm cap is only pennies per gallon (EPA 2000), an amount that Figure 14 shows to be negligible compared with historic variations in the price of diesel fuel.

Figure 14.
Historic Fluctuations in the Price of Diesel Fuel Surpass Extra Cost for Low Sulfur Diesel



Source: EIA International Energy Annual; EIA Weekly Petroleum Status

Incentives

While tighter standards for engines and fuel will continue to form the backbone of diesel cleanup strategies, voluntary incentives can be a valuable supplement. California has had a statewide diesel cleanup program for several years that provides financial incentives to diesel operators who choose to clean up their engines. To qualify for funding, projects must deliver at least a 30 percent reduction in nitrogen oxide emissions, and particulate reductions are strongly encouraged (and may be required in the future). The incentives have resulted in a demand that far outstrips available funds, highlighting the program's success. Incentive programs being debated at the federal level would provide tax credits for buying heavy-duty vehicles that run on alternative fuels, as well as for buying the fuel.

Cleanup incentives are an attractive policy avenue, but they require funding (either from general budgets or from user fees, such as fees collected on trucks or fuels) and aggressive marketing by state and local agencies. Further, incentives must contain environmental guarantees to ensure that public funds are delivering progress on the key health threats posed by diesel, namely nitrogen oxides, particulates, and toxic emissions. New programs should also focus on fuel-economy gains or on technologies, such as hybrids or fuel cells, that can simultaneously deliver air quality progress *and* reductions in heat-trapping emissions. Finally, while incentives can offer valuable public gains, they can only augment, not replace, aggressive regulations that require diesel engine cleanup.

Green Fleets

Fleet vehicles offer an early market opportunity for alternative fuels and advanced technologies, helping prove these new options and building sales volumes to help lower costs. Because fleets commonly operate in cities, the extra measure of health protection these technologies can provide is particularly valuable. Regulations that require the use of cleaner technologies, incentive programs, collective bids, and voluntary commitments are just a few of the policy tools available to help make fleets greener.

Research and Development

Strong, publicly funded research and development (R&D) is the necessary foundation for environmental gains in the truck market. Such programs are currently under way at all levels of government across the country. In April 2000, the federal government launched the 21st Century Truck Initiative, aimed at developing smaller heavy trucks with triple the fuel economy of today's vehicles and long-haul trucks with double the fuel economy. Working with industry, this program can develop valuable technologies that will be vital to protecting our economy, air, and climate. To succeed, however, R&D programs must set strong environmental targets that ensure progress in reducing both heat-trapping emissions and air pollution. Furthermore, R&D by itself is not enough. Strong market policies, such as incentives and standards, are the best way to ensure that technologies developed in the lab make it onto the road.

CHAPTER 5

CONCLUSIONS

New technologies and fuels promise to substantially reduce the impact of America's trucks on public health and the environment. Improvements to conventional diesel technology are an absolute priority, but clean fuels and advanced technologies offer much-needed supplementary gains.

One of the greatest challenges to delivering on the air quality promise of new truck technology is ensuring that vehicles equipped with sophisticated exhaust controls stay clean over their million-mile lifetimes. Cleaner fuel with virtually zero sulfur will be essential, but regulators must also establish strong in-use monitoring to catch problems. Without such real-world checks, the benefits of cleanup technology could be lost to malfunctioning or deteriorating equipment. One of the most prudent strategies for ensuring trucks remain low polluters is to encourage intrinsically clean vehicles powered by alternative fuels or advanced technologies.

Cutting trucks' pollutant emissions is the immediate priority, but addressing the environmental impact of trucking also means reducing emissions of the heat-trapping gases that cause global warming. Greater fuel economy is the key in the short term. Strategies for improving the fuel economy of diesel trucks must be accelerated. The stretch target is to double the efficiency of today's biggest trucks. But with rising truck travel these improvements will not be enough to substantially reduce heat-trapping emissions below today's levels. In particular, the role of low-carbon, renewable fuels in heavy trucks needs further study.

Strong policies will be needed to put the truck and bus industry on a greener path. Coupled with conventional technology improvements, alternative fuels, and advanced technologies, a green truck strategy could deliver sizeable gains in 2030 when cleaner technologies permeate the truck population:

- Preventing emission of one-quarter of a million tons of toxic soot
- Keeping over 60 million cars-worth of smog-forming exhaust out of the air
- Doubling truck travel without increasing oil use
- Reducing global warming pollution by 26 percent

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Appendix

Case Study Results

Table A-1. Case Study Results: Transit Buses—Urban Bus

	MY ‘00			MY ‘07		
	NOx	NMHC	SMOG	NOx	NMHC	SMOG
DSL	22.09	0.51	22.60	1.04	0.13	1.17
CNG	11.42	2.03	13.45	0.72	0.21	0.93
HEV	15.46	0.51	15.97	0.81	0.13	0.94
FCV	0.00	0.00	0.00	0.00	0.00	0.00

	MY '00	MY '07	MY '00	MY '30
	PM	PM	CO_2-eq	CO_2-eq
DSL	0.443	0.056	3195	2458
CNG	0.066	0.009	3167	2289
HEV	0.124	0.027	2556	1966
FCV	0.000	0.000	1661	1278

DSL = Conventional diesel
CNG = Compressed natural gas
HEV = Hybrid electric vehicle (includes particulate trap)
FCV = Fuel cell vehicle

MY ’00 = Model year 2000
MY ’07 = Model year 2007
MY ’30 = Model year 2030

NOx = Nitrogen oxides
NMHC = Nonmethane hydrocarbons
PM = Particulate matter
CO_2-eq = Carbon dioxide-equivalent global warming emissions

Table A-2. Case Study Results: School Buses—Class 8a

	MY ‘00			MY ‘07		
	NOx	NMHC	SMOG	NOx	NMHC	SMOG
DSL	11.16	0.19	11.36	0.53	0.05	0.58
CNG	5.77	0.77	6.55	0.36	0.08	0.44
HEV	7.81	0.19	8.01	0.41	0.05	0.46
FCV	0.00	0.00	0.00	0.00	0.00	0.00

	MY '00	MY '07	MY '00	MY '30
	PM	PM	CO2-eq	CO2-eq
DSL	0.558	0.056	2708	2083
CNG	0.094	0.009	2717	1943
HEV	0.156	0.027	2166	1666
FCV	0.000	0.000	1408	1083

DSL = Conventional diesel
CNG = Compressed natural gas
HEV = Hybrid electric vehicle (includes particulate trap)
FCV = Fuel cell vehicle

MY ’00 = Model year 2000
MY ’07 = Model year 2007
MY ’30 = Model year 2030

NOx = Nitrogen oxides
NMHC = Nonmethane hydrocarbons
PM = Particulate matter
CO_2-eq = Carbon dioxide-equivalent global warming emissions

Table A-3. Case Study Results: Parcel Delivery Trucks—Class 3

	MY '00			MY '07		
	NOx	NMHC	SMOG	NOx	NMHC	SMOG
DSL	3.96	0.32	4.28	0.22	0.02	0.25
CNG	1.58	0.12	1.69	0.14	0.01	0.15
HEV	2.77	0.31	3.08	0.17	0.02	0.19
FCV	0.00	0.00	0.00	0.00	0.00	0.00

	MY '00	MY '07	MY '00	MY '30
	PM	PM	CO2-eq	CO2-eq
DSL	0.558	0.056	1083	846
CNG	0.094	0.009	1352	803
HEV	0.156	0.027	570	361
FCV	0.000	0.000	563	375

DSL = Conventional diesel
CNG = Compressed natural gas
HEV = Hybrid electric vehicle (includes particulate trap)
FCV = Fuel cell vehicle

MY '00 = Model year 2000
MY '07 = Model year 2007
MY '30 = Model year 2030

NOx = Nitrogen oxides
NMHC = Nonmethane hydrocarbons
PM = Particulate matter
CO_2-eq = Carbon dioxide-equivalent global warming emissions

Table A-4. Case Study Results: Long-Haul Tractor-Trailers—Class 8b

	MY '00			MY '07		
	NOx	NMHC	SMOG	NOx	NMHC	SMOG
DSL	11.03	0.55	11.58	0.53	0.03	0.56
CNG	7.12	1.16	8.28	0.33	0.07	0.39
HEV	7.72	0.49	8.21	0.41	0.03	0.44

	MY '00	MY '07	MY '00	MY '30
	PM	PM	CO2-eq	CO2-eq
DSL	0.558	0.056	1907	954
CNG	0.094	0.009		
HEV	0.156	0.027		

DSL = Conventional diesel
CNG = Compressed natural gas
HEV = Hybrid electric vehicle (includes particulate trap)
FCV = Fuel cell vehicle

MY '00 = Model year 2000
MY '07 = Model year 2007
MY '30 = Model year 2030

NOx = Nitrogen oxides
NMHC = Nonmethane hydrocarbons
PM = Particulate matter
CO_2-eq = Carbon dioxide-equivalent global warming emissions

National Modeling Inputs

Table A-5. National Modeling Inputs: Light Heavy-Duty Truck

(8500–19500 lb GVW, Class 2B–5)

	Base Diesel	Advanced Diesel	Alternate Fuel	Diesel Hybrid w/Trap	Fuel Cell
MPG (diesel-equiv.)					
2000	11.8	11.8	8.9	22.4	23.6
2005	12.4	12.4	9.3	23.5	24.7
2010	12.9	12.9	9.7	24.5	25.8
2015	13.5	13.5	11.4	25.6	26.9
2020	14.0	14.0	11.9	26.6	28.0
2025	14.6	14.6	12.4	31.0	31.7
2030	15.1	15.1	12.8	35.4	35.4
NOx (g/mi)					
2000	4.05	4.05	1.61	2.83	0.00
2004	2.63	2.63	1.61	2.01	0.00
2007	0.23	0.23	0.14	0.17	0.00
HC (g/mi)					
2000	0.36	0.36	0.13	0.36	0.00
2004	0.25	0.25	0.13	0.25	0.00
2007	0.02	0.02	0.01	0.02	0.00
PM (g/mi)					
2000	0.56	0.56	0.09	0.16	0.00
2004	0.56	0.56	0.09	0.16	0.00
2007	0.06	0.06	0.01	0.03	0.00
Market Share (VMT by Size Class)					
2005	0%	98%	1%	1%	0%
2010	0%	89%	5%	5%	1%
2015	0%	60%	10%	20%	10%
2020	0%	42%	15%	18%	25%
2025	0%	31%	15%	17%	38%
2030	0%	20%	15%	15%	50%

Table A-6. National Modeling Inputs: Medium Heavy-Duty Truck

(19500–33000 lb GVW, Class 6–7)

	Base Diesel	Advanced Diesel	Alternate Fuel	Diesel Hybrid w/Trap	Fuel Cell
MPG (diesel-equiv.)					
2000	7.9	7.9	5.9	11.9	15.8
2005	8.0	8.0	6.0	12.0	16.0
2010	8.1	8.1	6.1	12.2	16.2
2015	8.2	8.2	7.0	16.4	16.4
2020	8.3	8.3	7.1	16.6	16.6
2025	8.4	8.4	7.1	16.8	16.8
2030	8.5	8.5	7.2	17.0	17.0
NOx (g/mi)					
2000	8.39	8.39	5.72	5.87	0.00
2004	4.81	4.81	3.09	3.68	0.00
2007	0.41	0.41	0.27	0.32	0.00
HC (g/mi)					
2000	0.79	0.79	1.55	0.79	0.00
2004	0.45	0.45	1.07	0.45	0.00
2007	0.05	0.05	0.11	0.05	0.00
PM (g/mi)					
2000	0.56	0.56	0.09	0.16	0.00
2004	0.56	0.56	0.09	0.16	0.00
2007	0.06	0.06	0.01	0.03	0.00
Market Share (VMT by Size Class)					
2005	0%	99%	1%	0%	0%
2010	0%	89%	10%	1%	0%
2015	0%	74%	15%	10%	1%
2020	0%	50%	20%	25%	5%
2025	0%	38%	20%	30%	13%
2030	0%	25%	20%	35%	20%

Table A-7. National Modeling Inputs: Heavy Heavy-Duty Truck

(>33000 lb GVW, Class 8)

	Base Diesel	Advanced Diesel	Alternate Fuel	Diesel Hybrid w/Trap	Fuel Cell
MPG (diesel-equiv.)					
2000	6.7	6.7	5.0	10.1	10.1
2005	6.8	6.8	5.1	10.2	10.5
2010	7.2	8.2	5.4	10.8	11.1
2015	7.4	9.6	6.3	11.2	11.7
2020	7.9	10.9	6.7	11.9	12.2
2025	8.2	12.1	7.0	12.4	12.8
2030	8.6	13.4	7.3	12.8	13.4
NOx (g/mi)					
2000	11.92	11.92	7.69	8.34	0.00
2004	6.87	6.87	4.25	5.21	0.00
2007	0.55	0.55	0.34	0.42	0.00
HC (g/mi)					
2000	0.98	0.98	2.92	0.98	0.00
2004	0.73	0.73	2.04	0.73	0.00
2007	0.06	0.06	0.16	0.06	0.00
PM (g/mi)					
2000	0.56	0.56	0.09	0.16	0.00
2004	0.56	0.56	0.09	0.16	0.00
2007	0.06	0.06	0.01	0.03	0.00
Market Share (VMT by Size Class)					
2005	0%	99%	1%	0%	0%
2010	0%	94%	5%	1%	0%
2015	0%	86%	10%	3%	1%
2020	0%	81%	10%	5%	4%
2025	0%	81%	8%	5%	7%
2030	0%	80%	5%	5%	10%

Table A-8. National Modeling Inputs: Urban Bus

	Base Diesel	Advanced Diesel	Alternate Fuel	Diesel Hybrid w/Trap	Fuel Cell
MPG (diesel-equiv.)					
2000	4.0	4.0	3.4	5.0	8.0
2005	4.2	4.2	3.6	5.3	8.4
2010	4.4	4.4	3.7	5.5	8.8
2015	4.6	4.6	3.9	5.8	9.2
2020	4.8	4.8	4.1	6.0	9.6
2025	5.0	5.0	4.3	6.3	10.0
2030	5.2	5.2	4.4	6.5	10.4
NOx (g/mi)					
2000	18.25	18.25	9.44	12.78	0.00
2004	10.34	10.34	7.10	8.05	0.00
2007	0.86	0.86	0.59	0.67	0.00
HC (g/mi)					
2000	0.37	0.37	1.49	0.37	0.00
2004	0.37	0.37	1.33	0.37	0.00
2007	0.09	0.09	0.33	0.09	0.00
PM (g/mi)					
2000	0.44	0.44	0.07	0.12	0.00
2004	0.44	0.44	0.07	0.12	0.00
2007	0.06	0.06	0.01	0.03	0.00
Market Share (VMT by Size Class)					
2005	0%	48%	42%	0%	10%
2010	0%	25%	50%	0%	25%
2015	0%	0%	50%	0%	50%
2020	0%	0%	25%	0%	75%
2025	0%	0%	13%	0%	88%
2030	0%	0%	0%	0%	100%

Table A-9. National Modeling Results: Fuel Use (bil gallons)

	Base Case	Green Case	*Green vs. Base Savings*
Light	6.00	4.44	*26%*
Medium	9.33	7.75	*17%*
Heavy	37.00	26.70	*28%*
Urban Bus	1.19	0.76	*36%*
Total	53.67	39.79	*26%*

Table A-10. National Modeling Results: Oil Use (bil gallons)

	Base Case	Green Case	*Green vs. Base Savings*
Light	6.00	2.45	*59%*
Medium	9.33	5.06	*46%*
Heavy	37.15	22.13	*40%*
Urban Bus	1.19	0.01	*99%*
Total	53.67	29.64	*45%*

Table A-11. National Modeling Results: Global Warming Gases (MMTCeq)

	Base Case	Green Case	*Green vs. Base Savings*
Light	20.92	14.85	*29%*
Medium	32.52	25.50	*22%*
Heavy	128.97	90.96	*29%*
Urban Bus	4.14	2.51	*39%*
Total	187.05	138.70	*26%*

Table A-12. National Modeling Results: Particulates (tons)

	Base Case	Green Case	*Green vs. Base Savings*
Light	53,591	2,748	*95%*
Medium	48,194	3,206	*93%*
Heavy	187,229	17,445	*91%*
Urban Bus	2,845	23	*99%*
Total	291,859	23,423	*92%*

Table A-13. National Modeling Results: Nitrogen Oxides (tons)

	Base Case	Green Case	*Green vs. Base Savings*
Light	251,090	14,351	*94%*
Medium	412,879	31,937	*92%*
Heavy	2,139,356	189,247	*91%*
Urban Bus	66,481	1,124	*98%*
Total	2,869,806	236,658	*92%*

Table A-14. National Modeling Results: Hydrocarbons (tons)

	Base Case	Green Case	*Green vs. Base Savings*
Light	21,622	1,584	*93%*
Medium	34,908	5,016	*86%*
Heavy	186,950	23,317	*88%*
Urban Bus	2,404	444	*82%*
Total	245,883	30,361	*88%*

Table A-15. National Modeling Results: HC + NOx (tons)

	Base Case	Green Case	*Green vs. Base Savings*
Light	272,712	15,935	*94%*
Medium	447,787	36,953	*92%*
Heavy	2,326,306	212,564	*91%*
Urban Bus	68,884	1,568	*98%*
Total	3,115,689	267,019	*91%*

Table A-16. National Modeling Results: Deterioration Analysis of EPA Rule

	Particles (tons)	HC+NOx (tons)	NOx (tons)	HC (tons)
EPA Rule with no deterioration	31,805	310,530	280,606	29,925
savings vs. base case	*89%*	*90%*	*90%*	*88%*
EPA Rule with deterioration	79,573	513,513	430,473	83,040
savings vs. base case	*73%*	*84%*	*85%*	*66%*
EPA Rule with deterioration and green technology	60,072	427,614	356,232	71,381
savings vs. base case	*79%*	*86%*	*88%*	*71%*

Table A-17. National Modeling Results: Comparison with EPA Estimates

	Fuel Use (bil gallons)	PM (tons)	HC+NOx (tons)	NOx (tons)	HC (tons)
EPA Base	51.89	106,000	3,292,000	3,000,000	292,000
EPA:UCS	**0.97**	**0.36**	**1.06**	**1.05**	**1.19**
EPA Base	51.89	8,000	344,000	313,000	31,000
EPA:UCS	**0.97**	**0.25**	**1.11**	**1.12**	**1.04**