# CLEANING UP TODAY'S DIRTY DIESELS

## Retrofitting and Replacing Heavy-Duty Vehicles in the Coming Decade


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# Why Retrofit And Replacement Programs Make Sense Now

To reduce harmful diesel emissions today—not in twenty years when the benefits of new engine standards are fully realized—existing diesel engines need to be cleaned up. NRDC believes that the most effective retrofit and replacement programs will (1) concentrate on urban vehicles because people living in dense city centers are exposed to more pollution from urban vehicles than from long-haul trucks operating outside city centers, and (2) maximize benefits and minimize costs by retrofitting older, dirtier vehicles before newer, relatively cleaner vehicles.

## Public health threats from dirty, diesel engines should be addressed today.

The significant health benefits of stringent upcoming diesel fuel and emissions standards in the United States and Europe may not be realized soon, because today's dirty diesel engines could last for two more decades.[1,2] Diesel buses and trucks operating today emit large amounts of particulate matter (PM) that trigger an array of cardiopulmonary health impacts; nitrogen oxides ($NO_x$) that contribute to ground-level ozone (smog), acid rain, and other environmental impacts; and dozens of toxic air pollutants that have been linked to cancer and other serious health impacts.

At the heart of NRDC's diesel emissions concerns is particulate matter. According to the World Health Organization, particulate emissions contribute to roughly 800,000 premature deaths worldwide each year.[3] And dozens of health studies link particulate emissions to other serious health effects such as increased asthma attacks and other lung diseases, heart disease, and cancers. In fact, emissions from diesel engines have been linked with more than 125,000 cancers annually in the United States alone.[4]

In urban areas, diesel vehicles disproportionately contribute to the overall inventory of particulate emissions. In New York City, more than half of all street-level particulate emissions come from a relatively small number of diesel vehicles.[5] In Mexico City, roughly half of all fine particulate matter ($PM_{2.5}$) comes from diesel vehicles.[6] To address the serious health threats from urban particulate emissions, the millions of diesel trucks, buses, and other engines should be cleaned up now.

## Retrofit and replacement programs are also cost-effective ways to meet Clean Air Act requirements in the United States.

Since the first Clean Air Act was passed by the U.S. Congress 35 years ago, policymakers have picked most of the "low-hanging fruit" (lower cost options of air pollution control) to meet their pollution-cutting requirements and keep transportation projects moving forward. Unfortunately, this leaves fewer cost-effective options available to state transportation officials and metropolitan planning organizations (MPOs) still challenged to meet the U.S. Environmental Protection Agency's (EPA) upcoming health-based ambient air quality standards for ground-level ozone and particulate matter under Clean Air Act Amendments.

However, retiring the oldest, dirtiest buses and trucks in a fleet and retrofitting the remaining vehicles can be an extremely cost-effective way to reduce emissions and to help states meet the requirements of the Clean Air Act. Later in this paper, NRDC outlines the cost-effectiveness of various retrofit and replacement options. These options compare favorably with many other transportation control measures used around the country.[7] Moreover, this near-term approach complements the long-term implementation of the EPA's highway diesel and nonroad diesel rules over the next decade.

# HOW TO STRUCTURE A DIESEL RETROFIT PROGRAM

Whether in the United States or abroad, retrofit programs to reduce emissions from diesel engines in the short-term should be carefully designed to address the particular pollution problem caused by the targeted vehicles and/or fleets.

In most cases, diesel retrofit programs should focus on PM emissions because of their serious health effects and because PM retrofit technology is more mature than $NO_x$ retrofit technology. Where resources are limited, it will usually make sense to focus PM reduction programs in urban areas where people's exposure to the health threat is highest. However, the absence of any identifiable threshold for PM exposure suggests that a national approach to PM reduction may be wise where resources permit. To the extent that $NO_x$ controls are considered, it is more practical to focus reductions in areas with high ground-level ozone or dense urban areas with heavy traffic where NOx levels can pose a serious health threat.

### Step 1: Pick the right fleets and vehicles.

Given the fierce competition for scarce government resources, vehicles and fleets must be prioritized for clean up, as it is unlikely that sufficient funds will be available to address all vehicles. Cost effectiveness of existing retrofit programs varies widely due to the wide variety of vehicles, fleet sectors, strategies, and technologies available. Factors such as the number of miles driven, availability and cost of fuels and controls, and the age of the replaced or retrofitted bus, truck, or equipment can affect costs considerably. The following characteristics should be identified and analyzed in order to determine which vehicles or fleets are most suitable for a retrofit program:

- engine year and type (mechanical or electronic)
- horsepower rating
- exhaust system type (single/dual)
- application or duty cycle
- (urban stop-and-go traffic, hauling, short- or long-distance driving)
- annual and lifetime mileage
- operating characteristics (temperature ranges, fuel
- used, etc.)
- location of operations (residential vs. industrial; urban vs. rural)
- emissions certification levels
- relevant maintenance histories of the vehicles in the targeted fleets

### Step 2: Pick the strategies most appropriate for the selected fleets and vehicles.

To maximize cost-effectiveness, it is critical to apply the appropriate strategy and/or technology. The following list highlights various diesel cleanup options:

#### *Replacement*

The oldest, most polluting vehicles should be retired first. Because two-stroke engines with no electronic controls are typically incompatible with most retrofits or repowers, these engines should be retired and replaced first. Further, because vehicles generally pollute more as they age, once all of the two-stroke engines have been retired, the oldest four-stroke engines should be replaced first. In general, 1980s and older vehicles fall into this category.

Old buses or trucks should be replaced with the cleanest available vehicles, based on engine certification standards for the new equipment, and matched to the sulfur level of the available diesel fuel. Where alternative fuel infrastructure exists or is feasible, it should be considered also. In addition to reducing both PM and NOx, it is worth noting that modern engines with electronic fuel controls will be more fuel-efficient than the older, dirtier engines that they are replacing.

#### *Retrofit*

Beginning around 1987, most engines have at least some electronic controls and have numerous retrofit options. Table 1 lists the various commercial control devices, pollutant reductions, fuel economy penalties, and costs. Explanations of these control devices follow.

**Active or passive diesel particulate filters (DPFs).8** Most engines built in 1994 or later, with electronic controls and moderate PM emissions, can be equipped with diesel particulate filters (DPFs), which can reduce PM by 85 percent or more. One company has coupled a DPF with a lean $NO_x$ catalyst, reducing NOx by roughly 25 percent in addition to substantial PM reductions. These technologies require ultra-low sulfur diesel fuel (15 ppm) and in some cases require high operating temperatures (above 250˚ Celsius more than half of the time). More than 150,000 heavy-duty vehicles around the world have been equipped with DPFs.

**Flow-through filters (FTFs).** FTFs can reduce PM by at least 50 percent on certain highway diesel engines with moderate PM emissions. These controls work best on engines built after 1990 with electronic controls and engine out emissions no higher than 0.2 gram per brake horsepower-hour (g/bhp-hr). FTFs also operate at sulfur levels of 500 ppm. They have only recently come into commercial use, and only one FTF has been verified by CARB to date.

**Table 1**
**Pollutants Reduced by Various Retrofit Technologies**

| Technologies | NOx | PM | CO | ROG | Fuel Sulfur Tolerance | Fuel Penalty | Cost |
|---|---|---|---|---|---|---|---|
| Active Diesel Particulate Filter (DPF) & Lean $NO_x$ Catalyst (LNC)[a] | 25-30% | 90% | 60-80% | 40-60% | Up to 15 ppm | 3 to 7% | ~$18,000 |
| Passive Diesel Particulate Filter (DPF) | -[b] | 90% | 60-90+% | 60-90+% | Up to 15 ppm | 2 - 4% | $5,000 - $8,000 |
| Flow Through Filter (FTF)[c] | - | 50% | 40-90% | 40-90% | Up to 500 ppm | 10% | $3,500 - $5,500 |
| Diesel Oxidation Catalyst (DOC) | - | 20-50%[d] | 40-90% | 40-90% | Up to 500 ppm | 0 - 2% | $1,000 - $3,000 |
| Exhaust Gas Recirculation (EGR)[e] | 40-50% | N/A | N/A | N/A | Up to 500 ppm | 0 - 5% | $13,000 - $17,000 |
| Lean $NO_x$ Catalyst[f] | 10–20% | N/A | N/A | N/A | Up to 250 ppm | 4 - 7% | $6,500 - $10,000 |

Notes: Some of these controls require ultra-low sulfur diesel, which costs approximately 5 to 10 cents more per gallon than regular on-road grade diesel in the U.S., depending on location. We do not have sufficient information to estimate the incremental costs of ultra-low sulfur diesel fuel in other countries. Some controls also require temperature and backpressure monitors, which cost roughly $1,000. Installation not included.

a Pollutant reductions as reported by CLEAIRE, currently the only manufacturer that has verified this type of retrofit technology.

b Verified DPFs are prone to producing more nitrogen dioxide (NO2), as its creation is required for proper regeneration of the system.

c FTF cost estimates are tentative, as this control is relatively new.

d Fuel sulfur above 500 ppm can increase PM emissions.

e EGR increases PM emissions slightly, and therefore should not be used without a PM control.

f LNCs are not yet commercially available alone; though they are available as a package with a DPF or DOC.

Sources: EPA Technical Summary of Potential Capabilities of Currently Available Retrofit Technologies, www.epa.gov/otaq/retrofit/retropotentialtech.htm; Personal communication, meeting with Cleaire, Feb. 10 2003, 14775 Wicks Blvd., San Leandro, CA; Personal communication, Daniel Serrano, Clean Air Systems, dserrano@cleanairsys.com, October 16, 2003; CARB, Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Airborne Toxic Control Measure for in-use Diesel Fuel Transport Refrigeration Units (TRU) and TRU Generator Sets, and Facilities where TRUs Operate, Oct. 28, 2003; Memo from Dale McKinnon," Manufacturers of Emission Controls Association, December 5, 2000; CARB, Diesel Risk Reduction Plan, October 2000; MECA, Retrofitting Emission Controls on Diesel-Powered Vehicles, March 2002; "Diesel Pollution Control Options Used at New York City Transit: Lessons for Asia," presented by Dana Lowell, MTA New York City Transit at the Better Air Quality for Asia Conference, December 2003; Personal communication, Rob Ferguson, Fleetguard Emission Solutions, 812-377-0140, November 4, 2004.

**Diesel oxidation catalysts (DOCs).** Most vehicles, no matter how old, can be outfitted with a DOC, which can reduce PM by 20 to 50 percent. Higher efficiency DOCs that reduce PM by more than 30 percent cost more because they use more expensive proprietary precious metal catalysts. These controls can tolerate sulfur levels up to 500 parts per million (ppm), so do not require ultra-low sulfur diesel fuel. More than 1.5 million DOCs have been installed on trucks, buses, and other heavy diesel engines since the mid-1990s.

**NOx reduction strategies.** Most advanced $NO_x$ reduction strategies are still in a research and development phase. Exhaust gas recirculation (EGR) can reduce $NO_x$ by as much as 40 percent, but retrofits with this technology have proven to be difficult on many vehicles as they can raise PM emissions and interfere with other exhaust controls. Selective catalytic reduction (SCR), which can achieve up to 90 percent $NO_x$ reductions, is still under development and demonstration and is quite expensive. Most significantly, SCR requires the use of urea or another reductant, which means that users of SCR must install or have access to area supplies and infrastructure. Lean $NO_x$ catalysts are commercially available as retrofits, but are also expensive and yield relatively low $NO_x$ reductions of roughly 20 percent.

#### *Repower*

In some cases, the useful life of the vehicle or equipment exceeds the useful life of the engine, and it makes sense to repower an existing vehicle or equipment with a newer engine. While not actually a retrofit situation, repowers are worth noting because they are commonly used by fleets—especially in the nonroad diesel sector (e.g., construction, agricultural or industrial uses). Very expensive, specialized equipment or vehicles are good candidates for repowers. However, it is extremely difficult and expensive to repower a mechanically controlled vehicle with a modern (electronically controlled) engine. Engine costs can be as low as $25,000 or less, but installation cost can be double that or higher. While repowers have been and will be used by many fleets, NRDC has not found that they are generally cost-effective, compared with retirements, replacements, and retrofits.

#### *Other Strategies*

Other diesel cleanup strategies, such as cleaner fuels, idling reductions, and improved maintenance may also be viable and/or cost-effective diesel clean up strategies. Cleaner fuels including alternative fuels such as natural gas, synthetic diesels like biodiesel and altered diesels such as diesel-water emulsions were not analyzed here because regional availability, fueling infrastructure, and cost vary widely. However, it should be noted that reducing sulfur levels in diesel fuel is an appropriate strategy everywhere, as it reduces sulfate PM and $SO_x$ emissions from all existing diesel vehicles, whether they are retrofit or not. Likewise, improving maintenance practices makes sense everywhere. Not only is an effective program required to ensure the effectiveness and durability of any retrofit strategy, but proper maintenance typically improves fuel economy and overall engine performance.

Idling reductions can and should be implemented wherever possible to reduce pollution and conserve fuel. However, real reductions of truck and bus idling are contingent on enforcement programs and, therefore, beyond the scope of this paper.

### Step 3: Evaluate the retrofit program options against a set of criteria.

Based on NRDC's review of retrofit programs in the United States, Mexico, and elsewhere, we believe that the following criteria are critical to a successful retrofit program:

### ✓ *Significant public health benefits*

Retrofitting the fleets that are the largest contributors to local pollution and/or health effects is critical. In some cases, it may make sense to prioritize pollution exposures to sensitive populations, such as children or the elderly. For example, retrofitting school or transit buses that emit PM directly at the breathing level in heavily-populated urban cores will yield larger health benefits than retrofitting long-haul trucks that emit high NOx levels at highway speeds farther away from populated urban centers. Likewise, exposing children or the elderly to diesel pollution will yield more health impacts than exposures to the general population, due to their greater sensitivity to pollution impacts.

### ✓ *Centralized fueling*

Centralized fueling ensures that the sulfur level of the diesel fuel is matched to the requirements of the retrofit technology. It also minimizes the risk of fuel adulteration, in areas where this is a problem. Given the sulfur sensitivity of most advanced emission control technologies, centralized fueling is a must-have in areas that do not mandate ultra-low sulfur diesel fuel for all fuel providers. Likewise, centralized fueling is necessary for any alternative fuel programs.

### ✓ *Sophisticated maintenance practices*

Most retrofit technologies require some maintenance to maximize and maintain benefits. In addition, modern diesel engines with electronic injection, turbocharging, and other complex components require more maintenance than older, dirtier diesels. Fleets with little or no culture of timely maintenance are unlikely to be able to properly service the needs of new engines or retrofit technologies, especially because retrofitted vehicles would not emit visible smoke like their predecessors, yielding no obvious "smoke signal" to mechanics.

### ✓ *Government funding, contracting, or licensing*

Fleets that use taxpayer funds or operate on government contracts or licenses should have a responsibility to provide their public service in the cleanest manner possible. Requiring cleaner fuels or retrofits as a precondition to public contracting creates a market for retrofits, and extends the reach of the retrofits deeper into the private sector.[9]

### ✓ *Highly visible fleets*

Focusing on highly visible fleets will generate and maintain public and political support for cleaner fuels and vehicles. Developing this support is critical in situations where the program has to compete for scarce public funds.

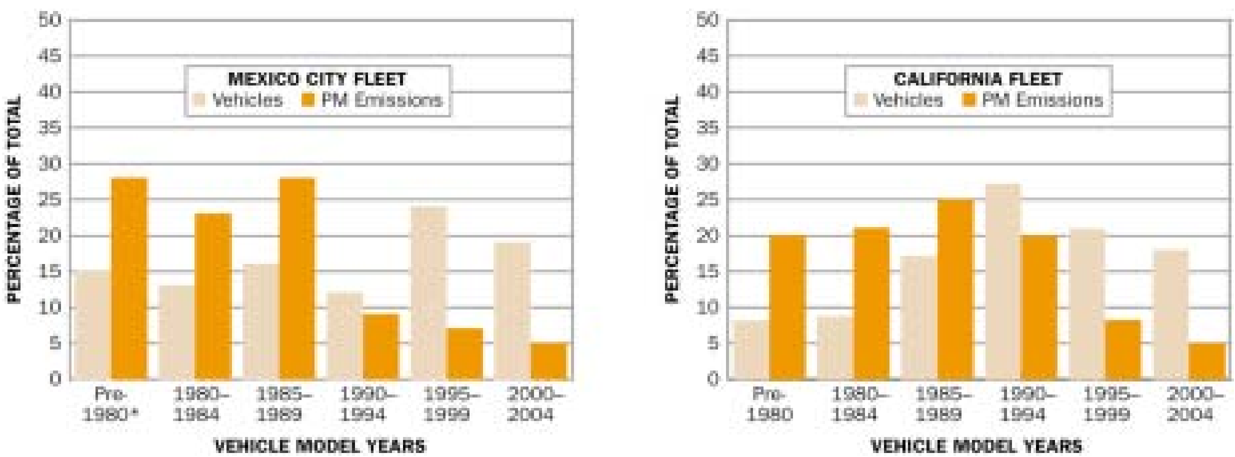
Whether in New York City, Mexico City, or elsewhere, buses are excellent initial targets for local retrofit and/or retirement programs because they typically emit higher levels of particulate matter and nitrogen oxides.[10] As discussed earlier, more than half of the PM measured in midtown Manhattan come from a relatively small number of diesel buses; in Mexico City autobuses contribute 15 percent to the region's fine particulate matter and heavy-duty buses contribute 31 and 11 percent of the region's fine particulate matter and nitrogen oxides, respectively.[11]

Moreover, buses are typically housed at central fueling and maintenance depots, financed with government funds, are highly visible, and often are at the center of political debates about transportation and/or transit issues (see criteria discussion in Step 3). Other successful retrofit and retirement programs targeted urban delivery trucks and construction, agricultural, airport, and seaport equipment.

### Step 4: Select the options that maximize health benefits and minimize costs.

NRDC compared truck and bus fleets in Mexico City and California to evaluate the relative cost-effectiveness of the various diesel clean-up strategies. These fleets were selected as representatives of newer and older fleets and also because information was readily available on the number of vehicles, their ages, and associated emission factors. The age of the vehicles and respective contributions to PM pollutions are shown in Figure 1. The age distributions of the fleets indicate an important trend: Regardless of a fleet's age variations, the oldest portion of the fleet is responsible for the majority of PM pollution—thereby making pre-1990 vehicles the ideal starting point for fleet cleanup.

**FIGURE 1**
**Vehicle Ages and Relative Contributions to PM Pollution of Heavy-duty Vehicles, Mexico City and California**




Note: Vehicle model years were converted from 2000 and 2002 data to vehicle age in years and then adjusted back to model years starting with 2004 as the first age group.

Source: Pam Burmich, CARB, faxed information based on EMFAC 2001, May 22, 2002; Inventario de Emisiones a la Atmosfera, Zona Metropolitana del Valle de Mexico, 2000 Secretaria del Medio Ambiente, Pages 119, 120, 123, A-102, http://www.sma.df.gob.mx/bibliov/modules.php?name=News&file=article&sid=204.

For four cleanup strategies (DOCs, FTFs, DPFs, and fleet modernization), we also compared the costs per pound of PM reduced to the total tons of PM reduced to help policymakers determine the most cost-effective approach for various engine ages in a fleet.[12] Figures 2 through 5 show the costs and amounts of particulate matter reduced by employing the four cleanup strategies over the various age groups of buses and trucks in Mexico City and California. Besides giving specific insight into the cost-effectiveness of each strategy in Mexico City and California, these figures provide general, illustrative guidance on the most appropriate clean up strategies for each vehicle age group in other settings also. In each case, the control with the lowest cost and the highest PM reductions will be the optimal choice.

**FIGURE 3***
**Cost and PM Reductions for Various Control Strategies Applied to 25,200 Mexico City Buses**

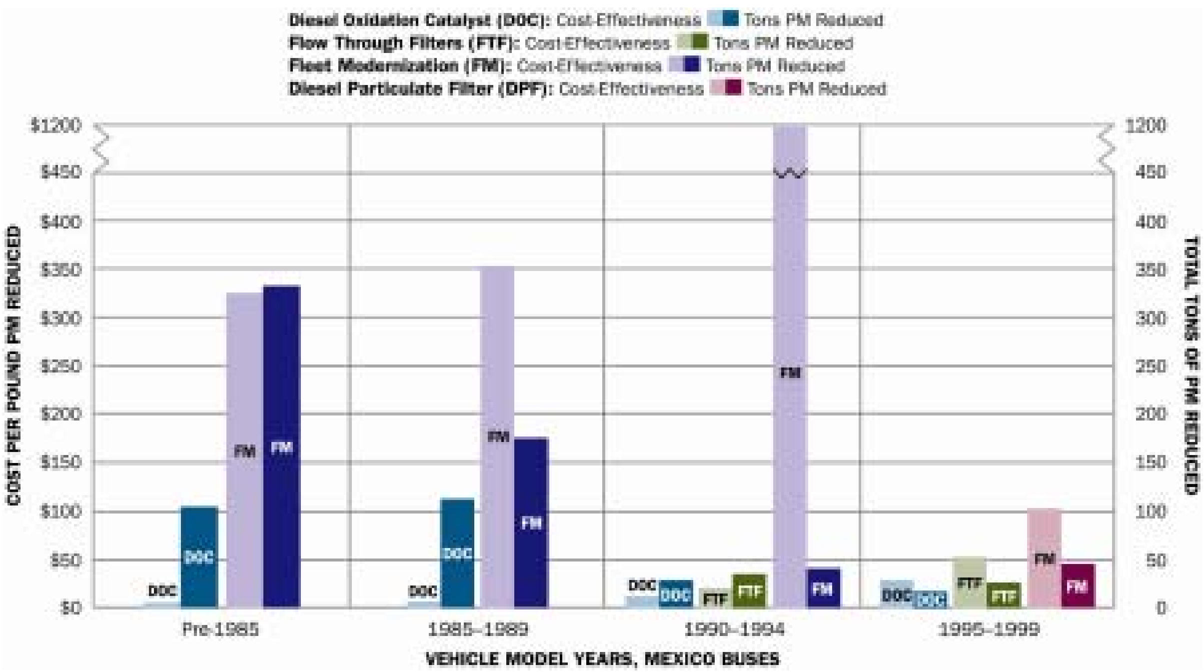
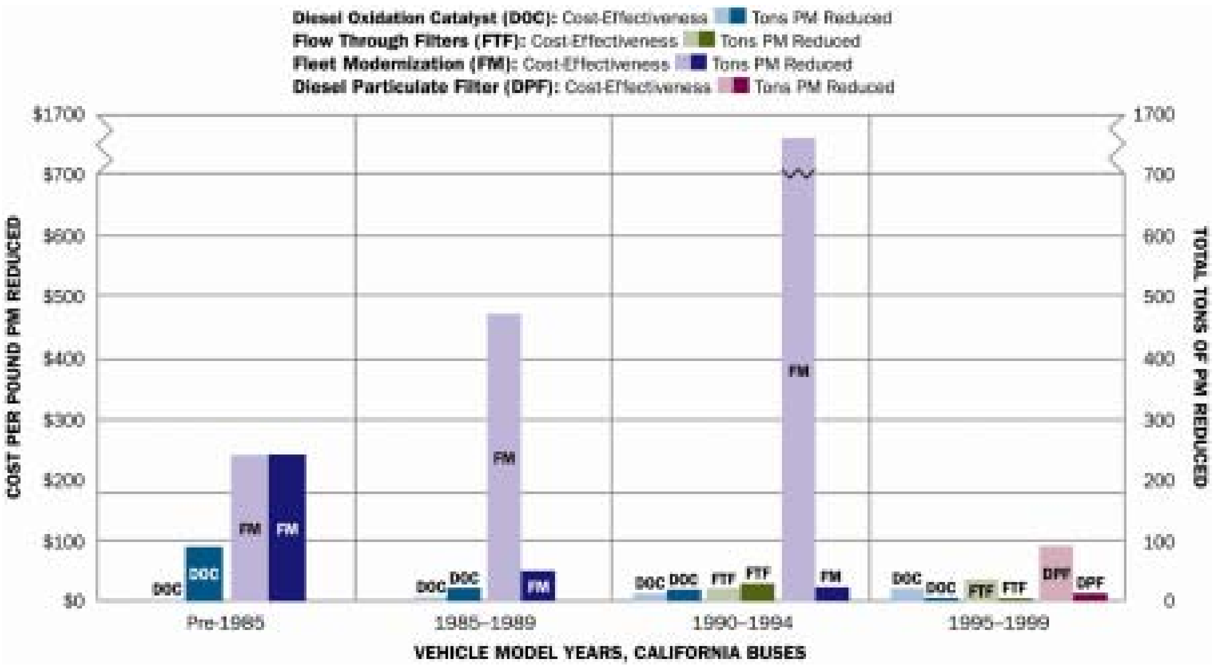


**FIGURE 5***
**Cost and PM Reductions for Various Control Strategies Applied to 9,800 California Buses**




*Notes for Figures 2-5:

General Assumptions of costs, PM reduction efficiency and applicability of control strategies were as follows:

DOC: 30% PM reduction, $2,000 for trucks; $1,500 for buses, can be applied to any all vehicle age groups;

FTF: 50% PM reduction, $5,000 for trucks; $4,500 for buses, can only be applied to 1990-1994 and 1995-1999 vehicle age groups;

DPF: 90% PM reduction, $6,500 for trucks; $6,000 for buses; can only be applied to 1995-1999 vehicle age group; and

Fleet Modernization: $40,000 for a new MY 1995 or newer trucks – associated emission factor of 0.3 g/mile was used; $300,000 for a new bus – associated emission factor is also 0.3 g/mile; only applies to pre-1985, 1985-1989 and 1990-1994 vehicle age groups.

Additional Assumptions:

Cost of controls are assumed to be $500 cheaper for buses than the same controls for trucks, due to smaller HP of engines.

Project life assumed to be 10 years for trucks and 14 years for buses.

The incremental cost of ULSD is based on [fuel cost per gallon] x [annual mileage/4 mpg] at $0.10/gallon

Average annual mileage was take from P. Burmich/CARB and Mexico City Inventory sources

Cost-effectiveness calculations were based on Carl Moyer guidelines

Mexico City Fleets: Emission factors were adjusted based on the Sierra Research report translation of Mexico to U.S. model years for heavy-duty vehicles and emission factors from Carl Moyer Guidelines

Sources for Figures 2-5:

Sierra Research, Critical Review of "Safety Oversight for Mexico-Domiciled Commercial Motor Carriers, Final Programmatic Environmental Assessment," Prepared by John A Volpe Transportation Systems Center, January 2002, Report No. SR02-04-01, April 16, 2002, Table 2, page 17; CARB, The Carl Moyer Memorial Air Quality Standards Attainment Program Guidelines, Approved Revision 2003, September 30, 2003; Pam Burmich, CARB, faxed information based on EMFAC 2001, May 22, 2002; 2002; Inventario de Emisiones a la Atmosfera, Zona Metropolitana del Valle de Mexico, 2000; Secretaria del Medio Ambiente, Pages 119, 120, 123, A-102

http://www.sma.df.gob.mx/bibliov/modules.php?name=News&file=article&sid=204

In short, we found that cost-effectiveness will be optimized as follows:

- For pre-1990s vehicles in all of the fleets, DOCs are the most cost-effective control strategy, but fleet modernization yields substantially higher PM reductions.
- For engines built between 1990 and 1994, FTFs yield higher PM reductions but are slightly more costly than DOCs.
- For post-1994 engines, DPFs yield at least twice the PM reductions as DOCs or FTFs and therefore are our preferred retrofit choice for this age group even though they are only half as cost-effective as the DOCs or FTFs.
- Retrofitting pre-1990 vehicles yields the largest PM reductions at the lowest cost.
- Our analysis demonstrates that there is no "one-size-fits-all" approach to retrofitting and replacing an existing diesel fleet. Rather, cost-effectiveness will be maximized by using different strategies to reduce emissions from different vehicles, based on the age of the vehicle or engine.

# CONCLUSION

NRDC urges policymakers to develop programs today that reduce emissions from existing heavy-duty fleets of diesel buses and trucks. Policymakers should not rely solely on new engine standards to cleanup pollution caused by diesel engines. It could take 25 to 30 years to fully retire existing dirty diesel engines; meanwhile, the harmful pollution emitted by these engines continues to pose health threats to people and the environment. By actively pursuing the retrofitting or replacing of older, dirtier engines now, policymakers can accelerate our goal to achieve clean air in the next decade. This paper provides compelling reasons to institute retrofit and replacement programs and policies today and provides a roadmap to get started.

Based upon NRDC's review of retrofit and replacement programs in the United States and around the world, we believe that the most effective retrofit and replacement programs will (1) concentrate on urban vehicles because people living in dense city centers are exposed to more pollution from urban vehicles than from long-haul trucks operating outside city centers, and (2) maximize benefits and minimize costs by retrofitting older, dirtier vehicles before newer, relatively cleaner vehicles.  Moreover, we have estimated the relative cost-effectiveness of retrofit and replacement strategies for Mexico City and California.  Based on these estimates, we conclude that optimal retrofit and replacement programs for these fleets will be designed to take advantage of the full range of retrofit and replacement options, as follows:

For pre-1990s vehicles in all of the fleets, DOCs are the most cost-effective control strategy, but fleet modernization yields substantially higher PM reductions.

For engines built between 1990 and 1994, FTFs yield higher PM reductions but are slightly more costly than DOCs.

For post-1994 engines, DPFs yield at least twice the PM reductions as DOCs or FTFs and therefore are our preferred retrofit choice for this age group even though they are only half as cost-effective as the DOCs or FTFs.

Retrofitting pre-1990 vehicles yields the largest PM reductions at the lowest cost.

The trends outlined above were consistent among the older Mexico City truck and bus fleets and the newer California truck and bus fleets. We consider them illustrative of the trends that would be found in any truck or bus fleet evaluation.

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# ENDNOTES

[1] 66 Federal Register 5001 et seq. (January 18, 2001) (the "Highway Diesel Rule;" and 69 Federal Register 38957 et seq. (June 29, 2004) (the "Nonroad Diesel Rule").

[2] http://www.dieselnet.com/standards.html#eu.

[3] Cohen, A, et al, "Mortality Impacts of Particulate Air Pollution in the Urban Environment," World Health Organization, Geneva, 2003.

[4] State and Territorial Air Pollution Program Administrators (STAPPA) and the Association of Local Air Pollution Control Officials (ALAPCO), Cancer Risk from Diesel Particulate: National and Metropolitan Area Estimates for the United States, March 15, 2000.

[5] New York State Department of Environmental Conservation, NY State Implementation Plan for Inhalable Particulate (PM10), September 1995, p11.

[6] Victor Hugo Paramo Figueroa, Mexico City Emissions Inventory, PowerPoint presentation from at the Mexico Air Pollution Workshop, April 2004.

[7] http://www.dieselforum.org/retrofit/why_bene.html, citing data collected by government agencies overseeing specific diesel retrofit projects; Median cost-effectiveness estimate from the Transportation Research Board's (TRB) 2002 study *The Congestion Mitigation and Air Quality Improvement Program: Assessing 10 Years of Experience,* p341; and cost-effectiveness calculations made by the Washington (DC) Council of Governments for specific projects.

8 Some active DPFs use an outside heat source generated by electricity or extra fuel to clean the soot or "regenerate" the trap and therefore can be used with vehicles that operate with lower exhaust temperatures, though the fuel economy is then typically diminished slightly. These active DPFs can also be used on older vehicles, though the PM reductions in that case are often closer to 50 to 60 percent instead of the 85 percent or higher reductions commonly associated with DPFs. Some active DPFs must be plugged into electrical sources and regenerated daily or frequently, requiring significant management effort.

[9] In 2003, NRDC teamed up with other NYC environmentalists to pass Local Law 77-2003 in New York City, which requires contractors to use ULSD and best available retrofit technologies on all construction equipment used on public contracts. The benefits of implementing Local Law 77 will extend beyond the City's public contracts into private construction, because contractors will not disable or install emissions control technologies on a case-by-case basis.

[10] In 2000, NRDC helped develop New York City Transit's Clean-Fuel Bus Program for North America's largest transit bus fleet. Rather than focus on new bus purchases only (as most other clean bus programs had done), the NYCT program is a fleet-wide emissions reduction plan that is expected to achieve a 90 percent emissions reduction in only five years. The program included an expedited replacement of the fleet's 600 two-stroke, pre-1991 diesel buses (in some cases, more than six years before their useful life ended); buying the cleanest available replacement buses, including more than 600 natural gas buses, almost 400 hybrid-electric buses and 2,900 advanced diesel buses equipped with PM filters and exhaust gas recirculation to reduce $NO_x$; retrofitting more than 2,800 existing buses with diesel particulate filter technology and repowering more than 600 older buses with new engines.

[11] Victor Hugo Paramo Figueroa, Mexico City Emissions Inventory, PowerPoint presentation from at the Mexico Air Pollution Workshop, April 2004.

[12] It is important to note that reducing sulfur levels in diesel fuel will reduce sulfate PM and $SO_x$ emissions from all existing diesel vehicles, whether they are retrofit or not. These sulfate PM and $SO_x$ emission reductions are not included in the cost-effectiveness analysis of this paper.