

# **MTA New York City Transit Bus Fleet Emissions**

## **1995 - 2006**

Submitted to: Natural Resources Defense Council  
40 West 20<sup>th</sup> Street  
New York, NY 10011

Submitted by:



M.J. Bradley & Associates  
1000 Elm Street, 2<sup>nd</sup> Floor  
Manchester, NH 03101

August 10, 2006



**Table of Contents**

1.0 Overview ..... 3

2.0 Summary of Emissions Results ..... 3

3.0 Emissions Model Methodology ..... 7

4.0 Major Assumptions Used in the Emissions Model ..... 7

    4.1 *Bus Assignment*..... 7

    4.2 *Annual Bus Mileage and Fuel Economy* ..... 8

    4.3 *NOx Emissions Rate* ..... 8

    4.4 *PM Emissions Rate*..... 9

**Acknowledgements**

The authors would like to acknowledge the assistance of MTA New York City Transit in providing much of the data required for the analysis summarized in this report. In particular, we would like to thank Mr. Millard L. Seay, Senior Vice President of the Department of Buses, as well as Gordon Coor, Gary LaBouff, and Doug Zupo.

## **1.0 Overview**

This report documents an analysis of changes in the annual inventory of particulate matter (PM) and oxides of nitrogen (NO<sub>x</sub>) emitted by MTA New York City Transit (NYCT) buses between 1995 and 2006. During that time period NYCT's bus fleet changed dramatically as new buses were purchased and older buses were retired.

In 1995 the 3,563 buses in the NYCT fleet were all 40-foot urban transit buses powered by diesel engines. Over the next ten years 83% of these buses that were operating in 1995 were retired and replaced by new, cleaner buses and an additional 14% were re-powered with new, cleaner diesel engines. The new buses included 40-foot transit buses, 60-foot articulated buses, and 45-foot coach buses. In addition, new propulsion technologies were added to the fleet.

The majority of new buses purchased between 1995 and 2006 were powered by diesel engines, but these newer diesels were certified to meet much stricter EPA emission standards than the older engines that they replaced. In addition, NYCT purchased and put into service a total of 480 buses powered by compressed natural gas and 325 buses powered by hybrid diesel-electric drive systems. Both of these bus types produce significantly lower NO<sub>x</sub> and PM emissions than standard diesel buses.

Beginning in 2001, NYCT also began using cleaner ultra-low sulfur diesel fuel in all of their diesel buses and implemented a program to retrofit older buses in the fleet with diesel particulate filters (DPF), which reduce PM emissions by 85% or more. At the same time, NYCT re-powered 637 older buses with new, cleaner diesel engines and retrofit DPFs.

As discussed below, all of these actions have contributed to significant reductions in total fleet emissions over the last ten years, despite the fact that 945 buses were added to the fleet over that time period. In 2006 the NYCT fleet had grown to a total of 4,508 buses, an increase of 27% in total fleet size compared to 1995.

## **2.0 Summary of Emissions Results**

Total emissions (tons) of PM and NO<sub>x</sub> from the NYCT bus fleet in each year as calculated by the emissions model used for this analysis are shown in Table 1 and presented graphically in Figures 1-4.

As shown, total annual NYCT bus fleet PM emissions fell by 290 tons between 1995 and 2006 (a 97% reduction), while NO<sub>x</sub> emissions fell by 2,781 tons (a 47% reduction). This was despite a 27% increase in fleet size (+945 buses) and a 17% increase in projected annual miles driven (+17 million miles) in 2006 compared to 1995.

On a per-bus basis emissions fell even further. Annual average per-bus emissions of PM and NO<sub>x</sub> were 0.084 tons and 1.67 tons, respectively, in 1995. In 2006 the model projects them to be 0.002 tons and 0.70 tons, respectively. This is a 97% reduction in per-bus annual PM emissions and a 58% reduction in per-bus annual NO<sub>x</sub> emissions.

Approximately 89% of the PM reduction was due to replacement of older diesel buses with new, cleaner diesel buses certified to lower PM emissions standards. Approximately

## MTA New York City Transit Bus Fleet Emissions 1995 - 2005

9% of the reduction was due to retrofit of older diesel buses with DPF and the introduction of hybrid buses fit with DPF, 1% of the reduction was due to the use of ULSD, and 1% was due to the introduction of CNG buses into the fleet.

Approximately 89% of the NOx reduction was due to replacement of older diesel buses with new, cleaner diesel buses certified to lower NOx emissions standards.

Approximately 6% of the reduction was due to the introduction of 480 CNG buses into the fleet, approximately 2% was due to the introduction of 325 hybrid buses into the fleet, and approximately 3% was due to repowering 637 older diesel buses with new, cleaner diesel engines certified to lower NOx emissions standards. In 2006 just less than 11% of the NYCT bus fleet were CNG buses, just over 11% were re-powered diesel buses, and just over 7% were hybrid buses.

Note that the increase in total annual NOx emissions from the bus fleet between 1996 and 1997 was due to the addition of 304 buses to the fleet. The average annual per-bus NOx emissions in 1997 was 1.45 tons/bus in 1997 compared to 1.48 tons/bus in 1996.

**Table 1 Total PM and NOx Emissions From NYCT Bus Fleet**

Year	Number of Buses	PM Emissions		NOx Emissions	
		Annual Tons	% of 1995	Annual Tons	% of 1995
1995	3,563	300	100%	6,935	100%
1996	3,551	226	75%	5,251	88%
1997	3,855	198	66%	5,580	94%
1998	4,100	147	49%	4,725	80%
1999	4,397	108	36%	4,705	79%
2000	4,483	81	27%	4,307	73%
2001	4,460	57	19%	4,027	68%
2002	4,454	47	16%	3,864	65%
2003	4,534	34	11%	3,617	61%
2004	4,506	18	6%	3,212	54%
2005	4,512	10	3%	3,156	53%
2006	4,508	10	3%	3,154	53%

MTA New York City Transit Bus Fleet Emissions 1995 - 2005

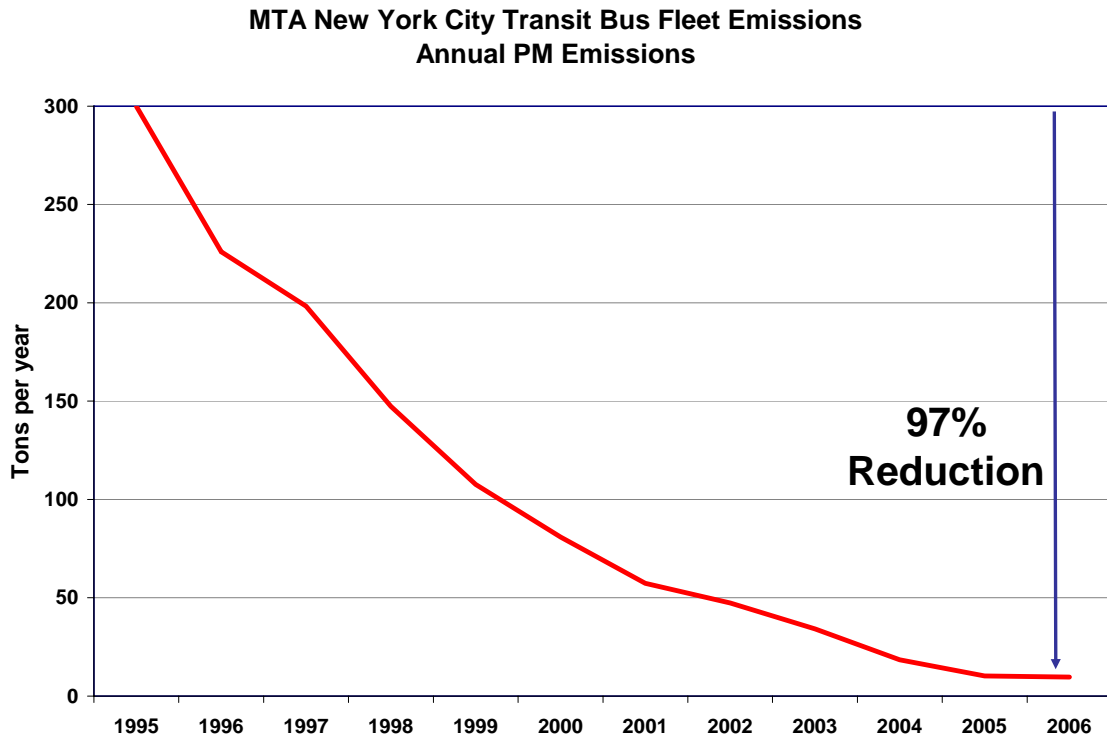


Figure 1 NYCT Bus Fleet PM Emissions 1995 – 2006

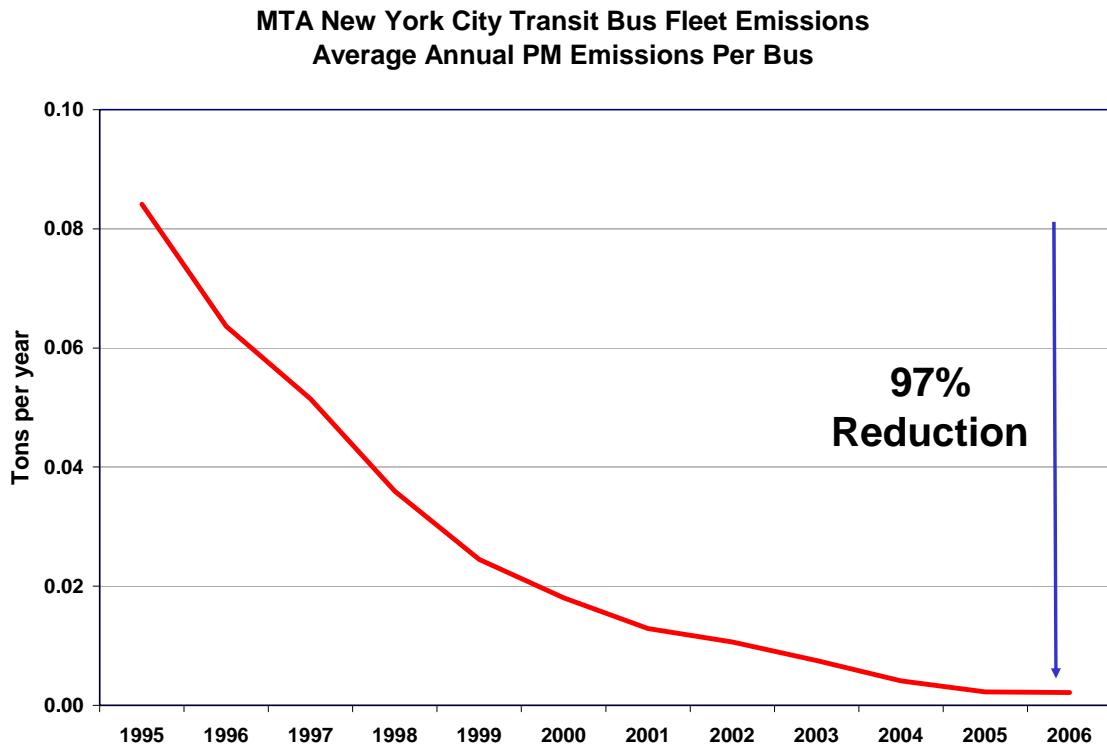


Figure 2 NYCT Per-Bus PM Emissions 1995 – 2006

MTA New York City Transit Bus Fleet Emissions 1995 - 2005

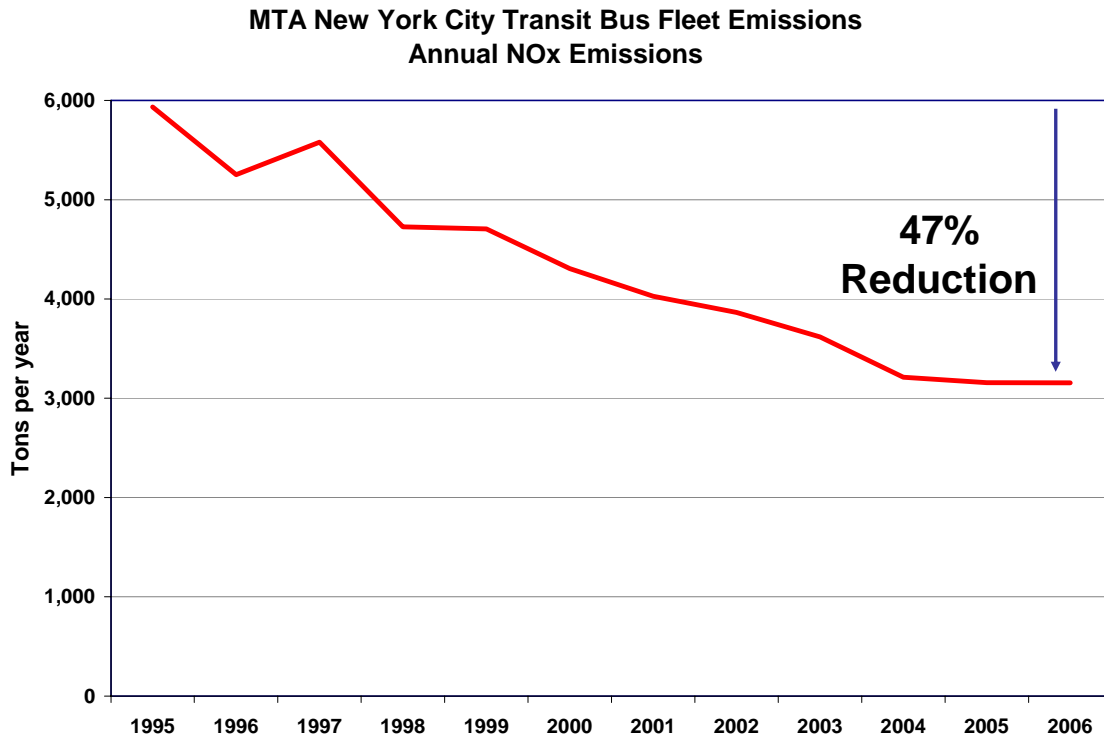


Figure 3 NYCT Bus Fleet NOx Emissions 1995 – 2006

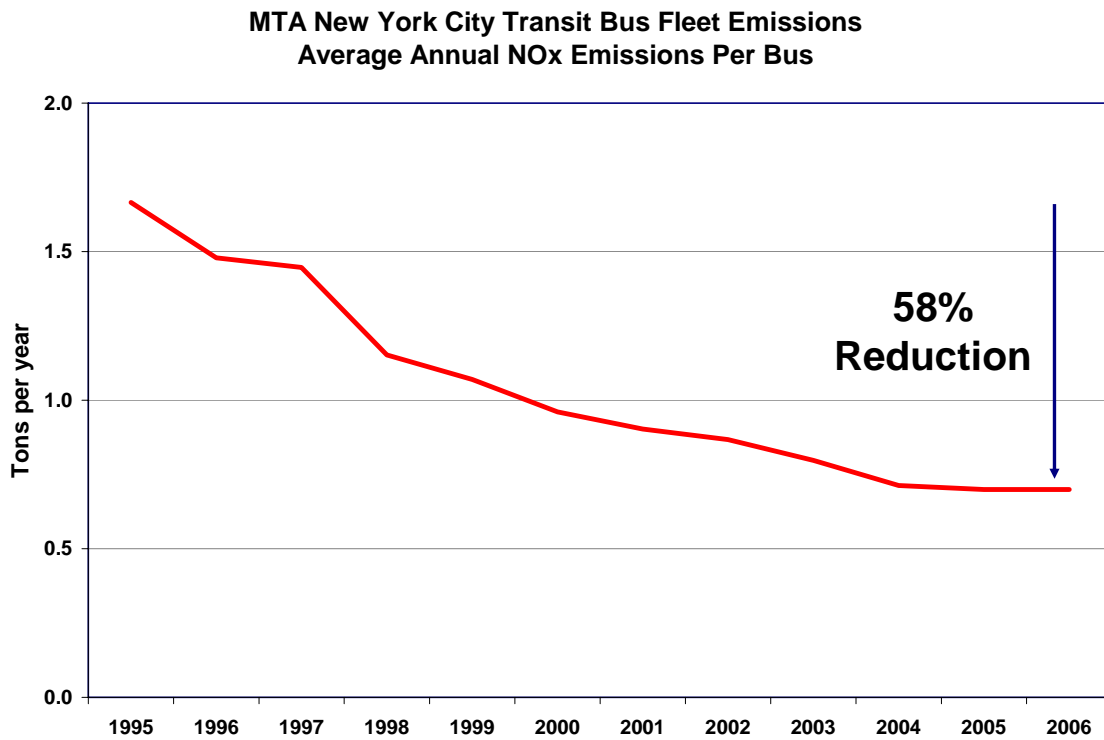


Figure 4 NYCT Per-Bus NOx Emissions 1995 – 2006



### 3.0 Emissions Model Methodology

The annual fleet emissions numbers discussed in this report were calculated using a spreadsheet-based inventory model. In this model, annual per-bus emissions are calculated using the following formula:

$$\text{Emissions}_{\text{tons/yr}} = \text{Emissions Rate}_{\text{g/bhp-hr}} \times \text{Engine Efficiency (\%)} \times \text{Diesel Fuel Energy Content}_{\text{hp-hr/gal}} \div \text{Fuel Economy}_{\text{miles/gallon}} \times \text{Annual Mileage}_{\text{miles}} \times 0.0000011 \text{ (tons/gram)}$$

To get total fleet emissions the results of the above calculation for each distinct type of bus in the fleet are multiplied by the number of buses of that type, and summed for all bus types.

In this formula emissions rate and engine efficiency are specific to a particular type and model year of engine. The emissions rate will vary depending on the EPA emissions certification for the engine, which varies by technology (diesel or natural gas) and by model year. Engine efficiency is assumed to be 33% for diesel engines and 28% for natural gas engines.

Fuel economy and annual mileage are specific to a particular fleet of buses, based on how they are operated in service.

The energy content of diesel fuel is assumed to be 50.3 hp-hr/gallon. This is equivalent to 128,000 btu/gallon, consistent with published data on #1 diesel fuel (the type used by NYCT).

### 4.0 Major Assumptions Used in the Emissions Model

Below is a discussion of the sources of the major assumptions used in the emissions inventory model.

#### 4.1 Bus Assignment

NYCT provided data on the number of buses of each type in the active fleet each year between 1995 and 2006. During this time period NYCT was always taking delivery of new buses and retiring older buses, so the actual number of buses of each type did vary throughout the year. For simplicity the model uses the number of buses of each type at the end of each year, and assumes that it was constant throughout the year.

Data was provided for each unique type of bus in the fleet based on the following factors: Model Year, Bus Type (40-ft, 45-ft, 60-ft), Manufacturer, and Engine Type (diesel, CNG, hybrid).

The NYCT bus fleet increased by 945 buses between 1995 and 2006, growing from 3,563 to 4,508.

The actual increase in the carrying capacity of the fleet is even greater than that implied by the increase in the number of buses, since the 2006 fleet includes larger 45-ft coaches

## MTA New York City Transit Bus Fleet Emissions 1995 - 2005

and 60-ft articulated buses. Both coach and articulated buses have approximately 40% greater passenger capacity than 40-ft transit buses. Given this, the 2006 NYCT bus fleet has equivalent capacity of 4,987 40-ft buses, a 40% increase compared to the 1995 fleet.

### 4.2 Annual Bus Mileage and Fuel Economy

NYCT provided data on the total mileage driven and average fuel economy (miles per gallon, MPG<sup>1</sup>) in 2005 for the following bus types:

Bus Type	Engine Type
40' Diesel Bus (RTS / Orion V)	Non-EGR ('94-'99)
	EGR (Repower '90-'93)
60' Articulated Bus	Non-EGR ('97-'00)
	EGR ('03)
45' Motor Coach	All ('98, '99, '01)
40' Hybrid Bus	Non-EGR ('03)
	EGR ('04)
40' CNG Bus	All ('94, '99, '03, '04)

Using total mileage and the number of buses in each group the average annual mileage per bus for 2005 was calculated. The model assumes that this per-bus annual mileage was constant throughout the analysis period for each bus type. The model also assumes that average fuel economy was constant throughout the analysis period for each bus type.

Assumed annual mileage per bus varies from 14,101 miles ('04 hybrid buses) to 29,595 miles ('03 hybrids). Assumed average fuel economy varies from 1.69 MPG (EGR articulated bus) to 3.69 MPG (motor coach).

Using the fleet assignment, average annual mileage, and average fuel economy the model assumes that in 1995 the NYCT bus fleet traveled 102 million miles and consumed 38 million gallons of diesel fuel, while in 2005 it traveled 119 million miles and consumed 41 million gallons of diesel fuel and 7 million diesel-equivalent gallons of natural gas.

### 4.3 NOx Emissions Rate

For all buses, the inventory model assumes a NOx emissions rate equivalent to the US EPA engine certification value for the engine in the bus, based on model year and fuel type (diesel or natural gas)<sup>2</sup>.

For diesel buses built prior to 1990 the assumed NOx emissions rate is either 10.2 or 8.8 g/bhp-hr. For diesel buses built between 1990 and 1997 the assumed NOx emissions rate

<sup>1</sup> For natural gas buses fuel economy was measured in miles per diesel-equivalent gallon. A diesel-equivalent gallon of natural gas has the same energy content as a gallon of diesel fuel, 128,000 btu. The model assumes that there are 1.28 therms of natural gas in a diesel-equivalent gallon.

<sup>2</sup> In some cases this data was taken from certification data sheets provided by the engine manufacturer for the specific engine in the buses. In other cases an assumed value was used, based on the EPA standards in effect for that model year and/or certification data sheets from similar engines of the same model year.

is 4.9 g/bhp-hr. For diesel buses built between 1998 and 2003 the assumed NO<sub>x</sub> emissions rate is 3.8 g/bhp-hr. The EGR engines used to repower 1990 buses beginning in 2002 are assumed to have a NO<sub>x</sub> emissions rate of 3.0 g/bhp-hr. The EGR engines used to repower 1993 buses beginning in 2001, and that were installed in the 2001 articulated buses, are assumed to have a NO<sub>x</sub> emissions rate of 3.5 g/bhp-hr. The EGR engines installed in the 2004 hybrid buses are assumed to have a NO<sub>x</sub> emissions rate of 2.5 g/bhp-hr. The engines in the 1994 and 1999 CNG buses are assumed to have NO<sub>x</sub> emissions rates of 1.7 and 1.8 g/bhp-hr, respectively, and the engines in the 2003 and 2004 CNG buses are assumed to have a NO<sub>x</sub> emissions rate of 1.5 g/bhp-hr.

Technically, the EPA NO<sub>x</sub> certification value is only valid for the EPA transient test cycle used for certification testing. Different duty cycles will have an effect on g/bhp-hr emissions rates. However, using the above noted assumptions for NO<sub>x</sub> emissions rate and average fuel economy, the model calculates that the NO<sub>x</sub> from a 1998-2003 NYCT diesel bus would be 23.6 g/mi. This is consistent with the results of chassis dynamometer emissions testing using the Central Business District test cycle<sup>3</sup>.

#### **4.4 PM Emissions Rate**

For all buses, the inventory model assumes a PM emissions rate equivalent to the US EPA engine certification value for the engine in the bus, based on model year and fuel type (diesel or natural gas)<sup>2</sup>.

For diesel buses built prior to 1990 the assumed PM emissions rate is 0.31 g/bhp-hr. For diesel buses built between 1990 and 1993 the assumed PM emissions rate is 0.17 g/bhp-hr. For 40-ft and 60-ft diesel buses built after 1994 the assumed PM emissions rate is 0.05 g/bhp-hr, while it is 0.09 g/bhp-hr for coach buses built during the same time period<sup>4</sup>. The engines in the 1994 CNG buses are assumed to have PM emissions rates of 0.02 g/bhp-hr and the engines in the other CNG buses are assumed to have a PM emissions rate of 0.01 g/bhp-hr.

Beginning in 2001, the use of ultra-low sulfur diesel fuel (ULSD) in diesel buses is assumed to have reduced PM emissions by 10% compared to the baseline emissions when standard diesel fuel was used. This is a conservative assumption based on the results of emissions testing conducted on NYCT buses in 2001 and 2002<sup>3</sup>, and is consistent with EPA guidance on the use of ULSD. The majority of the PM reduction from the use of ULSD was a reduction in solid sulfate particles rather than a reduction in the carbonaceous portion of the PM mass.

The addition of a diesel particulate filter (DPF) to a diesel bus is assumed to reduce PM emissions by 85% compared to the EPA engine certification value (which in all cases for the NYCT fleet is based on testing without a DPF in place). This is a conservative assumption based on the results of emissions testing conducted on NYCT buses in 2001

---

<sup>3</sup> See SAE 2001-01-0511, SAE 2002-01-0430, and SAE 2004-01-1085.

<sup>4</sup> Between 1996 and 2007 engines used in urban transit buses were held to a stricter PM standard than the engines used in other diesel vehicles. Coach buses are not considered by EPA to be urban transit buses so they were held to the more lenient standard.

## MTA New York City Transit Bus Fleet Emissions 1995 - 2005

and 2002<sup>3</sup>, and is consistent with California Air Resources Board certification testing for the specific DPF devices installed on NYCT buses.

NYCT's 2001 articulated and coach buses and 2003 and 2004 hybrid buses were all delivered from the factory with DPF installed. The majority of the other diesel buses in the NYCT fleet were retrofit with DPF between 2001 and 2005. As of mid-2006, a total of 3,583 NYCT diesel buses have DPF installed.

Technically, the EPA PM certification value is only valid for the EPA transient test cycle used for certification testing. Different duty cycles will have an effect on g/bhp-hr emissions rates. However, using the above noted assumptions for PM emissions rate, average fuel economy, and DPF reduction effectiveness the model calculates that the baseline level of PM from a 1998-2003 NYCT diesel bus would be 0.31 g/mi, while it would be 0.046 g/mi with a DPF in place. This is conservatively consistent with the results of chassis dynamometer emissions testing using the Central Business District test cycle<sup>3</sup>.