

Port Authority of Allegheny County Bus Fleet Emissions

2005 - 2019

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Acknowledgements

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1.0 Overview

This report documents an analysis of actual and projected changes in the annual inventory of particulate matter (PM) and oxides of nitrogen (NO_x) emitted by Port Authority of Allegheny County (Port Authority) buses between 2005 and 2019. Since 2005 the Port Authority's bus fleet has changed dramatically as new buses were purchased and older buses were retired; it is projected to continue to change over the next six years based on planned future new bus purchases.

In 2005 all of the 974 urban transit buses in the Port Authority fleet were powered by diesel engines. Eighty-seven percent of them were 40-ft buses, while 6% were shorter (35-ft) and 7% were longer (45-ft and 60-ft). The oldest buses in the fleet had been delivered in 1993 (12 years old) and the youngest had been delivered in 2003.

Today only 204 (22%) of the buses that were operating in 2005 are still in service; the rest have been retired. In the last eight years the total number of buses in the fleet has fallen to 685. In addition, the fleet has shifted toward larger buses – today 21% of the fleet is 60-ft buses.

The entire Port Authority fleet still operates on diesel fuel, but the newer buses have much cleaner engines, certified to meet more stringent EPA emission standards than the engines in the older buses that they replaced. Average emissions of PM and NO_x (grams per mile) from the newest diesel buses in the Port Authority fleet are 90% and 96% lower, respectively, than PM and NO_x emissions from the oldest buses that were in the fleet in 2005. Port Authority also currently operates 32 hybrid diesel-electric buses which get about 25% better fuel economy than similar diesel buses, and subsequently have lower emissions as well. In addition, in 2010 Port Authority repowered nine model year 2003 buses with new, cleaner engines that meet more stringent EPA emission standards.

The Port Authority fleet is projected to continue to get cleaner in the future as additional new buses are purchased and the oldest of the current buses are retired. By 2019, 100% of Port Authority buses are projected to meet the most stringent EPA PM standards, and 86% are projected to meet the most stringent EPA NO_x standards¹.

2.0 Summary of Emissions Results

Total estimated emissions (tons) of PM and NO_x from the Port Authority 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 and 2. Total reductions of PM and NO_x emissions each year, compared to 2005 levels, are shown in Appendix A.

As shown, total annual Port Authority bus fleet PM emissions fell by 7.7 tons between 2005 and 2013 (a 66% reduction), while total annual NO_x emissions fell by 553 tons (a 72% reduction). Approximately 23% of the reduction in fleet PM emissions and 19% of

¹ EPA emission standards apply to new engines when they are manufactured. The most stringent EPA new engine PM standards took effect in the 2007 model year, while the most stringent NO_x standards did not take effect until the 2010 model year.

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the reduction in fleet NOx emissions in 2013 compared to 2005 was due to a drop in total fleet size and annual fleet mileage in 2013 compared to 2005². The rest of the PM and NOx reduction, 43% and 53% respectively, was due to retirement of older buses and engines and replacement with new, cleaner buses and engines. Of the reductions attributable to fleet turnover, most were due to the replacement of older buses with entirely new buses. However, the Port Authority did repower nine model year 2003 buses with new 2007 model year engines. This repower project will result in a projected reduction 0.42 tons PM and 10.56 tons NOx between 2010 and 2016, compared to what would have been emitted if the original engines had remained in service.

Annual fleet mileage is projected to stay fairly steady over the next six years, but annual total emissions of both PM and NOx are projected to continue to drop. By 2019, total annual emissions of PM and NOx from the Port Authority bus fleet are projected to be only 1.2 tons and 37.5 tons, respectively. Compared to 2005, in 2019 annual total PM emissions will have been reduced by 90% and annual total NOx emissions will have been reduced by 95%.

Table 1 Total Estimated PM and NOx Emissions from Port Authority Bus Fleet

Calendar Year	Buses	Fleet Miles [mill mi]	Fleet Fuel Use [mill gal]	AVG Fuel Economy [MPG]	Total Fleet Emissions		Average Emissions per Bus		Average Emissions per Mile	
					NOx [ton]	PM [ton]	NOx [lb]	PM [lb]	NOx [g]	PM [g]
2005	974	42.1	11.1	3.78	766.6	11.6	1,574	23.9	16.5	0.25
2006	933	34.9	9.4	3.72	590.0	9.0	1,265	19.2	15.3	0.23
2007	861	29.9	8.2	3.66	462.3	7.5	1,074	17.5	14.0	0.23
2008	810	31.4	8.6	3.66	478.0	7.9	1,181	19.5	13.8	0.23
2009	816	30.3	8.3	3.65	409.5	6.7	1,004	16.4	12.3	0.20
2010	817	29.8	8.1	3.67	391.7	6.3	959	15.5	11.9	0.19
2011	783	26.7	7.3	3.68	327.5	5.2	837	13.4	11.1	0.18
2012	725	25.2	6.9	3.65	262.8	4.6	725	12.6	9.5	0.16
2013	685	25.0	6.8	3.69	214.1	4.0	625	11.6	7.8	0.14
2014	670	26.4	7.0	3.78	164.7	3.2	492	9.5	5.7	0.11
2015	670	24.5	6.4	3.81	134.1	2.6	400	7.7	5.0	0.10
2016	670	24.8	6.3	3.91	106.0	2.2	317	6.7	3.9	0.08
2017	670	25.3	6.3	3.98	79.0	1.8	236	5.4	2.8	0.06
2018	664	25.1	6.2	4.05	54.6	1.4	164	4.1	2.0	0.05
2019	670	25.9	6.3	4.12	37.5	1.2	112	3.5	1.3	0.04

² This estimate assumes that if Port Authority had continued to operate the same amount of annual bus mileage between 2006 and 2013 as they did in 2005, then they would have continued to operate the same number of buses each year as they did in 2005, and they would have increased total bus purchases between 2006 and 2013 to maintain an average bus age of between 6 and 7 years, consistent with actual bus age trends over that time period. This scenario was chosen as a baseline for comparison because it is consistent with past Port Authority practice relative to bus fleet turnover. An alternative would be to assume that Port Authority would not have increased new bus purchases between 2006 and 2013, beyond their actual purchases, despite continuing to maintain a larger fleet and continuing to operate more annual fleet miles than they in fact did. This scenario was not chosen as the baseline for comparison because it would have resulted in a significant increase in average bus age between 2006 and 2013 (from 6.5 to 9.1 years).

Port Authority of Allegheny County Bus Fleet Emissions 2005 - 2019

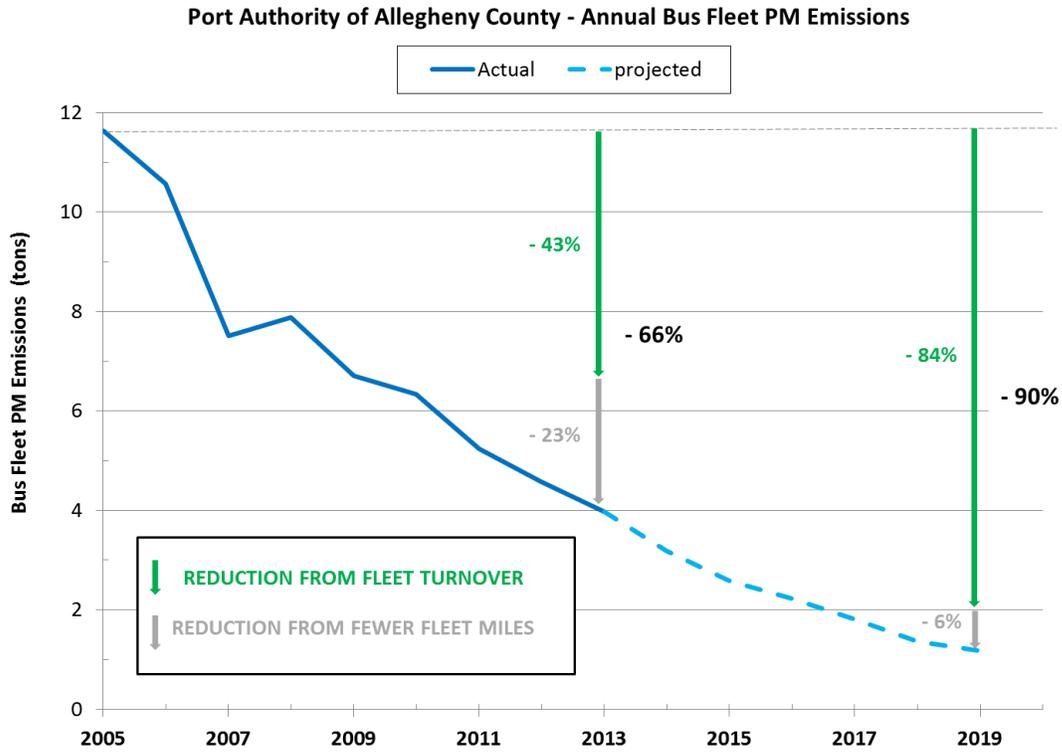


Figure 1 Estimated Annual Port Authority Bus Fleet PM Emissions 2005 – 2019

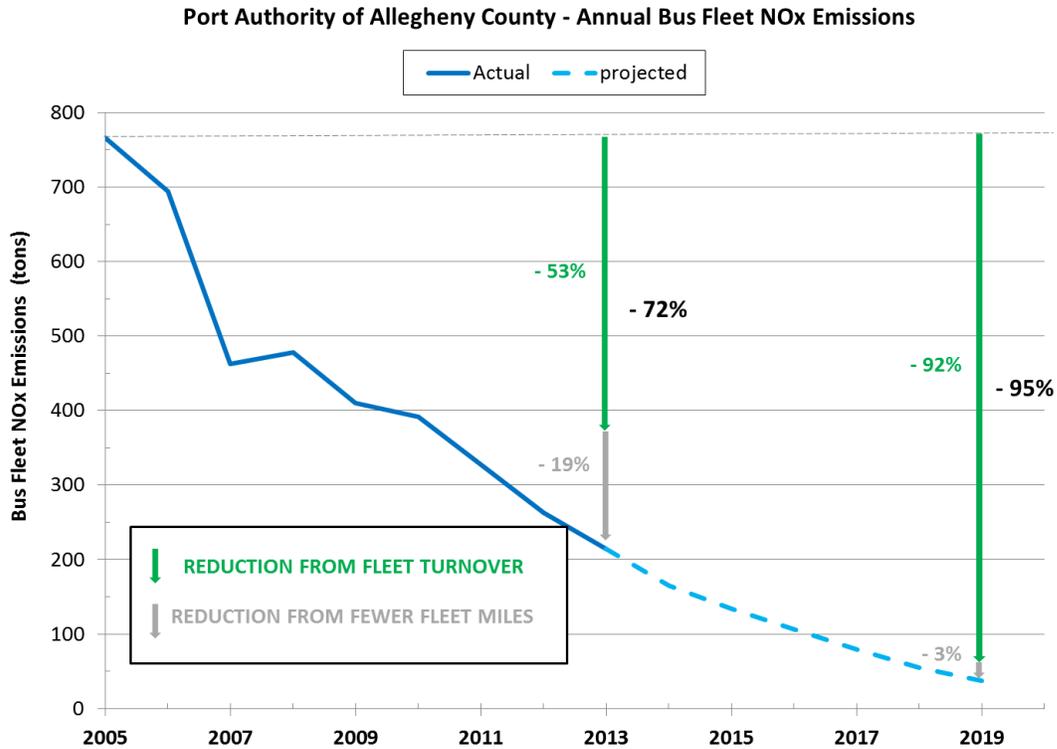


Figure 2 Estimated Annual Port Authority Bus Fleet NOx Emissions 2005 – 2019

Port Authority of Allegheny County Bus Fleet Emissions 2005 - 2019

Approximately 70% of the projected cumulative reductions in fleet PM emissions (68.8 tons) and 77% of the projected cumulative reductions in fleet NOx emissions (5,293 tons) from the Port Authority bus fleet between 2006 and 2019, compared to 2005 levels, will be due to fleet turnover to cleaner buses and engines (see Appendix A). Approximately 30% of projected cumulative PM reductions and 23% of projected cumulative NOx reductions over that time period will be due to the Port Authority operating fewer annual bus miles each year than they did in 2005.

See Figures 3 and 4 for estimated average emissions of NOx and PM emitted by the Port Authority Bus fleet per-mile of operation. As shown, average PM emissions are estimated to have dropped from 0.25 grams per mile (g/mi) in 2005 to 0.14 g/mi today, a reduction in average PM emissions of 43%. By 2019 average PM emissions are projected to fall to 0.04 g/mi – 83% lower than average PM emissions in 2005.

Average NOx emissions are estimated to have dropped from 16.5 g/mi in 2005 to 7.8 g/mi today, a reduction in average NOx emissions of 53%. By 2019 average NOx emissions are projected to fall to 1.3 g/mi – 92% lower than average NOx emissions in 2005.

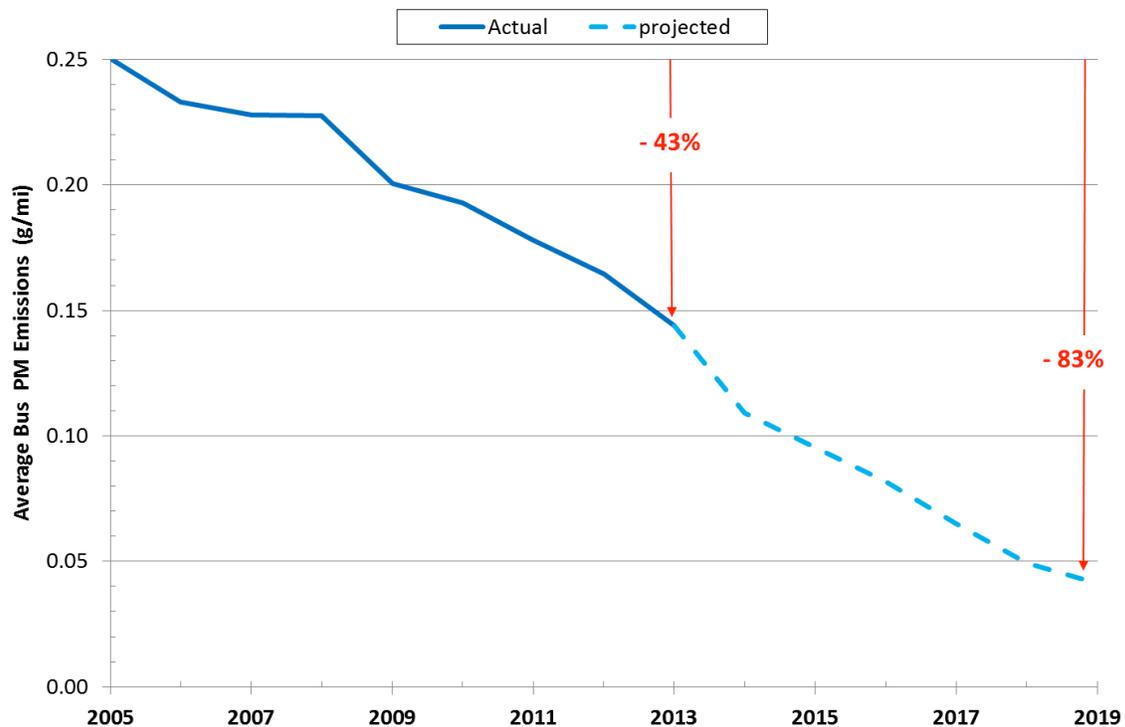


Figure 3 Estimated Port Authority Average per-Mile PM Emissions 2005 – 2019

Port Authority of Allegheny County Bus Fleet Emissions 2005 - 2019

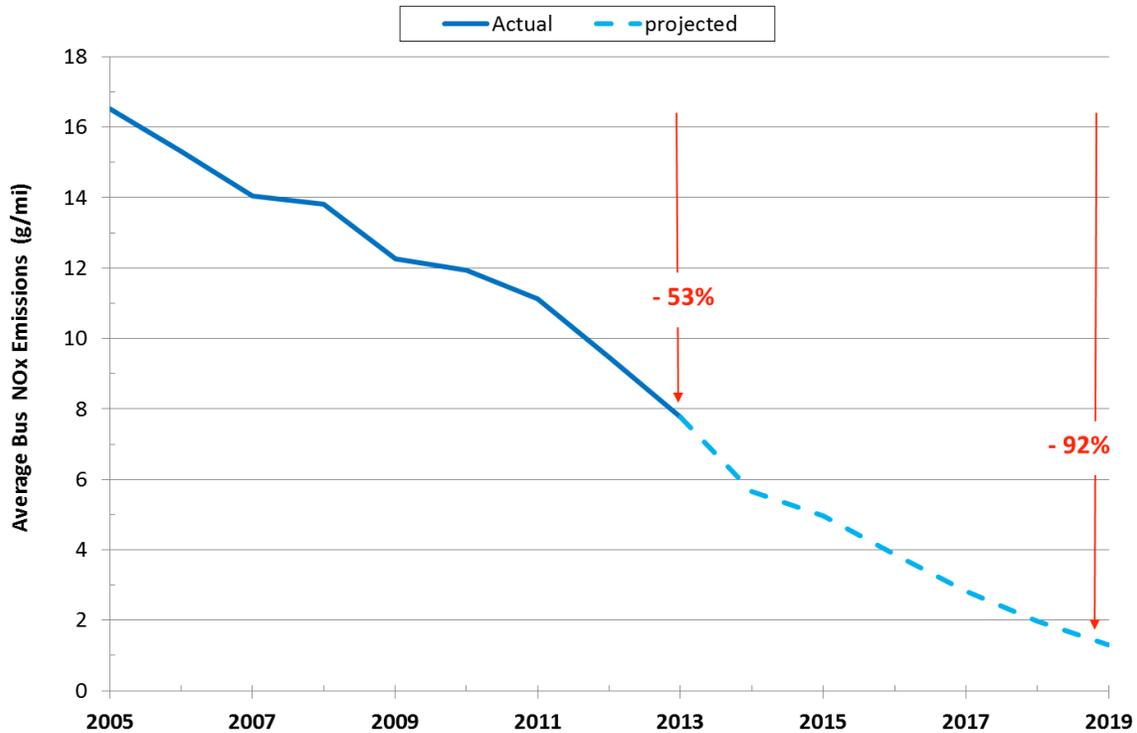


Figure 4 Estimated Port Authority Average per-Mile NOx Emissions 2005 - 2019

3.0 Emissions Model Methodology

The annual fleet emissions estimates 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:

$$Emissions_{tons/yr} = Emissions\ Rate_{g/bhp-hr} \times Engine\ Efficiency\ (\%) \times Diesel\ Fuel\ Energy\ Content_{hp-hr/gal} \div Fuel\ Economy_{miles/gallon} \times Annual\ Mileage_{miles} \times 0.0000011\ (tons/gram)$$

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 varies depending on the EPA emissions certification for the engine, which varies by model year. Engine efficiency is assumed to be 33% for all diesel 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 50.5 hp-hr/gallon. This is equivalent to 128,450 btu/gallon, consistent with published data on #2 diesel fuel (U.S. Department

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of Energy, Alternative Fuels & Advanced Vehicles Data Center (www.afdc.energy.gov/afdc/fuels/properties.html)).

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

Port Authority provided data on the number of buses of each type and model year in the active fleet each quarter of each year between 2005 and 2013, along with estimated quarterly delivery dates of additional new buses between 2014 and 2019, based on planned purchases.

Data was provided for each unique type of bus in the fleet based on the following factors: Model Year, Bus Size (35-ft, 40-ft, 45-ft, 60-ft), Manufacturer, and Propulsion Type (diesel, hybrid).

The active Port Authority bus fleet decreased by 304 buses between 2005 and 2013 (-31%). The effective passenger capacity of the fleet fell by only about 20%, however, due to an increase in the number of higher-capacity 60-ft buses in the fleet (increase from 25 to 144).

4.2 Annual Bus Mileage and Fuel Economy

Port Authority provided information about the average fuel economy and average annual mileage accumulation for every type of bus still in the fleet in 2013. This information was for fiscal year 2013, running from the third quarter of 2012 through the second quarter of 2013.

Older 35-ft, 40-ft, and 45-ft diesel buses currently average between 3.5 and 3.7 miles per gallon (MPG), while older 60-ft diesel buses currently average 2.8 – 2.9 MPG, and older 40-ft hybrid buses average 4.2 - 4.7 MPG.

Newer buses currently in the fleet (2011 and 2012 model year) have higher average fuel economy than older buses: 4.0 – 4.2 MPG for 40-ft diesel buses, 5.2 MPG for 40-ft hybrid buses, and 3.3 MPG for 60-ft diesel buses.

For all buses the emissions model assumes that fuel economy will stay constant throughout the bus' life. For all fleets for which 2013 data was available the 2013 average fuel economy was used in the model for that bus type. The average fuel economy for 40-ft buses retired between 2005 and 2013 (model year 1993 – 1996) was assumed to be 4.0 MPG, equivalent to the fuel economy in 2013 of model year 1999 buses still in the fleet. The fuel economy for 40-ft buses to be delivered in 2015 and 2016 was assumed to be 4.3 MPG, and the fuel economy for 40-ft buses to be delivered in 2017 and 2018 was assumed to be 4.4 MPG. This represents 3% and 5% less fuel use per mile, respectively, compared to model year 2012 40-ft buses currently in the fleet. Future buses are assumed to have lower fuel use due to the imposition of EPA fuel

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economy standards for heavy-duty engines, which will take effect starting in the 2014 model year.

Port Authority staff indicated that newer buses in the fleet typically accumulate more miles per year than older buses, because bus operators prefer to drive new buses. On weekends and during evening hours when fewer buses are required for service drivers choose only new buses, and the older buses stay parked.

See Figure 5 which plots fiscal year 2013 average mileage accumulation per bus versus bus age for all of the bus fleets currently in service. As shown, 40-ft buses typically accumulate more annual mileage than 60-ft buses throughout their life. Both types of buses accumulate significantly more miles each year when they are new than when they are near retirement.

Based on the data shown in Figure 5, the model used for this analysis assumes that in the first three years of service 35-ft, 40-ft, and 45-ft buses accumulate 55,000 miles per year, between years three and seven they accumulate 45,000 miles per year, between years seven and twelve they accumulate 30,000 miles per year, and after year twelve they accumulate 5,000 miles per year. The model assumes that in the first four years of service 60-ft buses accumulate 35,000 miles per year, between years four and twelve they accumulate 25,000 miles per year, and after year twelve they accumulate 20,000 miles per year.

For certain fleets in certain years these basic assumptions were modified slightly, primarily by increasing or decreasing annual mileage for the oldest buses still in the fleet in that year. This was done so that total annual fleet mileage in the model would match total annual fleet mileage as reported each year by Port Authority to the National Transit Database. For each year for which NTD data was available for comparison (2005 – 2011), total annual fleet miles used in the emissions model is within plus or minus 0.5% of NTD reported fleet mileage.

Between 2005 and 2011 the Port Authority's total annual fleet mileage, as reported to NTD, fell from 42.1 million miles to 26.7 million miles, a drop of 37%. Based on the actual bus fleet (number of buses, age of buses), as reported by Port Authority the emissions model projects that annual total bus fleet mileage continued to drop slightly for the next two years, reaching 25 million miles in 2013 (41% less than total 2005 fleet mileage). Based on Port Authority's current projections for the size and age of the bus fleet in future years the model predicts that total annual fleet mileage will be generally steady between 2014 and 2019, ranging between 24.5 and 26.4 million miles per year.

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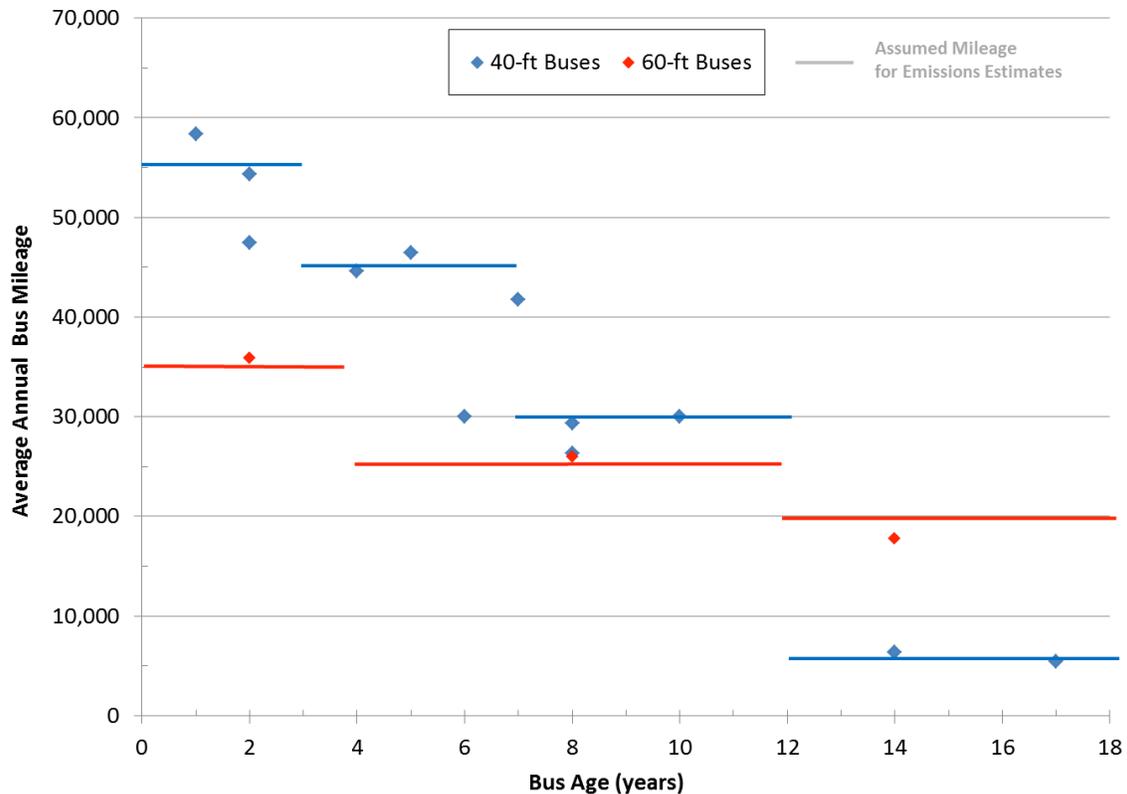


Figure 5 Port Authority Average Annual Mileage Accumulation versus Bus Age, FY2013

4.3 NO_x Emissions Rate

For all buses, the inventory model assumes a NO_x emissions rate equivalent to the US EPA engine certification standard for the engine in the bus, based on model year.

For buses delivered between 1993 and 1996 the NO_x emissions rate is assumed to be 5.0 g/bhp-hr. For buses delivered between 1997 and 2002 the assumed NO_x emissions rate is 4.0 g/bhp-hr. For buses delivered between 2003 and 2006 the assumed NO_x emissions rate is 2.5 g/bhp-hr. For buses delivered between 2007 and 2009 the assumed NO_x emissions rate is 1.5 g/bhp-hr. For buses delivered in 2010 and later the assumed NO_x emissions rate is 0.2 g/bhp-hr.

4.4 PM Emissions Rate

For all buses, the inventory model assumes a PM emissions rate equivalent to the US EPA engine certification standard for the engine in the bus, based on model year and fuel type.

For buses delivered in 1993 the PM emissions rate is assumed to be 0.10 g/bhp-hr. For buses delivered in 1994 and 1995 the assumed PM emissions rate is 0.07 g/bhp-hr. For buses delivered between 1996 and 2006 the assumed PM emissions rate is 0.05 g/bhp-hr. For buses delivered in 2007 and later the assumed PM emissions rate is 0.01 g/bhp-hr.

APPENDIX A Annual Fleet Emissions Reductions (2006 – 2019), Relative to 2005

Calendar Year	Annual Reductions Compared to 2005									
	NOX					PM				
	Reduction from Less Service	Reduction from Fleet Turnover	TOTAL	Reduction from Less Service	Reduction from Fleet Turnover	TOTAL	Reduction from Less Service	Reduction from Fleet Turnover	TOTAL	
[tons]	[tons]	[tons]	[tons]	[% of Total]	[% of Total]	[tons]	[tons]	[% of Total]	[% of Total]	
2005										
2006	40.3	32.4	72.7	55%	45%	0.6	0.4	58%	42%	1.1
2007	189.2	115.1	304.3	62%	38%	3.1	1.0	75%	25%	4.1
2008	163.3	125.2	288.6	57%	43%	2.7	1.1	72%	28%	3.8
2009	159.2	197.9	357.1	45%	55%	2.6	2.3	53%	47%	4.9
2010	162.5	212.3	374.8	43%	57%	2.6	2.7	50%	50%	5.3
2011	189.4	249.7	439.1	43%	57%	3.0	3.4	47%	53%	6.4
2012	176.0	327.8	503.8	35%	65%	3.1	4.0	43%	57%	7.1
2013	146.5	406.0	552.5	27%	73%	2.7	5.0	35%	65%	7.7
2014	110.9	491.1	602.0	18%	82%	2.1	6.4	25%	75%	8.4
2015	97.8	534.8	632.6	15%	85%	1.9	7.2	21%	79%	9.0
2016	74.8	585.9	660.7	11%	89%	1.6	7.8	17%	83%	9.4
2017	53.0	634.6	687.7	8%	92%	1.2	8.6	12%	88%	9.8
2018	37.3	674.9	712.1	5%	95%	0.9	9.3	9%	91%	10.3
2019	23.6	705.6	729.2	3%	97%	0.7	9.7	7%	93%	10.4
Cumulative 2006 - 2013	1,226	1,666	2,893	42%	58%	20.4	19.8	51%	49%	40.3
Cumulative 2014 - 2019	397	3,627	4,024	10%	90%	8.4	49.0	15%	85%	57.4
Cumulative 2006 - 2019	1,624	5,293	6,917	23%	77%	28.8	68.8	30%	70%	97.7

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For each year this table shows the reductions in total Port Authority bus fleet emissions of PM and NOx that year compared to total emissions in 2005 (i.e. $\text{Reductions}_{\text{year } x} [\text{ton}] = \text{Total Fleet Emissions}_{2005} [\text{ton}] - \text{Total Fleet Emissions}_{\text{year } x} [\text{ton}]$).

For each year the reductions compared to 2005 are composed of reductions that are attributable to Port Authority running fewer bus miles in that year than they did in 2005 (reductions from less service) and reductions that are attributable to changes in the composition of the bus fleet compared to 2005 (reductions from fleet turn over).

For example, in 2013 total bus fleet emissions of PM were 7.7 tons less than total bus fleet emissions of PM in 2005 (far right column). Of this total 7.7 ton reduction compared to 2005 PM emissions, 2.7 tons (35% of the total) were the result of running fewer bus miles and 5.0 tons (65% of the total) were the result of part of the fleet turning over to new, cleaner buses between 2005 and 2013.

The three rows at the bottom show cumulative reductions over various time periods – 2006 to 2013, 2014 – 2019, and 2006 – 2019. The numbers in these rows are calculated by summing the numbers in each column from the appropriate year rows above.