

## **APPENDIX C**

### **EMISSION BENEFITS AND COST EFFECTIVENESS ANALYSIS METHODOLOGY**

## **Emission Benefits and Cost Effectiveness of Proposed Rule**

The cost of an emission control measure is generally assessed in terms of dollars-per-pound, or dollars-per-ton, of air emissions reduced. This is referred to as the cost effectiveness. This appendix discusses the factors that were used to determine the cost effectiveness values estimated for this regulatory proposal. To calculate cost effectiveness, both the emission benefit from the proposal and the incremental cost of the proposal must be determined.

### **Costs**

Many factors were taken into account in order to estimate the cost effectiveness for the proposed rule. The costs considered in determining cost effectiveness include capital costs for both vehicle and infrastructure and operational costs. Only the incremental cost is used to determine the cost effectiveness of the proposed rule. The incremental capital cost for a CNG school bus is based on the differential cost for a CNG school bus in comparison to the cost of a conventional diesel fueled school bus. The incremental costs associated with infrastructure, maintenance, labor, and fuel costs for a CNG fueled school bus are based on comparisons to conventional diesel fueled school buses.

Incremental capital costs were generated using costs annualized over the life of the school bus and then discounted to present value. An annualized capital cost was calculated using a capital recovery factor based on a five percent discount interest rate. The annualized portion of the capital costs was then added to the annualized portion of the incremental operational cost. This sum was then discounted using the present value of money concept. A total cost associated with the proposed rule as it relates to cost effectiveness was then calculated by summing these discounted annual costs over the lifetime of the bus. It was assumed that the lifetime of a public school bus operating within the air district was 25 years.

### **Emission Reductions**

The emission reductions calculated for the different scenarios analyzed were based on the difference between baseline emission standards for each model year and the certification emission standard for the emission reduction strategy being used. In order to calculate the tons of oxides of nitrogen (NO<sub>x</sub>) and particulate matter (PM) reduced per year, an average annual mileage for the school buses was assumed as well as factors to convert brake-horsepower hours to miles traveled and to account for the reduction in NO<sub>x</sub> and PM emissions due to the use of ARB diesel as compared to EPA diesel fuel. In those cases where the NO<sub>x</sub> emission standard is stated as a limit for the combination of NO<sub>x</sub> and non methane hydrocarbons (NMHC), a factor is used to estimate the fraction of the emission limit value that could be attributed to NO<sub>x</sub>.

The following values and factors were used for all of the scenarios, where appropriate. The average number of miles traveled per school bus in the South Coast Air Quality Management District was determined from ARB's On-Road Mobile Source Emission Inventory Model EMFAC2002 (version 2.2 April 23, 2003) to be 13,666 miles per year. A conversion factor of 2.3 brake-horsepower-hr per mile was used which is consistent with Carl Moyer Program methodology (ARB 2003) for medium heavy-duty diesel engines. Fuel conversion factors of 0.87 for NOx and 0.90 for PM were used to account for the lower emission potential of CARB diesel fuel as compared to EPA diesel fuel. NOx fractions used to determine the NOx portion of a NOx + NMHC standard were 0.95 for diesel and 0.8 for CNG fueled vehicles.

### **Scenarios Analyzed**

In total, four scenarios were analyzed and are presented in this appendix. However, only two of the four, Scenarios One and Two, are presented in the body of the report. Scenario One was considered the most relevant because it is consistent with SCAQMD's choice to fund only alternative-fueled vehicles. Scenario Two was included in the main report because it was based on receiving funding specifically for DPF retrofits, which is a possible occurrence. The other two scenarios (Scenarios A and B) assume that the Lower Emission School Bus Program's state funding is allocated in a proportion consistent with the Lower Emission School Bus Guidelines of two thirds to alternative-fueled vehicles and one third to diesel fueled vehicles. These two scenarios are not discussed in the report because they are not probable funding allocation scenarios for the SCAQMD.

The number of vehicles purchased or retrofit in each scenario was based on the projected funding available from the incentive sources discussed in Chapter IX of the staff report and an estimate of the portion of the purchase price that would be funded. These funding sources are directed primarily at funding a substantial portion of the capital cost of clean bus purchases and consequently the funded amount is generally significantly higher than the incremental capital cost of the purchase. The assumed funded amounts were estimated based on approximate current bus prices minus the school district cost share assuming that they are replacing either a pre 1987 bus or a pre 1977 bus. The school district cost share is \$25,000 if a pre1987 bus is replaced and \$10,000 if a pre 1977 bus is replaced. Sales tax was included at seven percent.

#### ***Scenario One***

For the Scenario One analysis it was assumed that 92 new CNG school buses would be funded each year starting in 2005 and going through 2009. This was based on the funds available and an estimate of the portion of the purchase price that will be funded. The funding sources and allocations are given in Table 1.

Funding Source	Projected Annual Funding	Allocation		Assumed State Contribution /bus	Number of buses purchased
		Infrastructure	CNG buses		
Lower-Emission School Bus (AB 923)	\$9.33 mil	10%	90%	~\$127K	67
MSRC	\$1.5 mil	0%	100%	\$60K	25
Clean Fuels Fund (AB2766)	\$325K	100%	0%	--	N/A
Total	\$11.155 mil	--	--	--	92

The emission benefits and costs that were associated with these school buses were then determined. Both PM and NOx emission benefits would be realized for the 2005 and 2006 model years. However, in 2007 through 2009, no PM benefits will be realized because the PM emission standard for heavy duty engines will drop down to the level of the CNG buses. These standards are shown in Table 2 below.

Model Year	NOx + NMHC (g/bhp-hr)		PM (g/bhp-hr)	
	Standard	CNG Certification	Standard	CNG Certification
2005-2006	2.5	1.5	0.1	0.01
2007-2009	1.2 <sup>(a)</sup>	0.2 <sup>(b)</sup>	0.01	0.01

(a) most engines will conform to the fleet NOx average of approximately 1.2 g/bhp-hr NOx +NMHC  
(b) Level applies to NOx only

The cost effectiveness values calculated for Scenario One were determined to be \$60,000 per ton of NOx and \$405,000 per ton of PM, as show in Table 3. These cost effectiveness values are based on the assumption that half the costs of the model years 2005 and 2006 vehicles are attributed to NOx reductions and half to PM reductions and all costs for the model years 2007 through 2009 vehicles are attributed to NOx reductions.

Pollutant	Reductions (tons)	Cost	C/E
NOx	346	\$30.1M	\$60,000/ton
PM	13		\$405,000/ton

The incremental capital costs and operational costs are described in the following paragraphs.

### Capital Costs

The incremental capital costs associated with Scenario One were calculated on a per bus basis. These costs include the incremental cost of the initial purchase price of the bus, infrastructure required for refueling, maintenance facility upgrades, and replacement of the CNG onboard fuel tanks after 15 years of service.

The incremental capital cost for the CNG school bus was estimated at \$31,000 for model years 2005 and 2006, and \$29,300 for model years 2007-2009. This difference in capital costs for the school bus takes into account the fact that conventional diesel school buses will become more expensive in model years 2007-2009 in order to comply with the new 2007 federal emission standard for heavy-duty diesel engines. The capital cost for a new 2007 diesel bus with an OEM equipped DPF was based on estimates previously made for the purchase price of a new heavy duty engine meeting 2007 standards, corrected for inflation to 2005 dollars. The incremental cost, compared to a diesel engine meeting 2004 standards, was estimated to be an increase of \$1,705. This resulted in a decrease in incremental capital cost for a CNG bus from \$31,000 down to \$29,300.

CNG fueled school buses require specialized refueling infrastructure that may not be available to all fleets. The regulatory proposal specifies an allowance of \$13,000 per bus to either upgrade or install a refueling system. This amount was used as the incremental capital cost for refueling infrastructure.

Servicing CNG fueled school buses require upgrades to maintenance facilities that were originally developed to service diesel fueled school buses. The \$4,000 per bus allowance for maintenance facility upgrades was used as the incremental cost for upgrading school bus maintenance facilities to allow routine maintenance to be performed on CNG fueled school buses.

CNG school buses require that the onboard natural gas fuel be stored in high pressure gas cylinders. These cylinders have a lifetime of 15 years and after that time they must be replaced. It was assumed that \$15,000 would cover the cost of fuel cylinder replacement after 15 years of service. The replacement cylinders were assumed to last for the 10 remaining years of the school bus's useful life.

### Operational Expenses

The incremental cost of operating a CNG fueled school bus in comparison to a conventional diesel fueled school bus was set at \$0.01 per mile on average based on data from the South Coast Air Quality Management District's Results of School Bus and Infrastructure Survey, Draft White Paper, January 2005 (SQAQMD 2005). This value accounts for fuel cost, vehicle repair cost and the

normal cost of maintenance. Some school districts reported per mile costs larger than \$0.01 and some school districts reported a net savings on a per mile basis. This average value was used in combination with an average annual mileage of 13,666 miles per year to calculate an incremental annual operational cost of \$3416 for CNG school bus operation.

**Scenario Two**

Scenario Two deals with the retrofit of in-use diesel buses with diesel particulate filters (DPF). It is estimated that there are approximately 1300 diesel school buses in use in the SCQMD that are eligible for DPF retrofit but do not yet have DPFs. Currently there is no funding specified for these DPF retrofits, however funding could become available at some later date.

The analysis assumed that 325 in-use school buses could be fitted with diesel particulate filters every year for four years starting in 2006, resulting in a total of 1300 retrofits. It was assumed that the DPFs would have a lifetime of 11 years and that the buses would travel 13,666 miles per year, as determined from EMFAC2002. Since the majority of the public school bus fleet has already been retrofitted with DPFs, it was assumed that the remaining eligible school buses in the air district would be those school buses operated by private school bus contractors providing services to the public schools. Private school bus contractors tend to operate their school buses for fewer years than public schools before they are sold. Staff assumed that once DPF retrofitted private school buses were sold they would still operate within the air district under a different capacity, either as a public school bus or as a church bus, or a bus used in the transport of agricultural workers, or in some other capacity.

The emission reduction with the DPF was assumed to be an 85 percent reduction in PM and a 95 percent reduction in hydrocarbon (HC) emissions. These reductions were based on an engine certified to a 0.1 g/bhp-hr PM standard and a 0.125 g/bhp-hr HC standard.

The cost effectiveness calculated for Scenario Two was determined to be \$380,000 per ton of PM, as shown in Table 4 below.

Table 4 Scenario 2: DPF Retrofits on 1,300 Buses (06-09) No funding for retrofits specifically allocated			
Pollutant	Reductions (tons)	Cost	C/E
PM	38	\$15.6M	\$380,000/ton

Capital Costs

The DPF was assumed to cost \$8,000 per unit installed.

## Operational Costs

Operational incremental costs for the diesel bus with DPF were assumed to include DPF baking and deashing once every two years at a cost of \$800 per event. Typically, DPFs are designed to catalytically oxidize the collected PM using the heat generated by the engine's exhaust during normal operation. Such filters are described as passive because they do not require the external addition of heat to burn off the collected PM. School buses however, do not always reach the require operating temperature to light-off the collected PM. Therefore, it was assumed that a DPF installed on a school bus would need to have periodic baking to achieve temperature to burn off collected PM. DPFs regardless of the vehicles operating cycle will need to have collected ash removed from the filter and disposed of properly.

School districts may choose to purchase a DPF baker to reduce their costs, however that was not considered in this analysis.

DPFs require the use of ultra low sulfur diesel fuel (ULSDF). The incremental cost for the use of ULSDF was not considered since the use of ULSDF is already widespread within California and will be the only diesel fuel available in California in 2007.

### **Scenario A**

Scenario A was developed to determine the emission benefits and cost effectiveness if the Lower Emission School Bus Program's funding was split to include some funding for cleaner diesel buses. This scenario assumed that this funding was proportioned between alternative-fueled and diesel fueled buses in a ratio of two-thirds of the funds to purchase new CNG school buses and one-third to purchase new diesel school buses equipped with original equipment manufacturer (OEM) supplied DPFs. Beginning with the model year 2007, standard purchase diesel school buses will be equipped with DPFs by the engine manufactures in order to comply with the national 0.01 g PM per bhp-hr emission standard. Therefore, in this scenario the two-thirds one-thirds funding split would only be relevant for model years 2005 and 2006 school buses. Starting in 2007 all of the funding would go toward the purchase of new CNG school buses.

There would be adequate funding for 69 new CNG school buses and 27 new diesel school buses equipped with OEM supplied DPFs in 2005 and 2006 assuming that one third of the Lower Emission School Bus Program's funding was allocated to the diesel school buses and two thirds to the CNG. The funding allocation for 2005 and 2006 is shown in Table 5 below. The funding allocation for 2007 through 2009 was assumed to be similar to that given for Scenario One in Table 1, previously presented. Given these assumed allocations, there would be adequate funding for 92 CNG school buses per year for 2007 through 2009.

Funding Source	Projected Annual Funding	Allocation			Assumed State Contribution /bus	Number of buses purchased
		Infrastructure	CNG buses	Diesel Buses w/ DPF		
Lower-Emission School Bus (AB 923)	\$6.22 mil	10%	90%	--	~\$127K	44
	\$3.11 mil	--	--	100%	~\$112K	27
MSRC	\$1.5 mil	0%	100%	0%	\$60K	25
Clean Fuels Fund (AB2766)	\$325K	100%	--	--	--	N/A
Total	\$11.155 mil	--	--	--	--	69 CNG 27 Diesel

This scenario used the 13,666 average vehicle miles traveled per year derived from EMFAC2002 and the assumed public school bus lifetime of 25 years.

The emission reductions achieved with a new diesel bus with OEM supplied DPF would include PM, down to 0.01 g/bhp-hr, but not NOx. The emission reductions achieved with a new CNG bus would include both NOx and PM, as shown in Table 2, presented earlier in this appendix.

The cost effectiveness calculated for Scenario A was determined to be \$60,000 per ton of NOx and \$423,000 per ton of PM, as shown in Table 6 below. These cost effectiveness values are based on the assumption that half the costs for the model years 2005 and 2006 CNG-fueled vehicles are attributed to NOx reductions and half to PM reductions. All of the costs of the model years 2005 and 2006 diesel vehicles are attributed to PM reductions. Similarly, all of the costs for the model years 2007 through 2009 CNG-fueled vehicles are attributed to NOx reductions.

Pollutant	Reductions (tons)	Cost	C/E
NOx	307	\$28.4M	\$60,000/ton
PM	13		\$423,000/ton

### Capital Costs

The capital costs associated with Scenario A were calculated on a per bus basis.



## Diesel

The incremental capital cost for a new model year 2005 or 2006 diesel bus with an OEM equipped DPF was assumed to be approximately the same as a DPF retrofit, or \$8,000.

## CNG

The incremental capital costs for a new CNG bus include the incremental cost of the initial purchase price of the bus, infrastructure required for refueling, maintenance facility upgrades, and replacement of the CNG onboard fuel tanks after 15 years of service.

The incremental cost of the purchase price for a CNG school bus was estimated at \$31,000 for model years 2005 and 2006, and \$29,300 for model years 2007-2009. This difference in the incremental capital costs for the CNG school bus takes into account the fact that conventional diesel school buses will become more expensive in model years 2007-2009 in order to comply with the new 2007 federal emission standard for heavy-duty diesel engines.

CNG fueled school buses require specialized refueling infrastructure that may not be available to all fleets. The regulatory proposal specifies an allowance of \$13,000 per bus to either upgrade or install a refueling system. This amount was used as the incremental capital cost for refueling infrastructure.

Servicing CNG fueled school buses require upgrades to maintenance facilities that were originally developed to service diesel fueled school buses. The \$4,000 per bus allowance for maintenance facility upgrades was used as the incremental cost for upgrading school bus maintenance facilities to allow routine maintenance to be performed on CNG fueled school buses.

CNG school buses require that the onboard natural gas fuel be stored in high pressure gas cylinders. These cylinders have a lifetime of 15 years and after that time they must be replaced. It was assumed that \$15,000 would cover the cost of fuel cylinder replacement after 15 years of service. The replacement cylinders were assumed to last for the 10 remaining years of the school bus's useful life.

## Operational Expenses

### Diesel

Operational incremental costs for the diesel bus with DPF were assumed to include DPF baking and deashing once every two years at a cost of \$800 per event. Typically, DPFs are designed to catalytically oxidize the collected PM using the heat generated by the engine's exhaust during normal operation. Such filters are described as passive because they do not require the external addition of heat to burn off the collected PM. School buses however, do not always reach the require operating temperature to light-off the collected PM. Therefore, it was assumed that a DPF installed on a school bus would need to have periodic

baking to achieve temperature to burn off collected PM. DPFs regardless of the vehicles operating cycle will need to have collected ash removed from the filter and disposed of properly.

School districts may choose to purchase a DPF baker to reduce their costs, however that was not considered in this analysis.

DPFs require the use of ultra low sulfur diesel fuel (ULSDF). The incremental cost for the use of ULSDF was not considered since the use of ULSDF is already widespread within California and will be the only diesel fuel available in California in 2007.

## CNG

The incremental cost of operating a CNG fueled school bus in comparison to a conventional diesel fueled school bus was set at \$0.01 per mile on average based on data from the South Coast Air Quality Management District's Results of School Bus and Infrastructure Survey, Draft White Paper, January 2005 (SQAQMD 2005). This value accounts for fuel cost, vehicle repair cost and the normal cost of maintenance. Some school districts reported per mile costs larger than \$0.01 some school districts reported a net savings on a per mile basis. This average value was used in combination with an average annual mileage of 13,666 miles per year to calculate an incremental operational cost of \$3416 for CNG school bus operation.

### **Scenario B**

Scenario B is similar to Scenario A in that it assumes that the Low Emission School Bus funding is split between alternative-fueled and diesel fueled bus purchases in a ratio of two-thirds for alternative-fueled and one-third for diesel fueled. This scenario was developed in order to determine the emission benefits and cost effectiveness if the one-third funding for diesel fueled purchases was applied to new diesel school buses equipped with the Cleaire Alliance Longview.

The Cleaire Alliance Longview is a lean NOx catalyst mated with a DPF. The ARB verified the Cleaire Longview system for specific 1993 through 2003 model year diesel engines used with on-road applications operating on ultra low sulfur diesel fuel. Cleaire has expressed an interest to extend this verification to encompass model years 2004 through 2006 diesel engines.

Beginning with the model year 2007 school buses, standard purchase diesel school buses will be equipped with DPFs by the engine manufactures in order to comply with the national 0.01 g PM per bhp-hr emission standard. Consequently, equipping a new diesel bus with the Cleaire would not be applicable. Therefore, in this scenario, similar to Scenario A, the two-thirds one-thirds funding split would only be relevant for model years 2005 and 2006 school buses. Starting in 2007 all of the funding would go toward the purchase of new CNG school buses for this scenario.

It was estimated that in 2005 and 2006 there would be adequate funding for 69 CNG school buses and 25 new diesel school buses retrofitted with the Cleaire Alliance Longview. These funding allocations are shown in Table 7 below. The funding allocation for 2007 through 2009 was assumed to be similar to that given for Scenario One in Table 1 presented previously. Given these assumed allocations, there would be adequate funding for 92 CNG school buses per year.

Funding Source	Projected Annual Funding	Allocation			Assumed State Contribution /bus	Number of buses purchased
		Infrastructure	CNG buses	Diesel Buses w/ Cleaire		
Lower-Emission School Bus (AB 923)	\$6.22 mil	10%	90%	--	~\$127K	44
	\$3.11 mil	--	--	100%	~\$123K	25
MSRC	\$1.5 mil	0%	100%	0%	\$60K	25
Clean Fuels Fund (AB2766)	\$325K	100%	--	--	--	N/A
Total	\$11.155 mil	--	--	--	--	69 CNG 25 Diesel

The emission reductions assumed for this scenario for new diesel buses with the Cleaire Alliance Longview are a 25 percent reduction in NOx emissions and an 85 percent reduction in PM emissions.

The emission reductions assumed for the new CNG buses are illustrated in Table 2, presented earlier in this appendix.

This scenario used the 13,666 average vehicle miles traveled per year derived from EMFAC2002 and the assumed public school bus lifetime of 25 years.

The cost effectiveness values calculated for Scenario B were determined to be \$61,000 per ton of NOx and \$390,000 per ton of PM. These cost effectiveness values are based on the assumption that half the costs for the model years 2005 and 2006 vehicles are attributed to NOx reductions and half to PM reductions. All of the costs for the model years 2007 through 2009 vehicles are attributed to NOx reductions.

**Table 8 Scenario A: 69 New CNG buses and 27 new Diesel buses w/Cleaire Alliance Longview /yr (05-09): 92 new CNG buses/yr (07-09)**

Pollutant	Reductions (tons)	Cost	C/E*
NOx	328	\$29.5M	\$61,000/ton
PM	13		\$390,000/ton

Capital Costs

The capital costs associated with Scenario B were calculated on a per bus basis.

**Diesel**

Model years 2005 and 2006 new diesel fueled school buses would be retrofitted with the Cleaire Alliance Longview system. The Cleaire Alliance Longview was assumed to cost \$19,000 installed. The Longview has a useful life of about 11 years in a typical school bus duty cycle within the South Coast Air Quality Management District. Since the useful life of a school bus has been determined to be 25 years, a second Longview will need to be installed in year 12 or 13 of the bus’s life to extend the calculated emission reductions from this device until the end of the school bus’s useful life. It was assumed that the replacement Longview would cost \$19,000 in 2005 dollars.

**CNG**

The incremental capital costs for a new CNG bus include the incremental cost of the initial purchase price of the bus, infrastructure required for refueling, maintenance facility upgrades, and replacement of the CNG onboard fuel tanks after 15 years of service.

The incremental cost for the initial purchase price of the CNG school bus was estimated at \$31,000 for model years 2005 and 2006, and \$29,300 for model years 2007-2009. This difference in capital costs for the CNG school bus takes into account the fact that conventional diesel school buses will become more expensive in model years 2007-2009 in order to comply with the new 2007 federal emission standard for heavy-duty diesel engines.

Since CNG fueled school buses require specialized fueling infrastructure that is more expensive than standard diesel fueling infrastructure it was assumed that \$13,000 per bus would be sufficient for fueling system upgrades.

Servicing CNG fueled school buses require upgrades to maintenance facilities that were originally developed to service diesel fueled school buses. It was assumed that \$4,000 per bus would provide sufficient funding to upgrade school bus maintenance facilities to allow for routine maintenance to be performed on CNG fueled school buses.

CNG school buses require that the on board natural gas fuel be stored in high pressure gas cylinders. These cylinders have a lifetime of 15 years and after that time they must be replaced. It was assumed that \$15,000 would cover the cost of fuel cylinder replacement after 15 years of service. These replacement cylinders were assumed to last for the 10 remaining years of the school buses useful life.

### Operational Expenses

#### Diesel

There is a three percent fuel economy penalty associated with the use of the Longview. EMFAC2002 provides an average fuel economy for diesel fueled school buses within the South Coast Air Quality Management District of 6.46 miles per gallon. The average annual miles travel of 13,666 miles and an average diesel fuel cost of \$1.79/gallon were used to determine an incremental cost for this fuel penalty of \$114/year.

The Longview requires the use of ultra low diesel fuel (ULSDF). The incremental cost for the use of ULSDF was not considered since the use of ULSDF is already widespread within California and will be the only diesel fuel available in California in 2007.

Since the Cleaire Longview has a lean NOx catalyst coupled with a DPF, normal DPF maintenance must be performed. The lean NOx catalyst alone does not provide temperatures high enough to burn off the collected PM within the DPF. Engine exhaust temperature must be high enough to catalytically oxidize the collected PM. School buses however, do not always reach the require operating temperature to light-off the collected PM. Therefore, it was assumed that a DPF installed on a school bus will need to have periodic baking to achieve temperature to burn off collected PM. DPFs regardless of the vehicles operating cycle will need to have collected ash removed from the filter and disposed of properly. It was assumed that DPF baking and deashing would need to be done once every two years at a cost of \$800 per event.

#### CNG

The incremental cost of operating a CNG fueled school bus in comparison to a conventional diesel fueled school bus was set at \$0.01 per mile on average based on data from the South Coast Air Quality Management District's Results of School Bus and Infrastructure Survey, Draft White Paper, January 2005 (SQAQMD 2005). This value accounts for fuel cost, vehicle repair cost and the normal cost of maintenance. Some school districts reported per mile costs larger then \$0.01 and some school districts reported a net savings on a per mile basis. This average value was used in combination with an average annual mileage of 13,666 miles per year and a 25 year bus life to calculate a lifetime incremental operational cost of \$3417 for CNG school bus operation.

References:

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