APPENDIX C

COST EFFECTIVENESS METHODOLOGY

I.   METHODOLOGY

The basic methodology ARB uses to determine cost-effectiveness of a regulation is to determine what costs are involved to comply with the proposed regulation, and to compare those costs to the emission reduction benefits to the public. Staff summarizes this cost effectiveness as cost (in $) per pound of air pollutant reduced, in this case diesel particulate matter (PM). Staff calculated cost effectiveness two ways for this regulation because although this rule is primarily a PM-reduction measure, staff also estimates that reductions in HC and NOx emissions will take place.

A. Implementation Schedule

The implementation schedule for the proposed regulation dictates a phase-in by fleet and engine model year group (**Table 1**). Staff assumed a best available control technology (BACT) would be available for each model year engine. Staff also assumed municipalities and utilities would choose the least expensive BACT to comply with this regulation.

Table 1.   Implementation Schedule for Public and Utility Fleet Vehicles Model Years 1960 to 2006.

Group	Engine MY	Percentage of Group to Use Best Available Control Technology	Compliance Deadline
1[a]	1960 – 1987	20	December 31, 2007
		60	December 31, 2009
		100	December 31, 2011
2	1988 – 2002	20	December 31, 2006
		60	December 31, 2008
		100	December 31, 2010
3	2003 – 2006	50	December 31, 2009
		100	December 31, 2010

[a]Group 1: A municipality or utility not use Level 1 technology as BACT

B. Implementation Scenarios

PM emissions and exhaust temperatures are two criteria which usually dictate the type of diesel emission control strategy (DECS) that can be used on a particular vehicle. Based on available data on DECS, staff created a "most-likely" scenario (Table 2) to determine emission reductions and economic impacts:

Table 2. Most-Likely Verification Retrofit Scenario

Group	MY	%BACT	Implementation Date	Level 1[a]	Level 2[d]	Level 3	Repower
1	1960-1987[e]	20%	12/31/2007		10%		8%
		60%	12/31/2009				28%
		100%	12/31/2011			11%	33%
		Delay	12/31/2012				10%
2a	1988-1993	20%	12/31/2006	5%	5%	8%	
		60%	12/31/2008	2%	10%	25%	
		100%	12/31/2010			35%	
		Delay	12/31/2011			10%	
2b	1994-2002[d, f]	20%	12/31/2006	5%	5%	8%	
		60%	12/31/2008	2%	10%	25%	
		100%	12/31/2010			35%	
		Delay	12/31/2011			10%	
3	2003-2006[b,c]	50%	12/31/2009		20%	30%	
		100%	12/31/2010		20%	30%	

Notes:
[a]Assumes current Level 1 verification will be extended to 1960-1993 model years.
[b]Assumes current Level 3 verification will be extended to 2003-2006 model years.
[c]Assumes current Level 1 verification will be extended to 2003-2006 model years.
[d]Assumes current Level 2 verification will be extended to all model years
[e]Assumes a Level 3 verification will be available for some 1960-1987 model years.
[f]Assumes a Level 3 active DPF verification will be available for some 1988-2002 model years.

C. Cost Calculations

Two types of costs were accounted for in the cost effectiveness analysis, capital costs and operation and maintenance (O & M) costs. For each cost, ARB determined the range of costs from the published literature and from estimates supplied by experts during phone inquiries and meetings. Taking the collected data, staff calculated a low, average, and high amount for each cost. It is important to note that since most of these costs are predictive, they could vary significantly depending on the state of the economy, demand, competition, and other as yet unknown factors.

1. Capital Costs

As an example of how costs will likely decrease over time, staff compared future predicted and current capital costs for several diesel emission control strategies. For example, capital costs for a passive DPF include the cost of the device, an engine backpressure monitor, and its installation. In general, the horsepower of

the engine determines the cost of DECS. Table 3 provides an estimate of the current cost to retrofit on-road engines and vehicles with catalyst-based DPFs, Diesel Oxidation Catalysts (DOC), Engine Gas Recirculation plus DPFs (EGR+DPFs), and Lean NOx catalyst plus DPF (Lean NOx cat+DPF). This information provides a range of costs depending upon the horsepower of the engine. Basically the low end of the range is for medium heavy duty engines and the high end of range is for larger heavy heavy duty engines. MECA has provided some updated costs in a draft document entitled "MECA Response to ARB Questions," dated June 9, 2004. These questions were posed to MECA by ARB prior to an ARB, SCAQMD, and MECA meeting on May 18, 2004.

Table 3. Capital Costs Associated with a DECS Retrofit of On-Road Engines[1]

DECS	Low	High	Average
DOC	$1,000	$2,000	$1,500
Passive DPF	$6,000	$11,000	$8,500
EGR+DPF	$14,000	$18,000	$16,000
Lean NOx cat+DPF	$13,000	$17,000	$15,000

In contrast to the retrofit costs presented in **Table 3**, **Table 4** presents the United States Environmental Protection Agency's (U.S. EPA's) estimate of the future (2007) costs of applying DOC and passive DPFs to in-use on-road engines and vehicles (U. S. EPA 2004). The U.S. EPA estimates are based on higher production volumes, and they are similar to the future cost projections presented by manufacturers (MECA 2000, 2004).

Table 4. Future (2007) Catalyst-Based DOC and DPF Retrofit Costs for On-Road Engines

DECS	Average Cost
DOC	$540
DPF[2]	$2,500

Based on the costs from these two tables the average cost of a passive DPF installed could be a high of $8,500 currently to a low of $2,500 after the introduction of new 2007 DPF equipped engines. The current cost is consistent with costs quoted by two providers of DPFs that ranged from $7,000 to $8,200, which included the cost of backpressure monitors. A contrast therefore exists between the current costs associated with retrofitting existing engines and the future costs associated with retrofitting engines when the new 2007 engines and

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[1] The costs given include installation costs and any training that may be necessary.
[2] This cost is based on increased production and availability of technologies due to EPA's 2007 new engine requirements.

technology are available in large production volumes. The total cost of installation including any additional hardware such as an engine backpressure monitor were factored into these current and projected costs.

Also, the current costs are not representative of the higher end of the range of capital costs associated with a passive DPF. Additional sources quote costs upwards of $9,000 (Cai-infopool 2002) and $8,000 (Fuelstar 2000). These high end costs for passive DPF are reflective of the current costs associated with the capital costs associated with an active DPF. No capital active DPF costs were discovered in the literature, but from meetings with manufacturers and quotes for demonstration devices, ARB staff found the range of capital costs to be from $10,000 to $12,500 with an average cost of $11,250.

On the other hand, the current capital costs of DOCs are nearer the low end of the range of costs associated with passive DPF. The costs for these devices range from $540 to $3,150 with an average of $1,970 (MECA 2000, 2004, EPA 2004).

Those who do opt to use an ARB verified fuel DECS in lieu of low sulfur diesel fuel may do so. The only option currently available and verified by ARB, is Lubrizol's PuriNOx^{TM}, a fuel-water emulsion. The only capital cost for this option is for a fuel recirculation pump. Based upon the conversations with Lubrizol, it is estimated that the cost of a fuel recirculation pump could range from $1,000 to $10,000. The most common pump size used is about $4,000. The high end of the cost range is based upon a very large tank size.

2. Operation and Maintenance Costs

O & M costs considered by staff included the cost for cleaning the trap and an incremental fuel price if a fuel based DECS was utilized. The cost of increased inspection and DECS cleanings, which ranged from zero cost to $190 per occurrence. Some DPF manufacturers specify a cleaning interval based upon mileage of 25,000 to 60,000 (depending upon the device manufacturer). Therefore, staff estimated that a passive DPF on average would be cleaned once every three years. This would result in an average cost of $33 per year based on the average mileage of a public and utility fleet vehicle of 7,800. Of course the actually number of DPF cleaning per year would dependent on the DECS and other vehicle variables, such as oil consumption. PuriNOx^{TM} costs are based on incremental O & M costs of approximately 16 cents per gallon.

The costs for various DECS staff believes might be used as options to meet the requirements of this regulation, therefore, might vary substantially between the strategies. The option that is most cost effective (i.e., the least cost option responsible for the greatest decrease in diesel PM emissions) is the passive and active DPF. Since this option will likely not be available to all, staff have

accounted for the other technologies that might be used in the cost effectiveness of this regulation.

Table 5. Average Costs Associated with Possible DECS used for Public and Utility Fleet Vehicles.

Cost	Active/ Passive DPF	Flow Through Filter	PuriNOx™	DOC
Installed Cost and Associated Hardware	$7,600	$5,000	$4,000	$1,966
Annual O & M				
Increased Maintenance	$33	$0	N/A	$0
Incremental Fuel	$0	$0	$157	$0
Total	**$7,633**	**$5,000**	**$4,157**	**$1,966**

D. Repower Costs

The cost to repower an engine to meet a 0.01 g/bhp-hr PM emission standard (2007 or later model years) will vary according to the engine model year and vehicle type from which it is being converted. Replacing an electronically-controlled fuel injection engine (1994 and newer model years) with a 2007 or later model year engine is expected to cost less than replacing a mechanically-controlled fuel injection engine of earlier vintage due to the challenges associated with conversion of mechanical to electronic systems. In some instances it may not be possible to upgrade engines because of space constraints in the engine compartment of the vehicle. An owner would, therefore, need to consider using a DECS or replacing the entire vehicle. In other cases it may be more cost effective to comply by replacing a pre-1994 model year engine with a 1994 to 2006 model year engine and installing a diesel particulate filter.

Based upon discussions with fleets and engine installers, staff estimated two different kinds of repower situations. One was to repower a mechanically controlled engine with a newer electronically controlled engine. This typically would mean upgrading a pre-1993 to a 1998 to 2002 model year engine. Staff found the average cost to do this kind of repower ranged from $15,000 to $50,000, depending upon the engine horsepower rating. Staff assumed that if this regulation was not in-place that the municipality or utility would rebuild their engine at least once during the phase in of the regulation, since only the oldest engine model year group would be required to be repowered. Therefore, the cost of the rebuild was substracted out of the total cost of the repower. Since these engines would still require additional diesel emission control to meet the best available control technology requirement for this regulation, staff included the average cost of a DPF. Based on the data, the average total cost used in this analysis is $30,000 (Table 6)

Table 6. Average Engine Repower Capital Costs.

Newer Engine (1998-2002) Plus Installation	Capital Cost
Average Total Cost	$33,000
Average Cost of DPF	$7,600
Cost In-Frame Rebuild	($7,000)
Total Repower Capital Costs	**$29,986**

Staff calculated an alternative repower scenario where a mechanically controlled engine was upgraded to at least a 1991 to 1993 model year engine (also a mechanically controlled engine.) Based upon discussions with fleets and engine installers, the cost for this type of repower would range from $10,825 to $23,000. Staff also assumed that if this regulation was not in place that at least one rebuild would occur during the proposed implementation period, since only the oldest engines would be required to be repowered. Therefore, the cost of this rebuild was subtracted out of the total costs. Once again, additional controls would still be required for this repowered engine to be in compliance therefore; the average cost of a Level 2 Flow Through Filter was added. Based on this data, the average total cost used in this analysis was $12,000 (Table 7).

Table 7. Average Engine Repower Costs

Newer Engine (1991-1993) Plus Installation	Capital Cost
Average Total Cost	$17,000
Average Cost of FTF	$5,000
Cost In-Frame Rebuild	($7,000)
Total Repower Capital Costs	**$12,000**

Two benefits offset the initial cost of repowering an engine, increased fuel economy and decreased maintenance costs. The fuel economy benefit will vary depending on the engine replaced. However, using the fuel economy data from U.S. EPA's MOBILE 6.3 (EPA 2002) staff calculated that repowering a pre-1987 with a 1988 and newer engine would increase on average a public or utility vehicle mileage by approximately one mile per gallon. This fuel savings would help the owner recoup the costs associated with the repower. Similarly, decreased maintenance would result in increased time on the road and fewer repair costs, thus reducing repower costs.

E. Cost-Effectiveness Calculation

Staff determined the amount of PM, HC, and NOx reduced per year based on the implementation of this proposed regulation. Using one method, staff determined cost-effectiveness by dividing the total discounted capital costs plus annual O & M costs by the annual pounds of diesel PM reduced. Using the second method, staff allocated a portion of the costs to PM reduced and some of the costs to HC and NOx reduced.

In order to arrive at the discounted capital costs for the regulation, staff multiplied the capital costs by the capital recovery factor[3], and assumed a lifetime of the DECS based on the ten years with an annual interest rate of seven percent.[4] Certain technologies, such as a DPF, will likely last much longer than ten years in a well-maintained vehicle, as some DPFs have been operating for over 300,000 miles in the U.S. Public and utility fleet vehicles drive on average 7,800 miles per year[5] and based on this a DPF could be expected to last over 38 years. Ten years life for DECS was used in an effort to make a conservative estimate. Clearly, the cost-effectiveness would be lower if a DECS has a longer lifetime than estimated here.

1. All Costs Allocated to PM Reduction

The average costs of implementing the program from December 31, 2006, to December 31, 2010, were included in the cost-effectiveness calculation (Table 8). The average cost effectiveness of the program, considering the range of costs and most likely implementation scenario, is about $198 per pound diesel PM reduced. The staff predicts the cost may be lower than this average, based on past experience and because engine manufacturers will need to begin ordering DPFs to the meet 2007 federal PM emission standard of 0.01 g/bhp-hr, thus increasing volume.

Table 8. Average Cost Effectiveness Most-Likely Implementation Scenario: All Costs Allocated to PM Reduction.

Fiscal Year	Diesel PM Reduced (lb/yr)	Total Annual Cost ($/yr)	Cost per Pound PM Reduced
2006	14,844	$2,762,417	
2007	36,062	$6,448,860	
2008	58,958	$11,732,495	
2009	85,980	$16,565,015	
2010	112,137	$21,842,627	
TOTAL	307,981	$59,351,414	$193/lb

2. Costs Split Between PM and HC+NOx Reductions

Along with reducing diesel PM, each control technology also reduces HC emissions, and some, such as a new engine, also reduce NOx emissions. Staff therefore has calculated cost-effectiveness by allocating a certain portion of the costs to HC and NOx reductions and the rest to PM reductions. The cost attributed to HC and NOx reduction was 18%. This percentage was selected

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[3] Capital Recovery Rate Factor: $480r(1+r)^N/[(1+r)^N-1]$, where r = the annual interest rate, and N = lifetime of project (in years) (Linsley 1977).
[4] USEPA uses the factor to calculate costs of environmental programs.
[5] TIAX. 2003.

based upon historical cost effectiveness for control measures for HC and NOx which is about $11/lb. Using this method, the average 2010 cost-effectiveness of this rule is $10.92/lb HC+NOx and $159.95/lb PM reduced (Table 9).

Table 9. Average Cost-Effectiveness of Current Implementation Scenario: Costs Split Between PM and HC+NOX.

Fiscal Year	Diesel PM Reduced (lb/yr)	HC+NOX Reduced (lb/yr)	Annual Costs ($/yr)	Cost per Pound Reduced	
				92% PM	18% to HC+NOx
2006	14,844	39,469	$2,762,417		
2007	36,062	111,976	$6,448,860		
2008	58,958	189,111	$11,732,495		
2009	85,980	255,493	$16,565,015		
2010	112,137	327,785	$21,842,627		
TOTAL	**307,981**	**923,834**	**$59,351,413**	**$159.95/lb**	**$10.92/lb**

II.   OTHER COST FACTORS

A number of costs are not factored into the cost effectiveness analysis because of lack of available information. The costs accounted for above do not include administrative costs (see form 399 attachment for these). From discussions with trap manufacturers, ARB staff assumed the DECS manufacturer would provide maintenance training at no additional charge.

Staff assumed no fuel economy penalty would exist from the use of a DECS. This is based on staff experience with the verification procedure and the inability of studies to determine an impact, either positive or negative (LeTavec *et al* 2000, LeTavec *et al* 2002). A slight penalty or benefit may exist, but until more conclusive data is available staff assumed either would be negligible.

Based on the low miles traveled by public and utility fleets on average, staff assumed the cost for disposal of any ash generated would be negligible and did not include this cost in the overall cost effectiveness. From cleaning of the DPF during ARB demonstration and testing programs, ARB staff estimated the weight of weight ash to be approximately ten to 15 grams per disposal, which is dependent upon oil consumption. The quantity of ash would be greater with more than average oil consumption. Based on conversations with the DECS manufacturers and demonstration program experience, staff determined the number of cleanings would be every three years, dependent on the DECS and other vehicle variables, such as oil consumption.

III.   REFERENCES

ARB 2003. Proposed Diesel Particulate Matter Control Measure for On-Road Heavy-Duty Residential and Commerical Solid Waste Collection Vehicles Staff Report.

Clean Air Counts. 2002. Voluntary Diesel Retrofit Program for Clean Air Communities. www.cleanaircounts.org. July 31, 2002.

Department of Toxic Substances Control. 6/22/01.

Fuelstar. 2000. Fuelstar 2000 – Diesel Engines: Comparison of Fuelstar Combustion Catalysts with Diesel Oxidation Catalysts (DOC's) and Soot Traps. www.fuelstar.com. July 31, 2002.

Girstenson, Allen. June 2001. Personal communication.

Le Tavec, Chuck, Uihlein, Jim, Segal, Jack, Vertin. 2000. EC-Diesel Technology Validation Program Interim Report. SAE. 2000-01-1854.

LeTavec, Chuck, Chatterjee, Sougato, Hallstrom, Kevin, Chandler, Kevin, Coburn, Tim. 2002. Year-Long Evaluation of Trucks and Buses Equipped with Passive Diesel Particulate Filters. SAE. 2002-01-0433.

Linsley, Ray K. 1977. Water Resources Engineering. Harper & Row.

MECA. November 9, 2000. MECA Independent Cost Survey for Emission Control Retrofit Technologies. Washington, DC.

MECA. June 9, 2004. Response to ARB Questions for May 18, 2005 ARB/SCAQMD/MECA Meeting

Office of Management and Budget. October 29, 1992. Circular No. A-94 Revised (Transmittal Memo No. 64). Subject: Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs. www.whitehouse.gov/omb/circulars/a094/a094.html

TIAX. March 17, 2003. California Public Fleet Heavy-Duty Vehicle and Equipment Inventory.

U. S. EPA. May 2000. Draft Regulatory Impact Analysis for the Proposed Heavy-duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements Rule. EPA420-D-00-001. Washington, D.C.

U.S. EPA. August 2002. Draft Updating Fuel Economy Estimates in MOBILE6.3. EPA420-P-02-005. Washington, D.C.

U.S. EPA. October 2004. Draft Diesel Retrofit Technology, A Cost Effective Method to Reduce Particulate Matter Emissions from Heavy Duty Diesel Engines.

Worldbank. 2001.