APPENDIX F: COST METHODOLOGY FOR MDVS

I. Cost Methodology for Gasoline MDVs

In order to calculate the incremental cost of a medium-duty low-emission vehicle, a methodology is used which is similar to an analysis recently performed for light-duty low-emission vehicles. This methodology includes calculation of the following costs associated with vehicle production: variable costs (cost of parts, assembly, shipping and warranty), support costs (research, legal and administrative), investment recovery (machinery and equipment to manufacture the parts, assembly plant changes, vehicle development, and costs of capital recovery) and dealer costs (dealership operating costs and costs of capital recovery).

The first step in determining costs includes an analysis of the systems and technologies which will likely be used by manufacturers to meet the required emission levels. Based on the technology assessment described earlier in this report, staff has identified the most likely emission system configurations and hardware to be used in meeting the LEV and ULEV emission categories (see Figure 1). Since almost all gasoline medium-duty vehicles are eight-cylinder engines, only that configuration will be addressed in this analysis.

A. Variable Costs

This section addresses the four components of variable costs: the cost of the new parts needed for low-emission vehicles, new assembly operations, incremental shipping costs and additional warranty.

1. Cost of Components

Table 1 provides a detailed breakdown of expected component usage and costs for gasoline medium-duty LEV and ULEV emission control systems. In the earlier technology assessment, several technologies and strategies were identified which have already been developed for light-duty vehicles. These strategies include reduced engine out emissions, improved fuel preparation and advanced catalysts. Some of these improvements will first appear on Tier 1 vehicles currently being phased into production.

Table 1
INCREMENTAL COSTS OF MEDIUM-DUTY LEVs AND ULEVs
(8 cylinder gasoline vehicles)

	LEV				ULEV			
Emission Control Technology	**Cost**	**% Tier 1 using tech**	**% LEV using tech**	**Incremental cost**	**Cost**	**% Tier 1 using tech**	**% ULEV using tech**	**Incremental cost**
Sequential multi-point fuel injection (a)		100	100	0		100	100	0
Dual O_2 sensor compensation (b)		0	100	0		0	100	0
Improved fuel preparation (c)	16	0	100	16	16	0	100	16
Adaptive transient control (d)	0	0	100	0	0	0	100	0
Heat optimized exhaust pipe (e)	16	0	100	16	12	0	100	12
Reduced engine out emissions (f)	4	66	100	1.36	4	66	100	1.36
Leak-free exhaust system (g)	30	0	100	30	30	0	100	30
Greater catalyst loading (w/ improved washcoat) (h) a) Pd only b) Pt-Rh-Pd	0	0	100	0	20	0	100	20
Underbody or main catalyst	96	100	25	-72	96	100	0	-96
Toeboard/underfloor cascade catalyst	150	0	75	112.50	150	0	85	127.50
Dual close-coupled catalysts	132	0	25	33	132	0	0	0
Dual EHCs (w/o PM on htr) (i)	300	0	0	0	300	0	15	45
Electronic EGR	20	66	100	6.80	20	66	100	6.80
Supplemental air injection (j)	65	7	7	0	65	7	100	60.45
TOTAL INCREMENTAL COST				$143.66				$223.11

(a) Sequential fuel injection will be utilized on all Tier 1 vehicles and therefore, cost will not be ascribed to the LEV program.
(b) Dual O_2 sensor compensation software was developed for LDVs and can be applied to MDVs; the additional O2 sensor cost was ascribed to OBD II for catalyst efficiency monitoring.
(c) Air assisted injection requires minor redesign of the idle air control valve at no additional cost and addition of an adaptor to each injector at a cost of $2 each.
(d) Adaptive transient control constitutes software changes only; at no additional hardware cost.
(e) Heat optimized exhaust pipe is estimated at 6-8 feet in length, at a cost of $2 per foot incremental.
(f) Engine-out emissions will also be lower due to design changes (such as reduced crevice volumes) and will be obtained at a cost of $4/ vehicle to account for the cost of reduced crevice volume pistons.
(g) Leak free exhaust systems include corrosion-free flexible coupling and two flat flange gaskets, plus improved welding of catalyst assemblies.
(h) Active metals costs are estimated to be lower overall; but the improved washcoats are expected to restore the cost of the catalyst to its former level. For ULEVs, however, an additional $20 per vehicle was added to account for greater catalyst loading compared to LEVs.
(i) Dual EHC costs include costs of battery, alternator, and air pump upgrades, switches, cables, and additional volume and precious metal loading of the catalysts.
(j) Cost of air injection includes an electric air pump with integrated filter and relay, wiring, air shut-off valve with integral solenoid, check valve, tubing and brackets.

Improved Engine Out Emissions. Manufacturers are expected to reduce engine-out emissions by improving engine combustion through design changes such as reducing the crevice volume between the upper portion of the piston and cylinder wall. One manufacturer has estimated that the cost of reduced crevice volume pistons would be about $4 per vehicle. Staff has incorporated this estimate into the cost analysis. In addition, manufacturers are expected to utilize electronic exhaust gas recirculation to reduce NOx emissions. These electronic systems provide enhanced levels of exhaust gas recirculation during heavy load conditions compared to previous vacuum operated systems, and afford more precise operational control. ARB staff initially projected that all Tier I vehicles would require EGR; one manufacturer, however, has disclosed that they do not intend to include EGR on their Tier I vehicles. Accordingly, staff has incorporated this information into the analysis.

In addition to improving engine-out emissions, manufacturers are expected to improve exhaust system heat retention and rely on significantly improved catalysts. The use of laminated thin wall exhaust pipe will help retain exhaust gas heat during startup to facilitate rapid catalyst light-off. Staff has estimated that the cost of pipe for medium-duty vehicles will be $2.00 per foot. This cost is higher than for light-duty applications because larger exhaust pipes are required for these larger displacement engines. In addition, the larger vehicles will utilize greater lengths of exhaust pipe. In this analysis, it is assumed that heavier weight vehicles will meet the LEV emission category standards, while the lighter medium-duty vehicles are assumed to meet the more stringent ULEV standard. This is because manufacturers seem to agree that achieving lower emissions is easier with less costly hardware on the lighter vehicles. Since the staff proposal calls for no more than 40 percent ULEVs, this split works well since more than half the medium-duty vehicles are in the lighter weight categories. Therefore, since the heavier vehicles will dominate the LEV category, higher exhaust pipe costs are ascribed to larger medium-duty vehicles with greater length exhaust systems than the lighter ULEVs (see Table 1). Manufacturers will also likely utilize leak-free exhaust systems to prevent aspiration of air which can hamper the efficiency of the catalyst in reducing NOx emissions. For light-duty vehicles, suppliers have indicated that each leak-free joint and improved catalyst welding would add about $15-30 to the cost of the car, depending on the exhaust system configuration. Staff expects that upper range of this cost can be ascribed to medium-duty vehicles.

Improved Fuel Preparation. In order to provide better fuel delivery and control, manufacturers are expected to utilize sequential fuel injection, dual oxygen sensor compensation and adaptive transient controls. However, for the reasons stated below, no additional cost has been ascribed to medium-duty vehicles for these technologies. Staff expects that air-assisted injectors will also be utilized, however, and has ascribed additional cost for this technology.

Based on discussions with industry, it appears that all Tier 1 medium-duty vehicles will be equipped with sequential fuel injection before the 1998 model year (the first year that LEVs and ULEVs are required) so that no additional cost should be ascribed for this technology being utilized on low-emission medium-duty vehicles. Dual oxygen sensors will be employed by manufacturers on all medium-duty vehicles by the 1996 model year to monitor catalyst efficiency as required by the On-Board Diagnostic II (OBD II) regulations and will be used for adaptive fuel control as well. Vehicle manufacturers are already utilizing the additional oxygen sensor in light-duty vehicles to provide adaptive fuel system compensation strategies to correct for deterioration in the primary oxygen sensor (which is used for achieving precise fuel control). Therefore, the cost of the second sensor has already been ascribed to the OBD II regulations and the software development for the adaptive fuel compensation system has already been accomplished for the light-duty fleet. Beside using adaptive fuel compensation strategies to correct for deterioration of the primary oxygen sensor, all vehicles currently incorporate a more fundamental steady-state adaptive control system to ensure better fuel control due to varying temperature effects, barometric conditions, or wear of other fuel control components; future low-emission vehicles are expected to extend the use of these adaptive controls to transient operating conditions as well in order to maximize the amount of time the fuel system maintains the air/fuel mixture for maximum catalyst conversion of pollutants. Since these adaptive transient controls will consist of software changes already developed for light-duty low-emission vehicles, it is again expected that this improvement will not add measurable cost to medium-duty low-emission vehicles.

Air assisted injectors are being increasingly incorporated into light-duty applications because they can achieve more efficient fuel atomization, more efficient combustion and reduced emissions. Staff estimates that this strategy will also be incorporated into medium-duty low-emission vehicles. The incremental costs ascribed to these injectors for light-duty vehicles ($2 each) should be the same for medium-duty vehicle applications.

Improved Catalysts. To improve the in-use performance of medium-duty vehicles, the staff has estimated the new palladium-only and tri-metal catalysts with greater active metal loading will be incorporated because of their improved light-off performance and greater high temperature capability. Although one vehicle manufacturer has indicated to staff that they believe there is a significant likelihood some MDVs may also require dual EHCs to meet the ULEV requirements, staff is not convinced these catalysts will be needed considering the F150 trucks' low emissions with conventional catalyst technology (see Technological Feasibility section). In consideration of that manufacturer's concerns, however, for the purpose of cost estimating, staff has included dual EHCs in 15% of gasoline-powered ULEVs. Concerning the costs of the palladium-only and tri-metal catalysts, catalyst suppliers suggest that such catalysts would not be more expensive overall than current platinum-rhodium catalysts. While the active metals costs are lower overall, (even when considering increased catalyst loading) the more sophisticated washcoats tend to restore the new catalyst costs to their former level. The costs ascribed to light-duty close-coupled and underbody catalysts have been increased by 20%, however, to account for the greater size and loading needed for low-emission medium-duty vehicles (i.e., LEVs and ULEVs). Despite the 20% additional cost allocated for the increased size and loading of these catalysts, one manufacturer has indicated that ULEV systems will still require added size and loading. Accordingly, staff has allotted $20 per ULEV to account for additional catalyst loading.

Air Injection. In addition, staff estimates that supplemental air injection will probably be utilized on all ULEVs to further improve HC and CO emissions during the cold start and warm-up period. Because medium-duty vehicles may need larger air pumps due to higher exhaust flow and perhaps back pressure increases, a 30 percent increase in cost was ascribed to medium-duty air pumps compared to light-duty vehicles.

2. Cost of Assembly

Costs to assemble emission control systems for the low-emission medium-duty vehicles are not expected to differ significantly from Tier 1 vehicles. While Tier 1 vehicles utilize one underfloor catalyst, 75% of LEVs and all ULEVs are also expected to utilize a single unit catalyst, albeit an advanced cascade warm-up and main converter assembly located in the toeboard or underfloor area of the vehicle. Hence, no additional cost should be ascribed for assembly of this catalyst. On the other hand, the other 25 percent of LEVs are expected to utilize dual close-coupled catalysts in addition to the downstream underfloor or main converter. The additional assembly cost of this LEV configuration compared to a Tier 1 vehicle is estimated to be $1.00, assuming a cost of $0.50 for each additional catalyst to account for the welding operation. Based on the estimated costs ascribed to light-duty vehicles, the assembly cost for an electric air pump for the ULEVs should be approximately $2.00 per vehicle assuming a two minute installation time and a total labor cost of $60 per hour. These costs are summarized in the table below.

Incremental Assembly Operations

Tier 1	LEV	ULEV
1 underfloor catalyst	1 cascade underfloor catalyst 2 close-coupled cats. (25%) Incremental cost: $0.25	1 cascade underfloor catalyst 1 air pump Incremental Cost: $2.00

3. Cost of Warranty and Shipping

Since the exhaust system configuration of a Tier 1 medium-duty vehicle does not differ from an LEV or ULEV (even the 25 percent of the LEVs utilizing close coupled catalysts will still be shipped as a single pre-welded exhaust pipe assembly), shipping costs are not expected to change measurably from the Tier 1 systems. The cost of shipping the air pump components was estimated to be the same as ascribed to light-duty vehicles. The added cost was estimated at $0.25.

While it is expected that medium-duty vehicles will require some upgrades to their catalyst systems to improve emission durability and increase their NOx emission margin, staff does not expect that medium-duty LEVs or ULEVs will employ components that are significantly different than those required for corresponding Tier 1 medium-duty vehicles except for the addition of an air pump and dual EHC/light-off units coupled with an underfloor catalyst system for ULEVs. Therefore, staff assumes a 0.1% (same as light-duty applications) defect rate for the catalysts and air pumps and related hardware. However, the costs of catalysts on low-emission medium-duty vehicles is higher than Tier 1 vehicles, which will result in incremental increases in warranty and the low-emission vehicles using dual close-coupled catalysts or dual EHCs would result in additional warranty cost as well. Also adding to the warranty costs of LEVs and ULEVs is the projection of increased usage of electronic EGR on LEVs and ULEVs compared to Tier I vehicles. A 0.1% defect rate is also assumed to be applicable to electronic EGR.

For this analysis, staff estimates the replacement costs of parts to be double the original cost to the OEM because of handling, inventory, staffing etc. involved in the replacement parts inventory and distribution process, including dealer costs. A labor rate of $50 per hour was allocated for warranty labor. Details of these estimates are included in the following table:

Incremental Warranty Cost for Gasoline Low-Emission Vehicles Compared to Tier I Vehicles

	LEVs				**ULEVs**			
	% that have tech.	Replacement Component Cost ($)	Labor Cost ($)	Incr. Warr. Cost ($)	% that have tech.	Replacement Component Cost ($)	Labor Cost ($)	Incr. Warr. Cost ($)
Dual Close-Coupled Catalysts	25	264	50	0.08	0			
Toe Board, Underfloor Cascade	75	300	25	0.24	85	300	25	0.28
Air Pump (incl. controls)	0				100	90	25	0.11
Check Valve, Hoses, Brackets	0				100	40	25	0.06
Dual EHCs (w/o PM on htr)	0	600	50		15	600	50	.10
Electronic EGR	100	40	25	.02	100	40	24	.02
TOTAL COST				0.34				0.57

B. Support Costs

This category addresses the effect that research and development, legal issues and administrative costs have on the cost of a low-emission medium-duty vehicle. Since considerable light-duty technology will generally be utilized on medium-duty vehicles and since no substantially new and unproven technologies are likely to be used, staff does not expect there will be additional liability costs. Similarly, the legal cost of investigating existing patents has already been ascribed to light-duty vehicles. Therefore, no incremental legal costs should be attributable to medium-duty vehicles. In terms of administrative costs, even though LEVs and ULEVs will employ somewhat different emission control systems than Tier 1 vehicles, the net number of total parts will not be significantly different. Therefore, the incremental administrative costs (such as purchasing, scheduling, and tracking activities) over the long term would likely be insignificant.

It also appears that basic research needed for medium-duty vehicles will have been conducted for light-duty vehicles (such as development of high temperature palladium catalysts). However, due to the potential for accelerated degradation of catalysts in medium-duty vehicles because of their more severe duty cycles (e.g., driving with a heavy load), manufacturers will need to conduct additional advance research to ensure durability of the emission control system. For this research, staff assumes that six person-years would be required. Accordingly, allowance has also been made for five advance development vehicles. Each advance vehicle was assumed to cost $50,000. The following table contains the details of the assessment.

Support Costs

Emission Control Technology	Eng. Staff for Technology Development		Staff Cost ($)(a)	Dev. Vehicles Cost ($)(b)	Additional Equipment ($)	Cost/vehicle ($/veh)(c)
	(Person yrs.)	(Person hrs.)				
Advance Pd Catalysts	6	12,480	748,800	250,000	0	3.12

(a) Development cost includes personnel, overhead and other miscellaneous costs at a total rate of $60/hr.
(b) Prototype development vehicles are estimated to cost $50,000 each.
(c) Cost has been distributed over 40,000 vehicles per year for a total of 8 years.

C. Investment Recovery

Investment recovery includes accounting for machinery and equipment to manufacture parts, assembly plant changes, vehicle development and cost of capital recovery.

Staff expects that the majority of the new components for LEVs and ULEVs will be manufactured by suppliers. Therefore, the costs of machinery and equipment to manufacture the part are already included in the parts costs described in I.A above. With respect to projected assembly plant changes, several manufacturers have indicated that major powertrain changes will be instituted for medium-duty vehicles in the mid-1990s and again after the 2000 model year (e.g. a new series of modular engines with advanced electronics, including distributorless, coil-on plug ignition systems, etc.). Consequently, design changes needed for the low-emission vehicle program are expected to be integrated into the platform changes that are already scheduled. In fact, the staff phase-in proposal specifically allocates sufficient lead time to allow for an orderly, less disruptive phase-in of low-emission medium-duty vehicles - which also minimizes assembly plant changes and related costs. Therefore, it is not likely that there will be significant additional assembly plant costs attributable solely to low-emission medium-duty vehicles.

Again, because major powertrain changes scheduled for the mid-1990s and post-2000 model years will require new certification durability vehicles, these same vehicles could also incorporate the new hardware needed to meet the LEV and ULEV medium-duty requirements. Thus, there need not be an increase in the calibration/certification costs of these vehicles. Staff does expect, however, that manufacturers will have to conduct some additional advance engineering work (such as 50°F testing and advanced catalyst durability testing). It was assumed that manufacturers would build one medium-duty 50°F test cell with two full-time technicians for its operation and one engine dynamometer for catalyst durability testing with two full-time technicians to operate the facility. The cost for these facilities is shown below and has been amortized over 15 years.

Vehicle Development Costs

Facilities	Cost of Facility ($)	Number Required	Total Facility Cost ($)	Staff Required	Total staff cost ($/yr)(a)	Cost/vehicle ($/vehicle)(b)(c)
50°F Testing	2,400,000	1	2,400,000	2	166,400	4.27
Engine Dynamometer	500,000	1	500,000	2	166,400	1.10
Total						5.37

(a) Staff cost is estimated at a total rate of $40/hr.
(b) Facilities are assumed to have a 15-year life.
(c) Cost per year has been distributed over 40,000 vehicles.

The cost of capital recovery (return on investment) was calculated at six percent of the total costs to the manufacturer of the Low-Emission Vehicle Program (consistent with the cost methodology of one major manufacturer). Staff estimates that this cost is $9.16 for LEVs and $14.07 for ULEVs.

D. Dealership Costs

Dealership costs include accounting for recovery of operating costs and the cost of capital recovery. The operating costs consist of the increased commission paid to sales persons and was calculated at three percent of the differential wholesale price. No additional capital costs were ascribed to dealers in order to service and sell low-emission medium-duty vehicles, since these aspects of LEV and ULEV vehicles should not differ from Tier I medium-duty vehicles. Since most medium-duty vehicles are bought at light-duty vehicle dealerships, staff made the same assumptions for dealership costs that were made for light-duty vehicles. Since the price of the vehicle will increase due to the Low-Emission Vehicle program, it is appropriate to account for the additional interest which the dealer will pay for financing the cost of the vehicle and to cover the commission sales persons will receive as well. An interest rate of six percent was assumed on the incremental cost, and on average, vehicles were presumed to remain in the dealership inventory for one quarter.[1]

[1] This assumption may not be correct for medium-duty fleet vehicles greater than 8500 GVW because they are usually special ordered. However, the majority of medium-duty vehicles will be sold from the dealership stock of complete vehicles.

Incremental Consumer Cost of LEVs and ULEVs compared to Tier 1 MDVs

Gasoline Vehicles		**LEVs**	**ULEVs**
Variable Costs	Component	$143.66	$223.11
	Assembly	0.25	2.00
	Warranty	0.34	0.57
	Shipping	0	0.25
Support Costs	Research	3.12	3.12
	Legal	0	0
	Administrative	0	0
Investment Recovery Costs	Mach. & Equipment	0	0
	Assembly Plant	0	0
	Veh. Development	5.37	5.37
	Cost of Capital Recovery	9.16	14.07
Dealership Costs	Operating Costs	4.86	7.45
	Cost of capital recovery	2.45	3.75
Total Cost		$169.19	$259.69

II. Cost Methodology for Diesel Engines

In order to formulate a preliminary estimate of the incremental consumer costs of producing low-emission medium-duty diesel engines relative to similar engines certified to Tier I emission standards, ARB staff has defined the additional costs associated with producing and selling these engines. Since the sources of additional costs can vary considerably depending on the manufacturer and are closely guarded by industry, determining a costing framework which is representative of diesel engine manufacturers is formidable. Although the costing framework used herein was developed for the light-duty vehicle industry as described in the staff report, "1994 Low-Emission Vehicle and Zero-Emission Vehicle Program Review," the ARB staff believes that this framework would also be applicable for the medium-duty diesel engine industry. Therefore, this framework was utilized in the following preliminary cost analysis of low-emission medium-duty diesel engines.

A. Variable Costs

In order to determine variable costs, all associated emission control systems and hardware for complying with the different standards need to be defined. Based on certification data, discussions with manufacturers and EPA, and ARB funded studies, ARB staff has characterized the expected emission control technologies for LEVs and ULEVs in Table 2.

Table 2
Incremental Component Cost of Diesel Medium-Duty LEVs and ULEVs

Emission Control Technology	Cost ($)	% Tier 1 req. tech	LEV			ULEV		
			% LEV req. tech.	Incremental Cost	Inc. Cost to Refine (d)	% ULEV req. tech.	Incremental Cost	Inc. Cost to Refine (d)
Turbochargers	450	100	100	0	67.5	100	0	90
Charge Air Cooling	175	32	100	119	26.25	100	119	35
Electronically-controlled Fuel Injection (a)	100	100	100	0	15	100	0	20
Underfloor Oxidation Catalysts	100	100	100	0	15	100	0	20
Improved catalyst formulation	0	100	100	0	0	100	0	0
Engine improvements (b)	50	100	100	0	7.5	100	0	10
Electronic EGR (c)	50	50	50	0	7.5	100	25	0
Total Incremental Cost				119	138.75		144.00	175.00

(a) Electronically-controlled fuel injection consists of improvements to fuel preparation such as, increased pressure, swirl, and rate shaping.
(b) Engine improvements include combustion chamber and piston modifications.
(c) Cost of electronic EGR includes valves, controls, tubing, check valve, and brackets.
(d) Incremental hardware cost of improving existing Tier 1 technology was assumed to be 15% for LEVs and 20% for ULEVs.

1. Cost of Components

Although many of the components and modifications listed in Table 2 are not new technologies and are already used on some Tier 0 engines, it is projected that additional refinement and development of these components and systems would be necessary to allow compliance with the more stringent low-emission medium-duty vehicle requirements (i.e., LEV and ULEV). Components and systems already on today's engines such as turbochargers, charge air cooling, electronic fuel injection, and oxidation catalysts are projected to be further enhanced and refined for low-emission engine applications. Also, increased usage of EGR, and new combustion chamber and piston designs are also projected to reduce the engine-out emission performance of diesel engines.

Since many of these improvements to components are expected to occur incrementally (i.e., technology will improve first to LEV levels and then to ULEV levels) and largely involve design improvements, it is difficult to estimate the specific incremental cost of the new components. As a starting point, however, staff contacted aftermarket suppliers for estimates of component costs for low-emission medium-duty diesel engines. If supplier information was not available, staff estimated component costs based on light-duty vehicle technology with some increase in cost to account for the larger displacements and the more difficult duty cycles of medium-duty engines. Staff assumed that each more stringent emission category would require an incremental cost based on a percentage of the cost of the base technology (i.e., current Tier I technology). For example, the incremental cost of LEV emission controls was estimated to be

15% of the cost of current technology while ULEV costs would be 20% higher than current technology to account for the needed enhancements to Tier I technology. These costs are presented in Table 2.

2. Cost of Assembly

Costs to assemble emission control systems for low-emission diesel engines are not expected to be much different than for Tier I vehicles since the estimated required componentry is similar. The only component which may incur additional assembly operations is the electronic EGR system. Assembling the EGR system is estimated to require 8 minutes to complete. Assuming a rate of $60/hr is needed to cover the costs of labor and overhead, assembly costs amount to $8.00 per engine. The incremental cost of assembly for LEVs and ULEVs compared to Tier I engines is shown in Table 3.

Table 3
Assembly Costs for Diesel Low-Emission Engines

Assembly Operation	Installation Time (min.)	Labor/ Overhead ($/hr)	% of Tier 1 req. assembly	% LEV req. assembly	Incremental Cost of Assbly. ($)	% ULEV req. assembly	Incremental Cost of Assbly.
EGR Installation	8	60	50	50	0	100	4.00

3. Cost of Warranty and Shipping

Since the majority of the emission control components on low-emission medium-duty diesel vehicles are projected to be similar to Tier I vehicles, warranty claims and shipping costs are not expected to increase significantly either. However, since the cost of the components for LEV and ULEV engines is expected to be higher than Tier I components, warranty costs should be adjusted accordingly. In estimating the additional warranty costs, a failure rate of 0.05% was assumed for Tier I, LEV and ULEV engines. Warranty costs are summarized in Table 3. The only emission control component which is expected to incur additional shipping cost is electronic EGR. The cost of shipping the EGR components was estimated to add $0.25 to the cost of the system (assumes parts are shipped via manufacturer-owned trucks).

Table 4
Incremental Warranty Cost for Diesel LEVs

Warranted Part	Cost of Parts and Labor				% Tier 1 Req. Tech.	% LEV Req. Tech.	% ULEV Req. Tech.	Warranty Cost (e)	Warranty Cost (e)
	Tier 1 ($) (b)	LEV ($) (c)	ULEV ($) (c)	Labor ($/hr)(d)					
Turbochargers	900	1035	1080	50	100	100	100	0.0675	0.09
Charge Air Cooling	350	402.50	420	50	100	100	100	0.02625	0.035
Electronic Fuel Injection	200	230	240	50	100	100	100	0.015	0.02
Underfloor Oxidation Cat.	200	230	240	25	100	100	100	0.015	0.02
Engine Improvements (a)	0	0	0	1000	100	100	100	0	0
Electronic EGR	100	115	120	25	50	50	100	0.00375	0.04125
Total Cost	1750	2012.5	2100	1200				0.13	0.21

(a) Replacement cost of engine assumes the average component cost of rebuilding the engine is $2,000 for Tier 1 engine.
(b) The component price to the consumer was assumed to be twice the wholesale price.
(c) Cost was assumed to be 115 % of the Tier 1 component for LEVs and 120% for ULEVs.
(d) A labor rate of $50/hr was assumed.
(e) The component failure rate of 0.05% for LEVs and ULEVs was assumed to be equivalent to Tier 1 vehicles.

B. Support Costs

Support costs affecting the retail price of emission requirement changes include research costs, legal implications, and administrative increases. These are discussed in detail below.

1. Research

Research costs include basic research efforts and advance engineering research. Basic research involves activities needed to determine if new concepts or technologies have the potential to reduce emissions. Although suppliers tend to do the bulk of the basic research work for new technology, some of the larger engine manufacturers also may have a dedicated research staff to research new technologies such as lean NOx catalysts, particulate traps and other developing technologies. While the number of staff may increase to accommodate this research, the cost of researching developing technologies was not attributed to the medium-duty low-emission diesel vehicle program since staff estimates that lean NOx catalysts and particulate traps will not be required on LEVs and ULEVs in the 2004 timeframe.

Advance engineering research involves evaluating technologies to determine their feasibility for vehicle applications. Advance engineering research may involve activities such as durability and emission testing of new emission controls on prototype engines, and evaluating interactions with other vehicle systems. For the emission control components which are to be installed on medium-duty low-emission diesel engines, the costs of advance engineering research were allocated by estimating the additional staff, number of development engines, and additional equipment needed to perform the required research. The results of this additional research activity (i.e., the technology) was estimated to be useful for 12 years. Details of the analysis are presented in Table 5.

Table 5
Advance Engineering Research Costs

Emission Control Technology	Eng. Staff for Tech. Develop. (person/yrs.)	Eng. Staff for Tech. Develop. (person/hrs.)	Eng. Staff Cost ($) (a)	Dev. Vehicle Cost ($) (b)	Addtl. Eqpmt. ($)	Cost/vehicle ($) (c)
Variable Geometry Turbocharger	4	8,320	499,200	300,000	0	3.33
High Pressure Elec. Fuel Inj.	10	20,800	1,248,000	600,000	0	7.70
Engine Refinements	10	20,800	1,248,000	600,000	0	7.70
EGR	2	4,160	249,600	200,000	0	1.87
Oxidation Catalyst	6	12,480	748,800	400,000	0	4.79
TOTAL						25.39

(a) Development cost includes personnel, overhead and other miscellaneous costs at a total rate of $60/hr.
(b) Prototype development engines are estimated to cost $100,000 each.
(c) Cost has been distributed over 20,000 vehicles per year for a total of 12 years.

2. Legal Costs

Since emission controls on low-emission diesel engines are expected to be refinements of existing technology, the ARB staff believes that legal claims should remain similar to Tier I engines. The ARB staff does acknowledge, however, that the development or refinement of new technology often requires thorough searches of existing technology patents for infringement. Considering the additional workload on a manufacturer's legal staff which patent research is expected to produce, staff has assumed two additional legal staff would be required over a four year period. The costs of this activity were spread over 12 years of production since the usefulness of the technology is assumed to be 12 years. Also, spreading the costs over the lifetime of the technology gives a better assessment of the long term costs of this relatively short-term function. This cost is summarized in Table 6.

Table 6
Legal and Administrative Costs

	No. of Staff Required	Number of Years	Staff Cost ($)	Cost/vehicle ($/veh) (c)
Legal	2	4	1,600,000	8.00
Administrative	0	0	0	0.00

3. Administrative Costs

Since the number of additional emission control components for low-emission diesel engines compared to Tier I engines is expected to be insignificant, the total number of parts will be unchanged. Therefore no incremental purchasing, scheduling, and tracking activities and their associated costs would be required.

C. Investment Recovery Costs

This portion of the cost analysis includes accounting for machinery and equipment to manufacture the part, assembly plant changes (automation), vehicle development (engineering), and cost of capital recovery.

1. Machinery and Equipment

Since most of the emission control components for low-emission vehicles will be produced by suppliers (e.g., pistons, turbochargers, fuel injection components, etc.), machinery and equipment needed to manufacture these components are already included in the piece price. Perhaps an exception to this practice would be tooling modifications which might be needed to incorporate base engine changes for improved emission performance. These costs were estimated to be a fixed percentage of 5% of the total variable costs.

2. Assembly Plant Changes (Automation)

The primary change to low-emission engines compared to Tier I engines is the projected use of EGR for all ULEV engine families. Installation of an EGR system (possibly cooled) would require the addition of an EGR valve and controls, hoses, tubing, and a check valve. This installation, however, would not lend itself to automation. Therefore, no additional assembly operations are projected for low-emission diesel engines which would require additional investment in automatic tooling.

3. Vehicle Development

Investment costs to the manufacturer may include building new engine dynamometer facilities for advance engineering development and calibration. Considering that most manufacturers only produce only one diesel engine family for medium-duty vehicles, ARB staff estimates that the addition of one new engine dynamometer facility would be sufficient to comply with the requirements. The cost of the facility was estimated at $750,000 with 2 additional staff required. This dynamometer was amortized over 15 years and is detailed in Table 7.

Table 7
Diesel Vehicle Development Costs

Facilities	Cost of Facility ($)	Number Required	Total Facility Cost ($)	Staff Required	Total Staff Cost/Year ($/yr) (a)	Cost/vehicle ($/veh) (b)(c)
Engine Dynamometer	750,000	1	750,000	2	166,400	10.32
Total						10.32

(a) Staff cost is estimated at a total rate of $40/hr.
(b) Facilities are assumed to have 15-year life.
(c) Cost per year has been distributed over 20,000 vehicles.

4. Cost of Capital Recovery

The cost of capital recovery was calculated at six percent of the total costs to the manufacturer of the medium-duty low-emission diesel vehicle. This calculation is shown in Table 8.

Table 8
Incremental Consumer Cost of LEVs and ULEVs compared to Tier 1 MDVs

Diesel Vehicles		**LEVs**	**ULEVs**
Variable Costs	Component	$257.75	$319.00
	Assembly	0.00	4.00
	Warranty	0.13	0.21
	Shipping	0.00	0.13
Support Costs	Research	25.39	25.39
	Legal	8.00	8.00
	Administrative	0.00	0.00
Investment Recovery Costs	Mach. & Equipment	12.89	16.17
	Assembly Plant	0.00	0.00
	Veh. Development	10.32	10.32
	Cost of Capital Recovery	18.87	22.99
Dealership Costs	Operating Costs	10.00	12.19
	Cost of capital recovery	5.04	6.14
Total Cost		$348.39	$424.52

D. Dealership Costs

Dealership costs include accounting for recovery of operating costs and the cost of capital recovery. Operating costs consist of the increased sales commission which the dealer would have to pay when a low-emission vehicle is sold. This commission was calculated at three percent of the differential wholesale price. Since the price of the engine will increase due to the Low-Emission Vehicle program, it is appropriate to account for the additional interest which the dealer will pay for financing the cost of the vehicle and to cover the commission sales persons will receive. An interest rate of six percent was assumed on the incremental cost, and on-average, vehicles were presumed to remain in the dealership inventory for one quarter. This calculation is shown in Table 8.

III. Incremental Cost and Cost-Effectiveness of the Medium-Duty Vehicle Proposal

Table 9 contains a summary of the incremental costs and cost-effectiveness of medium-duty LEVs and ULEVs relative to Tier I vehicles. In calculating the emission benefits of the medium-duty proposal, the ARB staff utilized the EMFAC7F emission inventory model. The ARB emission inventory staff estimated the benefits of the proposal (without including other effects such as the expected benefits of enhanced I/M) by assuming that the zero-mile rate in-use and the emission deterioration rate should be adjusted to those of Tier I vehicles (without enhanced I/M) by the ratio of the standards being applied.

In calculating the incremental cost-effectiveness of the medium-duty vehicle proposal, the staff used two approaches. The first method is referenced in the "California Clean Air Act: Cost-Effectiveness Guidance" published by the Air Resources Board in 1990. This method divides the total cost of the proposal by the total emission reductions. The emissions include total hydrocarbons (HC), oxides of nitrogen (NOx) and carbon monoxide (CO) discounted by a factor of seven. The second approach was to apply one-half the cost to the reduction of criteria pollutants (HC plus NOx) and the other half to reduction of toxic air contaminants. The results of these analyses compared to the cost analysis for light-duty low-emission vehicles are favorable. For medium-duty low-emission vehicles, then, the cost-effectiveness relative to Tier I vehicles ranges from $0.17 per pound to $1.45 per pound. These values are within the range projected for light-duty vehicles of less than $1.00 per pound. These values are well within the typical range of motor vehicle control measures of up to $5 per pound of emissions reduced.

Table 9
Cost-Effectiveness of MDV Proposal

I. Incremental Cost Summary

	Gasoline Vehicles		Diesel Vehicles	
	LEVs	ULEVs	LEVs	ULEVs
Incremental Cost	$169.19	$259.63	$348.39	$424.52

II. Lifetime Emissions Reductions

Emission Category	ROG Emissions (lbs.)	CO Emissions (lbs.)	NOx Emissions (lb.)	Emission Reductions		
				ROG (lbs.)	ROG + NOx	ROG + NOx + CO/7
Gasoline						
Tier 1	369	6394	2033			
LEV	244	6394	1782	125	376	376
ULEV	182	6394	1445	187	775	775
Diesel						
Tier 1	80	2200	2261			
LEV	72	2200	2029	8	240	240
ULEV	60	2200	1742	20	539	539

III. Cost-Effectiveness

Emission Category	**ROG + NOx (a)**	**ROG + NOx + CO/7 (b)**
Incremental Cost of LEV/ULEV compared to Tier 1 ($/lb. reduced)		
Gasoline LEV	0.22	0.45
Gasoline ULEV	0.17	0.34
Diesel LEV	0.73	1.45
Diesel ULEV	0.39	0.79
Incremental Cost of ULEV compared to LEV ($/lb. reduced)		
Gasoline ULEV	0.11	0.23
Diesel ULEV	0.13	0.25

Assumptions:

(a) One-half of the added cost is allocated toward criteria pollutant reductions and the other one-half towards toxic air contaminant reductions.

(b) Based on the "California Clean Air Act: Cost-Effectiveness Guidance" document dated September 1990.