Chapter VI: Cost-Effectiveness

This Chapter will present the cost-effectiveness analysis we completed for our proposed new heavy-duty gasoline vehicle, heavy-duty diesel engine, and diesel fuel sulfur standards. This analysis relies in part on cost information from Chapter V and emissions information from Chapter II to estimate the dollars per ton of emission reductions produced from our proposed standards. We have calculated the cost effectiveness using two different approaches, a per-vehicle approach that considers the costs incurred and emission reductions produced for a single vehicle or engine, and a 30-year net present value approach that accounts for all costs and emission reductions over a 30 year period beginning in 2006. Finally, this Chapter compares the cost-effectiveness of the new provisions with the cost-effectiveness of other control strategies from previous and potential future EPA programs.

Sections VI.A, VI.B and VI.C describe the per-vehicle calculations for our combined heavy-duty diesel engine and diesel fuel sulfur standards, while Section VI.D describes the per-vehicle calculations for heavy-duty gasoline vehicles. Section VI.E describes the 30-year net present value cost effectiveness analysis. The results of all cost-effectiveness calculations are given in Section VI.F.

A. Overview of the Per-vehicle Analysis

The per-vehicle cost-effectiveness analysis conducted for our proposed standards focused on the costs and emission reductions associated with a single engine (or vehicle, in the case of heavy-duty gasoline vehicle standards) meeting the 2007 model year standards, and operating on low sulfur fuel. Both costs and emission reductions were calculated over the life of the engine and then discounted at a rate of seven percent. Costs and emission reductions were measured relative to a baseline consisting of the 2004 certification standards and average diesel sulfur levels falling under the current 500 ppm cap. The calculations were performed separately for each engine class and the results weighted according to the expected fleet mix. Details on our approach to cost-effectiveness follow. The presentation of the 30-year net present value cost effectiveness calculations can be found in Section VI.E. This latter approach includes the fuels costs incurred by the pre-2007MY fleet which are not accounted for in the per-vehicle analysis.

1. Temporal and Geographic Applicability

Our per-engine approach to our cost-effectiveness calculations produces $/ton values representing any controlled engine, no matter where that engine operates. In effect, this means that emission reductions in both attainment and nonattainment areas are included in our cost-effectiveness analysis. Although this may limit the usefulness of comparisons to stationary source controls, we believe that our approach is appropriate. Both the proposed engine and diesel sulfur programs are to apply nationwide, so that the same emission reductions will occur regardless of where the engine operates. Attainment area emission reductions also produce health benefits. In general, the benefits of NMHC reductions in ozone attainment areas include reductions in emissions of air toxics, reductions in the contribution from NMHC emissions to the formation of fine particulate matter, and reductions in damage to agricultural crops, forests, and ecosystems from ozone exposure. Emission reductions in attainment areas help to maintain clean air as the economy grows and new pollution sources come into existence. Also, ozone health benefits can result from reductions in attainment areas, although the most certain health effects from ozone exposure below the NAAQS appear to be both transient and reversible. The closure letter from the Clean Air Science Advisory Committee (CASAC) for the recent review of the ozone NAAQS states that there is no apparent threshold for biological responses to ozone exposure[1].

In the Regulatory Impact Analysis for a recent rulemaking for highway heavy-duty diesel engine standards[2], EPA also presented a regional ozone control cost-effectiveness analysis in which the total life-cycle cost was divided by the discounted lifetime NOx + NMHC emission reductions adjusted for the fraction of emissions that occur in the regions expected to impact ozone levels in ozone nonattainment areas. (Air quality modeling indicates that these regions include all of the states that border on the Mississippi River, all of the states east of the Mississippi River, Texas, California, and any remaining ozone nonattainment areas west of the Mississippi River not already included.). The results of that analysis show that the regional cost-effectiveness values were 13 percent higher than the nationwide cost-effectiveness values. Because of the small difference between the two results, EPA is presenting only nationwide cost-effectiveness results for this analysis.

Despite the fact that a per-engine approach to cost-effectiveness allows us to avoid the arbitrary choice of a specific year in which to conduct the analysis, there is some value in examining different points in time after the program is first implemented. The costs of the program will be higher immediately after it is implemented than they will be after several years, since engine and vehicle manufacturers and refiners can take advantage of decreasing capital and operating costs over time, and will learn how to produce their products more efficiently as time goes on. For the purposes of this rulemaking, therefore, we will present cost-effectiveness of our program on both a near-term and long-term basis. More details concerning per-engine costs are given in Section VI.B.2 for diesel engines and in Section VI.D.1 for heavy-duty gasoline vehicles.

We are also proposing that our combined engine/sulfur program (hereafter, this includes our proposed standards for heavy-duty diesel engines, heavy-duty gasoline vehicles, and diesel sulfur) be an annual program. Since cost-effectiveness only has relevance when compared to alternative strategies, we must use an approach to calculating the cost-effectiveness of our annual program that is consistent with the approaches taken for other rulemakings. For programs that generate emission reductions outside of the ozone season, we generally include those "winter season" reductions in the cost-effectiveness calculations. Thus our cost-effectiveness estimates will include all the emission reductions produced as a result of our proposed standards, no matter where or when those reductions occur. This is consistent with the methodology used in prior rulemakings and allows for an apples-to-apples comparison.

2. Baselines

There are two broad approaches to cost-effectiveness that can be taken, each of which requires a different baseline. These two approaches can be termed "incremental" and "average." Both incremental and average approaches to cost-effectiveness provide a measure of how much more stringent than the existing standards our standards can be before they cease to be cost-effective.

An incremental approach to cost-effectiveness requires that we evaluate a number of different potential standards, each of which is compared to the potential standards closest to it. Using this approach, the cost-effectiveness of our proposed standards would be calculated with respect to another set of potential standards which is less stringent than our standards. In this way, the $/ton values represent the last increment of control, highlighting any nonlinearities that exist in either the costs or emission reductions.

An average approach to cost-effectiveness, on the other hand, requires that we compare the costs and emission reductions associated with our standards to those for the previous set of standards that are being met by manufacturers. In this case, the $/ton values represent the full range of control from the last applicable standard to our standards.

As stated above, we must use an approach to cost-effectiveness that is consistent with the approach taken in other rulemakings in order to provide an apples-to-apples comparison. Most other mobile source rulemakings use average cost-effectiveness, including our recently promulgated standards for Tier 2 vehicles and gasoline sulfur. Therefore, we have chosen to calculate cost-effectiveness on an average rather than an incremental basis for our proposed standards.

Since today's program includes both fuel standards and engine standards, it was necessary for us to define a baseline for both fuels and engines. For highway diesel fuel, the previous standard was set in 1990, limiting the sulfur content to a maximum of 500 ppm starting in 1993. However, the average sulfur level has been significantly less than 500 ppm, closer to 340 ppm[3]. Therefore we have determined that the sulfur baseline should be 340 ppm.

For heavy-duty diesel engines, the previous set of standards was originally set in 1997 and applies to the 2004 model year. These standards included a 2.4 g/bhp-hr cap for NOx+NMHC or 2.5 g/bhp-hr with a 0.5 g/bhp-hr cap on NMHC. However, unlike the PM standards we are proposing today, 2004 model year urban buses are required to meet a different PM standard (0.05 g/bhp-hr) than other heavy-duty engines (0.1 g/bhp-hr). Thus we have used two different baselines for PM, one for urban buses and another for other heavy-duty engines. Despite this, we are calculating only a single set of cost-effectiveness values for all engines since we are proposing that a single set of standards apply to urban buses and other heavy-duty engines.

For heavy-duty gasoline vehicles, the previous set of standards also applies to the 2004 model year. They are still in proposal stage as of this writing, but we have determined that they form the most appropriate baseline nonetheless. For incompletes, these include a 1.0 g/bhp-hr NOx+NMHC standard, which we assume separates practically into a 0.8 g/bhp-hr standard for NOx and a 0.2 g/bhp-hr standard for NMHC. For Class 2b completes, the 2004 standards include 0.9 g/mile for NOx and 0.28 g/mile for NMHC. Finally, for Class 3 completes, the 2004 standards include 1.0 g/mi for NOx and 0.33 g/mi for NMHC.

B. Diesel Costs

The costs used in our cost-effectiveness calculations are the sum of the added costs of compliance with the 2007 engine and diesel sulfur standards on a per-engine basis, in comparison to the engine and fuel baselines. Costs result from discounting over the lifetime of a engine at a seven percent discount rate. In addition, all costs represent the fleet-weighted average of all light, medium, and heavy-heavy engines, as well as urban buses.

1. Near and Long-Term Cost Accounting

Since the costs of complying with the proposed 2007 engine standards will vary over time, we believe that it is appropriate to consider both near-term and long-term costs in our cost-effectiveness analysis. First, the capital costs associated with the manufacture of engines that will meet the 2007 standards would generally be amortized over five years. Thus in the sixth year of production, a portion of the capital costs become zero and the total costs of production drop. Manufacturers also gain knowledge about the best way to meet new standards as time goes on (the so-called "learning curve"), and as a result their operating costs decrease over time. The implications of this learning curve on engine costs is discussed in Section V.A.1.

Thus near-term costs represent the highest costs of the program, as they include all capital costs and no cost savings due to the manufacturer's learning curve. Long-term costs, on the other hand, represent the lowest costs of the program which occur after a portion of capital cost amortizations have ended and all learning curve cost savings have been accounted for. For the purposes of this rulemaking, therefore, we will present cost-effectiveness of our program on both a near-term and long-term basis. Details about the calculation of near and long-term engine costs can be found in Section V.A.

2. Diesel Engine and Fuel Costs

The per-engine costs used in our cost-effectiveness calculations were derived and presented in the preceding Section. Engine hardware costs were presented in Section V.A for the four engine categories affected by our proposed standards. For the purposes of calculating cost-effectiveness, we weighted the costs for those four individual engine categories by the expected fleet fractions (see Table VI-4 below) to obtain fleet-average costs for our proposed emissions standards. Also, we treated first-year production costs as the "near-term" costs, and sixth-year production costs as the "long-term" costs. For low sulfur diesel, we used the discounted lifetime costs presented in Table V.D.6-1 which include costs for desulfurization, lubricity additives, and distribution costs. The costs used in our cost-effectiveness calculations are shown in Table VI-1.

Table VI-1. Fleet-average, Per-engine Costs for HDDE

	NOx adsorber and PM trap ($)	*Fuel cost ($)*	*Total costs ($)*
Near-term	2005.13	1753.91	3759.04
Long-term	988.00	1753.91	2741.91

Note that the total costs in Table VI-1 were used for establishing "uncredited" cost-effectiveness values. As described in Section VI.B.4, the costs from Table VI-1 were also adjusted to produce "credited" cost-effectiveness values.

3. Methodology for assigning costs to NOx, NMHC, and PM

The object of our cost-effectiveness analysis is to compare the costs to the emission reductions in an effort to assess the program's efficiency in helping to attain and maintain the NAAQS. Thus the primary purpose of our standards is to reduce emissions of the ozone precursors hydrocarbons and oxides of nitrogen, as well as emissions of particulate matter. Therefore, consistent with our approach in previous rulemakings such as the recently finalized standards for Tier 2 vehicles and gasoline sulfur, we have calculated cost-effectiveness on the basis of total NOx + NMHC emissions.

However, since we are also proposing that a new standard be set for PM, we must develop a separate cost-effectiveness value for that pollutant. We do not think it appropriate to combine NOx, NMHC, and PM all into a single cost-effectiveness value, since there are separate NAAQS for ozone and PM, and these two pollutants do not have identical effects on human health and the environment. We must therefore determine a reasonable way to split the costs of compliance with our combined engine/diesel sulfur program between NOx+NMHC and PM.

As described in Section III.A, we expect that manufacturers will use both NOx adsorbers and PM traps to comply with our proposed engine standards. The costs for these two aftertreatment devices have been derived separately, and thus can be applied separately to the pollutants affected by these two technologies. We are also proposing a diesel fuel sulfur cap of 15 ppm in order to enable these aftertreatment devices to operate properly. Since the fuel sulfur standard applies equally to both aftertreatment devices, we believe it is appropriate to divide fuel costs evenly between the adsorber and trap.

However, the trap will produce reductions in both PM and NMHC. We therefore believe it is appropriate to divide all costs applicable to the trap (the hardware costs for the trap itself and half of the fuel costs) equally between PM and NMHC. As a result, 25 percent of total fuel costs would apply to the calculation of PM cost effectiveness, while the remaining 75 percent would apply to the calculation of cost effectiveness for NOx+NMHC. Likewise, half of the hardware costs for the PM trap would be included in the calculation of cost effectiveness for NOx+NMHC.

4. Cost Crediting for SO_2

The reduction in diesel sulfur levels that would result from our proposed standards will necessarily result in reductions in sulfur-containing compounds that exit the engine. These compounds are limited to sulfur dioxide (SO_2) and sulfate particulate matter. The latter will be taken into account as manufacturers seek to comply with our new PM standard, and thus will be automatically represented in our cost-effectiveness estimates of $/ton PM. However, there is no engine standard for SO_2. Since reductions in emissions of SO_2 are beneficial and represent a true value of our proposed program, we believe it is appropriate to account for them in our cost-effectiveness analysis.

The primary benefit of reductions in SO_2 emissions is a reduction in secondary PM, formed when SO_2 reacts with water and ammonia in the atmosphere to form ammonium sulfate. Therefore, we believe that any crediting for reductions in SO_2 should be applied to our PM costs.

To account for reductions in emissions of SO_2 in our cost-effectiveness calculations, we have calculated a second set of $/ton values in which we credit some of the costs to SO_2, with the remaining costs being used to calculate $/ton PM. As a result, we have produced both "credited" and "uncredited" $/ton PM values; the former takes into account the SO_2 emission reductions associated with our standards, while the latter does not.

Cost-effectiveness values for the control of SO_2 represent conservative estimates of the cost of measures that would need to be implemented in the future in order for all areas to reach attainment. Such cost-effectiveness values are therefore an appropriate source for estimating the amount of the costs to credit to SO_2. As a result, we credited some costs to SO_2 through the application of cost-effectiveness ($/ton) values for this pollutant drawn from other sources.

In concept, we would consider the most expensive program needed to reach attainment to be a good representation of the ultimate value of SO_2. However, in this rulemaking, we chose to simplify by using more conservative approaches to establish crediting values for SO_2. The potential future programs evaluated as part of the NAAQS revisions rulemaking (discussed in more detail in Section VI.F below) provided a reasonable source for identifying the value of SO_2 in terms of its cost-effectiveness. In this process we did not make a distinction between SO_2 emissions from mobile or stationary sources since there is little data to suggest that a tons of SO_2 from one source contributes differently to PM or acid rain problems than a ton of SO_2 from another source.

Out of the nine SO_2 control programs evaluated in the NAAQS revisions rule, eight were actually used in the modeling of ambient concentrations of PM based on their contribution to secondary PM (sulfate) levels in PM nonattainment areas. The cost-effectiveness of the eight SO_2 control programs ranged from $1600/ton to $111,500/ton. In this particular rulemaking, we have for simplicity's sake used the average cost effectiveness of the eight SO_2 control programs, calculated to be $4800 a ton. This average value of $4800/ton was used in the crediting of some costs to SO_2, and represents a conservative valuation of SO_2.

The cost crediting was applied after all costs associated with compliance with our standards were calculated and summed. The per-engine tons reduced of SO_2 was multiplied by the representative cost-effectiveness value of $4800/ton (see Section VI.C.2 below for SO_2 tons calculations). As a result, $446 of the total costs were apportioned to SO_2 in the calculation of PM cost-effectiveness. This amount is independent of whether we are considering a near-term or long-term cost-effectiveness calculation, since the lifetime tons reduced for this compound is the same, on a per-engine basis, in any year of the program. A summary of the costs used in our cost-effectiveness calculations is given below in Table VI-2, including all engine, fuel, and fuel economy costs.

Table VI-2. Fleet Average Per-Engine Costs for HDDE Used in Cost-effectiveness

	Near-term costs ($)		*Long-term costs ($)*	
	NOx+NMHC	PM	NOx+NMHC	PM
Total uncredited costs	2887.24	871.80	2090.01	651.90
SO_2 credit allocation	n/a	-445.99	n/a	-445.99
Total credited costs	2887.24	425.81	2090.01	205.91

C. Emission Reductions from Diesel Engines

In order to determine the overall cost-effectiveness of the standards we are proposing, it was necessary to calculate the lifetime tons of each pollutant reduced on a per engine basis. This section will describe the steps involved in these calculations. In general, emission reductions were calculated for NOx, NMHC, PM, and SO_2 in a manner analogous to the discounted lifetime fuel costs described in Section V.D.6.

1. NOx, NMHC, and PM

The discounted lifetime tonnage numbers for NOx, NMHC, and PM for our combined diesel engine and diesel fuel standards were based on the difference between emissions produced by engines meeting our proposed 2004 and proposed 2007 standards, as described in Section II.B.1. These in-use emission levels were expressed in terms of average g/bhp-hr emissions for each year in a engine's life, up to 30 years. From this basis, lifetime tonnage estimates were developed using the following procedure:

1) Annual mileage accumulation levels for MOBILE6 were applied to the in-use emission rates for each year in a engine's life to generate total mass emissions produced in each year by that engine (this step included the use of bhp-hr/mile conversion factors)

2) The resultant mass emissions were multiplied by the probability of survival in the appropriate year, known as the "survival" rate.

3) A seven percent annual discount factor, compounded from the first year of the engine's life, was then applied for each year to allow calculation of net present value lifetime emissions.

Converting to tons and summing across all years results in the total discounted lifetime per-engine tons. This calculation can be described mathematically as follows:

$$LE = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \bullet (ER)_i \bullet (CF) \bullet (K)\}/(1.07)^{i-1}]$$

Where:

LE	= Discounted lifetime emissions in tons/engine
$(AVMT)_i$	= Annual miles traveled in year i of a engine's operational life[4]
$(SURVIVE)_i$	= Probability of engine survival after i years of service
$(ER)_i$	= Emission rate, g/bhp-hr in year i of an engine's operational life
CF	= Heavy-duty engine conversion factor, bhp-hr/mile (see Appendix VI-A)
K	= Mass conversion factor, 1.102×10^{-6} tons/gram
i	= Engine years of operation, counting from 1 to 30

For NOx, NMHC, and PM, we generated discounted lifetime tonnage values for each engine class (LH, MH, HH, and urban buses) using the above equation. This was done separately for the baseline and control cases. The baseline case included the 2004 model year engine standards and the in-use diesel sulfur level of 340 ppm. The control case entailed our proposed 2007 model year engines standards and 7 ppm diesel sulfur. The tonnage values that we calculated according to this procedure are shown in Table VI-3.

Table VI-3. Per-engine Discounted Lifetime Tons for HDDE

	NOx	*NMHC*	*PM*
Baseline			
LH	0.409	0.037	0.017
MH	0.970	0.086	0.041
HH	3.661	0.325	0.157
Urban bus	4.300	0.174	0.097
Control			
LH	0.035	0.004	0.001
MH	0.084	0.009	0.002
HH	0.320	0.035	0.009
Urban bus	0.357	0.039	0.010

The final step before calculating the cost-effectiveness of our program was to weight the discounted lifetime tonnage values for each engine class by their respective fraction of the HDDE fleet. These fractions were based on engine count projections for use in MOBILE6 for the year 2020 for diesel-powered heavy-duty engines (see Appendix VI-A). Table VI-4 presents the final weighting factors we used to develop fleet-average tonnage values.

Table VI-4. Engine Class Sales Weighting Factors for HDDE

Light-heavy duty	0.342
Medium-heavy duty	0.323
Heavy-heavy duty	0.326
Urban buses	0.009

The final discounted lifetime tonnage values for an average fleet engine meeting either the 2004 or 2007 standards are shown in Table VI-5. It is these values that were used directly in calculating the cost-effectiveness of our program.

Table VI-5. Fleet average, Per-engine Discounted Lifetime Tons for HDDE

	NOx + NMHC	PM
Baseline: 2004 standards with 340 ppm fuel	1.8329	0.07117
Control: 2007 standards with 7 ppm fuel	0.1629	0.00399
Reduction	1.6700	0.06718

2. Sulfur Dioxide

The sulfur contained in diesel fuel exits the tailpipe as either sulfuric acid, a sulfate which is a component of primary particulate matter, or as sulfur dioxide (SO_2). Sulfur dioxide is formed in the engine, and its conversion into sulfuric acid is a function of the type of aftertreatment and temperature in the tailpipe. If there is no aftertreatment (as is expected to be the case for engines meeting the 2004 standards), only about 2 percent of sulfur ends up being converted into sulfuric acid, with the remaining 98 percent being retained as SO_2. For engines meeting our 2007 standards, however, we expect the conversion rate of SO_2 to sulfuric acid to be much higher, closer to 30 percent, due to the use of particulate traps. Thus the calculation of tons of SO_2 reduced due to our proposed program compares a baseline of 340 ppm and 98 percent SO_2 retention to a control of 7 ppm and 70 percent SO_2 retention.

Discounted lifetime tons of SO_2 reduced is calculated as the difference between tons of SO_2 for the baseline minus tons of SO_2 for our proposed program, where tons are calculated according to the following equation:

$$LE = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \div (FE) \bullet (D) \bullet (SUL) \bullet (F) \bullet (MC) \bullet (CF) \bullet (K)\}/(1.07)^{i-1}]$$

Where:

LE = Discounted lifetime emissions of SO_2 in tons/engine for either the baseline or our proposed control program
$(AVMT)_i$ = Annual engine miles traveled in year i of a engine's operational life
$(SURVIVE)_i$ = Fraction of engines still operating after i years of service
FE = Fuel economy by engine class (see Appendix VI-A)
D = Density of diesel, 7.1 lb/gal

SUL	= Diesel sulfur concentration, 3.4 $x10^{-4}$ lb sulfur/lb fuel (340 ppm) for the baseline and 0.07 $x10^{-4}$ lb sulfur/lb fuel (7 ppm) for our proposed program
F	= Fraction of total sulfur which exits the tailpipe as SO_2 (0.98 for baseline case and 0.70 for control case)
MC	= Molar conversion factor, 2 lb SO_2 per lb sulfur
CF	= Heavy-duty engine conversion factor, bhp-hr/mile
K	= Mass conversion factor, 5.0 x 10^{-4} tons/lb
i	= Engine years of operation, counting from 1 to 30

After applying the above equation separately for each engine class and weighting the resulting tonnage values according to the factors presented in Table VI-4, we determined that the fleet-average, per-engine discounted lifetime tons of SO_2 reduced is 0.0929. This is the value that was used to determine the SO_2-based credit that was applied to the total costs as described in Section VI.B.4 and summarized in Table VI-2.

D. Costs and Emission Reductions for Heavy-duty Gasoline Vehicles

Since we are also proposing new standards for heavy-duty gasoline vehicles (HDGV), we have calculated the costs and tons reduced for these standards as well. We did this on a per-vehicle basis, consistent with our approach for diesel engines described above. However, unlike for our proposed diesel engine standards, our proposed HDGV standards are not associated with new gasoline specifications, since a standard of 30 ppm sulfur has already been set in the preceding Tier 2/gasoline sulfur rulemaking. Note that the discussion of temporal and geographic applicability and baselines from Section VI.A above also applies to HDGV.

1. Gasoline Vehicle Costs

The impact of our proposed standards for HDGV was discussed in Section III.B and the associated compliance costs were discussed in Section V.B.5. We have made use of the per-vehicle costs shown in Table V.B-5 in our cost-effectiveness analysis, assuming that near-term costs are represented by the 2007-2011 values, and long-term costs are represented by the 2012+ values. We weighted the costs for the incompletes, Class 2b completes, and Class 3 completes by their respective contributions to the 2020 fleet (see Table VI-8). The fleet-average costs are repeated in Table VI-6 below.

Table VI-6. Fleet-average, Per-vehicle Costs for HDGV Used in Cost-effectiveness

	Total costs ($)
Near-term	182.20
Long-term	151.74

2. Emission Reductions from Gasoline Vehicles

The discounted lifetime tonnage numbers for NOx and NMHC for our proposed HDGV standards were based on the difference between emissions produced by vehicles meeting our proposed 2004 and proposed 2007 standards. Section II.C.1 describes the base emission factors, conversions, and adjustments used to calculate the in-use emissions in grams/mile produced by HDGVs for each year of a vehicle's life. From this basis, lifetime tonnage estimates were developed using the following procedure:

1) Annual mileage accumulation levels for MOBILE6 were applied to the in-use emission rates for each year in a vehicle's life to generate total mass emissions produced in each year by that vehicle

2) The resultant mass emissions were multiplied by the probability of survival in the appropriate year, known as the "survival" rate.

3) A seven percent annual discount factor, compounded from the first year of the engine's life, was then applied for each year to allow calculation of net present value lifetime emissions.

Converting to tons and summing across all years results in the total discounted lifetime per-vehicle tons. This calculation can be described mathematically as follows:

$$LE = \sum [\{(AVMT)_i \bullet (SURVIVE)_i \bullet (ER)_i \bullet (K)\}/(1.07)^{i-1}]$$

Where:

LE	= Discounted lifetime emissions in tons/vehicle
$(AVMT)_i$	= Annual miles traveled in year i of a HDGV's operational life
$(SURVIVE)_i$	= Probability of survival after i years of service
$(ER)_i$	= Emission rate, g/mi in year i of a vehicle's operational life
K	= Mass conversion factor, 1.102×10^{-6} tons/gram
i	= Vehicle years of operation, counting from 1 to 24

For NOx and NMHC, we generated discounted lifetime tonnage values for each vehicle class (incompletes, Class 2B completes, and Class 3 completes) using the above equation. This was done separately for the baseline and control cases. The baseline case included the proposed 2004 model year vehicle standards, while the control case entailed our proposed 2007 model year vehicle standards. The tonnage values that we calculated according to this procedure are shown in Table VI-7.

Table VI-7. Per-vehicle Discounted Lifetime Tons for HDGV

	NOx + NMHC
Baseline	
Incompletes	0.247
Class 2B completes	0.271
Class 3 completes	0.269
Control	
Incompletes	0.165
Class 2B completes	0.166
Class 3 completes	0.192

The final step before calculating the cost-effectiveness of our program was to weight the discounted lifetime tonnage values for each vehicle class by their respective fraction of the HDGV fleet. These fractions were based on vehicle count projections for 2020 for gasoline-powered heavy-duty vehicles. Table VI-8 presents the final weighting factors we used to develop fleet-average tonnage values.

Table VI-8. Vehicle Class Sales Weighting Factors for HDGV

Incompletes	0.288
Class 2B completes	0.692
Class 3 completes	0.020

The final discounted lifetime tonnage values for an average fleet engine meeting either the 2004 or 2007 standards are shown in Table VI-9. It is these values that were used directly in calculating the cost-effectiveness of our program.

Table VI-9. Fleet average, Per-vehicle Discounted Lifetime Tons for HDGV

	NOx + NMHC
Baseline: 2004 standards	0.264
Control: 2007 standards	0.166
Baseline - control	0.098

Note that although we are proposing new PM standards for HDGV in order to establish consistency with the proposed HDDE PM standards, current HDGV are believed to already meet this proposed PM standard. Therefore, there are no PM emission reductions associated with HDGV.

Since we are calculating a single set of cost-effectiveness values for both diesel engines and gasoline vehicles, it was necessary for us to weight the costs and emission reductions for HDDE and HDGV by the fraction of diesel-powered and gasoline-powered heavy-duty vehicles in the fleet. According to projections for MOBILE6, in year 2020 the in-use heavy-duty fleet will be composed of approximately 50 percent diesel-powered and 50 percent gasoline-powered vehicles. We applied this weighting to the NOx+NMHC costs from Tables VI-2 and VI-6 to obtain per-vehicle costs representing all heavy-duty vehicles (PM reductions are only produced by our proposed HDDE standards, so the PM cost-effectiveness values represent only HDDE). We likewise applied the 50:50 weighting to the NOx+NMHC tons reduced from Tables VI-5 and VI-9. Final costs and tons reduced for the entire heavy-duty fleet on a per-vehicle basis are given in Table VI-10 below.

E. 30-year Net Present Value Cost-Effectiveness

The per-vehicle approach described in the preceding sections is designed to show the cost-effectiveness of our program for 2007 and later model year engines complying with our proposed new standards. It presumes that all phase-ins and delays have been completed and the fleet has fully turned over to engines meeting our proposed standards. However, the per-vehicle approach does not account for costs and emission reductions associated with the existing (pre-2007 model year) fleet due to operation on diesel fuel meeting our proposed 15 ppm cap.

We have also calculated the cost effectiveness of our proposed program using a "30-year net present value " approach that includes all nationwide emission reductions and costs for a 30 year period. This timeframe captures both the early period of the program when very few vehicles/engines meeting our proposed standards will be in the fleet, and the later period when essentially all vehicles/engines in the fleet will meet our proposed standards. The 30-year net present value approach also accounts for cost and emission impacts of our proposed 15 ppm sulfur cap on engines manufactured before model year 2007. The 30-year net present value approach does have one important drawback in that it includes the engine costs for engines sold 30 years after the program goes into effect, but includes almost none of the emission benefits from those engines. Thus the 30-year net present value approach does not necessarily match all costs with all the emission reductions that those costs are intended to produce. It is presented here, nevertheless, as a reasonable measure of the cost effectiveness of this combined vehicle-fuel program.

We have calculated this "30-year net present value " cost-effectiveness using the net present value of the annual emission reductions and costs described in Sections II and V, respectively. The calculation of 30-year net present value cost-effectiveness follows the pattern described above for the per-engine analysis:

$$DNAE = \sum (NE)_i /(1.07)^{i-2006}$$

Where:

DNAE	= Reduction in nationwide 30-year net present value emissions in tons
$(NE)_i$	= Reduction in nationwide emissions in tons for year i of the program
i	= Year of the program, counting from 2006 to 2035

and

$$DNAC = \sum (NC)_i /(1.07)^{i-2006}$$

Where:

DNAC	= Nationwide 30-year net present value costs in dollars
$(NC)_i$	= Nationwide costs in dollars for year i of the program
i	= Year of the program, counting from 2006 to 2035

The 30-year net present value cost-effectiveness is produced by dividing DNAC by DNAE. The nationwide reductions in emissions for each year are given in Section II. The nationwide costs are given in Section V, Table V.E-1. The results are given in VI-11 below.

F. Results

We calculated the cost-effectiveness of our proposed standards using two different approaches. The first divides the total per-vehicle, discounted lifetime costs by the total per-vehicle, discounted lifetime tons reduced for our proposed HDDE standards, diesel sulfur standard, and HDGV standards. The results are given in Table VI-10.

Table VI-10. Per-vehicle Cost-effectiveness of the Proposed Standards

Pollutants	*Discounted lifetime vehicle & fuel costs*	*Discounted lifetime emission reductions (tons)*	*Discounted lifetime cost effectiveness per ton*	*Discounted lifetime cost effectiveness per ton with SO_2 credit*[a]
Near-term costs				
NOx + NMHC	$1535	0.8838	$1,736	$1,736
PM	$872	0.0672	$12,977	$6,338
Long-term costs				
NOx + NMHC	$1121	0.8838	$1,268	$1,268
PM	$652	0.0672	$9,704	$3,065

[a] $446 credited to SO_2 (at $4800/ton) for PM cost effectiveness

We also calculated the cost-effectiveness of our program on an 30-year net present value basis for our proposed diesel engine, diesel fuel sulfur, and gasoline vehicle standards. To do this, we summed net present value of total costs from Section V.E, and divided by the sum of the net pesent value of tons reduced from Sections II.B.2.f and II.C.2. These costs and emission reductions are repeated in Appendices VI-B and VI-C. The results are given in Table VI-11.

Table VI-11. 30-year Net Present Value Cost-effectiveness of the Proposed Standards

	30-year n.p.v. engine, vehicle, & fuel costs	*30-year n.p.v. reduction (tons)*	*30-year n.p.v. cost effectiveness per ton*	*30-year n.p.v. cost effectiveness per ton with SO_2 credit*[a]
NOx + NMHC	$28.9 billion	18.9 million	$1,531	$1,531
PM	$8.8 billion	0.79 million	$11,248	$1,850

[a] $7.4 billion credited to SO_2 (at $4800/ton)

Because the primary purpose of cost-effectiveness is to compare our program to alternative programs, we made a comparison between the values in Tables VI-10 and VI-11 and the cost-effectiveness of other programs. Table VI-12 summarizes the cost effectiveness of several recent EPA actions for controlled emissions from mobile sources for NOx and NMHC, while Table VI-13 does the same for PM.

Table VI-12. Cost-effectiveness of Previous Mobile Source Programs for NOx + NMHC

Program	*$/ton*
Tier 2 vehicle/gasoline sulfur	1,311 - 2,211
2004 Highway HD diesel	207 - 405
Off-highway diesel engine	416 - 660
Tier 1 vehicle	2,010 - 2,732
NLEV	1,888
Marine SI engines	1,146 - 1,806
On-board diagnostics	2,263
Marine CI engines	23 - 172

Note: costs adjusted to 1998 dollars

Table VI-13: Cost-effectiveness of Previous Mobile Source Programs for PM

Program	*$/ton*
Marine CI engines	511 -3797
1996 urban bus	12,000 - 19,200
Urban bus retrofit/rebuild	29,600
1994 highway HD diesel	20,450 - 23,940

Note: costs adjusted to 1998 dollars

By comparing values from Tables VI-10 and VI-11 for NOx+NMHC to those in Table VI-12, we can see that the cost-effectiveness of our proposed engine/diesel sulfur standards falls within the range of these other programs. Our proposed program overlaps the range of the recently promulgated standards for Tier 2 light-duty vehicles and gasoline sulfur shown in Table V.F-3. Our proposed program also overlaps the cost-effectiveness of past programs for PM. It is true that some previous programs have been more cost efficient than the program we are proposing today. However, it should be expected that the next generation of standards will be more expensive than the last, since the least costly means for reducing emissions is generally pursued first.

The primary advantage of making comparisons to previously implemented programs is that their cost-effectiveness values were based on a rigorous analysis and are generally accepted as representative of the efficiency with which those programs reduce emissions. Unfortunately, previously implemented programs can be poor comparisons because they may not be representative of the cost-effectiveness of potential future programs. Therefore, in evaluating the cost-effectiveness of our proposed engine/diesel sulfur program, we also considered whether our proposal is cost-effective in comparison with potential future means of controlling emissions. In the context of the Agency's rulemaking which would have revised the ozone and PM NAAQS[a], the Agency compiled a list of additional known technologies that could be considered in devising new emission reductions strategies.[5] Through this broad review, over 50 technologies were identified that could reduce NOx, VOC, or PM. The cost-effectiveness of these technologies averaged approximately $5,000/ton for VOC, $13,000/ton for NOx, and $40,000/ton for PM. Although a $10,000/ton limit was actually used in the air quality analysis presented in the NAAQS revisions rule, these values clearly indicate that, not only are future emission control strategies likely to be more expensive (less cost-effective) than past strategies, but the cost-effectiveness of our proposed engine/diesel sulfur program falls within the range of potential future strategies.

In summary, given the array of controls that will have to be implemented to make progress toward attaining and maintaining the NAAQS, we believe that the weight of the evidence from alternative means of providing substantial NOx + NMHC and PM emission reductions indicates that our proposed engine/diesel sulfur program is cost-effective. This is true from the perspective of other mobile source control programs or from the perspective of other stationary source technologies that might be considered.

[a] This rulemaking was remanded by the D.C. Circuit Court on May 14, 1999. However, the analyses completed in support of that rulemaking are still relevant, since they were designed to investigate the cost-effectiveness of a wide variety of potential future emission control strategies.

APPENDIX VI - A: Factors Used in Diesel Engine Calculations for Cost-effectiveness

MOBILE6 engine class	*Weight category*[α]	*Sales weighting*[β]	*Conversion factors, bhp-hr/mi*[ϐ]	*Fuel economy, miles/gal*[δ]
Class 2B	LH	0.199	1.09	12.96
Class 3	LH	0.060	1.25	11.66
Class 4	LH	0.056	1.458	10.2
Class 5	LH	0.027	1.573	9.88
Class 6	MH	0.115	1.942	8.71
Class 7	MH	0.164	2.409	7.53
Class 8A	HH	0.098	2.763	6.59
Class 8B	HH	0.227	3.031	6.3
School buses	MH	0.044	2.989	6.18
Urban transit buses	HH	0.009	4.679	3.79

[α] LH = Light heavy duty, MH = Medium heavy duty, HH = Heavy heavy duty

[β] Based on 2020 heavy-duty diesel engine count, Tables 17 & 18 from EPA Report Number EPA420-P-99-011, April 1999, "Fleet characterization data for MOBILE6: development and use of age distributions, average annual mileage accumulation rates and projected vehicle counts for use in MOBILE6."

[ϐ] Tables 28 and 30 from EPA Report Number EPA420-P-98-015, May 1998, "Update heavy-duty engine emission conversion factors for MOBILE6: Analysis of BSFCs and calculation of heavy-duty engine emission conversion factors"

[δ] Tables 14 and 15 from EPA Report Number EPA420-P-98-014, May 1998, "Update heavy-duty engine emission conversion factors for MOBILE6: Analysis of fuel economy, non-engine fuel economy improvements, and fuel densities

APPENDIX VI - B: Costs used in 30-year Net Present Value Cost Effectiveness Analysis ($millions)

	Diesel NOx adsorber	*Diesel PM trap*	*Gasoline vehicle*	*Diesel sulfur*
2006	(84)	(64)	0	1,304
2007	372	282	77	1,764
2008	513	390	79	1,791
2009	506	385	73	1,818
2010	629	478	74	1,845
2011	492	374	75	1,873
2012	454	345	70	1,901
2013	447	340	71	1,929
2014	439	334	72	1,958
2015	431	328	73	1,987
2016	440	334	74	2,017
2017	448	340	75	2,047
2018	456	346	76	2,078
2019	463	352	77	2,109
2020	470	358	78	2,141
2021	477	363	79	2,173
2022	484	368	80	2,206
2023	490	373	81	2,239
2024	497	378	82	2,272
2025	503	382	83	2,306
2026	509	387	84	2,341
2027	515	391	86	2,376
2028	520	396	87	2,412
2029	526	400	88	2,448
2030	532	404	89	2,485
2031	537	408	90	2,522
2032	543	412	91	2,560
2033	548	417	92	2,598
2034	553	421	93	2,637
2035	559	425	94	2,677

APPENDIX VI - C: Emission Reductions Used in 30-year Net Present Value Cost Effectiveness Analysis (thousand tons)

	Diesel NOx	*Diesel VOC*	*Diesel PM*	*Diesel SOx*	*Gasoline NOx*	*Gasoline VOC*
2006	0	0	7	99	0	0
2007	32	11	13	101	3	1
2008	121	31	21	102	8	3
2009	260	48	29	104	12	5
2010	449	64	36	106	16	6
2011	660	83	43	108	20	8
2012	863	103	49	110	24	9
2013	1,048	121	54	112	27	10
2014	1,216	138	59	113	30	11
2015	1,369	153	64	115	33	12
2016	1,510	167	68	117	35	14
2017	1,639	179	73	119	38	15
2018	1,758	191	76	120	40	16
2019	1,869	202	80	122	42	17
2020	1,971	211	83	124	45	19
2021	2,067	220	87	125	47	20
2022	2,156	229	90	127	49	21
2023	2,239	236	93	128	50	22
2024	2,317	243	95	130	52	23
2025	2,390	250	98	131	54	25
2026	2,459	256	101	133	56	26
2027	2,524	261	103	134	58	27
2028	2,585	266	106	136	59	28
2029	2,644	271	108	137	61	29
2030	2,699	274	111	139	63	30
2031	2,751	278	113	140	65	32
2032	2,801	280	115	142	67	33
2033	2,847	283	118	143	68	34
2034	2,891	284	120	144	70	35
2035	2,932	285	122	146	72	36

Chapter VI References.

1. U.S. EPA; Review of NAAQS for Ozone, Assessment of Scientific and Technical Information, Office of Air Quality Planning and Standards Staff Paper; document number: EPA-452\R-96-007.

2. "Final Regulatory Impact Analysis: Control of Emissions of Air Pollution from Highway Heavy-Duty Engines." September 16, 1997. Alan Stout, U.S. EPA, OAR/OMS/EPCD.

3. "A Review of Current and Historical Nonroad Diesel Fuel Sulfur Levels", Memorandum from David J. Korotney to EPA Air Docket A-97-10, March 3, 1998, Docket Item II-B-01.

4. Table 6, Agency Report Number EPA420-P-99-011, "Fleet characterization data for MOBILE6: development and use of age distributions, average annual mileage accumulation rates and projected vehicle counts for use in MOBILE6," April 1999.

5. “Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule,” Appendix B, “Summary of control measures in the PM, regional haze, and ozone partial attainment analyses,” Innovative Strategies and Economics Group, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, July 17, 1997.