Chapter IX: Diesel Fuel Program Alternatives

We have considered several potential diesel fuel sulfur alternatives in developing the proposed rulemaking. This chapter presents these different sulfur alternatives and the ways each would impact the emission control technology, fuel costs, the emissions standards and reductions, and the cost effectiveness associated with the program. The discussion assumes a 15 ppm cap program as a baseline, so the impacts of the other sulfur levels are considered relative to the proposed 15 ppm cap. The sulfur levels we considered are shown in Table IX-1.

Table IX-1 Diesel Fuel Sulfur Levels Considered

	Regulatory Sulfur Cap	*Regulatory Sulfur Average*	*Expected In-Use Sulfur Average*
Alternative 1	5 ppm	None	<5 ppm
Alternative 2	15 ppm	None	~7 ppm
Alternative 3	25 ppm	15 ppm	~15 ppm
Alternative 4	50 ppm	30 ppm	~30 ppm

Alternative 1 would require that fuel sulfur be no greater than 5 ppm. With such a low sulfur level cap, we would expect an average in-use sulfur level somewhere around two ppm, but such a low level is difficult even to measure, so we would consider the average to be simply “below” 5 ppm. Alternative 2 requires a sulfur level cap of 15 ppm, with no requirement on the average sulfur level. To ensure compliance with the cap, we would expect refiners to produce a fuel well below that level with the resultant in-use sulfur level being around seven ppm. This alternative is evaluated as the control case in previous chapters. Alternative 3 would require a 15 ppm average supplemented by a 25 ppm cap to ensure sulfur levels would not stray too high. Under such a program, we would expect the average in-use sulfur level to be roughly 15 ppm. The final alternative considered, Alternative 4, would require a 30 ppm average and a 50 ppm cap, with the resultant in-use sulfur level averaging around 30 ppm.

A. 15 ppm Average with a 25 ppm Cap

1. Emission Control Technology Enablement

As discussed at length in Chapter III, fuel sulfur level adversely impacts the effectiveness of all known and projected aftertreatment devices. Despite this, we believe that the design, precious metal loading, and application of aftertreatment devices would be fundamentally similar under a 15 average/25 cap program as it would be under the proposed 15 cap program. However, we would expect that the aftertreatment devices would not operate at the same level of efficiency as expected under the proposed 15 ppm cap program, and would have a higher potential for adverse durability impacts, thus presenting increased technological challenges compared to a 15 ppm sulfur cap.

Because of the relationship between fuel sulfur level and sulfate make, in-use sulfate emissions would probably increase due to the higher sulfur level in the fuel. As shown in Table IX-1, we would expect the in-use average sulfur level under a 15 average/25 cap program to be roughly double the in-use average under a 15 cap program. The higher in-use sulfur level would roughly double in-use sulfate PM emissions. This would not necessitate an increase in the PM standard provided the sulfur level in compliance fuel was set at the regulated average level of 15 ppm.[a] Also, PM trap regeneration may be compromised a small amount due to sulfur's adverse impacts on the NO to NO_2 conversion necessary for completely passive PM trap regeneration.[1] As a result, a 15 average/25 cap fuel program might require that this issue be addressed with some active form of back-up PM trap regeneration, particularly for the lighter applications having lower operating temperatures. Such an active regeneration scheme could take the form of a fueling strategy capable of increasing exhaust temperature, as opposed to an electrical heater or some other "added" hardware. Furthermore, we believe that such an active regeneration scheme would be incorporated into the design as a backup, or protective measure, and that the active regeneration scheme would not be functioning at all times. Instead, the active regeneration would activate only under extreme conditions such as very cold ambients or extended idles where exhaust temperatures might be too low for too long to enable passive regeneration. This would help to ensure that reliable regeneration occurs under all operating conditions.

We also have concerns that fuel economy might be slightly reduced due to the slightly higher, on average, PM trap backpressure. This would likely occur due to the slightly higher soot loading, on average, resulting from less efficient passive trap regeneration. This higher backpressure would probably occur on all applications, not just the lighter applications. Nonetheless, we believe that the fuel economy effect would probably be negligible, particularly on the larger engines where fuel economy concerns are most critical.

Concerning NOx adsorbers, we expect that a 15 average/25 cap program would be sufficient to enable this technology. However, although the NOx adsorber would continue to adsorb and subsequently reduce NOx despite the higher sulfur fuel, the frequency of sulfur regeneration events, referred to as desulfation in Chapter III, would roughly double. The increased frequency of desulfation would increase fuel consumption probably on the order of one percent and would be realized on all diesel applications equipped with NOx adsorber technology. Additionally, the increased frequency of desulfation may adversely impact NOx adsorber durability because the thermal strain placed on the adsorber during any desulfation event would increase in frequency.

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[a] The maximum sulfur level of compliance fuel under the proposed 15 ppm cap program is proposed to be 15 ppm; therefore, under this scenario, the 15 cap and 15 average/25 cap programs would carry the same PM standard.

Also, because of the increased frequency of desulfation events, there would be a corresponding decrease in the likelihood of being able to perform the desulfation during ideal operating conditions. This may cause more thermal strain on the NOx adsorber and/or less efficient desulfation with a corresponding increase in fuel usage. The result being a decrease in our level of confidence that the NOx adsorber would be capable of fulfilling the demands of the heavy diesel industry in terms of fuel consumption and durability.

2. Vehicle and Operating Costs for Diesel Vehicles to Meet Proposed Emissions Standards with a 15 ppm Average Standard

As pointed out above, we believe it may be possible that the design, precious metal loading, and application of aftertreatment devices could be fundamentally similar under both a 15 ppm cap and a 15 ppm average. Therefore, we believe that having a 15 ppm average sulfur standard would have a negligible impact on the cost of emission control hardware relative to the costs associated with a 15 ppm cap standard. However, as mentioned, we would expect a one percent fuel economy decrease (i.e., a one percent increase in fuel consumption) due to the increased frequency of desulfation of the NOx adsorber. This fuel economy decrease would result in consumption of more fuel and, therefore, would result in higher cost. We have estimated the increased discounted lifetime cost of this one percent fuel economy impact at $108, $207, $755, and $893 for a light, medium, heavy heavy-duty diesel, and urban buses, respectively. This assumes a diesel fuel cost of 84.8 cents/gallon and desulfurization, distribution, and lubricity additive costs of 3.4 cents/gallon (see below).[2] Table IX.A-1 shows details of this calculation.

Table IX.A-1. Increased Lifetime Fuel Costs Associated with a 15 ppm Average Standard Relative to a 15 ppm Cap Standard

	LHDD	*MHDD*	*HHDD*	*UrbanBus*
Discounted Lifetime Mileage	144,000	179,000	531,000	376,000
Base Fuel Economy	11.9	7.7	6.3	3.8
1% Decrease in Fuel Economy	11.8	7.6	6.2	3.7
Base Gallons	12,047	23,264	84,751	100,237
Increased Gallons	12,168	23,499	85,607	101,249
Difference in Gallons	122	235	856	1,013
cost/gallon	$0.882	$0.882	$0.882	$0.882
Discounted Lifetime Cost	$108	$207	$755	$893

3. Fuel Costs Under a 15 ppm Average Standard

A 15 ppm sulfur average standard, coupled with relaxing the sulfur cap of 25 ppm, would reduce both the cost of producing and transporting diesel fuel relative to the proposed 15 ppm cap. Overall, we would expect this approach to provide more flexibility to refiners and distributors, and directionally help in addressing concerns that have been expressed about the difficulties of distributing diesel fuel with very low sulfur specifications.

As summarized in Chapter IV, vendors of diesel desulfurization technology project that a number of additions to the existing diesel desulfurization units would be made to enable a refiner to meet a 25 ppm cap, 15 ppm average sulfur standard. This would be done by adding hydrotreating subunits such as a hydrogen sulfide scrubbing unit, a PSA unit to increase hydrogen purity, an interstage stripper and a second reactor which would either be the same pressure or a higher pressure vessel than the existing reactor. A new, high activity catalyst would also replace today's catalyst and the second reactor may be operated at a higher temperature. Many refiners blending low amounts of light cycle oil (LCO) into their diesel fuel would likely be capable of meeting a 15 ppm average with a one-stage unit (thus not add an interstage stripper). The remaining refiners would essentially require the same two-stage hydrotreating unit that would be required to meet the proposed 15 ppm cap. In all cases, hydrogen consumption would be somewhat less than that required to meet the proposed 15 ppm cap standard.

We utilized the process operations and capital cost information provided by the diesel desulfurization technology vendors summarized in Tables V.D-4 and V.D-5 in Chapter V to estimate the costs for controlling the sulfur concentration in diesel fuel. Since the vendors did not provide desulfurization cost information specifically for the 15 ppm average, 25 ppm cap standard, we estimated the cost by making a straight line interpolation of the lower and higher sulfur points. We presumed that the actual average diesel sulfur level under this scenario would be 13 ppm, allowing for a slightly higher compliance margin than that provided for by the difference between the proposed average standard and the cap standard. The estimation methodology for calculating the capital, fixed, and variable operating costs are the same as those described in Chapter V. As in the 15 ppm cap cost analysis, we included the cost of a storage tank to store offspec product, and a finishing reactor for the hydrocracker. In addition, we assumed that one third of the refineries meeting the 25 ppm cap standard, 15 ppm average standard would have to replace or better seal their heat exchangers to prevent leaking of the feed into the product.

In Table IX.A-2 we summarize our estimate of the average and small refinery capital and operating costs, and the per-gallon cost of desulfurizing diesel fuel from 340 ppm down to 13 ppm under a 25 ppm cap standard. Table IX.A-3 shows the estimated average per-gallon cost and nationwide aggregate refinery cost. This analysis assumes a 7% return on investment before taxes, operating costs in 1999 dollars, and capital costs in 1999 dollars.

Table IX.A-2. Estimated Per-Refinery Capital and Operating Costs and Per-Gallon Cost for an Average Refinery and a Small Refinery Meeting a 25 ppm Cap, 15 ppm Average Standard

Average Sized Refinery	
Capital Cost ($Million)	24
Operating Cost ($Million/yr)	6
Per-Gallon Cost (¢/gallon)	3.0
Small Sized Refinery	
Capital Cost ($Million)	17
Operating Cost ($Million/yr)	4
Per-Gallon Cost (¢/gallon)	4.0

Table IX.A-3 Fuel Costs for a 25 ppm Cap, 15 ppm Average Compared to a 15 ppm Cap

	25 ppm Cap 15 ppm Average	*15 ppm Cap*
Per-Gallon Cost (¢/gallon)		
Typical Sized Refinery	3.0	4.0
Small Sized Refinery	4.0	5.4
Aggregate Capital Cost ($Billon)	3.2	4.1
Aggregate Annual Operating Cost ($Billion/yr)	0.8	1.1

As expected, the estimated refining costs are lower for the 25 ppm cap, 15 ppm average standard compared to the proposed 15 ppm cap standard. The estimated small refiner costs are almost 1 ½ times higher than the average sized refinery cost, however, in absolute terms the cost difference is 1.4 cents per gallon instead of 2 cents per gallon.

Based on two different information sources from Vendor B, we realized that we could derive two different capital cost estimates for desulfurizing diesel fuel to 13 ppm using Vendor B's technology. The first source of information, which is the source which results in the cost estimate which we present in the table above, and which is summarized in Chapter V, is $7 million for desulfurizing diesel fuel to10 ppm. However, the 10 ppm capital cost was derived earlier and perhaps is more uncertain than Vendor B's more recent costs. The more recent capital cost estimates are for desulfurizing diesel fuel to 20 ppm and 5 ppm, and they are $6 million and $15 million, respectively. These more recent cost figures suggest that the capital cost of desulfurizing diesel fuel to 13 ppm is about $11 million based on a straight line interpolation between those two costs. If we estimate the diesel fuel desulfurization cost based on this higher capital cost, we estimate that the cost of desulfurizing diesel fuel under the 25 ppm cap, 15 ppm average standard to increase by 0.15 c/gal.

As for fuel distribution, under the proposed 15 ppm cap on diesel sulfur content, we estimate that sulfur contamination in the distribution system can be adequately controlled at modest additional cost through the consistent and careful observation of current industry practices. A 0.2 cents per gallon increase in distribution cost is anticipated due to the need for an increase in pipeline shipment interface volumes, increased quality testing at product terminals, and the need to distribute an increased volume of fuel to meet the same level of consumer demand due to a reduction in energy density.

We do not expect that having a 15 ppm average rather than a 15 ppm cap standard would substantially change our estimate of the impact on distribution costs. There may be a somewhat smaller increase in pipeline interface volumes under a 15 ppm average standard than under the proposed 15 ppm cap standard. However, the savings from such a potential reduction in interface volumes would be relatively small. To adequately prevent contamination from higher sulfur products such as off-highway diesel fuel (at 3,400 ppm average sulfur content) which would abut shipments of ultra low sulfur diesel (ULSD) fuel in the pipeline, we anticipate that pipeline operators would make their interface cuts at a point into the ULSD stream where essentially no mixing with adjacent products takes place. It seems likely that pipeline operators would make such conservative cuts, because of the low tolerance for mixing of ULSD with other products with a greater than a 200 fold difference in sulfur content. In determining the placement of the interface cuts, the difference in sulfur levels between a cap or average standard is relatively insignificant compared to the difference with other high sulfur products in the pipeline. Another factor that would tend to promote a conservative approach is the high risk associated with having to downgrade an entire shipment of ULSD to a higher sulfur and lower value product, if the interface cut was not sufficiently conservative to prevent contamination.

To estimate the potential impact on distribution costs due to a reduction in interface volumes, we assumed a linear relationship between interface volumes and the sulfur cap. This provides an upper bound estimate of the extent to which distribution costs under a 15 ppm average standard might be lower than under a 15 ppm average standard of 0.003 cents per gallon. This potential savings would be substantially smaller if the difference in interface volumes is not proportional to the difference in the sulfur caps.

Overall, we project that the average cost of meeting the 15 ppm average at the refinery would be about 3.0 cents per gallon, about 1.0 cents per gallon less than the corresponding cost for fuel meeting a 15 ppm sulfur cap. Adding the cost of lubricity additives and increase in distribution costs, the final cost for the 15 ppm average / 25 ppm cap fuel would be 3.4 cents/gallon, as compared to 4.4 cents per gallon under the proposed 15 ppm cap standard.

4. Emission Reductions Under a 15 ppm Average Standard

As discussed above, we believe that the same basic aftertreatment technology could be used to reduce exhaust emissions from HDDEs even if we required a fuel sulfur cap of 25 ppm rather than 15 ppm. However, there would be penalties in durability, fuel consumption, and emissions.

At this higher fuel sulfur level, we believe that the particulate trap will still result in large reductions of HC, CO, and carbon soot. We also believe that the 0.2 g/bhp-hr NOx standard can be achieved using a NOx adsorber. However, meeting this NOx standard with a 25 ppm fuel sulfur cap would likely result in a one percent fuel consumption penalty compared to meeting it with a 15 ppm fuel sulfur cap. The reasons for this fuel economy penalty are discussed in Chapter III (see Table III.A-2). Table IX.A-4 presents projected nationwide HDDE fuel consumption for the baseline and control cases for this regulatory alternative.

Table IX.A-4. Nationwide HDDE Fuel Consumption (billion gallons) for the 25 ppmS Cap-15 ppmS Average Regulatory Alternative

Calendar Year	*Baseline*	*Control*	*Fuel Penalty*
2007	37.6	37.6	0.01
2010	39.6	39.7	0.10
2015	43.0	43.3	0.29
2020	46.2	46.6	0.39
2030	51.9	52.4	0.51

The same total PM reductions cannot be achieved with the higher sulfur fuel. Sulfur in the fuel impacts the amount of direct sulfate PM in the exhaust gas. While in the 15 ppmS cap case we considered a PM level of 0.005 g/bhp-hr in use, we believe that these same engines would emit 0.009 g/bhp-hr in use when operating on 25 ppmS fuel. These in-use emission factors are based on averages of 7 ppmS and 15 ppmS for the lower and higher sulfur caps respectively. The derivation of these emission factors as a function of fuel sulfur level is described in more detail in Chapter III (see Table III.A-2). Table IX.A-5 presents projected nationwide HDDE PM emissions for the baseline and control cases for this regulatory alternative.

Table IX.A-5. Nationwide HDDE PM Emissions (thousand short tons) for the 25 ppmS Cap / 15 ppmS Average Alternative

Calendar Year	*Baseline*	*Controlled*	*Reduction*	*Reduction under 15 ppmS cap (for comparison)*
2007	100.1	88.6	11.5	11.7
2010	94.3	60.1	34.2	35.7
2015	93.4	32.5	60.9	63.8
2020	98.4	19.1	79.3	83.2
2030	118.9	13.4	105	110.7

Increasing fuel sulfur level also increases SOx emissions. We assume that the sulfur in the fuel that is not converted to DSPM is converted to SO_2. Because we base SOx emissions on the amount of sulfur through the engine, the increase in fuel consumption also increases SOx emissions. Table IX.A-6 presents projected nationwide HDDE SOx reductions for this regulatory alternative and for the proposal.

Table IX.A-6. Nationwide HDDE SOx Emission Reductions (thousand short tons) for the 25 ppmS Cap-15 ppmS Average Regulatory Alternative

Calendar Year	*25 ppmS cap*	*15 ppmS cap*
2007	86	88
2010	91	93
2015	99	102
2020	107	109
2030	120	123

5. Cost Effectiveness of a 15 ppm Average Standard

The methodology used to determine the cost effectiveness of this alternative standard follows that described in Chapter VI for a program with a 15 ppm cap. The only notable difference in methodology is the inclusion of a fuel economy impact. The alternative standard of 15 ppm on average does have impacts on specific values in the calculations, including lower desulfurization and distribution costs, lower in-use PM benefits, and lower SO_2 benefits. Engine costs are assumed to remain the same as for our proposed program of a 15 ppm cap, since the engine standards are not changing. We have calculated cost effectiveness using both the per-vehicle and 30-year net present value approaches, consistent with our cost effectiveness presentation for our proposed program.

As described above, we estimate that the combination of a 15 ppm average sulfur standard and our proposed engine standards would result in a 1 percent loss of fuel economy in comparison to our proposed program, due to an increased frequency of sulfur regeneration events in the NOx adsorber. This loss of fuel economy can be converted into a per-engine cost using the following equation:

$$\text{LFEC} = \sum [\{(\text{AVMT})_i \bullet (\text{SURVIVE})_i \bullet (\text{P}) \div (\text{FE})\}/(1.07)^{i-1}] \bullet [1/(1-\text{FE}\%/100)-1]$$

Where:

LFEC	= Lifetime fuel economy costs in $/engine
$(\text{AVMT})_i$	= Annual engine miles travelled in year i of a engine's operational life
$(\text{SURVIVE})_i$	= Fraction of engines still operating after i years of service
P	= Price of diesel fuel, $/gallon
FE	= Normal fuel economy in miles per gallon (Appendix VI-A)
FE%	= Percent loss in fuel economy
i	= Engine years of operation, counting from 1 to 30

The price of diesel fuel P has been estimated as the base price of 84.8 ¢/gal[b] plus costs associated with the new sulfur standard. These costs include the desulfurization cost of 3.0 ¢/gal for the 15 ppm average standard, distribution costs of 0.18 ¢/gal, and lubricity additives costing 0.2 ¢/gal, bringing the total fuel price to 88.2 ¢/gal. The total, per-engine fuel costs are given in Table IX.A-7, where "direct" costs include desulfurization, distribution and lubricity additive costs. As described in Chapter VI, direct fuel costs were assigned first to the engine technologies, then the pollutants, resulting in a 75:25 direct fuel cost split between NOx+NMHC and PM.

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[b] Energy Information Administration estimate for 2000, minus taxes.

Table IX.A-7. Fleet-average, Per-engine fuel costs for HDDE for 15 ppm average program

	NOx+NMHC	PM
Direct fuel costs, $	1021	340
Fuel economy loss, $	355	0
Total fuel costs per engine, $	1376	340

The methodology for calculating the remaining costs of this alternative sulfur program parallels that described in Chapter VI. Engine costs are given in Table VI-1. Total costs for the 15 ppm average sulfur program, including all engine hardware and fuel costs, are given in Table IX.A-8.

Table IX.A-8. Fleet Average Per-Engine Costs for HDDE Used in Cost Effectiveness for 15 ppm average sulfur program

	Near-term costs ($)		*Long-term costs ($)*	
	NOx+NMHC	PM	NOx+NMHC	PM
Total uncredited costs	2948	774	2150	554
SO_2 credit allocation	n/a	-440	n/a	-440
Total credited costs	2948	333	2150	113

For NOx, NMHC, and PM, we generated discounted lifetime tonnage values for each engine class (LH, MH, HH, and urban buses) according to the methodology described in Chapter VI. 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 13 ppm diesel sulfur. The discounted lifetime tonnage values for each engine class were then weighted by their respective fraction of the HDDE fleet. The tonnage values that we calculated according to this procedure are shown in Table IX.A-9.

Table IX.A-9. Fleet average, Per-engine Discounted Lifetime Tons for HDDE for 15 ppm average program

	NOx + NMHC	PM
Baseline: 2004 standards with 340 ppm fuel	1.83	0.071
Control: 2007 standards with 13 ppm fuel	0.16	0.007
Reduction	1.67	0.064

The final per-vehicle cost effectiveness values for the alternative 15 ppm average program are given in Table IX.A-10. Note that these values include the costs and emission reductions associated with our proposed standards for heavy-duty gasoline vehicles.

Table IX.A-10. Per-vehicle cost effectiveness of the alternative 15 ppm average program

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]
<u>Near-term costs</u>				
NOx + NMHC	$1565	0.88	$1,800	$1,800
PM	$774	0.064	$12,100	$5,200
<u>Long-term costs</u>				
NOx + NMHC	$1151	0.88	$1,300	$1,300
PM	$554	0.064	$8,700	$1,800

[a] $440 credited to SO_2 (at $4800/ton) for PM cost effectiveness

We have also calculated the cost effectiveness of the alternative 15 ppm average program using a 30-year net present value approach that includes the net present value of all nationwide emission reductions and costs for a 30 year period. The net present value costs are given in Table IX.A-11. The final 30-year net present value cost effectiveness for the alternative 15 ppm program is given in Table IX.A-12.

Table IX.A-11. 30-year net present value costs for alternative 15 ppm average program

	NOx+NMHC	*PM*
Diesel engines, $billion	8.1	2.2
Gasoline vehicles, $billion	1.0	0
Diesel fuel, $billion	17.4	5.8
Total, $billion	26.4	8.0

Table IX.A-12. 30-year Net Present Value Cost Effectiveness of the Alternative 15 ppm Average Standard

	30-year NPV costs	*30-year NPV reduction (tons)*	*30-year NPV cost effectiveness per ton*	*30-year NPV cost effectiveness per ton with SO_2 credit[a]*
NOx + NMHC	$26.4 billion	18.9 million	$1,400	$1,400
PM	$8.0 billion	0.75 million	$10,700	$1,100

[a] $7.2 billion credited to SO_2 (at $4800/ton)

B. 5 ppm Cap

1. Emission Control Technology Enablement

Capping diesel fuel sulfur at 5 ppm would clearly strengthen the viability of new emissions control technologies enabled at 15 ppm, although we are aware of no additional technologies that this lower sulfur level would enable. PM traps would emit somewhat less sulfate PM, but non-sulfate PM emissions and certification test measurement tolerances would effectively limit the extent to which the standard could be lowered from the proposed 0.01 g/bhp-hr level at this time. Given the level of precision implicit in the 0.01 numerical standard, we would not expect a 5 ppm sulfur cap to result in a lower PM standard.

The robustness of the PM trap regeneration process would also be directionally aided by the near zero sulfur fuel, because less of the catalyst sites that promote regeneration would be blocked by sulfur poisoning. This propensity for sulfur poisoning is a critical issue in PM trap design because robustness of the regeneration process directly impacts trap performance and durability. In fact, designers could further increase regeneration robustness by increasing precious metal loading without fear of inordinate sulfate production because of the lower fuel sulfur level (though at added cost). However, we have not quantified this directional benefit or cost difference because we deem the 15 ppm level adequate for robust regeneration already.

Five ppm sulfur fuel would also benefit NOx adsorber technology. Adsorber desulfation would be needed about four times less often than that required under a 15 ppm sulfur cap, providing a projected 1% improvement in fuel economy (see discussion in Chapter III.A.7.b for more detail on this estimate). Directionally, there should also be a gain in NOx adsorber durability due to the less frequent thermal cycling built into the desulfation process. However, available evidence suggests that at any fuel sulfur level under 15 ppm, these cycles are not likely to be so numerous or severe over the vehicle life as to seriously constrain durability (see discussion in Chapter III.A.7.b for more detail on this conclusion). NOx emissions would not be much affected because the basic NOx storage and removal processes would occur in much the same way, and desulfation events would be programmed to occur frequently enough to maintain NOx reduction efficiencies high enough to meet the standard with a minimum of fuel consumption.

Overall, the engineering challenges associated with designing high-efficiency exhaust emissions controls to accommodate some sulfur in diesel fuel should be significantly less under a 5 ppm cap than under a 15 ppm cap.

2. Cost for Diesel Vehicles to Meet Standards with a 5 ppm Sulfur Cap

Other than programming the NOx adsorber regeneration frequency to take advantage of the slower sulfur poisoning in order to optimize fuel economy, it does not appear that the 5 ppm sulfur case would differ from the 15 ppm case with regard to the design of engines and exhaust emission control devices. Therefore, the vehicle costs are the same.

3. Fuel Costs Under a 5 ppm Sulfur Cap

We have not performed an extensive analysis of the refining cost of meeting a 5 ppm sulfur cap because of a lack of reliable vendor and refinery data for desulfurization to these levels. However, Mathpro, under contract to EMA, did estimate the refining cost of producing diesel fuel with an average sulfur level of 2 ppm, a reasonable average under a 5 ppm cap. Mathpro examined two sets of cases where average on-highway diesel fuel sulfur levels were reduced from 20 ppm to 2 ppm, one with off-highway diesel fuel sulfur at 350 ppm (Mathpro cases 1 and MP1) and the other with off-highway diesel fuel sulfur at 20 ppm (cases 4 and 8). From these cases, Mathpro's estimated cost of reducing highway diesel fuel sulfur from 20 ppm to 2 ppm ranges from 1.7 to 2.1 cents per gallon. Assuming a linear relationship between sulfur and cost per gallon in this range, the cost of reducing average sulfur levels from 7 ppm (that projected under the proposed 15 ppm cap) to 2 ppm would be 0.7-0.8 cents per gallon. Although it is possible that the cost per ppm of sulfur reduced would actually increase as sulfur was reduced, the extent of this increase is difficult to estimate. Thus, the best cost that can be projected at this time is 0.7-0.8 cents per gallon, incremental to the cost of the 15 ppm sulfur cap program.

Although we have not attempted to analyze in detail the cost impacts of distributing a fuel with a cap on sulfur content as low as 5 ppm, the American Petroleum Institute recently had a contractor do so.[3] That study estimated that, compared to current costs, distribution costs would increase by 0.9 to 2.1 cents per gallon if a 5 ppm standard were adopted for the entire highway diesel pool.[4] The following reasons were cited for why, as the sulfur specification is decreased, it becomes more difficult to maintain product purity and supply:

- There is increased difficulty and cost associated with correcting off-specification batches in the distribution system.
- Measurement accuracy becomes more limiting.
- The pipeline compliance margin becomes more limiting at refineries.
- Supply outages due to off-specification product will become more common.
- The difference between the sulfur content of highway diesel fuel and that of abutting higher sulfur products in the pipeline system becomes larger.

Even with the estimated increase in distribution costs, the report still concluded that it was probably impractical to attain continuous supply availability of diesel fuel in all areas and outlets within the current distribution system at a 5 ppm cap on fuel sulfur content. If such problems are to be avoided, additional, more costly measures may be necessary. Should a segregated distribution system be needed to control contamination, including dedicated pipelines and tank trucks, the costs would be considerably higher than the 0.9 to 2.1 cents per gallon estimated in the report.

We too are concerned that the measures which form the basis for the 0.9 to 2.1 cents per gallon cost estimate in the API-sponsored study may not ensure widespread compliance. Under a 5 ppm standard, sulfur measurement variability would need to be reduced appreciably from current tolerances, perhaps to a level of 1 ppm or less, and the test equipment purchases and quality control steps needed to attain this could prove costly. Yet the bulk of the impact would come from the major shift likely to be needed in the practices used to avoid contamination in the distribution system. Assuming an extremely demanding maximum sulfur specification of 3 ppm at the refinery gate and a test variability of 1 ppm, only 1 ppm contamination through the distribution system could be tolerated, and this would need to be maintained nationwide and year round in a distribution system that routinely handles products with sulfur levels of up to several thousand ppm. Refiners would also need to take additional measures to meet the 3 ppm refinery gate standard that would likely be set by pipeline operators. Similar to the distribution system, the measures that refiners would need to take to further reduce sulfur content and limit process variability are unclear, and might prove quite costly.

4. Emission Reductions Under a 5 ppm Sulfur Cap

We analyze the impacts of two differences between this case and the base case (15 ppm sulfur cap): sulfate emissions are lower and NOx adsorber de-sulfation events occur less frequently. The reduction in the NOx adsorber de-sulfation cycles leads to an improvement in fuel economy of 1 percent. Table IX.B-1 presents these projected fuel savings. We do not anticipate any further reductions in HC or CO beyond the base case.

Table IX.B-1. Nationwide HDDE Fuel Consumption (billion gallons) with a 5 ppm Cap

Calendar Year	*Baseline*	*Control*	*Fuel Savings*
2007	37.6	37.5	0.01
2010	39.6	39.5	0.10
2015	43.0	42.8	0.28
2020	46.2	45.9	0.39
2030	51.9	51.4	0.50

There would be an in-use PM benefit compared to a 15 ppm cap, because the average fuel sulfur would be lower (perhaps 2-3 ppm compared to about 7 ppm) and so new vehicles would emit less sulfate PM. For this case we use a PM emission factor of 0.002 g/bhp-hr in-use for controlled engines. Table IX.B-2 presents projected nationwide HDDE PM emissions for the baseline and control cases for this program.

Table IX.B-2. Nationwide HDDE PM Emissions (thousand short tons) with a 5 ppm Cap

Calendar Year	*Baseline*	*Controlled (5 ppmS cap)*	*Reduction (5 ppmS cap)*	*Reduction (15 ppmS cap)*
2007	100.1	88.1	12.0	11.7
2010	94.3	57.4	36.9	35.7
2015	93.4	27.3	66.1	63.8
2020	98.4	12.2	86.2	83.2
2030	118.9	4.2	114.6	110.7

Lower sulfate PM emissions in the existing fleet would provide a 105 tons per year additional PM benefit (in 2007 when this benefit peaks) from adoption of a 5 ppm sulfur cap compared to a 15 ppm cap. However this is quite small compared to the corresponding 7100 ton per year PM benefit of reducing fuel sulfur from typical current average levels of around 340 ppm to levels near 15 ppm, which in turn is a small fraction of the total direct PM emissions benefit of the proposed 15 ppm cap, most of which comes from enabling PM traps on new engines (see Figure II.D-2). Table IX.B-3 presents DSPM reductions from the existing fleet due to lower sulfur in the fuel. These existing fleet reductions include those from spillover of HDDE fuel into other applications such has light-duty, off-highway, and tax-exempt applications.

Table IX.B-3. Nationwide Direct Sulfate PM Emissions Reductions (short tons) From the Existing Fleet with a 5 ppm Cap Compared to a 15 ppm Cap

Calendar Year	*HDDE Reductions*	*Other Reductions*	*Total Reductions*
2007	92	13	105
2010	63	9	72
2015	32	4	38
2020	16	2	17
2030	2	0	2

Because SOx emissions are directly a function of fuel consumption and sulfur level, SOx and SOx-derived secondary PM would also be reduced. Table IX.B-4 presents the projected nationwide HDDE SOx reductions for this program compared to the base case.

Table IX.B-4. Nationwide HDDE SOx Emission Reductions (thousand short tons) with a 5 ppm Cap

Calendar Year	*5 ppmS cap*	*15 ppmS cap*
2007	90	88
2010	95	93
2015	103	102
2020	111	109
2030	125	123

5. Cost Effectiveness of a 5 ppm Sulfur Cap Program

The methodology used to determine the cost effectiveness of this program follows that described in Chapter VI for a program with a 15 ppm cap. The only notable difference in methodology is the inclusion of a fuel economy benefit of 1 percent, the calculation methodology for which is given in Section IX.A.5. The 5 ppm cap program also has impacts on specific values in the calculations, including higher desulfurization and distribution costs, higher in-use PM benefits, and higher SO_2 benefits. Engine costs are assumed to remain the same as for our proposed program of a 15 ppm cap, since the engine standards are not changing. We have calculated cost effectiveness using both the per-vehicle and 30-year net present value approaches, consistent with our cost effectiveness presentation for our proposed program.

The total price of diesel fuel excluding taxes under a 5 ppm cap is estimated to be 91.3 ¢/gal. This price includes the base price of 84.8 ¢/gal, desulfurization cost of 4.75 ¢/gal (0.75 ¢/gal more than the desulfurization cost under a 15 ppm cap), distribution costs of 1.5 ¢/gal (the midpoint of the range 0.9 - 2.1 ¢/gal), and lubricity additive costs of 0.2 ¢/gal. As a result, the total per-vehicle fuel costs for HDDE under the alternative 5 ppm cap are estimated to be $1909 for NOx+NMHC and $636 for PM. In addition, the credit associated with SO_2 reductions has been estimated at $451 per-vehicle, slightly higher than the $446 used for our proposed program because the 5 ppm cap would produce slightly more SO_2 reductions.

Since we are assuming that the standards for HDDE would not change under a 5 ppm cap, the NOx+NMHC emission reductions would not change. There would, however, be some small additional in-use benefits from PM due to lower sulfate production. We estimate that the per-vehicle reductions in PM for HDDE under a 5 ppm cap would be 0.070 tons, as compared to 0.067 tons for our proposed 15 ppm cap.

The final per-vehicle cost effectiveness values for the 5 ppm cap program are given in Table IX.B-5. Note that these values include the costs and emission reductions associated with our proposed standards for heavy-duty gasoline vehicles.

Table IX.B-5. Per-vehicle Cost Effectiveness of a 5 ppm Cap

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	\$1652	0.88	\$1,900	\$1,900
PM	\$1070	0.070	\$15,400	\$8,900
Long-term costs				
NOx + NMHC	\$1238	0.88	\$1,400	\$1,400
PM	\$850	0.070	\$12,200	\$5,700

[a] \$451 credited to SO_2 (at \$4800/ton) for PM cost effectiveness

We have also calculated the cost effectiveness of the 5 ppm cap program using a 30-year net present value approach that includes the net present value of all nationwide emission reductions and costs for a 30 year period. The final 30-year net present value cost effectiveness for the 5 ppm cap program is given in Table IX.B-6.

Table IX.B-6. 30-year Net Present Value Cost Effectiveness of a 5 ppm Cap

	30-year NPV costs	*30-year NPV reduction (tons)*	*30-year NPV cost effectiveness per ton*	*30-year NPV cost effectiveness per ton with SO_2 credit*[a]
NOx + NMHC	\$35.9 billion	18.9 million	\$1,900	\$1,900
PM	\$11.2 billion	0.81 million	\$13,800	\$4,500

[a] \$7.5 billion credited to SO_2 (at \$4800/ton)

C. 50 ppm Cap

1. Emission Control Technology Enablement

As discussed in detail in Chapter III, we believe that diesel fuel needs to be desulfurized to the 15 ppm level to enable emission control technologies capable of meeting the proposed standards. Setting a fuel sulfur cap of 50 ppm would require that the PM standard be set at a less stringent level to accommodate the approximate tripling of sulfate PM production in the trap compared to a 15 ppm cap. However, increased fuel sulfur could have an even larger effect on robust trap regeneration than on sulfate production, bringing into question the very viability of PM traps at the higher sulfur levels. We believe that failures of the severity experienced with 50 ppm fuel in Finland would be unacceptable (see discussion in section III for more details on field experiences in Europe on 50 ppm sulfur fuel). These problems could become even more pronounced in light-duty applications, which tend to involve cooler exhaust streams, making regeneration more difficult. Field data with such applications is still sparse.

One means of attempting to resolve these problems is through use of an active regeneration mechanism, such as electric heaters or fuel burners. These could potentially introduce additional hardware and fuel consumption costs. They would also raise reliability concerns, based on past experience with such approaches. Active regeneration failures in PM traps would be of more concern than in NOx exhaust emission control devices because they involve the potential for complete exhaust stream plugging, runaway regeneration at very high temperatures, trap melting, engine stalling, and stranding of motorists in severe weather. As a result, we do not consider dependence on active PM trap regeneration to be a sufficient basis for establishing PM trap feasibility.

NOx adsorber technology would likely be infeasible with 50 ppm sulfur fuel as well, due to the rapid poisoning of NOx storage sites. Desulfation would be needed much more frequently and with a much higher resulting fuel consumption. Even if the fuel economy penalty could somehow be justified, we expect that overly frequent desulfation could cause unacceptable adsorber durability or driveability problems (because of the difficulty in timing the desulfation to avoid driving modes in which it might be noticed by the driver). A less stringent NOx standard could help to mitigate these concerns by allowing the NOx storage bed to sulfate up to a greater degree before desulfating. However, this might then cause deeper sulfate penetration into the storage bed and thus possible long-term degradation because of the difficulty of removing this deeper sulfate (see Chapter III for details of the effect of sulfur on NOx adsorbers).

Instead, we expect that diesel fuel with an average fuel sulfur level of 30 ppm and a cap of 50 ppm could enable lean NOx catalyst technology (described in Chapter III). These devices can provide modest NOx reductions and, because of their reliance on precious metal catalyst, also serve the function of a diesel oxidation catalyst, removing some of the gaseous hydrocarbons and the soluble organic fraction of PM. Unfortunately, lean NOx catalysts also share the oxidation catalyst’s tendency to convert fuel sulfur into sulfate PM, and do so even more aggressively because they require higher precious metal loadings to reduce NOx. They also require a fairly large addition of diesel fuel to accomplish NOx reduction, typically about 4% or more of total fuel consumption, based on DECSE testing data.[5] The injected fuel also makes it difficult to achieve an overall hydrocarbon reduction, despite the potential to convert much of the engine-out hydrocarbons over the catalyst. Typically, current lean NOx catalyst designs actually show a net hydrocarbon increase. In testing completed for the DECSE fuel sulfur program, HC slip from the lean NOx catalyst resulted in a doubling of HC emissions over the engine’s baseline levels.

We have assumed that lean NOx catalysts could be developed over time to deliver 20 percent reductions in NOx (beyond their current proven performance over the Federal Test Procedure) with a net PM reduction of 20 percent and no net increase in gaseous hydrocarbons, and with a four percent fuel economy penalty. Although this PM reduction level is below that achieved by current diesel oxidation catalysts, it represents an ambitious target to designers attempting to balance NOx reduction with sulfate production from the still substantial sulfur in the fuel. Results from the DECSE test program showed a 16 percent decrease in PM emissions with three ppm low sulfur diesel fuel, but a no reduction with 30 ppm sulfur diesel fuel. NOx reductions in the test program were approximately 15 percent at all sulfur levels with fresh catalysts.[6]

Based on a 2.3 g/bhp-hr NOx component of the 2.5 g/bhp-hr NOx+NMHC standard for baseline (pre-2007) engines (see Chapter II.B.1.b), the resulting NOx standard with a 20% reduction would then be 1.8 g/bhp-hr NOx. Likewise, a 20% reduction from the 0.10 g/bhp-hr baseline PM standard provides a 0.08 g/hp-hr PM standard. Because the enabled technologies do not allow very large emission reductions and stringent emission standards, it is conceivable that continued progress in engine design may eventually allow these standards to be met through improvements in EGR and combustion optimization, although we cannot outline such a technology path at this time. It is likely that such a path would still involve a substantial fuel economy penalty.

2. Cost for Diesel Vehicles to Meet Standards with a 50 ppm Sulfur Cap

We have estimated that lean NOx catalysts (including their diesel oxidation catalyst function) would add an average of $1200 to the cost of an engine. This cost estimate includes costs for both the lean NOx catalyst and associated fuel injection hardware required to provide the diesel fuel as a reductant.[7] The long term estimates of these system costs are reduced to account for the learning curve effect as described for the 15 ppm case in section V. Cost estimates for each vehicle class and model year of the program are presented in Table IX.C-1. These costs are lower than the cost increase for technologies enabled by 15 ppm sulfur fuel.

Table IX.C-1. Estimated Cost for Lean NOx Catalyst

Model Year	*Light HD*	*Medium HD*	*Heavy HD + Urban Bus*
2007-2008	$889	$1,108	$1,579
2009-2010	$711	$886	$1,263
2011+	$569	$709	$1,011

3. Fuel Costs Under a 50 ppm Sulfur Cap

The cost of meeting a 50 ppm sulfur cap at the refinery would be substantially less costly than meeting the proposed cap of 15 ppm. In some cases, refiners may be able to meet a 50 ppm cap with only relatively minor capital investment of a few million dollars for a new hydrogen sulfide scrubbing unit and a PSA unit to increase hydrogen purity and using a new, high activity catalyst which is available today. In most cases, especially if the refinery is processing LCO, a second reactor would probably have to be installed. Finally, some refiners may even require essentially the same two-stage hydrotreating unit that would be required to meet the proposed 15 ppm standard. In all cases, hydrogen consumption would be significantly less than that required to meet the proposed 15 ppm cap standard.

We utilized the process operations and capital cost information provided by the diesel desulfurization technology vendors summarized in Tables V.D-4 and V.D-5 in Chapter V to estimate the costs for controlling the sulfur concentration in diesel fuel. Since only one vendor provided desulfurization cost information specifically for the 30 ppm average, 50 ppm cap standard, we estimated the cost by the other vendor by making a straight line interpolation of the lower and higher sulfur points. The estimation methodology for calculating the capital, fixed, and variable operating costs are the same as those described in Chapter V. Because this scenario is less severe than the other cases which we analyzed, we did not include the cost of a storage tank to store offspec product, and a finishing reactor for the hydrocracker. Nor did we assume that the refineries meeting this standard would have to replace or better seal their heat exchangers to prevent leaking of the feed into the product.

The capital and operating cost inputs were combined to estimate the overall cost of desulfurizing highway diesel fuel from the base sulfur level of 340 ppm to an average of 30 ppm. These costs were developed for each of the two characteristic refineries. Nationwide average costs were developed based on volume weighting the diesel desulfurization costs of each group of refineries. The per-refinery capital and operating costs, and the per-gallon cost for refineries in each of the two groups is summarized in Table IX.C-2 below. Table IX.C-3 shows the estimated average per-gallon cost and nationwide aggregate refinery cost for each of three sulfur standards evaluated. This analysis assumes a 7% return on investment before taxes, operating costs in 1999 dollars, and capital costs in 1999 dollars.

Table IX.C-2. Estimated Per-Refinery Capital and Operating Costs and Per-Gallon Cost for a 50 ppm Cap

	Nationwide Average Refinery
Average Sized Refinery	
Capital Cost ($Million)	19
Operating Cost ($Million/yr)	5
Per-Gallon Cost (¢/gallon)	2.3

Table IX.C-3 Fuel Costs for a 50 ppm Cap Compared to a 15 ppm Cap

	50 ppm Cap	*15 ppm Cap*
Per-Gallon Cost (¢/gallon)	2.3	4.0
Aggregate Capital Cost ($Billon)	2.6	4.1
Aggregate Annual Operating Cost ($Billion/yr)	0.6	1.1

We project that the average refining cost of meeting the 50 ppm standard would be about 2.3 cents per gallon, about 1.7 cents per gallon less than the corresponding cost for fuel meeting a 15 ppm sulfur cap. It might also be slightly less expensive to distribute the 50 ppm sulfur fuel than the 15 ppm sulfur fuel because the pipeline interface volume between highway diesel fuel and higher sulfur products that must be sold with the higher sulfur product to ensure quality of the highway diesel fuel could be reduced. However, similar to the alternative case which examined distribution costs under a 25 ppm cap / 15 ppm average standard rather than the proposed 15 ppm cap standard, the extent to which interface volumes would decrease under a 50 ppm standard is likely to be small. If under a 50 ppm cap standard, pipeline operators were also compelled to make their interface cuts at a point into the ULSD stream where essentially no mixing with adjacent products takes place, there may be little difference on distribution costs under a 50 ppm vs the proposed 15 ppm standard. To provide an estimate of the potential change in distribution costs under a 50 ppm cap vs a 15 ppm cap standard, we assumed a linear relationship between interface volumes and the sulfur cap. Using this assumption, we estimate the savings in distribution costs under a 50 ppm cap vs a 15 ppm cap standard to be about 0.01 cents per gallon of diesel fuel.

4. Emission Reductions Under a 50 ppm Sulfur Cap

As discussed above, we believe that this sulfur limit would not enable the use of particulate traps or NOx adsorber catalysts. However, some emissions reductions could be achieved through the use of a diesel oxidation catalyst and a lean NOx catalyst. However, the fuel injected into the lean NOx catalyst would lead to about a 4 percent increase in fuel consumption. Nationwide HDDE fuel consumption for this case is presented in Table IX.C-4. Also, we would expect some hydrocarbon slip through the lean NOx catalyst. For this reason, we would not anticipate any NMHC benefits under this program.

Table IX.C-4. Nationwide HDDE Fuel Consumption (billion gallons) with a 50 ppm Cap

Calendar Year	*Baseline*	*Control*	*Fuel Penalty*
2007	37.6	37.6	0.03
2010	39.6	40.0	0.42
2015	43.0	44.2	1.17
2020	46.2	47.9	1.63
2030	51.9	54.0	2.11

We anticipate a small reduction in PM emissions due to the reduction in average in-use fuel sulfur levels and due to engine design flexibility associated with the diesel oxidation catalyst and lean NOx catalyst. For this scenario, we model PM emissions considering a 20% reduction from baseline levels. Table IX.C-5 presents these results.

Table IX.C-5. Nationwide HDDE PM Emissions (thousand short tons) with a 50 ppm Cap

Calendar Year	*Baseline*	*Controlled (50 ppmS cap)*	*Reduction (50 ppmS cap)*	*Reduction (15 ppmS cap)*
2007	100.1	93.2	6.8	11.7
2010	94.3	84.3	10.0	35.7
2015	93.4	79.5	13.9	63.8
2020	98.4	81.7	16.7	83.2
2030	118.9	97.5	21.4	110.7

With the fuel consumption penalty discussed above, we believe that about a 0.5 g/bhp-hr reduction in NOx can be achieved through the use of a lean NOx catalyst beyond baseline levels. Table IX.C-6 presents nationwide HDDE NOx emissions for this regulatory alternative.

Table IX.C-6. Nationwide HDDE NOx Emissions (thousand short tons) with a 50 ppm Cap

Calendar Year	*Baseline*	*Controlled (50 ppmS cap)*	*Reduction (50 ppmS cap)*	*Reduction (15 ppmS cap)*
2007	3,120	3,090	34	35
2010	2,790	2,600	192	465
2015	2,660	2,260	398	1,400
2020	2,740	2,200	538	2,020
2030	3,130	2,410	719	2,760

Because SOx emissions are directly a function of fuel consumption and sulfur level, SOx and SOx-derived secondary PM emissions would be higher than the base case. Table IX.C-7 presents the projected nationwide HDDE SOx reductions for this regulatory alternative compared to the base case.

Table IX.C-7. Nationwide HDDE SOx Emission Reductions (thousand short tons) with a 50 ppm Cap

Calendar Year	*50 ppmS cap*	*15 ppmS cap*
2007	82	88
2010	87	93
2015	94	102
2020	101	109
2030	114	123

5. Cost Effectiveness of a 50 ppm Sulfur Cap Program

The methodology used to determine the cost effectiveness of this alternative standard generally follows that described in Chapter VI for a program with a 15 ppm cap. There are, however, two important differences. The first is that a four percent reduction in fuel economy must be incorporated into the calculation of NOx+NMHC cost-effectiveness. The methodology for calculating fuel economy impacts on per-vehicle costs is described in Chapter IX.A.5 above. The second important difference is that the approach to allocating total costs to the various pollutants must change, since this alternative program would have only a lean NOx catalyst and would produce no NMHC benefits (other than crankcase reductions). In this case, the low sulfur would enable a single engine technology which produced reductions in both NOx and PM.. Therefore, we have divided fuel costs equally between NOx and PM in our calculation of cost-effectiveness. This is significantly differently than for our proposed standard of a 15 ppm cap, in which fuel costs were divided equally among the two engine technologies being enabled, adsorbers and traps, and then further divided equally between PM and NMHC for the trap.

The alternative standard of a 50 ppm cap also has impacts on specific values in the calculations, including lower desulfurization, distribution, and engine costs, and lower NOx, PM, and SO_2 benefits. We have calculated cost effectiveness using both the per-vehicle and 30-year net present value approaches, consistent with our cost effectiveness presentation for our proposed program.

The total price of diesel fuel excluding taxes under an alternative 50 ppm cap is estimated to be 87.5 ¢/gal. This price includes the base price of 84.8 ¢/gal, desulfurization cost of 2.3 ¢/gal, distribution costs of 0.16 ¢/gal, and lubricity additive costs of 0.2 ¢/gal. As a result, the total per-vehicle fuel costs for HDDE under the alternative 50 ppm cap are estimated to be $1105. These costs were divided equally between the NOx+NMHC calculation and the PM calculation. In addition, the credit associated with SO_2 reductions has been estimated at $424 per-vehicle, slightly lower than the $446 used for our proposed program because the alternative 50 ppm cap would produce slightly less SO_2 reductions.

As described above, the standards for HDDE would change under an alternative 50 ppm cap. Thus both the engine costs and emission reductions would be lower than for our proposed 15 ppm cap program.. The per-vehicle emission reductions for HDDE are shown in Table IX.C-8, while the costs are shown in Table IX.C-9.

Table IX.C-8. Fleet average, Per-engine Discounted Lifetime Tons for HDDE under a 50 ppm Cap Program

	NOx + NMHC	*PM*
Baseline: 2004 standards with 340 ppm fuel	1.83	0.071
Control: 2007 standards with 30 ppm ave fuel	1.45	0.058
Reduction	0.38	0.013

Table IX.C-9. Fleet Average Per-Engine Costs for HDDE Used in Cost-effectiveness under a 50 ppm Cap Program

	Near-term costs ($)		*Long-term costs ($)*	
	NOx+NMHC	PM	NOx+NMHC	PM
Total uncredited costs	2515	1062	2270	818
SO_2 credit allocation	n/a	-424	n/a	-424
Total credited costs	2515	638	2270	394

The engine costs which were included in Table IX.C-9 are based on the values in Table IX.C-1, corrected to include the costs of meeting our crankcase emissions standard and savings resulting from reduced maintenance. The final per-vehicle cost effectiveness values for the alternative 50 ppm cap program are given in Table IX.C-10. Note that these values include the costs and emission reductions associated with our proposed standards for heavy-duty gasoline vehicles.

Table IX.C-10. Per-vehicle Cost Effectiveness of a 50 ppm Cap Program

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]
<u>Near-term costs</u>				
NOx + NMHC	$1348	0.24	5,600	5,600
PM	$1062	0.013	81,800	49,100
<u>Long-term costs</u>				
NOx + NMHC	$1211	0.24	5,100	5,100
PM	$818	0.013	63,000	30,300

[a] $424 credited to SO_2 (at $4800/ton) for PM cost effectiveness

We have also calculated the cost effectiveness of the alternative 50 ppm cap program using a 30-year net present value approach that includes the net present value of all nationwide emission reductions and costs for a 30 year period. The net present value costs are given in Table IX.C-11. The final 30-year net present value cost effectiveness for the alternative 50 ppm cap program is given in Table IX.C-12.

Table IX.C-11. 30-year Net Present Value Costs for 50 ppm Cap Program

	NOx+NMHC	*PM*
Diesel engines, $billion	2.6	2.6
Gasoline vehicles, $billion	1.0	0
Diesel fuel, $billion	14.6	14.6
Total, $billion	18.2	17.2

Table IX.C-12. 30-year Net Present Value Cost Effectiveness of 50 ppm Cap Standard

	30-yr NPV costs	*30-year NPV reduction (tons)*	*30-year NPV cost effectiveness per ton*	*30-year NPV cost effectiveness per ton with SO_2 credit*[a]
NOx + NMHC	$18.2 billion	5.0 million	$3,600	$3,600
PM	$17.2 billion	0.18 million	$94,200	$56,700

[a] $6.9 billion credited to SO_2 (at $4800/ton)

Chapter IX References

1. Cooper and Thoss, Johnson Matthey, SAE 890404.

2. 1997 average price of highway diesel fuel at retail outlets, excluding taxes, according to *Petroleum Marketing Annual 1998*. Table 16.

3. "Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel", Turner, Mason, & Company Consulting Engineers", February 2000. EPA Docket A-99-06, item II-G-49.

4. "Costs/Impacts of Distributing Potential Ultra Low Sulfur Diesel", Turner, Mason, & Company Consulting Engineers", February 2000. EPA Docket A-99-06, item II-G-49.

5. "Diesel Emission Control Sulfur Effects (DECSE) Program," Phase I Interim Data Report No.1 August 1999.

6. "Diesel Emission Control Sulfur Effects (DECSE) Program," Phase I Interim Data Report No.1 August 1999. Table 3.3-1

7. "Economic Analysis of Diesel Aftertreatment System Changes Made Possible by Reduction of Diesel Fuel Sulfur Content," Engine, Fuel, and Emissions Engineering, Incorporated, December 15, 1999.